Part 1: Convolutional neural networks in caffe

Part 2: CNNs for retinal vessels segmentation

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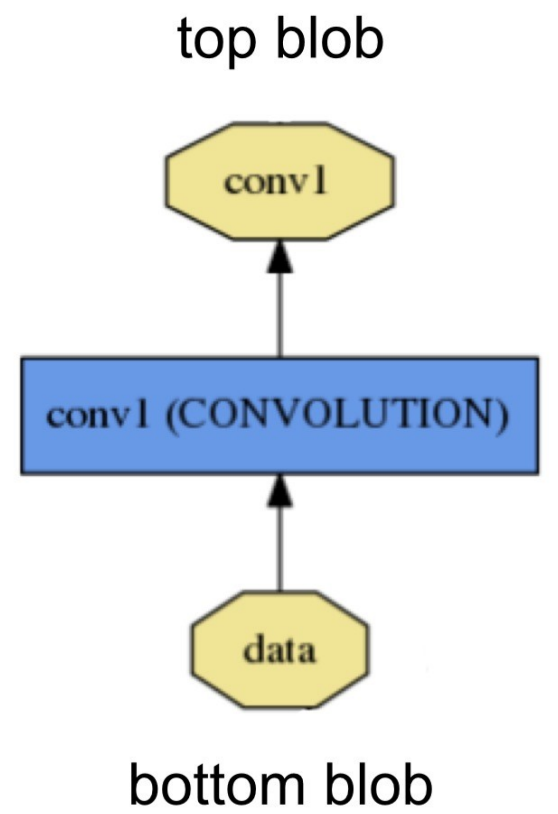
Caffe

- “Caffe is a deep learning framework made with expression, speed, and modularity in mind.”
- Developed by Berkeley Vision and Learning Center (BVLC)
- C++ with Python and MATLAB wrappers
- Open source
  - https://github.com/BVLC/caffe

Caffe

- Modular design
- Data is passed as “blobs”
- Most layer types have one bottom (input) and one top (output blob)

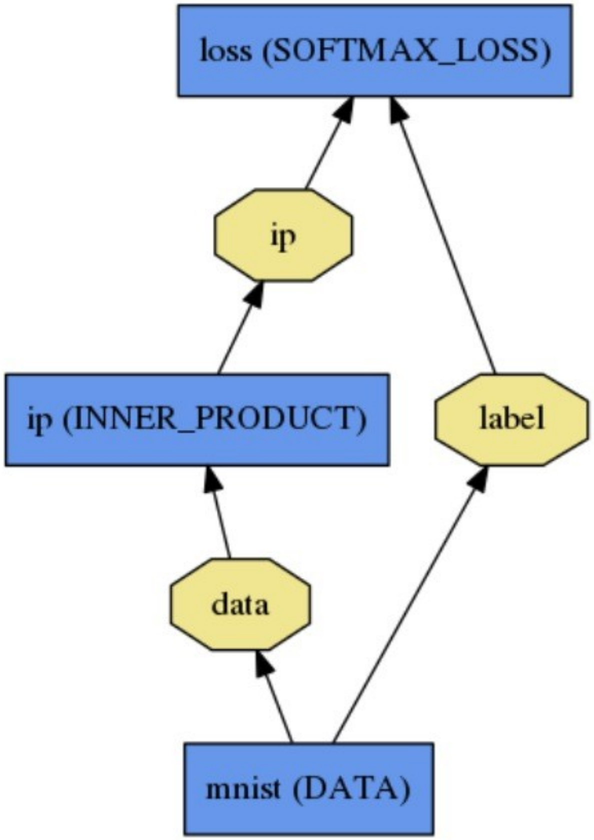


Caffe

- Two configurations need to be defined:
  - Network architecture
  - Solver
    - Both as protocol buffers
    - Both configurations can be put in a single .prototxt file

Logistic regression example

```
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"
}
```



Optimization

```
solver_mode: GPU
solver_type: NESTEROV

base_lr: 0.01
momentum: 0.9
weight_decay: 0.0001

lr_policy: "fixed"

max_iter: 200000

snapshot: 1000
snapshot_prefix: "path/to/output/folder"

test_iter: 100
test_interval: 1000

display: 100
average_loss: 100
```

