Deep Learning Basics
Lecture 6: Convolutional NN

Princeton University COS 495
Instructor: Yingyu Liang
Review: convolutional layers
Convolution: two dimensional case

Input

Kernel/filter

Feature map

\[
\begin{align*}
wa + bx + ey + fz &= bw + cx + fy + gz \\
\end{align*}
\]
Convolutional layers

the same weight shared for all output nodes

Figure from *Deep Learning*, by Goodfellow, Bengio, and Courville
Terminology

Complex layer terminology
- Next layer
- Convolutional Layer
  - Pooling stage
  - Detector stage:
    Nonlinearity
    e.g., rectified linear
  - Convolution stage:
    Affine transform
- Input to layer

Simple layer terminology
- Next layer
- Pooling layer
- Detector layer: Nonlinearity
  e.g., rectified linear
- Convolution layer:
  Affine transform
- Input to layers

Figure from *Deep Learning*, by Goodfellow, Bengio, and Courville
Case study: LeNet-5
LeNet-5

• Proposed in “Gradient-based learning applied to document recognition”, by Yann LeCun, Leon Bottou, Yoshua Bengio and Patrick Haffner, in Proceedings of the IEEE, 1998
LeNet-5

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• Apply convolution on 2D images (MNIST) and use backpropagation
LeNet-5

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• Apply convolution on 2D images (MNIST) and use backpropagation

• Structure: 2 convolutional layers (with pooling) + 3 fully connected layers
  • Input size: 32x32x1
  • Convolution kernel size: 5x5
  • Pooling: 2x2
Figure from *Gradient-based learning applied to document recognition*, by Y. LeCun, L. Bottou, Y. Bengio and P. Haffner
LeNet-5

Figure from *Gradient-based learning applied to document recognition*, by Y. LeCun, L. Bottou, Y. Bengio and P. Haffner
LeNet-5

Filter: 5x5, stride: 1x1, #filters: 6

Figure from *Gradient-based learning applied to document recognition*, by Y. LeCun, L. Bottou, Y. Bengio and P. Haffner
LeNet-5

Pooling: 2x2, stride: 2

Figure from *Gradient-based learning applied to document recognition*, by Y. LeCun, L. Bottou, Y. Bengio and P. Haffner
LeNet-5

Figure from *Gradient-based learning applied to document recognition*, by Y. LeCun, L. Bottou, Y. Bengio and P. Haffner
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Figure from Gradient-based learning applied to document recognition, by Y. LeCun, L. Bottou, Y. Bengio and P. Haffner
LeNet-5

Weight matrix: 400x120

Figure from *Gradient-based learning applied to document recognition*, by Y. LeCun, L. Bottou, Y. Bengio and P. Haffner
LeNet-5

Figure from *Gradient-based learning applied to document recognition*, by Y. LeCun, L. Bottou, Y. Bengio and P. Haffner
Software platforms for CNN

Updated in April 2016; checked more recent ones online
Platform: Marvin (marvin.is)

Marvin
A minimalist GPU-only N-dimensional ConvNet framework

Learn more  Questions?

Marvin thinks, therefore Marvin is.

Never before has it been so easy to learn so deeply. Marvin was born to be hacked, relying on few dependencies and basic C++. All code lives in two files (marvin.hpp and marvin.cu) and all numbers take up two bytes (FP16). Win friends and influence people in four easy steps:
Platform: Marvin by PRINCETON VISION GROUP
LeNet in Marvin: convolutional layer

```json
{
    "in": ["data"],
    "type": "Convolution",
    "name": "convl",
    "num_output": 20,
    "window": [5, 5],
    "padding": [0, 0],
    "stride": [1, 1],
    "upscale": [1, 1],
    "weight_lr_mult": 1.0,
    "weight_filler": "Xavier",
    "bias_lr_mult": 2.0,
    "bias_filler": "Constant",
    "bias_filler_param": 0.0,
    "out": ["convl"]
}
```
LeNet in Marvin: pooling layer

```json
{
    "in": ["conv1"],
    "type": "Pooling",
    "name": "pool1",
    "mode": "max",
    "window": [2, 2],
    "padding": [0, 0],
    "stride": [2, 2],
    "out": ["pool1"]
}
```
LeNet in Marvin: fully connected layer

```json
{
  "in": ["pool2"],
  "type": "InnerProduct",
  "name": "ipl",
  "num_output": 500,
  "weight_lr_mult": 1.0,
  "weight_filler": "Xavier",
  "bias_lr_mult": 2.0,
  "bias_filler": "Constant",
  "bias_filler_param": 0.0,
  "out": ["ipl"]
}
```
Platform: Caffe (caffe.berkeleyvision.org)

