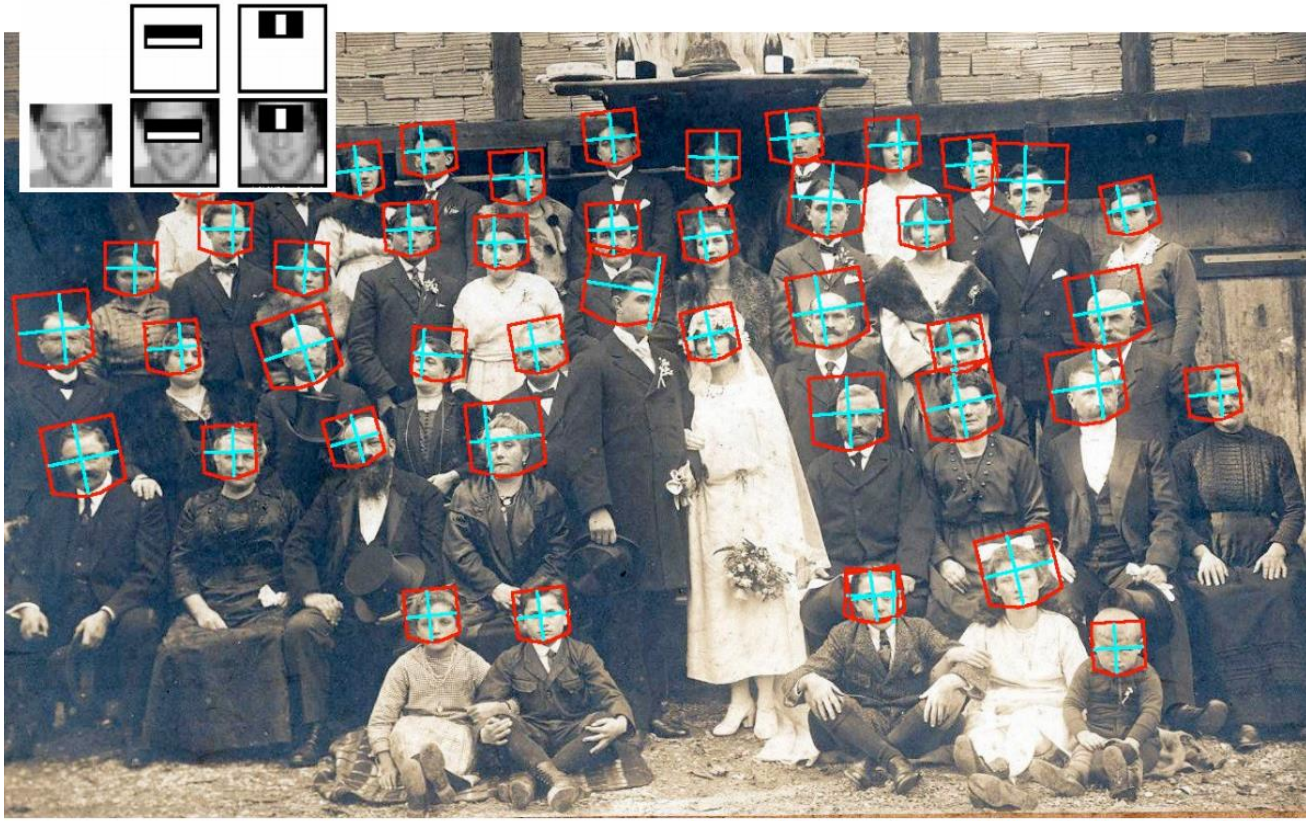
Deep Neural Networks Basics

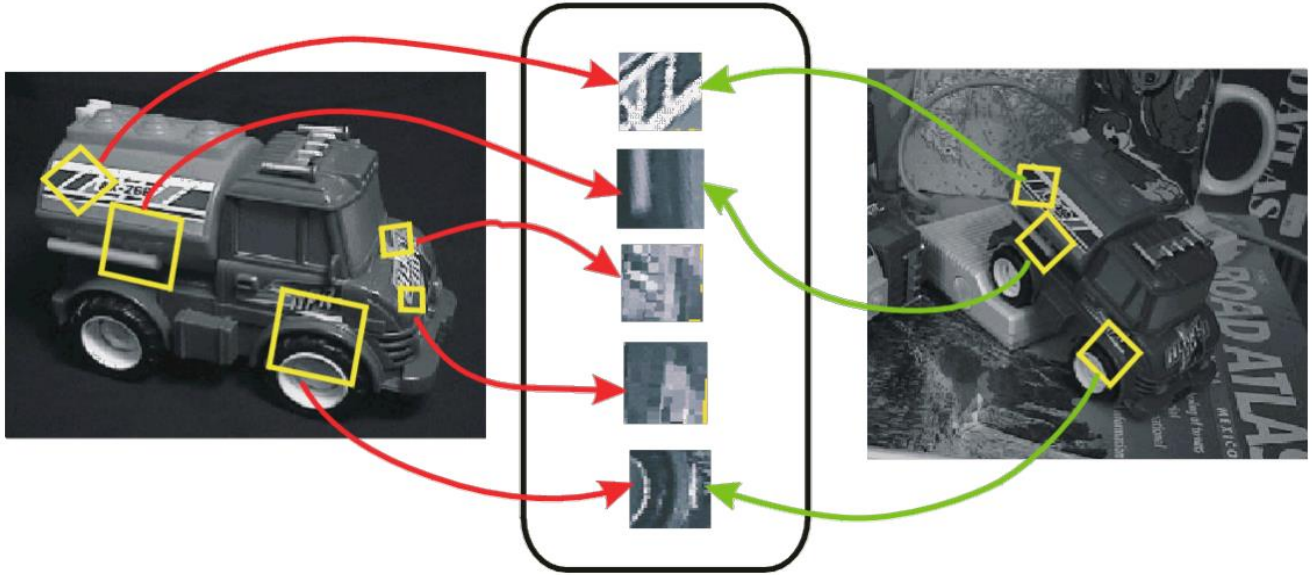
For ECS 289G
Presented by Fanyi Xiao

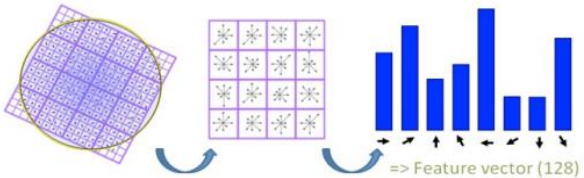
Computer Vision in the Pre-DNN Era



Face Detection, Viola & Jones, 2001

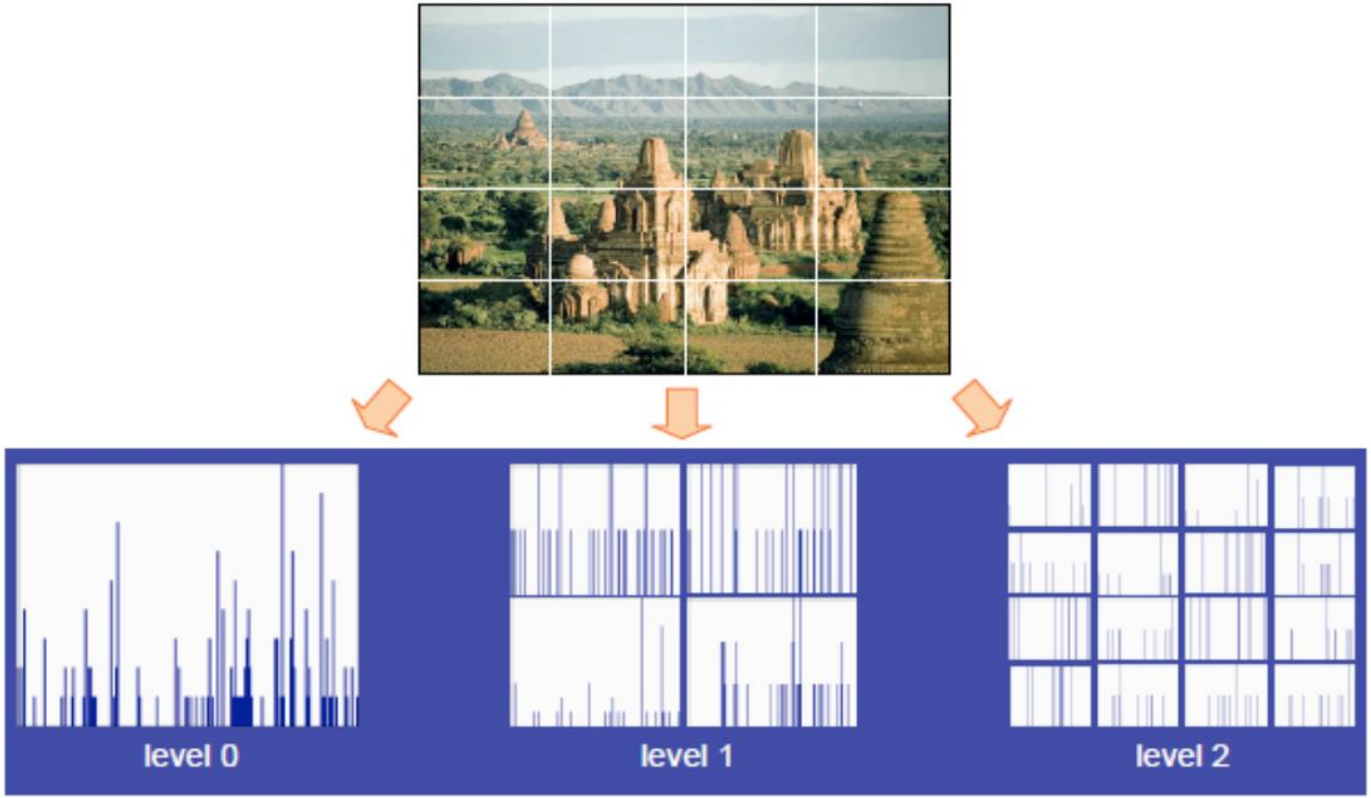
Computer Vision in the Pre-DNN Era





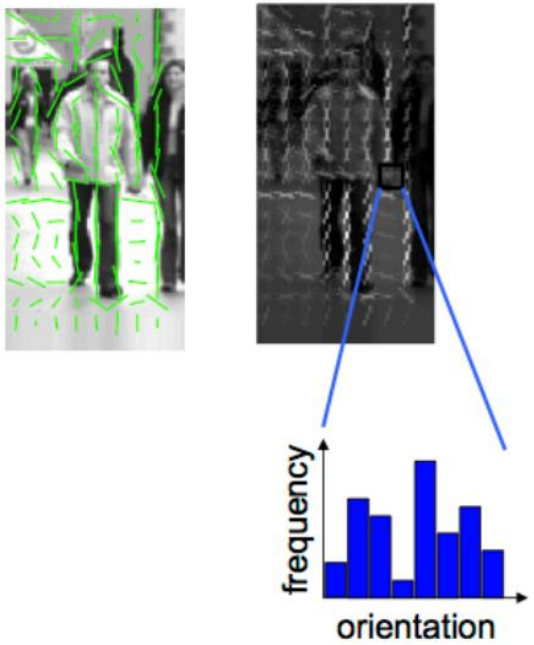
"SIFT" & Object Recognition, David Lowe, 1999

Computer Vision in the Pre-DNN Era

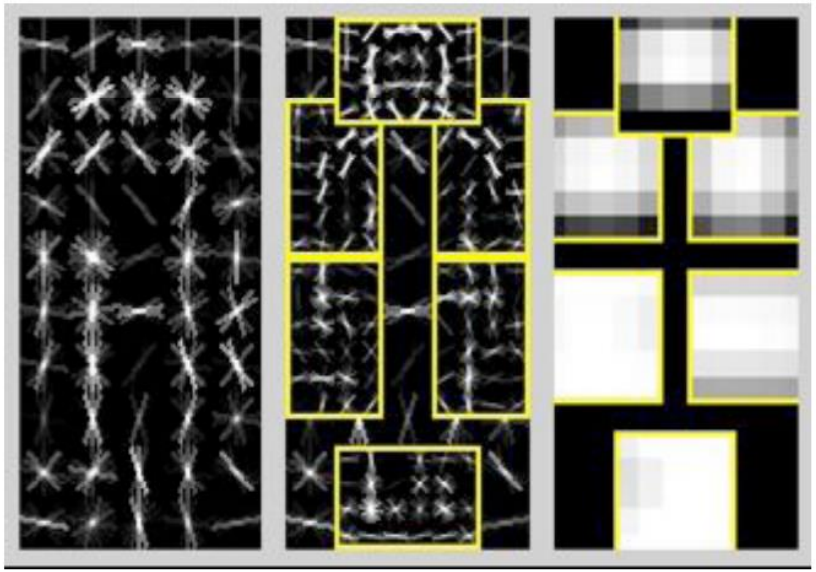


Spatial Pyramid Matching, Lazebnik, Schmid & Ponce, 2006

Computer Vision in the Pre-DNN Era

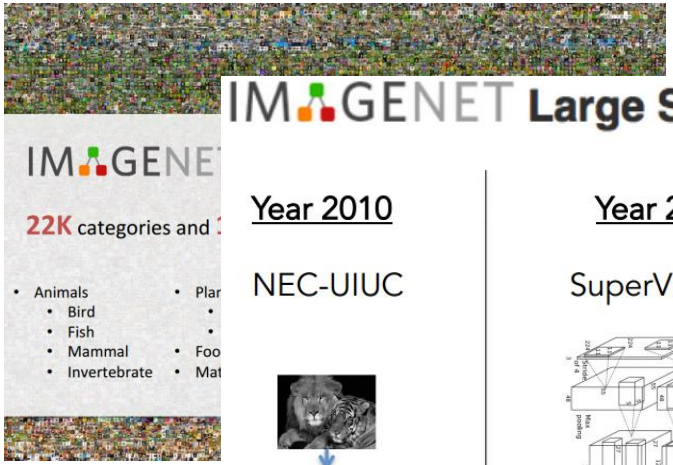


Histogram of Gradients (HoG)
Dalal & Triggs, 2005



Deformable Part Model
Felzenswalb, McAllester, Ramanan, 2009

Emergence of DNNs in Vision



IMAGENET Large Scale Visual Recognition Challenge

Year 2010

NEC-UIUC

Dense grid descriptor: HOG, LBP

Coding: local coordinate, super-vector

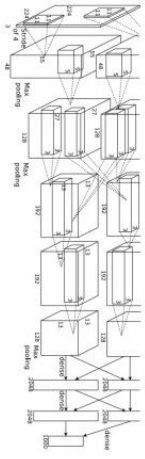
Pooling, SPM

Linear SVM

[Lin CVPR 2011]

