CS 231A Section: Computer Vision Libraries Overview

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Overview

- **Opencv**
- Deep Learning Frameworks
  - **Caffe**
  - Torch
  - Tensorflow

Other CV libraries

- **Vlfeat:** An Open source library with popular computer vision algorithms specializing in image understanding and local features extraction and matching.
- **scikit-learn:** An open source Python library that implements a range of machine learning, preprocessing, cross-validation and visualization algorithms.
- **PCL:** A standalone, large scale, open project for 2D/3D image and point cloud processing.
- **SLAM frameworks (bundler, visualsfm, meshlab):** Applications for 3D reconstruction using structure from motion (SFM).
- **Libraries for specific tasks:** e.g. tracking libraries, Detection libraries …

OpenCV

Introduction to OpenCV

- Open source computer vision and machine learning library
- Contains implementations of a large number of vision algorithms
- Written natively in C++, also has C, Python, Java, and MATLAB interfaces
- Supports Windows, Linux, Mac OS X, Android, and iOS

Installation

- Download from http://opencv.org and compile from source
- Windows: Run executable downloaded from OpenCV website
- Mac OS X: Install through MacPorts, easy_install, …
- Linux: Install through the package manager (e.g. yum, apt) but make sure the version is sufficiently up-to-date for your needs

Basic OpenCV Structures

- **Point, Point2f** - 2D Point
- **Size** - 2D size structure
- **Rect** - 2D rectangle object
- **RotatedRect** - Rect object with angle
- **Mat** - image object

Point

- 2D Point Object
  - int x, y;
- Sample Functions
  - Point.**dot**(<Point>) - **computes dot product**
  - Point.**inside**(<Rect>) - **returns true if point is inside**

```
int main(int argc, char* argv[]){

  Point a(1,1);
  Point b(2,2);
  Point c = a+b;

  cout << c.x << ", " << c.y << endl;
  c = a*2;
  cout << c.x << ", " << c.y << endl;
  cout << norm(b) << endl;

  if(a==b)
    cout << "A == B" << endl;
  else
    cout << "A != B" << endl;
  if(b != c)
    cout << "B != C" << endl;
  else
    cout << "B == C" << endl;
  return 0;
}
```

Math operators, you may use

-Point operator +

-Point operator +=

-Point operator -

-Point operator -=

-Point operator *

-Point operator *=

-bool operator ==

-bool operator !=

-double norm

Size

- 2D Size Structure
  - int width, height;
- Functions
  - Size.area() - returns (width * height)

Rect

- 2D Rectangle Structure
  - int x, y, width, height;
- Functions
  - Rect.tl() - return top left point
  - Rect.br() - return bottom right point

cv::Mat

- The primary data structure in OpenCV is the Mat object. It stores images and their components.
- Main items
  - rows, cols - length and width(int)
  - channels - 1: grayscale, 3: BGR
  - depth: CV_<depth>C<num chan>

```
int main(int argc, char* argv[]){

  Mat image = imread(argv[1]);

  cout << "Colums = " << image.cols << endl;
  cout << "Rows   = " << image.rows << endl;
  cout << "Type   = ";

  if(image.type() == CV_8UC1)  cout << "CV_8UC1" << endl;
  else if(image.type() == CV_8UC3)  cout << "CV_8UC3" << endl;
  else if(image.type() == CV_32FC1) cout << "CV_32FC1" << endl;
  else if(image.type() == CV_32FC3) cout << "CV_32FC3" << endl;
  else cout << "Unknown" << endl;

  return 0;
```

- See the manuals for more information

cv::Mat- Functions

- Mat.**at**<datatype>(row, col)[channel] - **returns pointer to image location**
- Mat.**channels**() - **returns the number of channels**
- Mat.**clone**() - **returns a deep copy of the image**
- Mat.**create**(rows, cols, TYPE) - **re-allocates new memory to matrix**
- Mat.**cross**(<Mat>) - **computes cross product of two matricies**
- Mat.**depth**() - **returns data type of matrix**
- Mat.**dot**(<Mat>) - **computes the dot product of two matrices**

Pixeltypes

- PixelTypes shows how the image is represented in data
  - **BGR** - The default color of imread(). Normal 3 channel color
  - **HSV** - Hue is color, Saturation is amount, Value is lightness. 3 channels
  - **GRAYSCALE** - Gray values, Single channel
- OpenCV requires that images be in BGR or Grayscale in order to be shown or saved. Otherwise, undesirable effects may appear.