Caffe

Deep learning framework by the BVLC

Created by
Yangqing Jia
Lead Developer
Evan Shelhamer

Caffe is a deep learning framework made with expression, speed, and modularity in mind. It is developed by the Berkeley Vision and Learning Center (BVLC) and by community contributors. Yangqing Jia created the project during his PhD at UC Berkeley. Caffe is released under the BSD 2-Clause License.

Check out our web image classification demo!
LeNet in Caffe

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"
        }
    }
}
Platform: Tensorflow (tensorflow.org)
conv = tf.nn.conv2d(data,
                     conv1_weights,
                     strides=[1, 1, 1, 1],
                     padding='SAME')

# Bias and rectified linear non-linearity.
relu = tf.nn.relu(tf.nn.bias_add(conv, conv1_biases))

# Max pooling. The kernel size spec {ksize} also follows the layout of
# the data. Here we have a pooling window of 2, and a stride of 2.
pool = tf.nn.max_pool(relu,
                      ksize=[1, 2, 2, 1],
                      strides=[1, 2, 2, 1],
                      padding='SAME')
# Fully connected layer. Note that the '+' operation automatically broadcasts the biases.
hidden = tf.nn.relu(tf.matmul(reshape, fcl_weights) + fcl_biases)
# Add a 50% dropout during training only. Dropout also scales activations such that no rescaling is needed at evaluation time.
if train:
    hidden = tf.nn.dropout(hidden, 0.5, seed=SEED)
Others

• **Theano** – CPU/GPU symbolic expression compiler in python (from MILA lab at University of Montreal)

• **Torch** – provides a Matlab-like environment for state-of-the-art machine learning algorithms in lua

• **Lasagne** - Lasagne is a lightweight library to build and train neural networks in Theano

• See: http://deeplearning.net/software_links/
Optimization: momentum
Basic algorithms

• Minimize the (regularized) empirical loss

\[ \hat{L}_R(\theta) = \frac{1}{n} \sum_{t=1}^{n} l(\theta, x_t, y_t) + R(\theta) \]

where the hypothesis is parametrized by \( \theta \)

• Gradient descent

\[ \theta_{t+1} = \theta_t - \eta_t \nabla \hat{L}_R(\theta_t) \]
Mini-batch stochastic gradient descent

• Instead of one data point, work with a small batch of $b$ points $$(x_{tb+1}, y_{tb+1}), \ldots, (x_{tb+b}, y_{tb+b})$$

• Update rule

$$
\theta_{t+1} = \theta_t - \eta_t \nabla \left( \frac{1}{b} \sum_{1 \leq i \leq b} l(\theta_t, x_{tb+i}, y_{tb+i}) + R(\theta_t) \right)
$$
Momentum

• Drawback of SGD: can be slow when gradient is small

• Observation: when the gradient is consistent across consecutive steps, can take larger steps

• Metaphor: rolling marble ball on gentle slope
Momentum

Contour: loss function
Path: SGD with momentum
Arrow: stochastic gradient

Figure from *Deep Learning*, by Goodfellow, Bengio, and Courville
Momentum

• work with a small batch of $b$ points
  \[(x_{tb+1}, y_{tb+1}), \ldots, (x_{tb+b}, y_{tb+b})\]

• Keep a momentum variable $v_t$, and set a decay rate $\alpha$

• Update rule

\[
v_t = \alpha v_{t-1} - \eta_t \nabla \left( \frac{1}{b} \sum_{1 \leq i \leq b} l(\theta_t, x_{tb+i}, y_{tb+i}) + R(\theta_t) \right)
\]

\[
\theta_{t+1} = \theta_t + v_t
\]
Momentum

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• Update rule

\[
v_t = \alpha v_{t-1} - \eta_t \nabla \left( \frac{1}{b} \sum_{1 \leq i \leq b} l(\theta_t, x_{tb+i}, y_{tb+i}) + R(\theta_t) \right)
\]

\[
\theta_{t+1} = \theta_t + v_t
\]

• **Practical guide:** $\alpha$ is set to 0.5 until the initial learning stabilizes and then is increased to 0.9 or higher.