Year 2012

SuperVision



[Krizhevsky NIPS 2012]

Year 2014

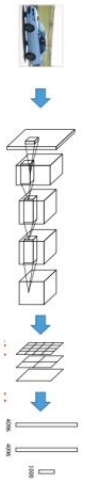
GoogLeNet

[Szegedy arxiv 2014]

VGG

[Simonyan arxiv 2014]

MSRA



[He arxiv 2014]

Neural Networks

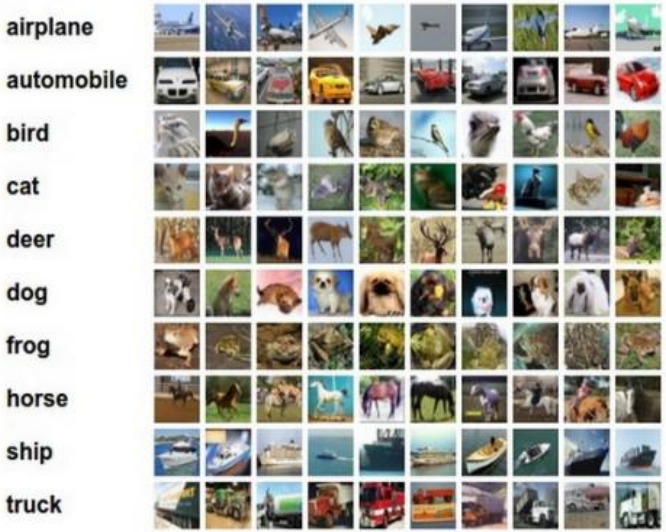
Image Classification

assume given set of discrete labels
{dog, cat, truck, plane, ...}

cat

Learn visual features "end-to-end"

Data-driven approach



Neural Networks

Compositional Models

Learned End-to-End

Hierarchy of Representations

- vision: pixel, motif, part, object
- text: character, word, clause, sentence
- speech: audio, band, phone, word

concrete → learning → abstract

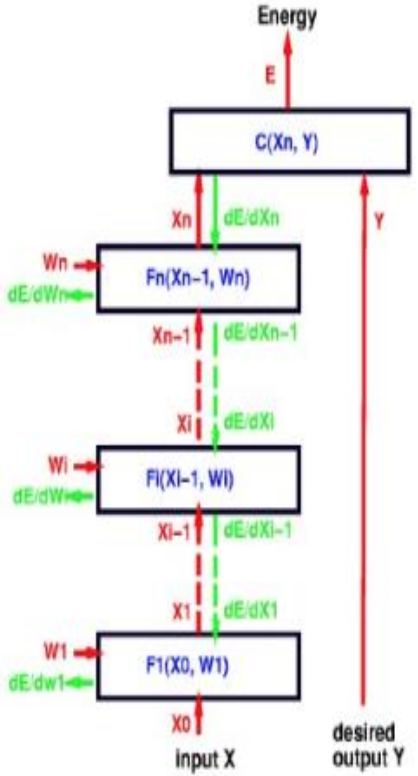


figure credit Yann LeCun, ICML '13 tutorial

Neural Networks

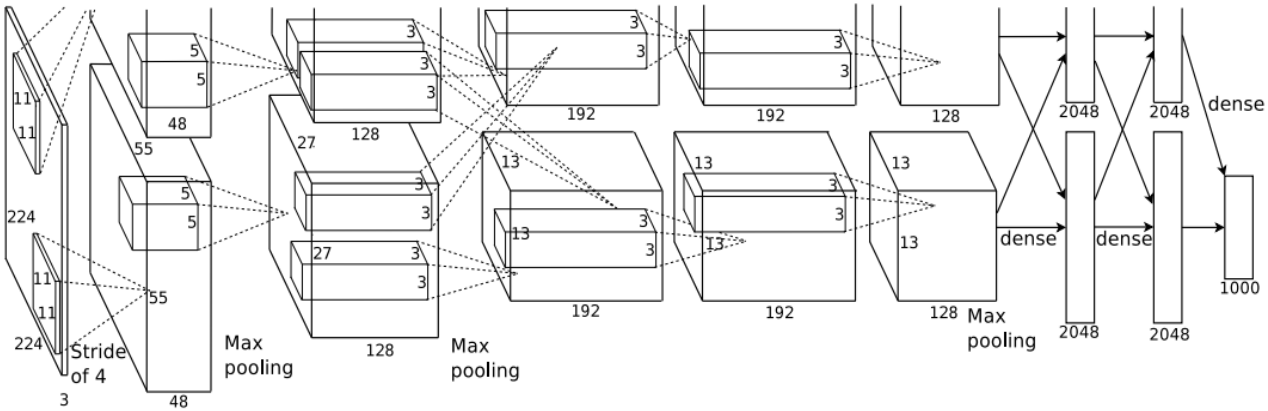
Three key ingredients for training an NN:

1. Score function
2. Loss function
3. Optimization

Neural Networks

Three key ingredients for training an NN:

1. Score function: y=f(x,W)



x -- 224*224*3 image patch
y -- 1000d vector

Neural Networks

Three key ingredients for training an NN:

2. Loss function: for example max-margin loss and cross-entropy loss

$$L_i = \sum_{j \neq y_i} \max(0, f(x_i, W)_j - f(x_i, W)_{y_i} + \Delta)$$

$$L_i = -\log\left(\frac{e^{f_{y_i}}}{\sum_j e^{f_j}}\right)$$

Neural Networks

Three key ingredients for training an NN:

3. Optimization: simple gradient descent!

$$\frac{df(x)}{dx}$$

Neural Networks

Three key ingredients for training an NN:

3. Optimization: in practice, *stochasitic (mini-batch) gradient descent*!

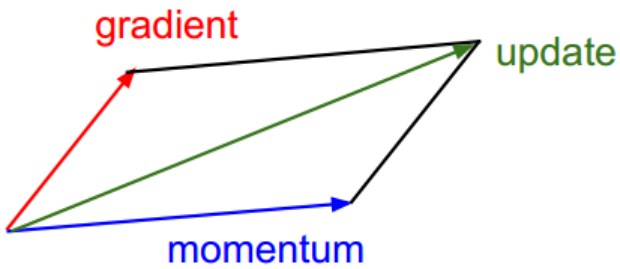
```
# Vanilla Minibatch Gradient Descent

while True:
  data_batch = sample_training_data(data, 256) # sample 256 examples
  weights_grad = evaluate_gradient(loss_fun, data_batch, weights)
  weights += - step_size * weights_grad # perform parameter update
```

Neural Networks

Three key ingredients for training an NN:

3. Optimization: in practice, stochasitic (mini-batch) gradient descent + *momentum*! (Many other optimization methods like adagrad/rmsprop)

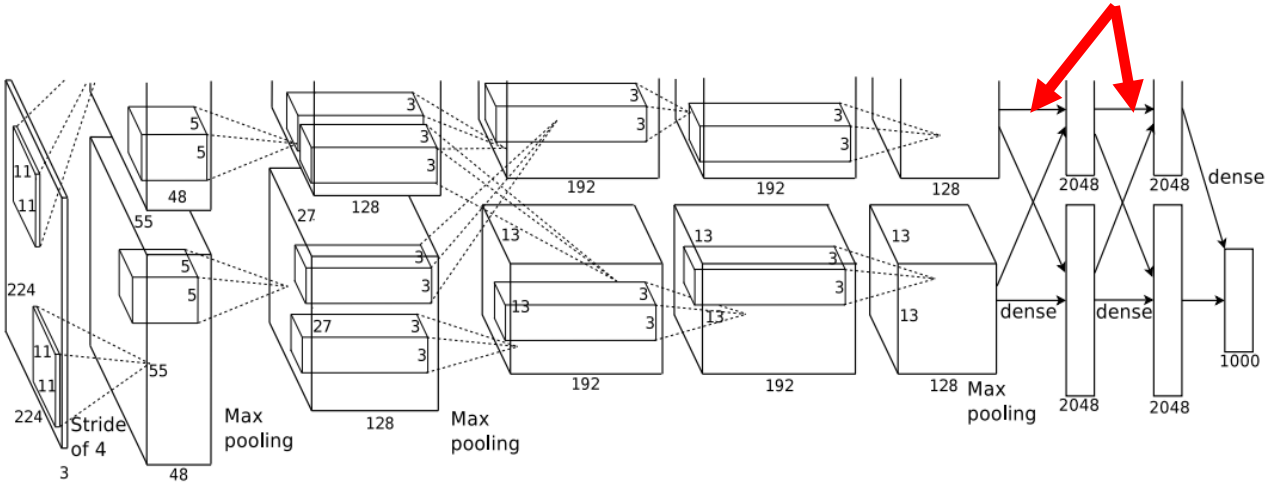



```
weights_grad = evaluate_gradient(loss_fun, data, weights)
vel = vel * 0.9 - step_size * weights_grad
weights += vel
```