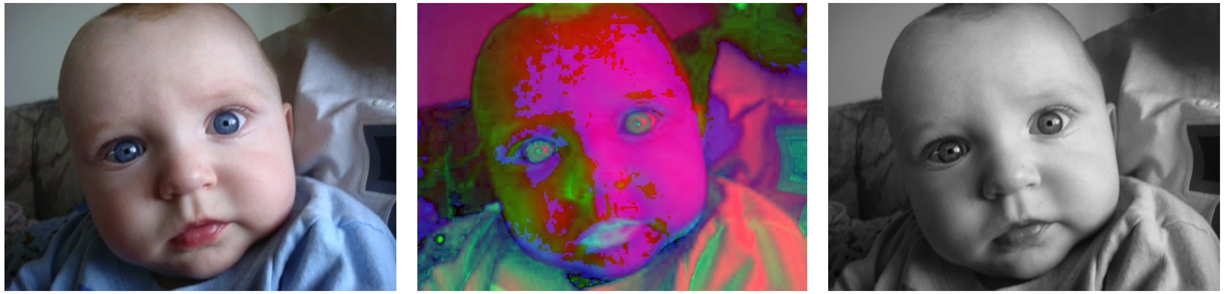


Image Normalization and Thresholding

- Normalization remaps a range of pixel values to another range of pixel values
  - void normalize(InputArray src,OutputArray dst,…)

- OpenCV provides a general purpose method for thresholding an image
  - double threshold(InputArray src,OutputArray dst,double thresh,double maxval,int type)
  - Specify thresholding scheme specified by the type variable

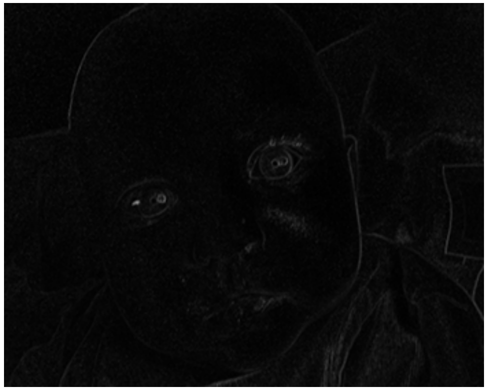




Image Smoothing

- Reduces the sharpness of edges and smooths out details in an image

- OpenCV implements several of the most commonly used methods

- void GaussianBlur(InputArray src,OutputArray dst,…)
- void medianBlur(InputArray src,OutputArray dst,…)

- Other functions include generic convolution, separable convolution, dilate, and erode.

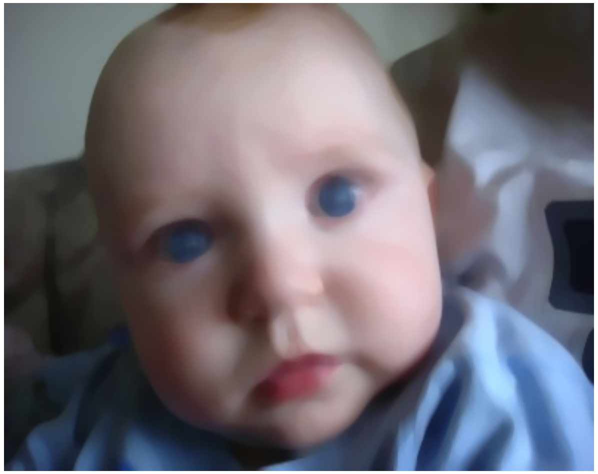
Image Smoothing: Code

```
#include <cv.h>
#include <cvaux.h>
#include <highgui.h>

int main(int argc,char** argv){
    //Read in colored image
    cv::Mat image=cv::imread(argv[1]);
    cv::imwrite("photo.jpg",image);
    //Apply Gaussian blur
    cv::Mat image_gaussian_blur;
    image.convertTo(image_gaussian_blur,CV_8UC3);
    cv::GaussianBlur(image_gaussian_blur,image_gaussian_blur,cv::Size(0,0),9);
    cv::imwrite("photo_gaussian_blur.jpg",image_gaussian_blur);

    //Apply median blur
    cv::Mat image_median_blur;
    image.convertTo(image_median_blur,CV_8UC3);
    cv::medianBlur(image_median_blur,image_median_blur,17);
    cv::imwrite("photo_median_blur.jpg",image_median_blur);
}
```

Image Smoothing: Sample Image

Original

Gaussian Blur



Median Blur

Edge Detection

- OpenCV implements a number of operators to help detect edges in an image
  - Sobel Operator
    - void cv::Sobel(image in, image out, CV_DEPTH, dx, dy);
  - Scharr Operator
    - void cv::Scharr(image in, image out, CV_DEPTH, dx, dy);
  - Laplacian Operator
    - void cv::Laplacian(image in, image out, CV_DEPTH);
- OpenCV also implements multi-stage edge detection algorithms such as Canny edge detection
- Tip: If your image is noisy, then edge detection will often exaggerate the noise
- Sometimes smoothing the image before running edge detection gives better results

Edge Detection: Code

```
#include <cv.h>
#include <cvaux.h>
#include <highgui.h>

int main(int argc,char** argv){
    //Read image as grayscale, delete zero to read in color
    cv::Mat image=cv::imread(argv[1],0);
    cv::imwrite("photo_gray.jpg",image);

    //Calculate x-gradient using Sobel operator
    cv::Mat image_gradient_x;
    image.convertTo(image_gradient_x,CV_32FC1);
    cv::Sobel(image_gradient_x,image_gradient_x,CV_32FC1,0,1);
    //Absolute value and normalize
    cv::convertScaleAbs(image_gradient_x,image_gradient_x);

    //Calculate y-gradient using Sobel operator
    cv::Mat image_gradient_y;
    image.convertTo(image_gradient_y,CV_32FC1);
    cv::Sobel(image_gradient_y,image_gradient_y,CV_32FC1,1,0);
    //Absolute value and normalize
    cv::convertScaleAbs(image_gradient_y,image_gradient_y);

    //Average the x and y gradients into one image
    cv::Mat image_gradient;
    cv::addWeighted(image_gradient_x,0.5,image_gradient_y,0.5,0,image_gradient);
    cv::imwrite("photo_gradient.jpg",image_gradient);
}
```

Edge Detection: Sample Results

Face Detection: Viola-Jones

- Robust and fast
- Introduced by Paul Viola and Michael Jones
  - http://research.microsoft.com/~viola/Pubs/Detect/violaJones_CVPR2001.pdf
- Haar-like Features

And Many More …

- Object Tracking using OpenCV
- Handwritten Digits Classification : An OpenCV (C++ / Python) Tutorial
- Eye Detector using OpenCV
- Image Recognition and Object Detection
- Head Pose Estimation using OpenCV
- Configuring Qt for OpenCV
- …

Deep Learning Frameworks

Deep Learning Frameworks

- Caffe
- Torch/PyTorch
  - NYU
  - scientific computing framework in Lua
  - supported by Facebook
- TensorFlow
  - Google
  - Python
- Theano/Pylearn2
  - U. Montreal
  - Python
  - symbolic computation and automatic differentiation
- MatConvNet
  - Oxford U.
  - Deep Learning in MATLAB

Framework Comparison

- More alike than different
  - All express deep models
  - All are open-source (contributions differ)
  - Most include scripting for hacking and prototyping

- No strict winners, experiment and choose the framework that best fits your work

Caffe: Overview

- What is Caffe?
- Training/Finetuning a simple model
- Deep dive into Caffe!

What is Caffe?

- A deep learning framework
- Open framework, models, and worked examples for deep learning
- 4000+ citations, 250+ contributors, 11,000+ forks
- Focus has been vision, but branching out: sequences, reinforcement learning, speech + text

Caffe

- Pure C++ / CUDA architecture for deep learning
  - command line, Python, MATLAB interfaces
- Fast, well-tested code
- Tools, reference models, demos, and recipes
- Switch between CPU and GPU
  - Caffe::set_mode(Caffe::GPU);

Installation

- http://caffe.berkeleyvision.org/installation.html •
- CUDA, OPENCV
- BLAS (Basic Linear Algebra Subprograms): operations like matrix multiplication, matrix addition, both implementation for CPU(cBLAS) and GPU(cuBLAS). provided by MKL(INTEL), ATLAS, openBLAS, etc.
- Boost: a c++ library. > Use some of its math functions and shared_pointer.
- glog,gflags provide logging & command line utilities. > Essential for debugging.
- leveldb, lmdb: database io for your program. > Need to know this for preparing your own data.
- protobuf: an efficient and flexible way to define data structure. > Need to know this for defining new layers.