Convolution Neural Networks

Let's take a closer look at AlexNet

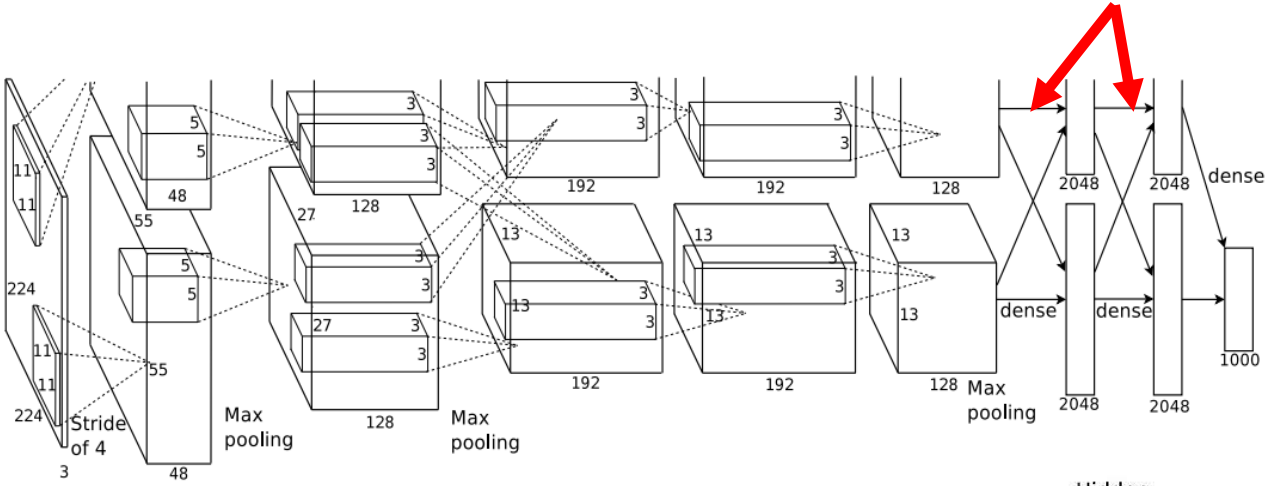
Linear transformation:
y'=Wx+b

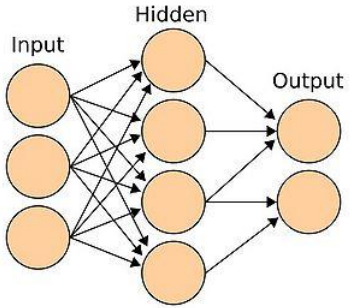


Convolution Neural Networks

Let's take a closer look at AlexNet

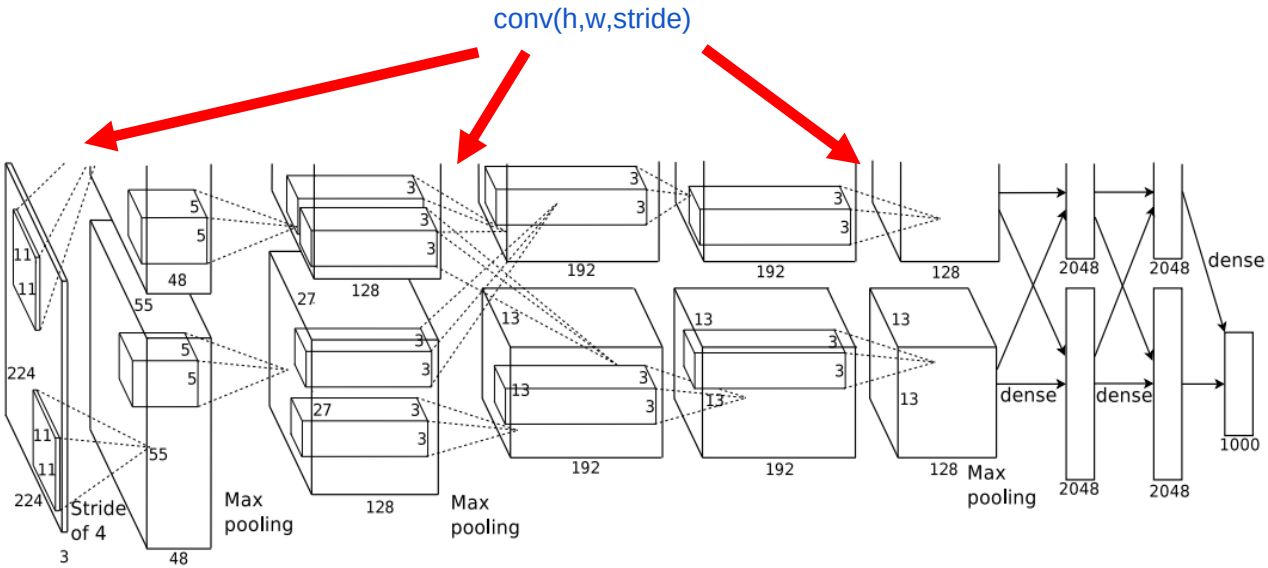
Linear transformation:
y'=Wx+b





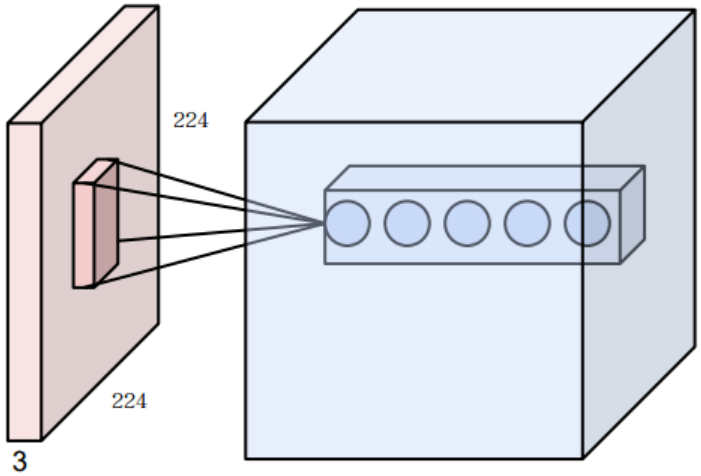
Convolution Neural Networks

Let's take a closer look at AlexNet



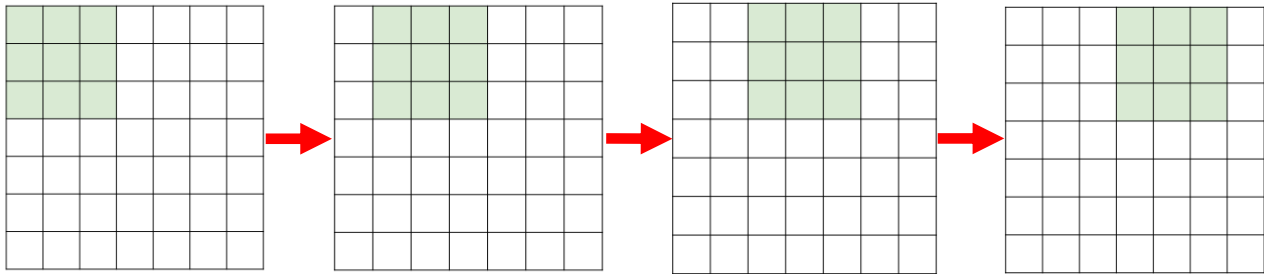
Convolution Neural Networks

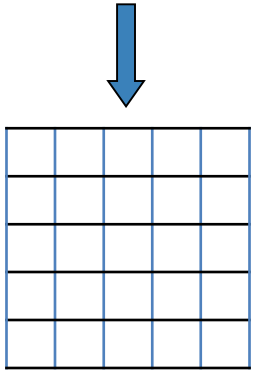
conv(h,w,stride)



Convolution Neural Networks

Example: conv(h=3,w=3,stride=1)

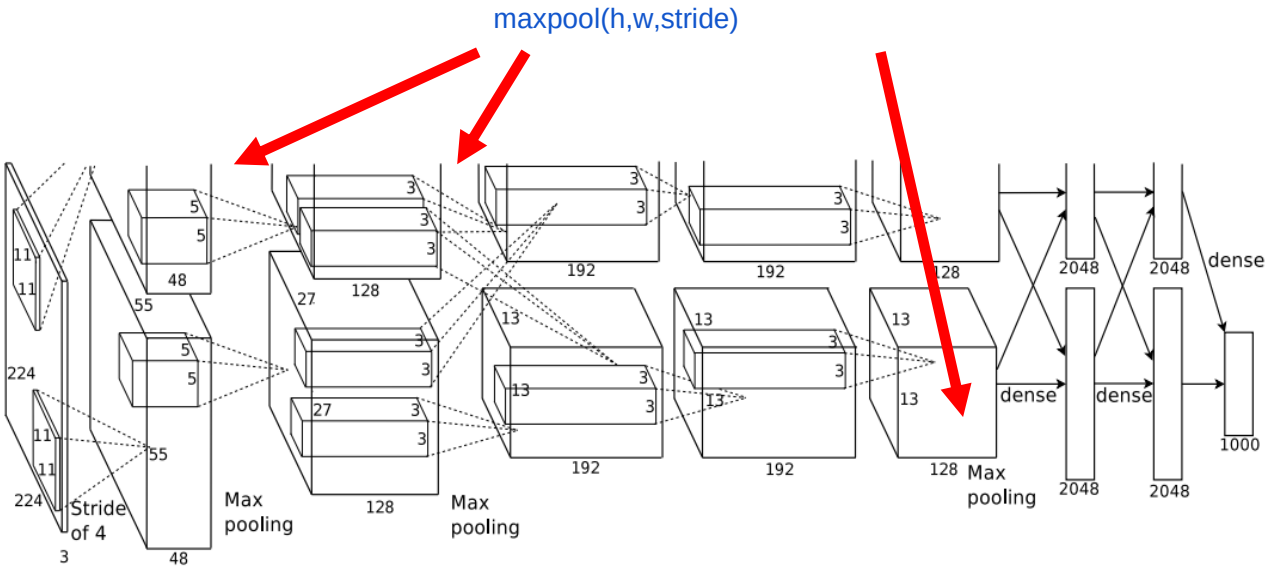




(7-3)/1+1=5
End up as a 5*5 feature map

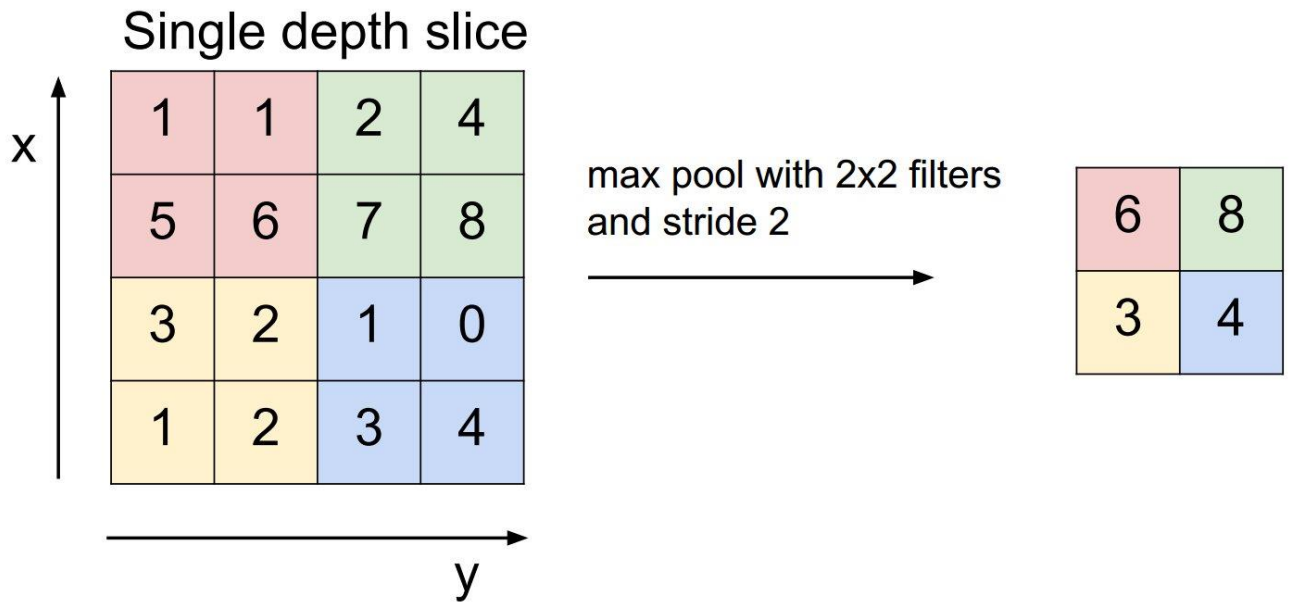
Convolution Neural Networks

Let's take a closer look at AlexNet



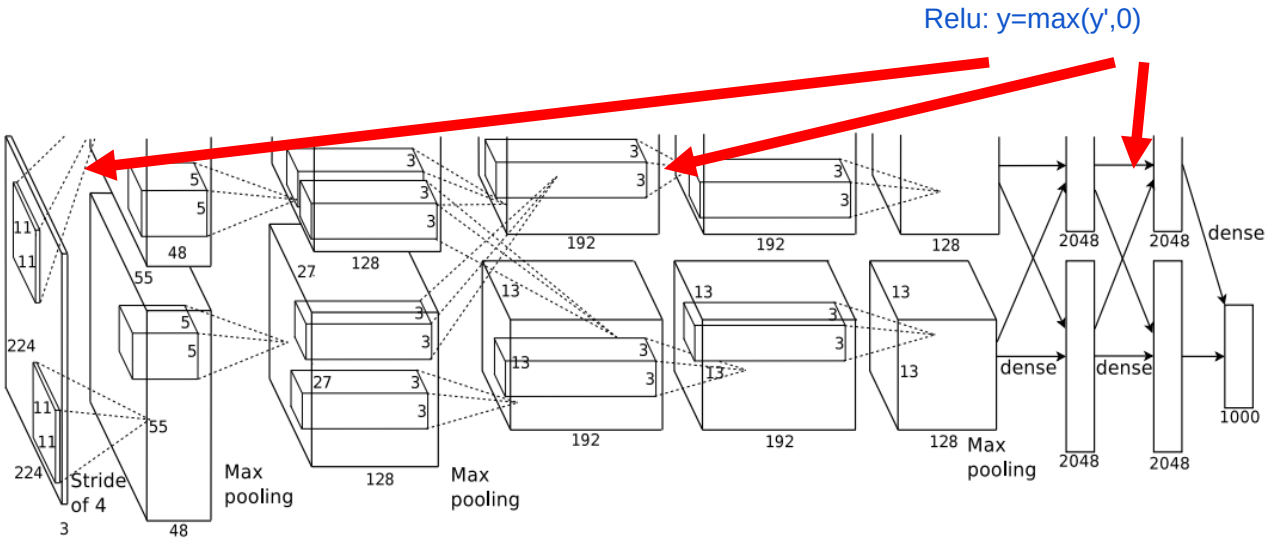
Convolution Neural Networks

Example: maxpool(h=2,w=2,stride=2)



Convolution Neural Networks

Let's take a closer look at AlexNet

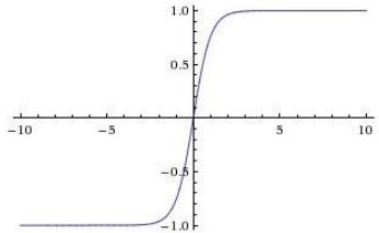


Convolution Neural Networks

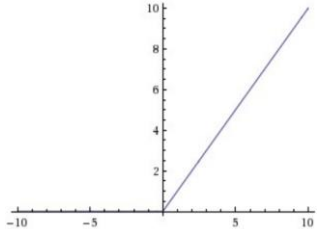
$$\tanh x = \frac{e^x - e^{-x}}{e^x + e^{-x}}$$

f(x) = max(0,x)

Problems with tanh: Saturated response



tanh(x)



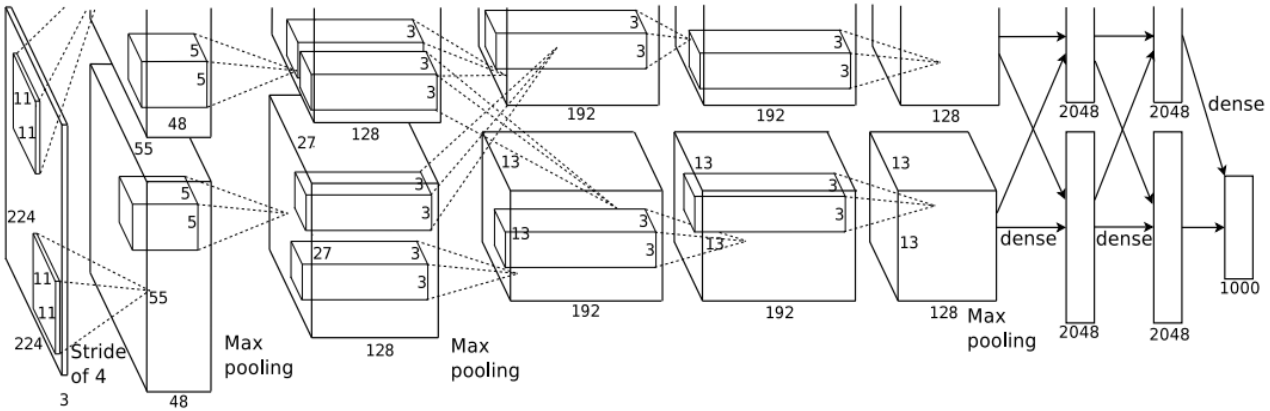
ReLU

Relu: y=max(y',0)
- Does not saturate
- Very computationally efficient
- Converges much faster than sigmoid/tanh in practice!