Caffe Tutorial

- Nets, Layers, and Blobs: the anatomy of a Caffe model.
- Forward / Backward: the essential computations of layered compositional models.
- Loss: the task to be learned is defined by the loss.
- Solver: the solver coordinates model optimization.
- Interfaces: command line, Python, and MATLAB Caffe.
- Data: how to caffeinate data for model input.

http:/caffe.berkeleyvision.org/tutorial/

Caffe

- Blob: Storage and Communication of Data
  - Data blobs are N x C x H x W
- Net: Contains all the layers in the networks
  - Performs forward/backward pass through the entire network
- Solver: Used to set training/testing parameters
  - Number of iterations, back propagation method, etc..

Training: Step 1

- Create a lenet_train.prototxt
- Data Layers
- Operational Layers
- Loss Layers

Network Definition(train.prototxt)

```
name: "LeNet"
layer {
  name: "mnist"
  type: "Data"
  top: "data"
  top: "label"
  include {
    phase: TRAIN
  }
  transform_param {
    scale: 0.00390625
  }
  data_param {
    source: "examples/mnist/mnist_train_lmdb"
    batch_size: 64
    backend: LMDB
  }
}
```

```
layer {
  name: "conv1"
  type: "Convolution"
  bottom: "data"
  top: "conv1"
  param {
    lr_mult: 1
  }
  param {
    lr_mult: 2
  }
  convolution_param {
    num_output: 20
    kernel_size: 5
    stride: 1
    weight_filler {
      type: "xavier"
    }
    bias_filler {
      type: "constant"
    }
  }
}
```

Network Definition(train.prototxt)

```
layer {
  name: "pool2"
  type: "Pooling"
  bottom: "conv2"
  top: "pool2"
  pooling_param {
    pool: MAX
    kernel_size: 2
    stride: 2
  }
}
```

```
layer {
  name: "relu1"
  type: "ReLU"
  bottom: "ip1"
  top: "ip1"
}
```

```
layer {
  name: "ip1"
  type: "InnerProduct"
  bottom: "pool2"
  top: "ip1"
  param {
    lr_mult: 1
  }
  param {
    lr_mult: 2
  }
  inner_product_param {
    num_output: 500
    weight_filler {
      type: "xavier"
    }
    bias_filler {
      type: "constant"
    }
  }
}
```

Network Definition(train.prototxt)

```
layer {
  name: "loss"
  type: "SoftmaxWithLoss"
  bottom: "ip2"
  bottom: "label"
  top: "loss"
}
```

Training: Step 2

- Create a lenet_solver.prototxt

```
train_net:        "lenet_train.prototxt"
base_lr:          0.01
momentum:         0.9
weight_decay:     0.0005
max_iter:         10000
snapshot_prefix:  "lenet_snapshot"
# … and some other options …
```

Solver(solver.prototxt)

```
# The train/test net protocol buffer definition
net: "examples/mnist/lenet_train_test.prototxt"
# test_iter specifies how many forward passes the test should carry out.
# In the case of MNIST, we have test batch size 100 and 100 test iterations,
# covering the full 10,000 testing images.
test_iter: 100
# Carry out testing every 500 training iterations.
test_interval: 500
# The base learning rate, momentum and the weight decay of the network.
base_lr: 0.01
momentum: 0.9
weight_decay: 0.0005
# The learning rate policy
lr_policy: "step"
gamma: 0.1
stepsize: 3000
# Display every 100 iterations
display: 100
# The maximum number of iterations
max_iter: 10000
# snapshot intermediate results
snapshot: 5000
snapshot_prefix: "examples/mnist/lenet"
# solver mode: CPU or GPU
solver_mode: GPU
```

Training: Step 2

- Some details on SGD parameters

Momentum → μ, LR → α, Decay → λ

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

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

Training: Step 3

- # train LeNet
  - caffe train -solver examples/mnist/lenet_solver.prototxt
- # train on GPU 2
  - caffe train -solver examples/mnist/lenet_solver.prototxt -gpu 2
- # resume training from the half-way point snapshot
  - caffe train -solver examples/mnist/lenet_solver.prototxt -snapshot examples/mnist/lenet_iter_5000.solverstate

Network Definition(test.prototxt)

Previously

```
name: "LeNet"
layer {
  name: "mnist"
  type: "Data"
  top: "data"
  top: "label"
  include {
    phase: TRAIN
  }
  transform_param {
    scale: 0.00390625
  }
  data_param {
    source: "examples/mnist/mnist_train_lmdb"
    batch_size: 64
    backend: LMDB
  }
}
```

```
layer {
  name: "mnist"
  type: "Data"
  top: "data"
  top: "label"
  include {
    phase: TEST
  }
  transform_param {
    scale: 0.00390625
  }
  data_param {
    source: "examples/mnist/mnist_test_lmdb"
    batch_size: 100
    backend: LMDB
  }
}
```

Network Definition(test.prototxt)

Previously

```
layer {
  name: "loss"
  type: "SoftmaxWithLoss"
  bottom: "ip2"
  bottom: "label"
  top: "loss"
}
```

```
layer {
  name: "accuracy"
  type: "Accuracy"
  bottom: "ip2"
  bottom: "label"
  top: "accuracy"
  include {
    phase: TEST
  }
}
```

PyCaffe (Training in Python)

- Add caffe python directory to path and import caffe

```
caffe_root = '../'  # this file should be run from {caffe_root}/examples (otherwise change this li
ne)

import sys
sys.path.insert(0, caffe_root + 'python')
import caffe
```

Use NetSpec to define layers

```
from caffe import layers as L, params as P

def lenet(lmdb, batch_size):
    # our version of LeNet: a series of linear and simple nonlinear transformations
    n = caffe.NetSpec()

    n.data, n.label = L.Data(batch_size=batch_size, backend=P.Data.LMDB, source=lmdb,
                             transform_param=dict(scale=1./255), ntop=2)

    n.conv1 = L.Convolution(n.data, kernel_size=5, num_output=20, weight_filler=dict(type='xavie
r'))
    n.pool1 = L.Pooling(n.conv1, kernel_size=2, stride=2, pool=P.Pooling.MAX)
    n.conv2 = L.Convolution(n.pool1, kernel_size=5, num_output=50, weight_filler=dict(type='xavie
r'))
    n.pool2 = L.Pooling(n.conv2, kernel_size=2, stride=2, pool=P.Pooling.MAX)
    n.fc1 =   L.InnerProduct(n.pool2, num_output=500, weight_filler=dict(type='xavier'))
    n.relu1 = L.ReLU(n.fc1, in_place=True)
    n.score = L.InnerProduct(n.relu1, num_output=10, weight_filler=dict(type='xavier'))
    n.loss =  L.SoftmaxWithLoss(n.score, n.label)

    return n.to_proto()

with open('mnist/lenet_auto_train.prototxt', 'w') as f:
    f.write(str(lenet('mnist/mnist_train_lmdb', 64)))

with open('mnist/lenet_auto_test.prototxt', 'w') as f:
    f.write(str(lenet('mnist/mnist_test_lmdb', 100)))
```

Define solver and train network

```
caffe.set_device(0)
caffe.set_mode_gpu()

### load the solver and create train and test nets
solver = None  # ignore this workaround for lmdb data (can't instantiate two solvers on the same d
ata)
solver = caffe.SGDSolver('mnist/lenet_auto_solver.prototxt')
```

```
# each output is (batch size, feature dim, spatial dim)
[(k, v.data.shape) for k, v in solver.net.blobs.items()]
```

```
[('data', (64, 1, 28, 28)),
 ('label', (64,)),
 ('conv1', (64, 20, 24, 24)),
 ('pool1', (64, 20, 12, 12)),
 ('conv2', (64, 50, 8, 8)),
 ('pool2', (64, 50, 4, 4)),
 ('fc1', (64, 500)),
 ('score', (64, 10)),
 ('loss', ())]
```

```
solver.net.forward()  # train net
```

Access Net data

```
# we use a little trick to tile the first eight images
imshow(solver.net.blobs['data'].data[:8, 0].transpose(1, 0, 2).reshape(28, 8*28), cmap='gray'); ax
is('off')
print 'train labels:', solver.net.blobs['label'].data[:8]
```

```
train labels: [ 5.  0.  4.  1.  9.  2.  1.  3.]
```

PyCaffe (Testing in Python)