However, non-bounded response and dead when less than 0
(improved version leaky ReLU)

Convolution Neural Networks

There are two key differences to Vanilla Neural Nets: neurons arranged in 3D volumes have local connectivity, share parameters

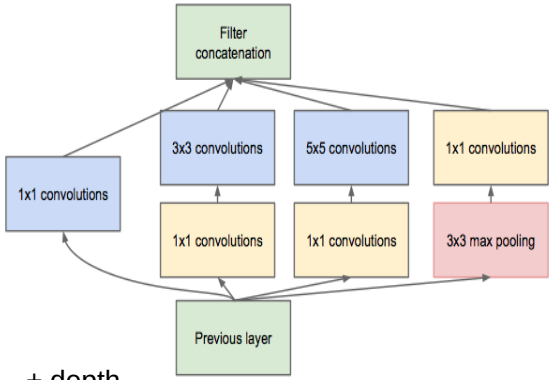


Convolution Neural Networks

GoogLeNet

ILSVRC14 Winners: **~6.6% Top-5 error**

- GoogLeNet: composition of multi-scale dimension-reduced modules (pictured)
- VGG: 16 layers of 3x3 convolution interleaved with max pooling + 3 fully-connected layers



+ depth
+ data
+ dimensionality reduction

Convolution Neural Networks

Object Detection

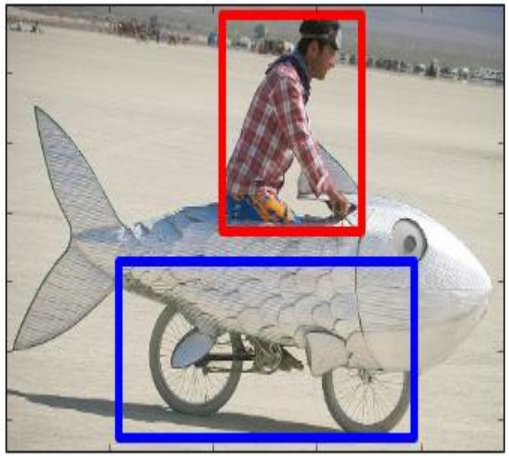
R-CNN: Region-based Convolutional Networks

http://nbviewer.ipython.org/github/BVLC/caffe/blob/master/examples/detection.ipynb

Full R-CNN scripts available at

https://github.com/rbgirshick/rcnn

Ross Girshick et al.
Rich feature hierarchies for accurate object detection and semantic segmentation. CVPR14.

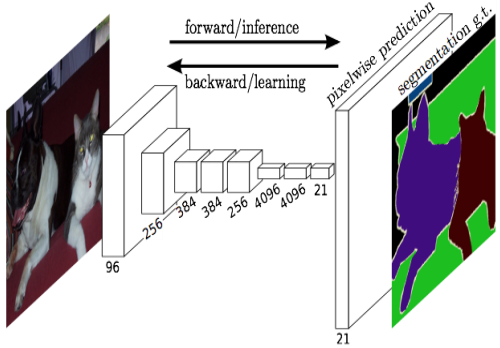


Fast R-CNN

arXiv and code

Segmentation

Fully convolutional networks for pixel prediction
applied to semantic segmentation
end-to-end learning
efficiency in inference and learning
175 ms per-image prediction
multi-modal, multi-task

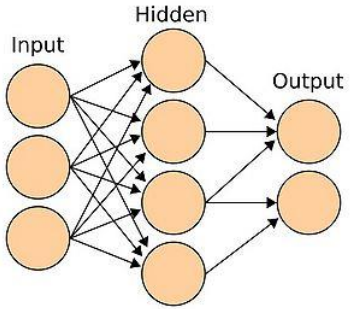


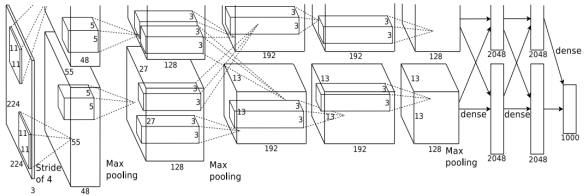
Further applications
- depth estimation
- denoising

[arXiv](#) and [pre-release](#)

Jon Long* & Evan Shelhamer*,
Trevor Darrell

Problem with Feed-forward Nets

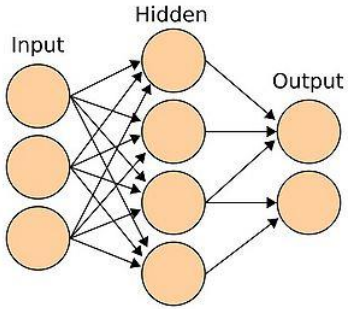


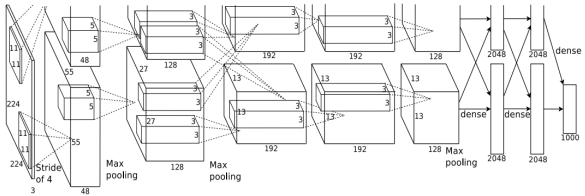


What if we want to be able to have a model telling us what's the probability of the following two sententes, resepctively:

1. The cat sat on the mat
2. The mat is having dinner with the cat

Problem with Feed-forward Nets





What if we want to be able to have a model telling us what's the probability of the following two sententes, resepctively:

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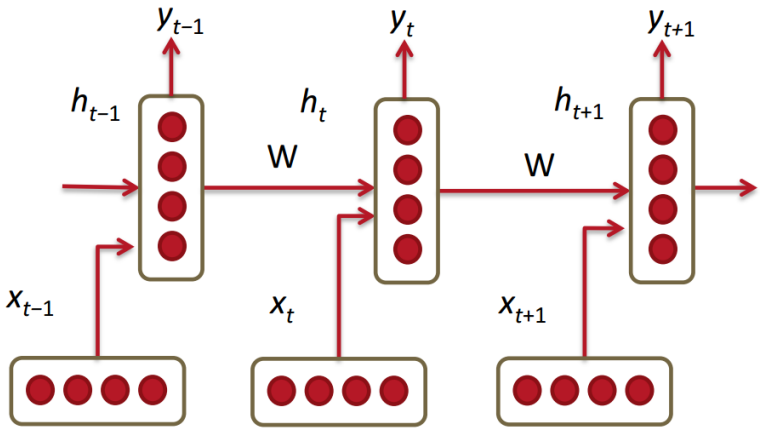
Cannot handle variable length input

Recurrent Neural Net

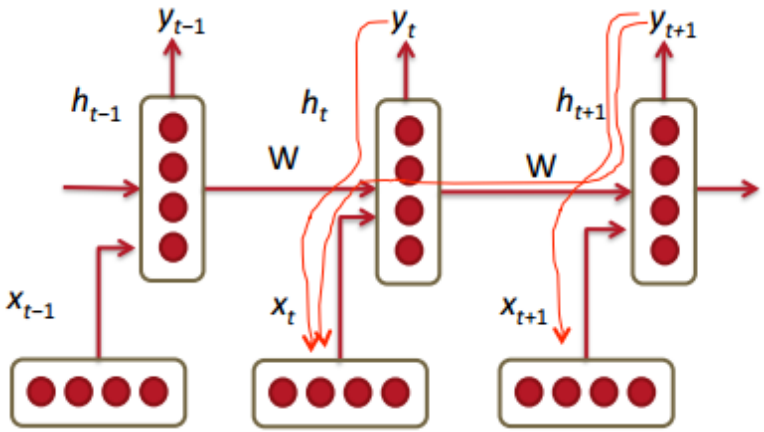
RNNs tie the weights at each time step



$$h_t = \sigma\left(W^{(hh)}h_{t-1} + W^{(hx)}x_{[t]}\right)$$
$$\hat{y}_t = \text{softmax}\left(W^{(S)}h_t\right)$$

Recurrent Neural Net

Training of RNNs is hard...

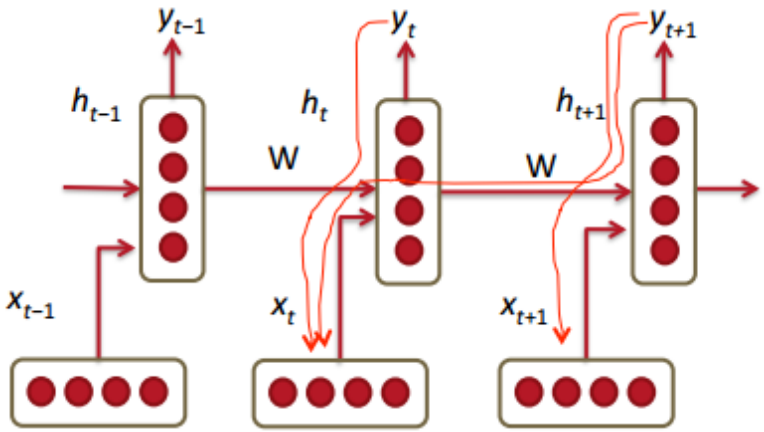


$$h_t = W f(h_{t-1}) + W^{(hx)} x_{[t]}$$

$$\frac{\partial h_t}{\partial h_k} = \prod_{j=k+1}^{t} \frac{\partial h_j}{\partial h_{j-1}} = \prod_{j=k+1}^{t} W^T \mathrm{diag}[f'(h_{j-1})]$$

Recurrent Neural Net

Training of RNNs is hard...



Solution 1: clip the gradient!

Algorithm 1 Pseudo-code for norm clipping the gradients whenever they explode

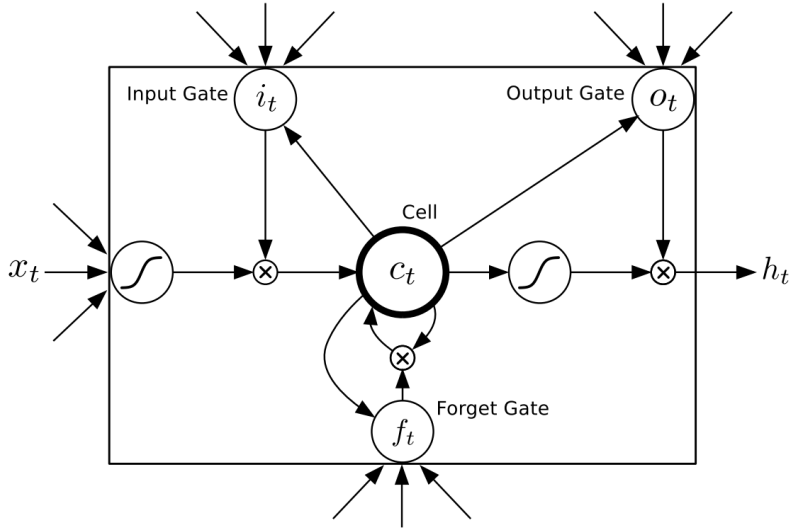
$\hat{\mathbf{g}} \leftarrow \frac{\partial \mathcal{E}}{\partial \theta}$
if $\|\hat{\mathbf{g}}\| \geq threshold$ **then**
  $\hat{\mathbf{g}} \leftarrow \frac{threshold}{\|\hat{\mathbf{g}}\|} \hat{\mathbf{g}}$
end if

Some theory: On the difficulty of training recurrent neural networks, Pascanu et al. ICML2013

Recurrent Neural Net

Training of RNNs is hard...

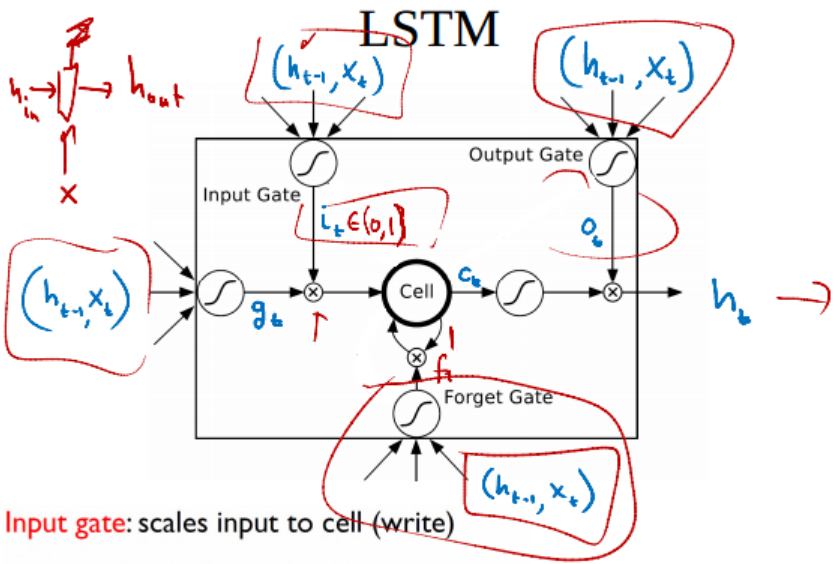
Solution 2: NNs with gating units (LSTM/GRU)



Recurrent Neural Net

Training of RNNs is hard...

Solution 2: nets with gating units (LSTM/GRU)



Input gate: scales input to cell (write)

Output gate: scales output from cell (read)

Forget gate: scales old cell value (reset)

Recurrent Neural Net

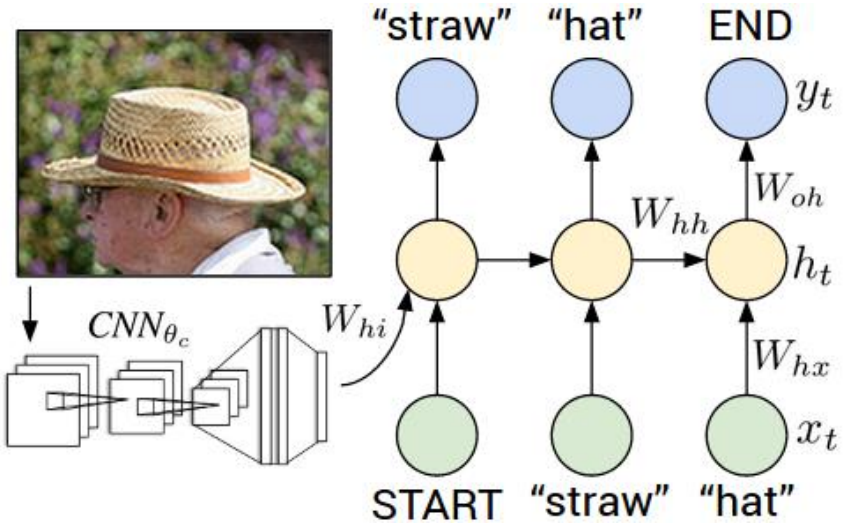
Training of RNNs is hard...

Solution 2: nets with gating units (LSTM/GRU)

$$\mathbf{i}_t = Sigm(\boldsymbol{\theta}_{xi}\mathbf{x}_t + \boldsymbol{\theta}_{hi}\mathbf{h}_{t-1} + \mathbf{b}_i)$$
$$\mathbf{f}_t = Sigm(\boldsymbol{\theta}_{xf}\mathbf{x}_t + \boldsymbol{\theta}_{hf}\mathbf{h}_{t-1} + \mathbf{b}_f)$$
$$\mathbf{o}_t = Sigm(\boldsymbol{\theta}_{xo}\mathbf{x}_t + \boldsymbol{\theta}_{ho}\mathbf{h}_{t-1} + \mathbf{b}_o)$$
$$\mathbf{g}_t = Tanh(\boldsymbol{\theta}_{xg}\mathbf{x}_t + \boldsymbol{\theta}_{hg}\mathbf{h}_{t-1} + \mathbf{b}_g)$$
$$\mathbf{c}_t = \mathbf{f}_t \odot \mathbf{c}_{t-1} + \mathbf{i}_t \odot \mathbf{g}_t$$
$$\mathbf{h}_t = \mathbf{o}_t \odot Tanh(\mathbf{c}_t)$$

RNN in vision

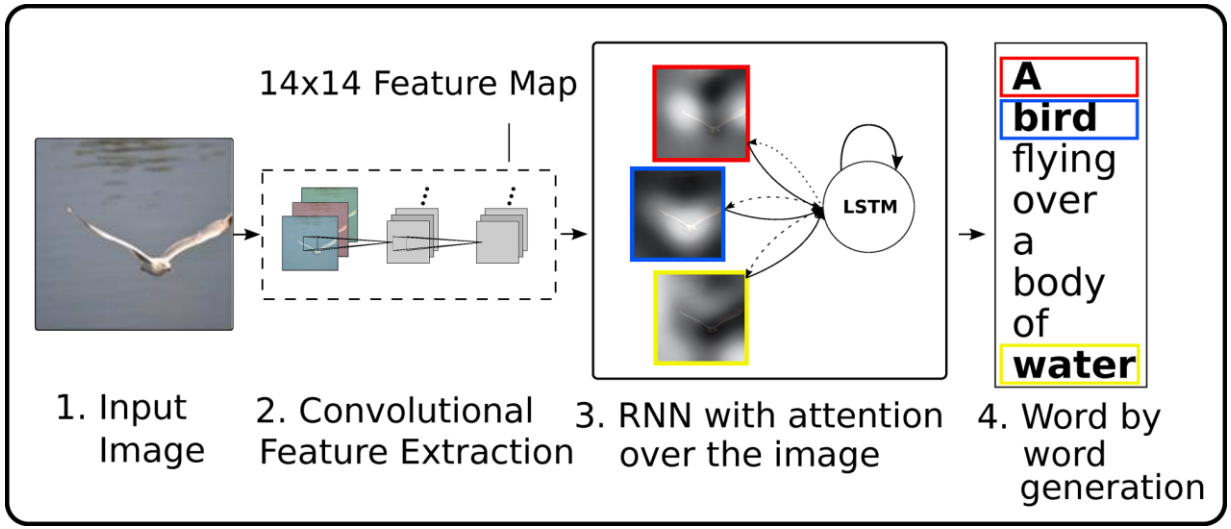
Image captioning



Deep Visual-Semantic Alignments for Generating Image Descriptions, Andrej Karpathy et al.

RNN in vision

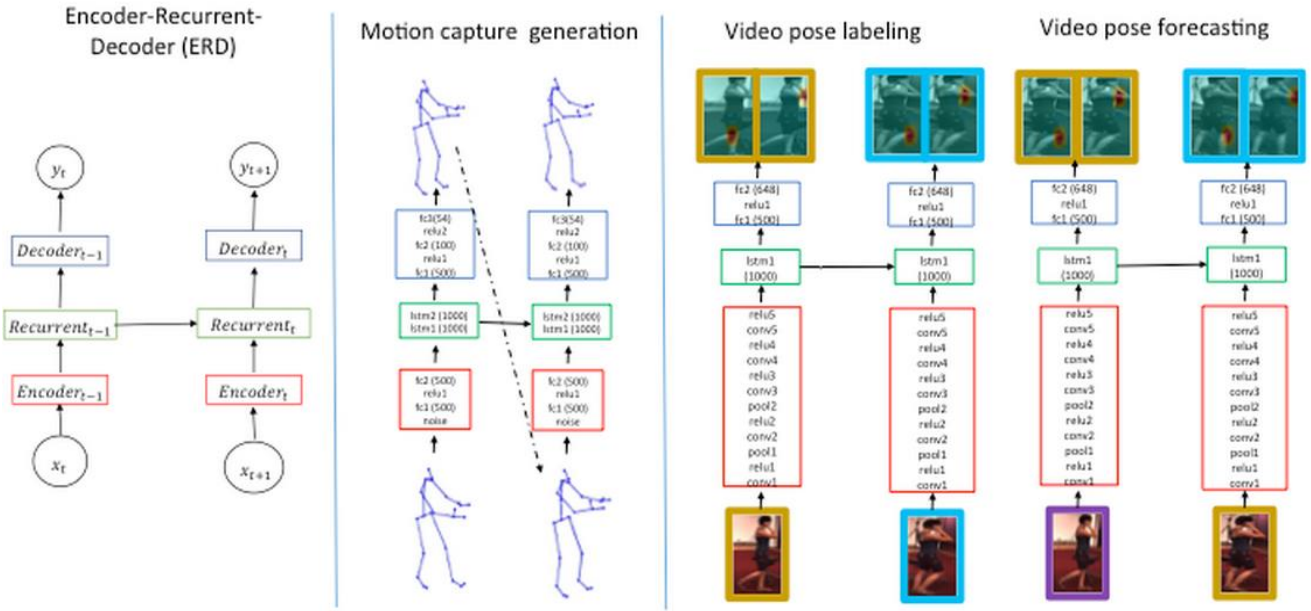
Visual attention model



Show, Attend and Tell: Neural Image Caption Generation with Visual Attention, Kelvin Xu et al.

RNN in vision

RNNs for Human Dynamics



Recurrent Network Models for Human Dynamics, Katerina Fragkiadaki et al.

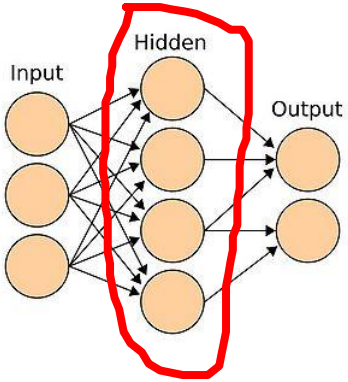
Tricks

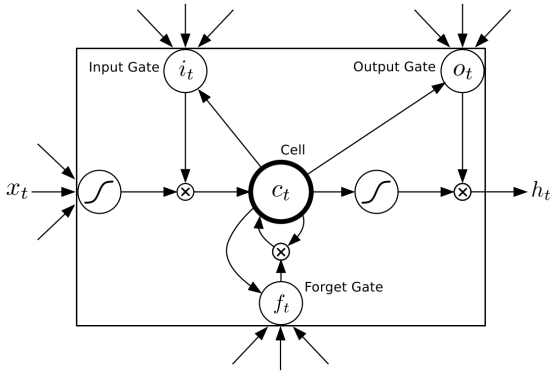
1. Numerical gradient check

```
fx = f(x) # evaluate function value at original point
grad = np.zeros_like(x)
# iterate over all indexes in x
it = np.nditer(x, flags=['multi_index'], op_flags=['readwrite'])
while not it.finished:

  # evaluate function at x+h
  ix = it.multi_index
  oldval = x[ix]
  x[ix] = oldval + h # increment by h
  fxph = f(x) # evalute f(x + h)
  x[ix] = oldval - h
  fxmh = f(x) # evaluate f(x - h)
  x[ix] = oldval # restore

  # compute the partial derivative with centered formula
  grad[ix] = (fxph - fxmh) / (2 * h) # the slope
  if verbose:
    print ix, grad[ix]
  it.iternext() # step to next dimension
```

Tricks

1. Numerical gradient check
2. Modulize layers: only three functions needed
   (1) output=forward(input,model)
   (2) dJ_dW=computeParamGrad(input,outputGrad,model)
   (3) dJ_dInput=computeInputGrad(input,outputGrad,model)
   Everything else is just putting together lego pieces





Questions?

Thanks!

Caffe Tutorial

For ECS 289G

Presented by Krishna Kumar Singh

*Some slides taken from CVPR 2015 deep learning and Caffe tutorial

What is Caffe?

Open framework, models, and worked examples
for deep learning

- 1.5 years
- 300+ citations, 100+ contributors
- 2,000+ forks, >1 pull request / day average
- focus has been vision, but branching out: sequences, reinforcement learning, speech + text

Prototype

Train

Deploy

What is Caffe?

Open framework, models, and worked examples
for deep learning

- Pure C++ / CUDA architecture for deep learning
- Command line, Python, MATLAB interfaces
- Fast, well-tested code
- Tools, reference models, demos, and recipes
- Seamless switch between CPU and GPU

Prototype

Train

Deploy

Caffe is a Community

project pulse

BVLC / caffe

Unwatch 682 | Unstar 3,821 | Fork 2,279

May 6, 2015 – June 6, 2015

Period: **1 month**

Overview

62 Active Pull Requests

168 Active Issues

45 Merged Pull Requests	**17** Proposed Pull Requests	**122** Closed Issues	**46** New Issues

Excluding merges, **43 authors** have pushed **75 commits** to master and **203 commits** to all branches. On master, **154 files** have changed and there have been **46,336 additions** and **5,964 deletions**.

Brewing by the Numbers...

- Speed with Krizhevsky's 2012 model:
  - 2 ms / image on K40 GPU
  - <1 ms inference with Caffe + cuDNN v2 on Titan X
  - 72 million images / day with batched IO
  - 8-core CPU: ~20 ms/image
- 9k lines of C++ code (20k with tests)

Share a Sip of Brewed Models

demo.caffe.berkeleyvision.org
demo code open-source and bundled

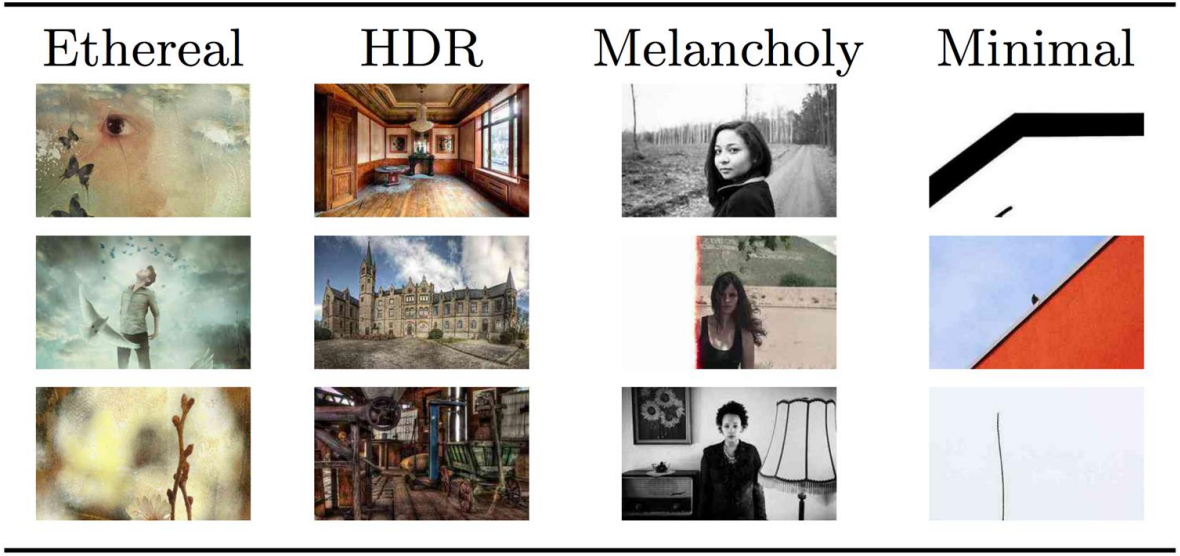
Maximally accurate | Maximally specific

cat	1.80727
domestic cat	1.74727
feline	1.72787
tabby	0.99133
domestic animal	0.78542

Training Network for Style Recognition

Visual Style Recognition

Karayev et al. *Recognizing Image Style*. BMVC14. Caffe fine-tuning example.
Demo online at http://demo.vislab.berkeleyvision.org/ (see Results Explorer).



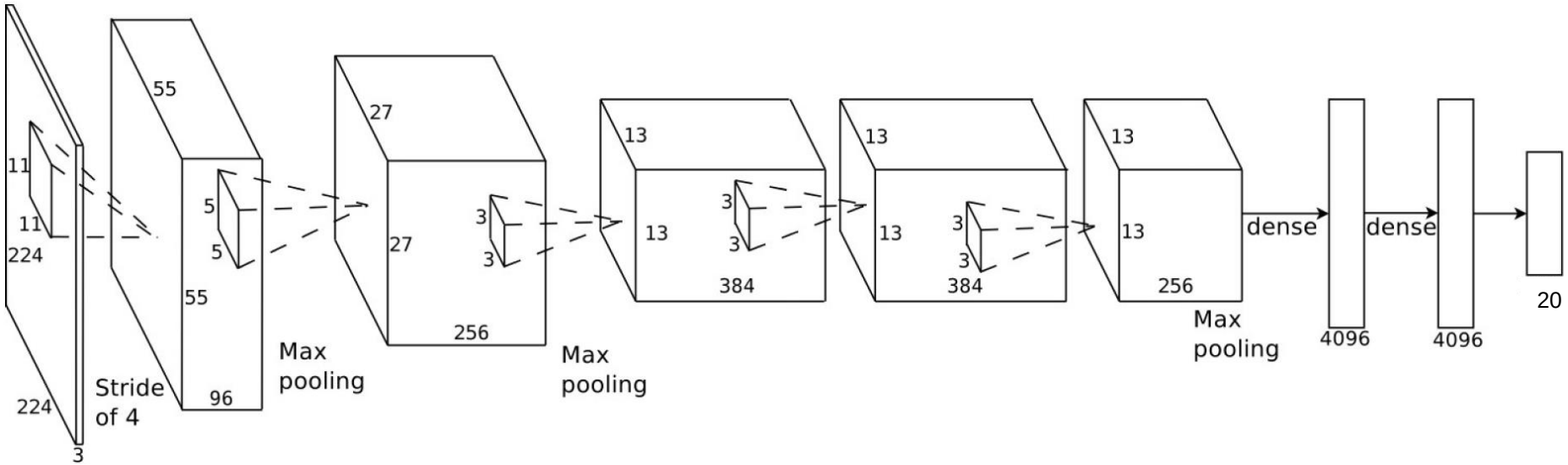
[Image-Style]

Other Styles:

Vintage
Long Exposure
Noir
Pastel
Macro
… and so on.