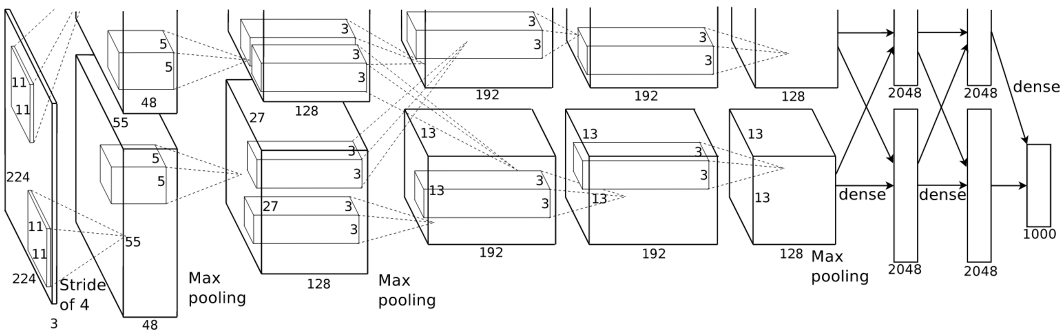
```
#load the model
net = caffe.Net('models/bvlc_reference_caffenet/train.prototxt',
                'models/bvlc_reference_caffenet/train_iter30000.caffemodel',
                caffe.TEST)

# load input and configure preprocessing
transformer = caffe.io.Transformer({'data': net.blobs['data'].data.shape})
transformer.set_mean('data', np.load('ilsvrc_2012_mean.npy').mean(1).mean(1))
transformer.set_transpose('data', (2,0,1))
transformer.set_channel_swap('data', (2,1,0))
transformer.set_raw_scale('data', 255.0)

#note we can change the batch size on-the-fly
#since we classify only one image, we change batch size from 10 to 1
net.blobs['data'].reshape(1,3,227,227)

#load the image in the data layer
im = caffe.io.load_image('examples/images/cat.jpg')
net.blobs['data'].data[...] = transformer.preprocess('data', im)

#compute
out = net.forward()

# other possibility : out = net.forward_all(data=np.asarray([transformer.preprocess('data', im)]))

#predicted predicted class
print out['prob'].argmax()
```

Open Model Collection

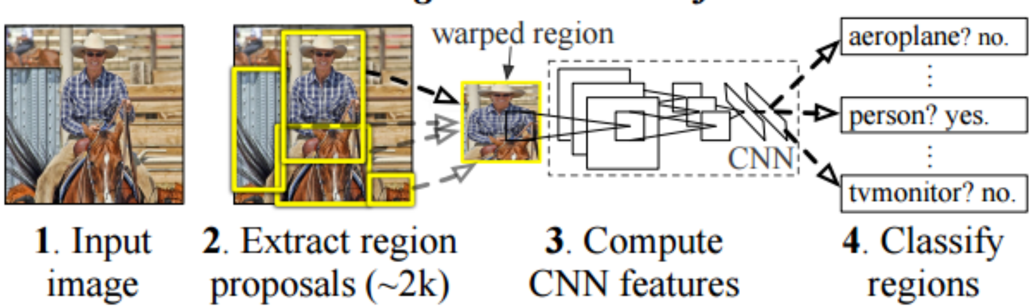
- The Caffe Model Zoo
- open collection of deep models to share innovation
  - VGG ILSVRC14 + Devil models in the zoo
  - Network-in-Network / CCCP model in the zoo
    - MIT Places scene recognition model in the zoo
  - Help reproduce research
  - Bundled tools for loading and publishing models
- Share Your Models! with your citation + license of course

Reference Models

Alexnet: Imagenet Classification



R-CNN: *Regions with CNN features*



Caffe offers the

- Model definitions
- Optimization settings
- Pre-trained weights so you can start right away.

When to Fine-tune?

- A good first step!
  - More robust optimization
  - good initialization helps
  - Needs less data
  - Faster learning

- State-of-the-art results in
  - recognition
  - detection
  - segmentation

Fine-tuning Tricks

- Learn the last layer first
  - Caffe layers have local learning rates: blobs_lr
  - Freeze all but the last layer for fast optimization and avoiding early divergence.
  - Stop if good enough, or keep fine-tuning
- Reduce the learning rate
  - Drop the solver learning rate by 10x, 100x –
  - Preserve the initialization from pre-training and avoid thrashing

CNN Training tips

- Before running final/long training
  - Make sure you can overfit on a small training set
  - Make sure your loss decreases over first several iterations
  - Otherwise adjust parameter until it does, especially learning rate

- Separate train/val/test data

Any Questions?