20 Classes

Alexnet for Flickr Style Recognition



* Image taken from Alex Krizhevsky slides

Training

- Network Schema: Define layers and connection between them
  - models/finetune_flickr_style/train_val.prototxt

- Solver: oversees the network optimization
  - models/finetune_flickr_style/solver.prototxt

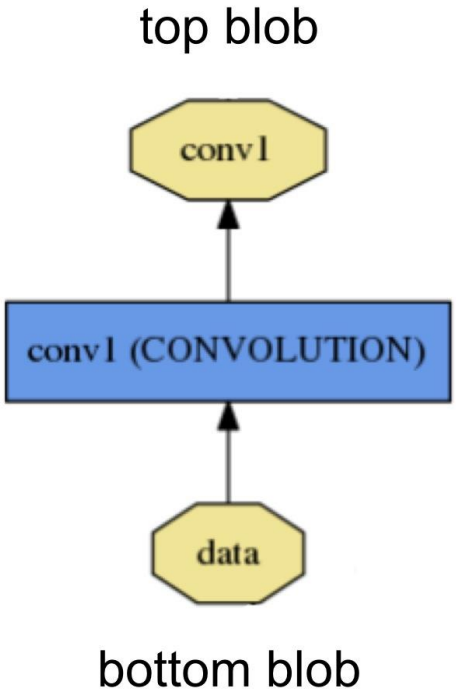
Basic Definitions

- Learning Rate: Decides the rate of change of parameters.
- Batch Size: Number of images processed together in the network.
- Epoch: Number of iterations required to feed the training data.
  - Training images: 1000, Batch Size = 50, then 1 epoch = 1000/50 = 20 iterations
- Testing: Compute accuracy and loss of intermediate models.
  - Does not affect the network parameters.

Defining Network Schema in Caffe

Please open models/finetune_flickr_style/train_val.prototxt

Layers



- Network is defined as series of layers.
- Layers type:-
  - Convolution
  - Inner Product
  - Data
  - Loss
  - Pooling
  - …….
- Each layer has input as bottom blob and output as top blob.

*image taken from Caffe Tutorial

Network

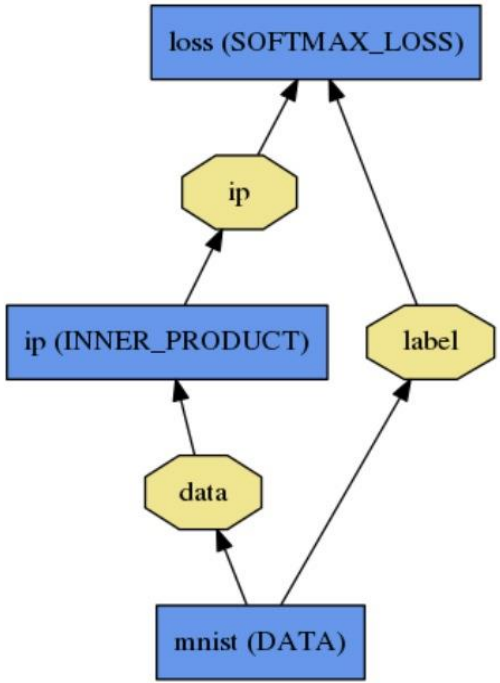
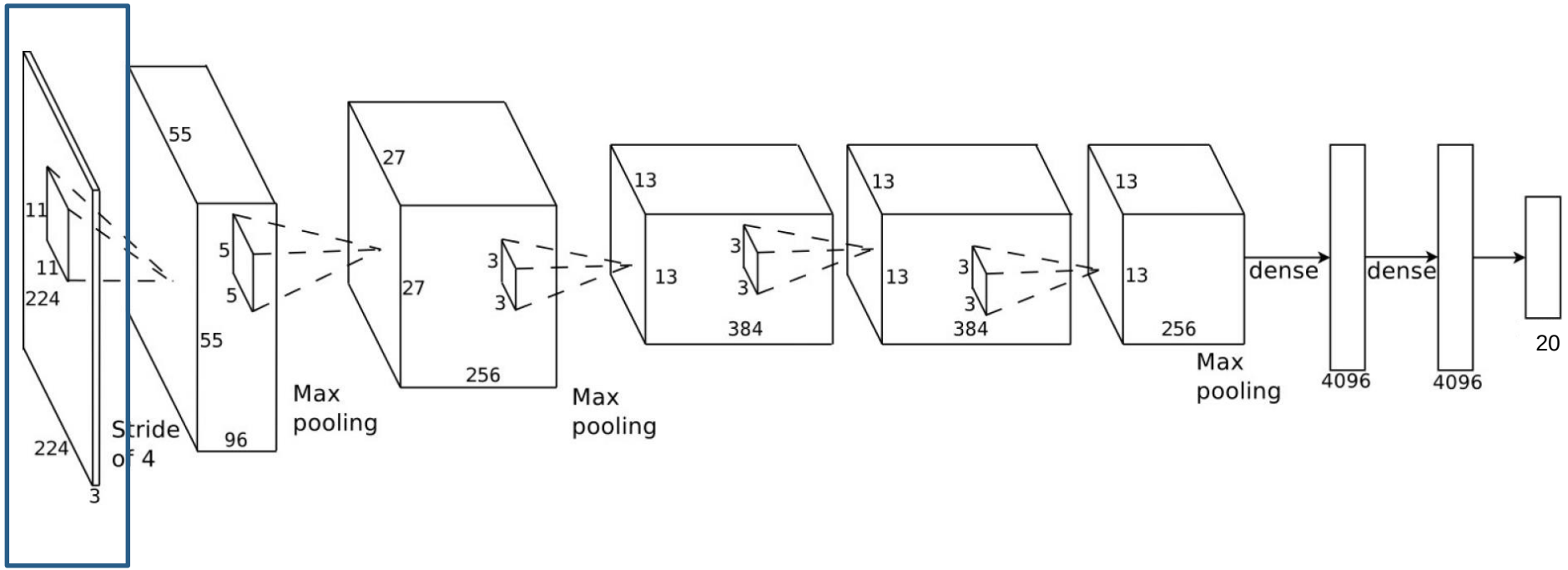


*image taken from Caffe Tutorial

```
name: "LogReg"
layer {
  name: "mnist"
  type: "Data"
  top: "data"
  top: "label"
  data_param {
    source: "input_leveldb"
    batch_size: 64
  }
}
layer {
  name: "ip"
  type: "InnerProduct"
  bottom: "data"
  top: "ip"
  inner_product_param {
    num_output: 2
  }
}
layer {
  name: "loss"
  type: "SoftmaxWithLoss"
  bottom: "ip"
  bottom: "label"
  top: "loss"
}
```

Data Layer



+ labels

Data Layer

Input Image

Image Label

(Number between 0 to 19)

*image taken from Caffe Tutorial

Data Layer

```
layer {
  name: "data"
  type: "ImageData"
  top: "data"
  top: "label"
  include {
    phase: TRAIN
  }
  transform_param {
    mirror: true
    crop_size: 227
    mean_file: "data/ilsvrc12/imagenet_mean.binaryproto"
  }
  image_data_param {
    source: "data/flickr_style/train.txt"
    batch_size: 50
    new_height: 256
    new_width: 256
  }
}
```

Layer Output

Randomly flip training images

Subtract mean from images

List of training images with labels

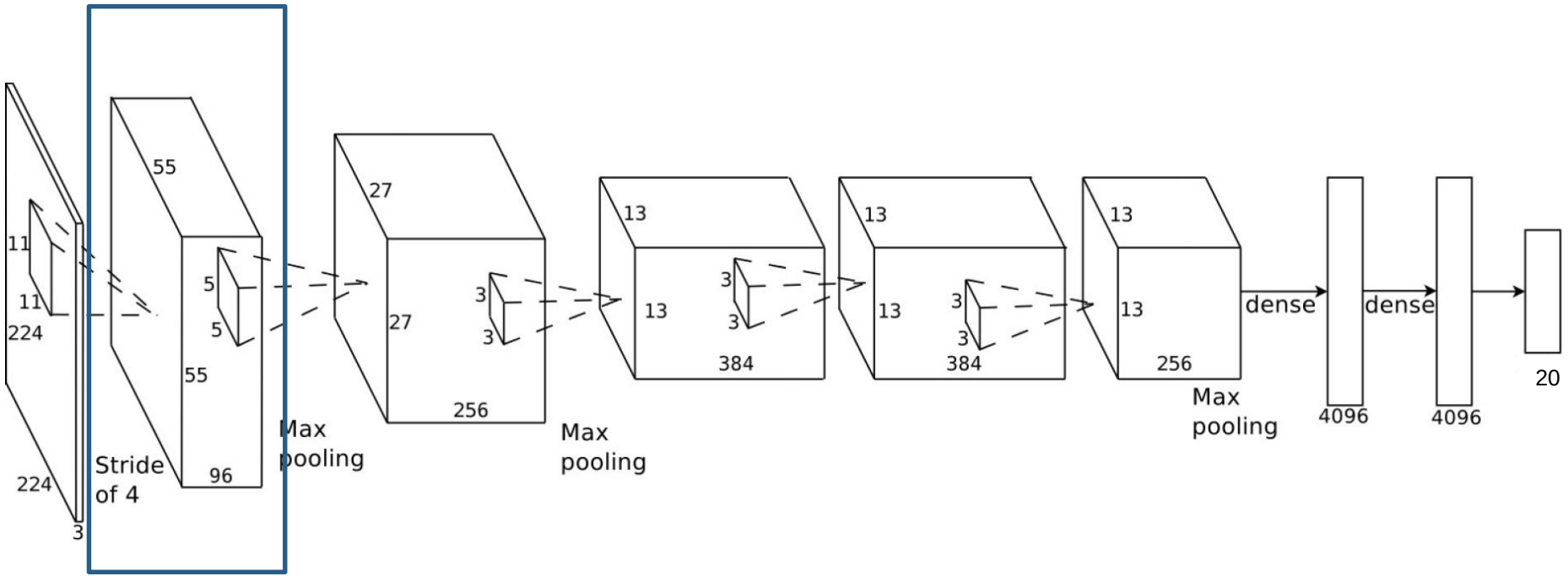
Resize image

Input File Format

- Open /data/flickr_style/train.txt
- Format: <Image Path> <Class Label>
- Example:-

/home/krishna/Downloads/caffe-master/data/flickr_style/images/12123529133_c1fb58f6dc.jpg 16
/home/krishna/Downloads/caffe-master/data/flickr_style/images/11603781264_0a34b7cc0a.jpg 12
/home/krishna/Downloads/caffe-master/data/flickr_style/images/12852147194_4c07cf49a1.jpg 9
/home/krishna/Downloads/caffe-master/data/flickr_style/images/8516303191_c243a80454.jpg 10
/home/krishna/Downloads/caffe-master/data/flickr_style/images/12223105575_581855dc34.jpg 2
/home/krishna/Downloads/caffe-master/data/flickr_style/images/9838077083_1b18cfca00.jpg 0
/home/krishna/Downloads/caffe-master/data/flickr_style/images/8660745510_dee5e4d819.jpg 14

Conv1 Layer



+ labels

Conv1 Layer

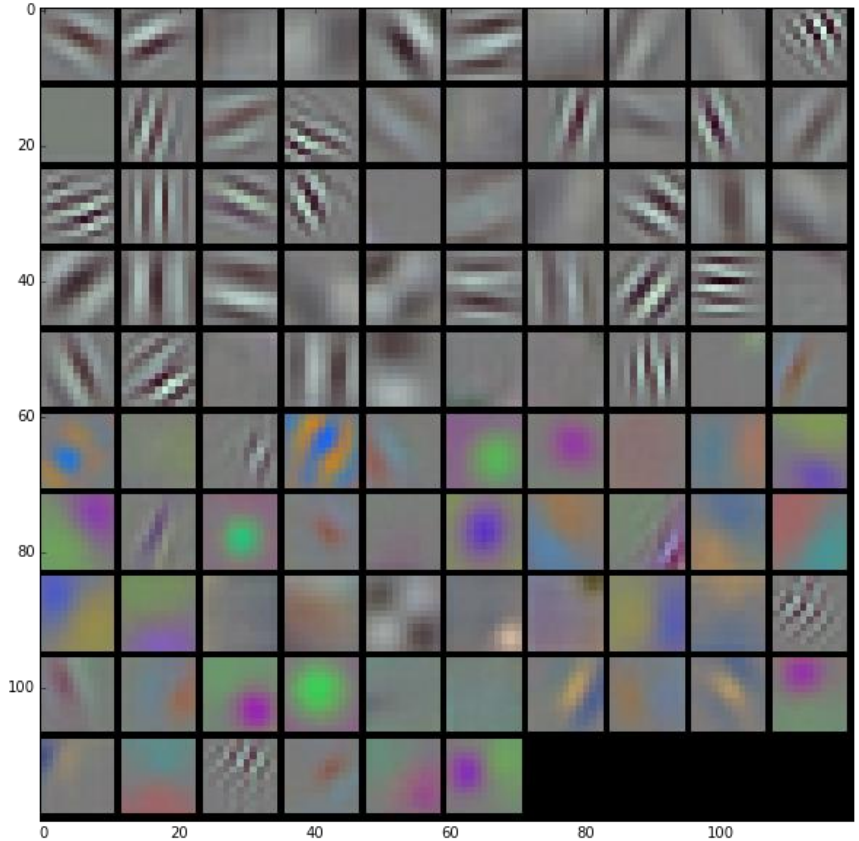
```
layer {
  name: "conv1"
  type: "Convolution"
  bottom: "data"
  top: "conv1"
  param {
    lr_mult: 1
    decay_mult: 1
  }
  param {
    lr_mult: 2
    decay_mult: 0
  }
  convolution_param {
    num_output: 96
    kernel_size: 11
    stride: 4
```

Learning rate and decay multiplier for weights

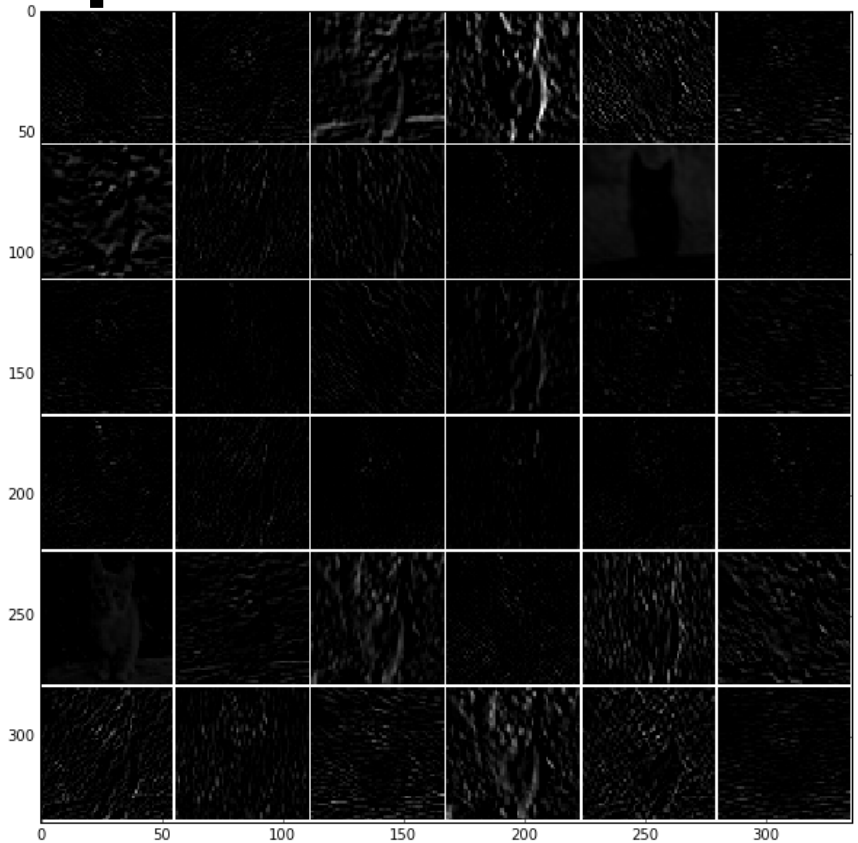
Learning rate and decay multiplier for bias

Filter Size: 96 X 11 X 11

Conv1 Filters and Response



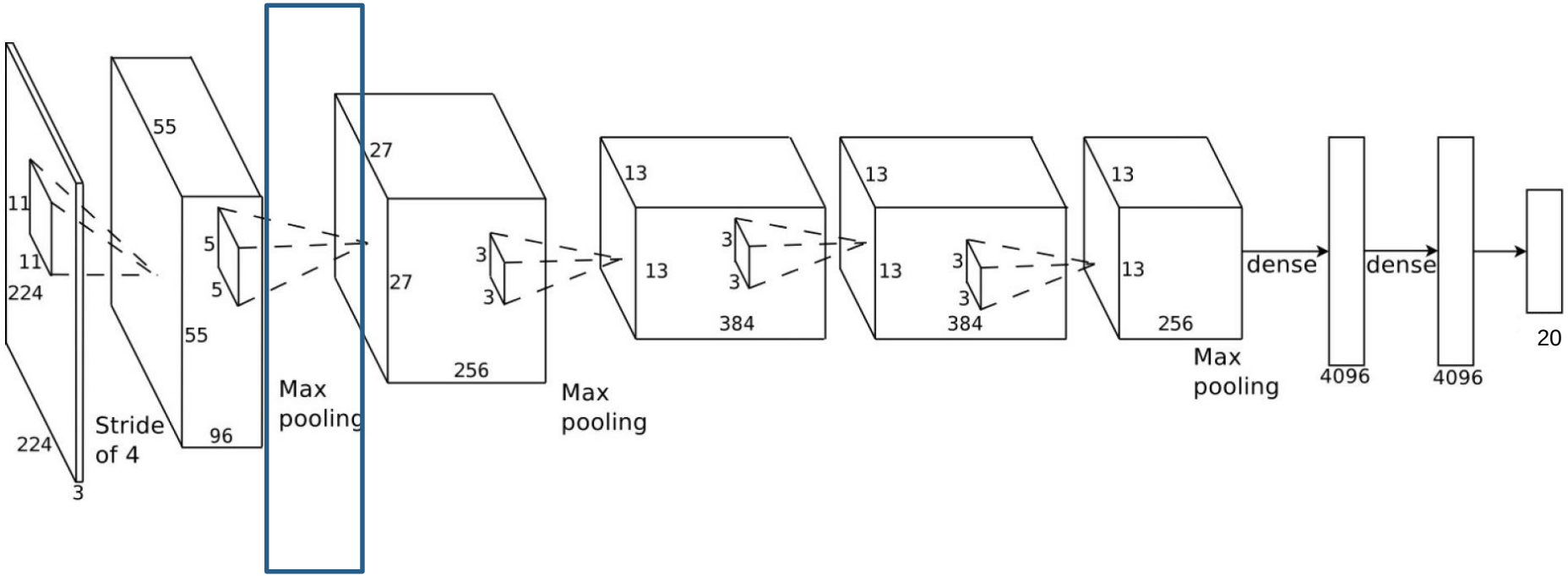
96 conv1 filters



conv1 output, first 36 only

*images taken from Caffe Tutorial

Max Pool Layer



+ labels

Max Pool Layer

```
layer {
  name: "pool1"
  type: "Pooling"
  bottom: "conv1"
  top: "pool1"
  pooling_param {
    pool: MAX
    kernel_size: 3
    stride: 2
  }
}
```

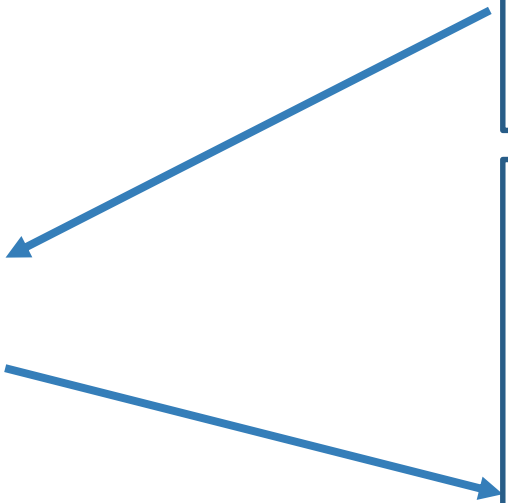
Max Pooling

```
layer {
  name: "relu1"
  type: "ReLU"
  bottom: "conv1"
  top: "conv1"
}
```

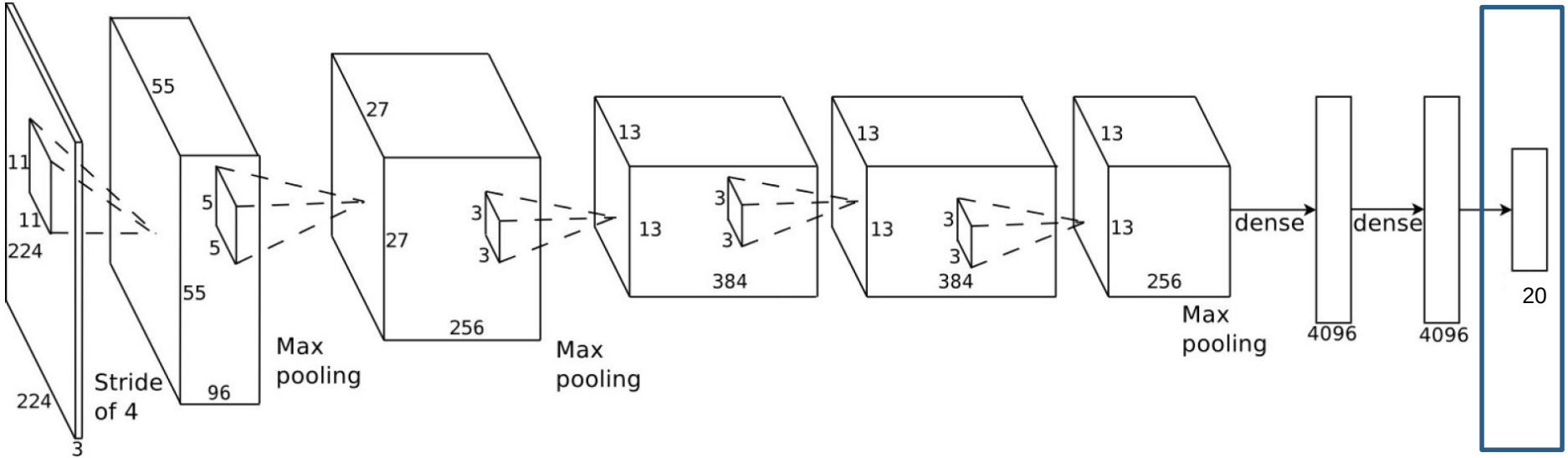
Rectified Linear

```
layer {
  name: "norm1"
  type: "LRN"
  bottom: "pool1"
  top: "norm1"
  lrn_param {
    local_size: 5
    alpha: 0.0001
    beta: 0.75
  }
}
```

Normalization



FC8 Layer



+ labels

FC8 Layer

```
layer {
  name: "fc8_flickr"
  type: "InnerProduct"
  bottom: "fc7"
  top: "fc8_flickr"
param {
    lr_mult: 1
    decay_mult: 1
  }
  param {
    lr_mult: 2
    decay_mult: 0
  }
  inner_product_param {
    num_output: 20
```

Number of classes

Loss Layer

```
layer {
  name: "loss"
  type: "SoftmaxWithLoss"
  bottom: "fc8_flickr"
  bottom: "label"
  top: "loss"
}
```

$Loss = -\log(Prob(X_{label}))$

$fc8\_flickr = [X_0 , X_1 , \ldots\ldots\ldots , X_{19}]$

$Prob(X_{label}) = \frac{e^{X_{label}}}{\sum_{i=0}^{19} e^{X_i}}$

Simplified Form

Test Phase

```
layer {
  name: "data"
  type: "ImageData"
  top: "data"
  top: "label"
  include {
    phase: TEST
  }
  transform_param {
    mirror: false
    crop_size: 227
    mean_file: "data/ilsvrc12/imagenet_mean.binaryproto"
  }
  image_data_param {
    source: "data/flickr_style/test.txt"
    batch_size: 50
    new_height: 256
    new_width: 256
  }
}
```

Check intermediate model on test images.

Contains test image list

Solving the Network

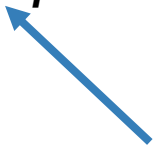
Please open models/finetune_flickr_style/solver.prototxt

Solver

net: "models/finetune_flickr_style/train_val.prototxt"
test_iter: 100
test_interval: 1000
base_lr: 0.001
lr_policy: "step"
gamma: 0.1
stepsize: 20000
display: 20
max_iter: 100000
momentum: 0.9
weight_decay: 0.0005
snapshot: 10000
snapshot_prefix: "models/finetune_flickr_style/finetune_flickr_style"
solver_mode: CPU

Solver

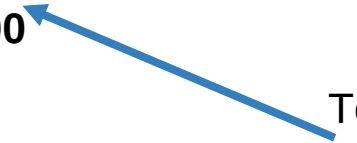
net: "models/finetune_flickr_style/train_val.prototxt"
test_iter: 100
test_interval: 1000
base_lr: 0.001
lr_policy: "step"
gamma: 0.1
stepsize: 20000
display: 20
max_iter: 100000
momentum: 0.9
weight_decay: 0.0005
snapshot: 10000
snapshot_prefix: "models/finetune_flickr_style/finetune_flickr_style"
solver_mode: CPU



File path of network Schema

Solver

net: "models/finetune_flickr_style/train_val.prototxt"
test_iter: 100
test_interval: 1000
base_lr: 0.001
lr_policy: "step"
gamma: 0.1
stepsize: 20000
display: 20
max_iter: 100000
momentum: 0.9
weight_decay: 0.0005
snapshot: 10000
snapshot_prefix: "models/finetune_flickr_style/finetune_flickr_style"
solver_mode: CPU

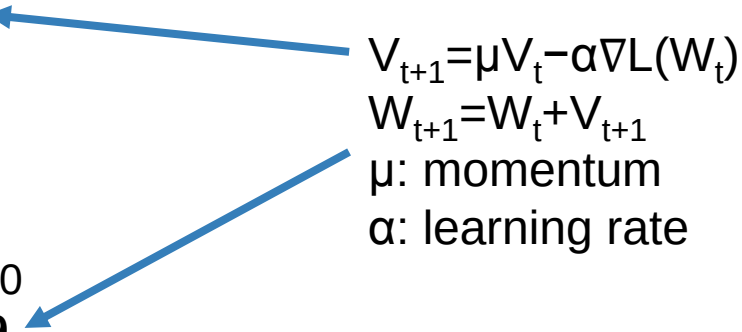


Test_iter: Number of batches for which testing will take place after test_interval iterations.

For ex:- test batch_size =50
Then after every 1000 iterations testing will take place on 5000 (100*50) images

Solver

net: "models/finetune_flickr_style/train_val.prototxt"
test_iter: 100
test_interval: 1000
base_lr: 0.001
lr_policy: "step"
gamma: 0.1
stepsize: 20000
display: 20
max_iter: 100000
momentum: 0.9
weight_decay: 0.0005
snapshot: 10000
snapshot_prefix: "models/finetune_flickr_style/finetune_flickr_style"
solver_mode: CPU



$V_{t+1} = \mu V_t - \alpha \nabla L(W_t)$

$W_{t+1} = W_t + V_{t+1}$

μ: momentum

α: learning rate

Solver

net: "models/finetune_flickr_style/train_val.prototxt"
test_iter: 100
test_interval: 1000
base_lr: 0.001
lr_policy: "step"
gamma: 0.1
stepsize: 20000
display: 20
max_iter: 100000
momentum: 0.9
weight_decay: 0.0005
snapshot: 10000
snapshot_prefix: "models/finetune_flickr_style/finetune_flickr_style"
solver_mode: CPU

After stepsize iterations decrease the learning rate by the factor of gamma

Solver

net: "models/finetune_flickr_style/train_val.prototxt"
test_iter: 100
test_interval: 1000
base_lr: 0.001
lr_policy: "step"
gamma: 0.1
stepsize: 20000
display: 20
max_iter: 100000
momentum: 0.9
weight_decay: 0.0005
snapshot: 10000
snapshot_prefix: "models/finetune_flickr_style/finetune_flickr_style"
solver_mode: CPU

Number of iterations after which loss is displayed

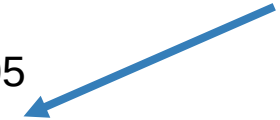
Solver

net: "models/finetune_flickr_style/train_val.prototxt"
test_iter: 100
test_interval: 1000
base_lr: 0.001
lr_policy: "step"
gamma: 0.1
stepsize: 20000
display: 20
max_iter: 100000 ← Number of iterations for which training will take place
momentum: 0.9
weight_decay: 0.0005
snapshot: 10000
snapshot_prefix: "models/finetune_flickr_style/finetune_flickr_style"
solver_mode: CPU

Solver

net: "models/finetune_flickr_style/train_val.prototxt"
test_iter: 100
test_interval: 1000
base_lr: 0.001
lr_policy: "step"
gamma: 0.1
stepsize: 20000
display: 20
max_iter: 100000
momentum: 0.9
weight_decay: 0.0005
snapshot: 10000
snapshot_prefix: "models/finetune_flickr_style/finetune_flickr_style"
solver_mode: CPU

After Snapshot iterations intermediate model is saved at snapshot_prefix

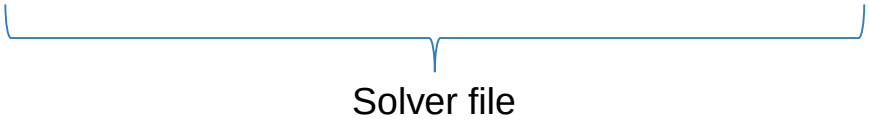


Solver

net: "models/finetune_flickr_style/train_val.prototxt"
test_iter: 100
test_interval: 1000
base_lr: 0.001
lr_policy: "step"
gamma: 0.1
stepsize: 20000
display: 20
max_iter: 100000
momentum: 0.9
weight_decay: 0.0005
snapshot: 10000
snapshot_prefix: "models/finetune_flickr_style/finetune_flickr_style"
solver_mode: CPU  If uncommented use CPU instead of GPU

Training Command

- Go to caffe root directory
- ./build/tools/caffe train -solver models/finetune_flickr_style/solver.prototxt



Training Command

- Go to caffe root directory
- ./build/tools/caffe train -solver models/finetune_flickr_style/solver.prototxt

Solver file

Slow convergence and limited training data, Fine-tuning will be better

Fine Tuning

- In normal training parameters are initialized by random numbers.
- In finetuning, training starts with parameters initialized with already learned model’s parameters.
- Finetune style recognition with model learned for Imagenet 1000 classes classification task.
- Copy parameters(weights) from Imagenet model except last layer.
- models/finetune_flickr_style/train_val.prototxt is already modified for finetuning.
- Open models/bvlc_reference_caffenet/train_val.prototxt to see the differences.

From Imagenet to Style

Imagenet

```
layer {
  name: "fc8"
  type: "InnerProduct"
  bottom: "fc7"
  top: "fc8"
param {
  lr_mult: 1
  decay_mult: 1
  }
  param {
  lr_mult: 2
  decay_mult: 0
  }
  inner_product_param {
  num_output: 1000
```

Same layer name parameters copied, Different name start from random

Higher learning rate because this layer is starting from random while the others are already trained

Different number of classes

Style

```
layer {
  name: "fc8_flickr"
  type: "InnerProduct"
  bottom: "fc7"
  top: "fc8_flickr"
param {
  lr_mult: 10
  decay_mult: 1
  }
  param {
  lr_mult: 20
  decay_mult: 0
  }
  inner_product_param {
  num_output: 20
```

Fine-tuning Command

./build/tools/caffe train --solver=<solver.prototxt> --weights=<caffemodel>

./build/tools/caffe train -solver models/finetune_flickr_style/solver.prototxt -weights models/bvlc_reference_caffenet/bvlc_reference_caffenet.caffemodel

Fine-tuning Command

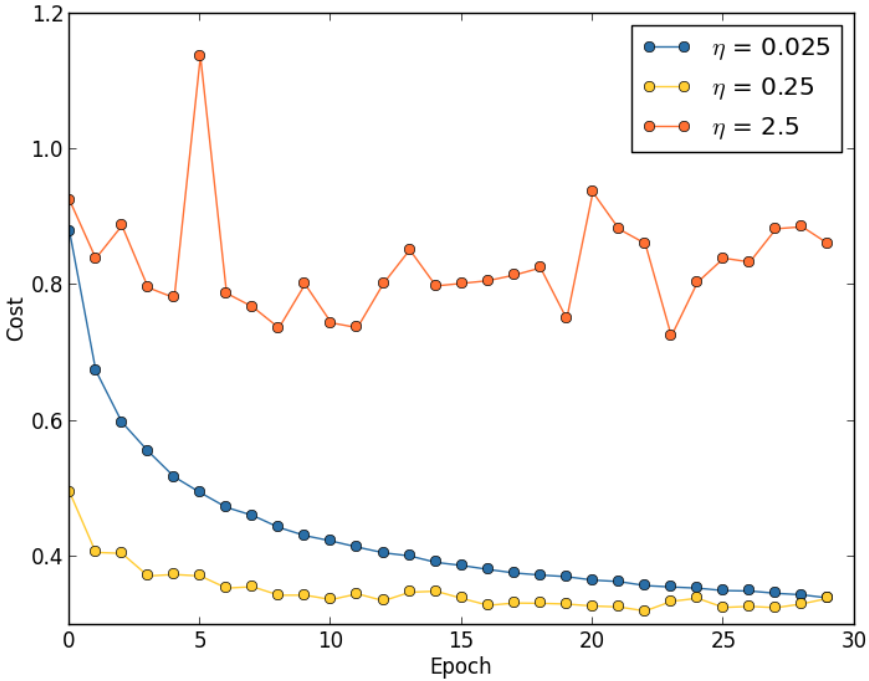
./build/tools/caffe train --solver=<solver.prototxt> --weights=<caffemodel>

./build/tools/caffe train -solver models/finetune_flickr_style/solver.prototxt -weights models/bvlc_reference_caffenet/bvlc_reference_caffenet.caffemodel

Model learns faster, better accuracy at faster rate

Deciding Base Learning Rate

- Too high learning rate make loss –nan.
- Too low learning rate make learning slow.
- Ideal learning rate while training from scratch is 0.01 and while fine-tuning is 0.001.
- Ideally loss should decrease with iterations.



*Graph taken from chapter 3 of “Improving the way neural networks learn”

Deciding Step Size and Max Iterations

- Decrease step size after ~18 epochs.
- Keep max iterations to be ~54 epochs.
- Monitor loss and accuracy on testing data.

Data Shuffling

- Training data and test data should be shuffled in random order.
- Allow non bias training:

```
/home/krishna/Downloads/caffe-master/data/flickr_style/images/12123529133_c1fb58f6dc.jpg 16
/home/krishna/Downloads/caffe-master/data/flickr_style/images/11603781264_0a34b7cc0a.jpg 12
/home/krishna/Downloads/caffe-master/data/flickr_style/images/12852147194_4c07cf49a1.jpg 9
/home/krishna/Downloads/caffe-master/data/flickr_style/images/8516303191_c243a80454.jpg 10
/home/krishna/Downloads/caffe-master/data/flickr_style/images/12223105575_581855dc34.jpg 2
/home/krishna/Downloads/caffe-master/data/flickr_style/images/9838077083_1b18cfca00.jpg 0
/home/krishna/Downloads/caffe-master/data/flickr_style/images/8660745510_dee5e4d819.jpg 14
```

Data Augmentation

- Useful when you don’t have enough training data.

- Some techniques:-
  - Rotate image by small angle.
  - Random crops.
  - Flipping image.
  - Translate image.
  - Adding random noise in RGB channel.

- Data augmentation should be uniformly distributed among classes.

Model Snapshot and Solverstate

- Take snapshot of your intermediate model frequently.
- Snapshot consist of :-snapshot_prefix_iterations.caffemodel and snapshot_prefix_iterations.solverstate.
- Solverstate allows you to resume training.
  ./build/tools/caffe train --solver=<solver.prototxt> --snapshot=<solverstate>
- Install screen, useful for doing long training remotely.

Extract Features

- build/tools/extract_features.bin <model_name> <network definition> <blob name> <output fie> <number of batches> <db_type> <device>

- In network definition file source should point to file containing list of images for which features have to be extracted.

- build/tools/extract_features.bin models/bvlc_reference_caffenet/bvlc_reference_caffenet.caffemodel examples/feature_extraction/imagenet_val.prototxt fc7 out_fc7 10 lmdb GPU

Time Benchmarking

- build/tools/caffe time -model <train_val prototxt> -iterations <number of iterations>
- Gives runtime analysis for each layer as well as for forward and back propagation.
- Bigger the batch size more the run time.

Regression

- Predict numbers associated with images.
- ‘image_data’ only allows single label per image.
- ‘HDF5Data’ allows image and label to be provided as vector.
- In fc8 layer, num_output will be equal to length of number vector you want to predict.
- Change Softmax loss to Euclidian loss.

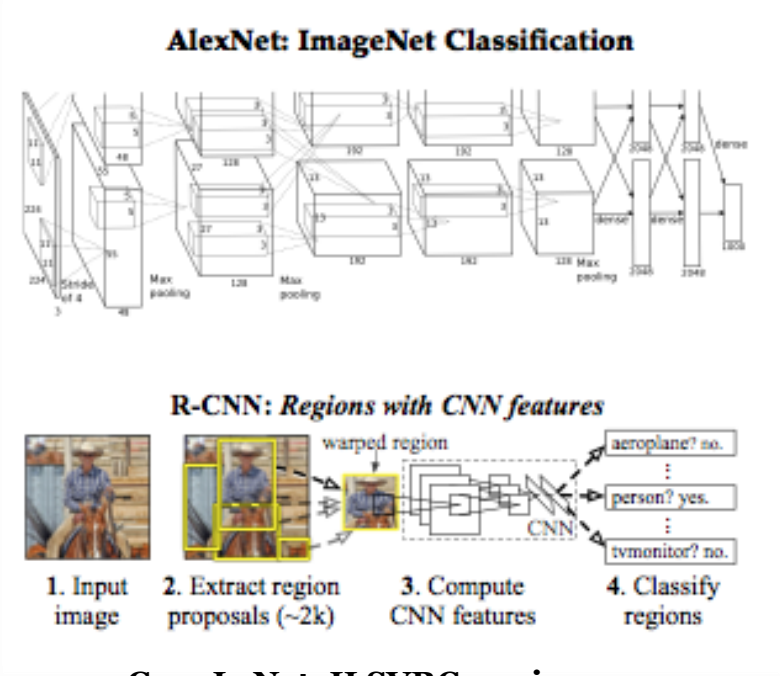
Adding Layers

- src/caffe/layers

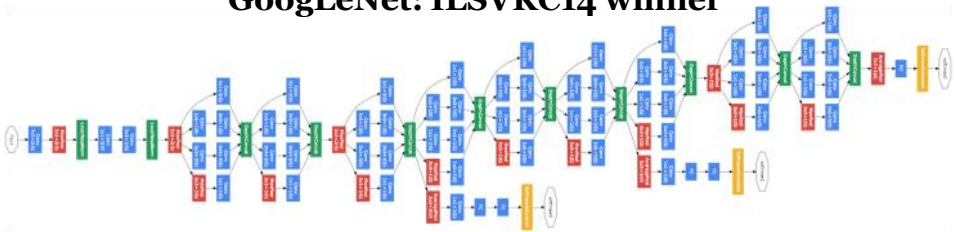
- CPU implementation: xx_layer.cpp
  - Forward_cpu
  - Backward_cpu

- GPU implementation: xx_layer.cu
  - Forward_gpu
  - Backward_gpu

Reference Models



GoogLeNet: ILSVRC14 winner



Caffe offers the

- model definitions
- optimization settings
- pre-trained weights

so you can start right away.

The BVLC models are licensed for unrestricted use.

The community shares models in Model Zoo.

Caffe Help

- http://caffe.berkeleyvision.org/tutorial/
- https://groups.google.com/forum/#!forum/caffe-users
- https://gitter.im/BVLC/caffe

Thank You