- The solver defines the optimization method and parameters
  - Default is SGD

Input

```
layer {
  name: "images"
  type: "Data"
  top: "data"
  top: "label"
  transform_param {
    mirror: true
    mean_value: 111
    scale: 0.015
  }
  data_param {
    source: "/path/to/training/training/db"
    backend: LMDB
    batch_size: 256
  }
  include: { phase: TRAIN }
}
```

- Caffe supports several input formats
  - Databases (LevelDB, LMDB)
  - Files on disk (HDF5, common image formats)
- The data layer handles the reading of the input in batches and basic preprocessing (scaling, mean subtraction)

Convolutional 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: 48
        kernel_size: 6
        stride: 1
        weight_filler {
          type: "xavier"
        }
        bias_filler {
          type: "constant"
        }
      }
    }
```

- The number of inputs is implicitly defined with the bottom blob
- weight_filler and bias_filler define the initialization method
  - Weights and biases can have different learning rates and regularization strenghts

Nonlinearity and max-pooling

```
layer {
  name: "nonlin1"
  type: "TanH"
  bottom: "conv1"
  top: "conv1"
}

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

- The nonlinearity can operate “in place”
  - Saves memory
- No trainable parameters → no initialization needed

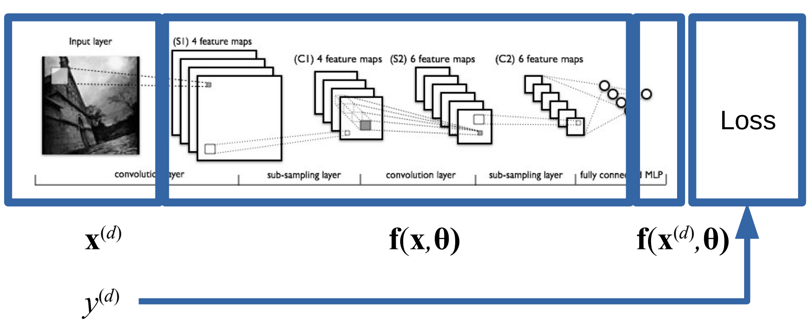
Fully connected layer

```
layer {
      name: "ip1"
      type: "InnerProduct"
      bottom: "pool4"
      top: "ip1"
      param {
        lr_mult: 1
        decay_mult: 1
      }
      param {
        lr_mult: 2
        decay_mult: 0
      }
      inner_product_param {
        num_output: 100
        weight_filler {
           type: "xavier"
        }
        bias_filler {
          type: "constant"
        }
      }
    }
```

- Called “inner product” for obvious reasons
- The initialization is defined in a similar manner to convolutional layers

Loss layer

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



- Softmax and loss layers are combined in one layer because this way the "gradient computation is more numerically stable"
- At test time, this can be replaced by a softmax layer

Deployment

- Caffe outputs two types of files
  - .caffemodel: Contains the weights of the model
    - This is what you deploy!
  - .solverstate: Snapshot of the solver, can be used to resume training
- Separate deployment .prototxt needs to be defined

Running caffe

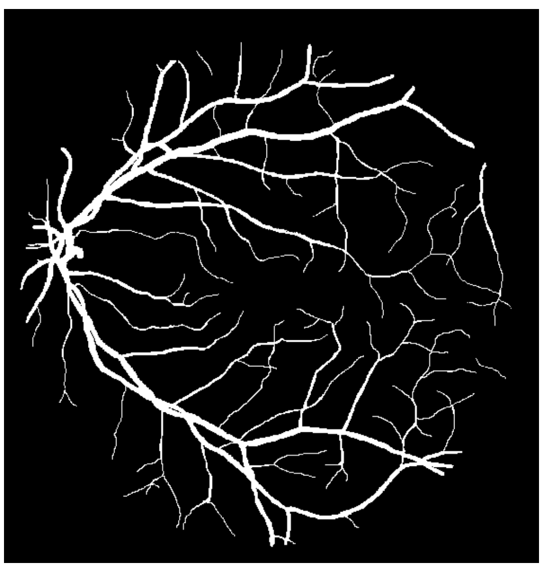
```
$ caffe.bin train -solver solver.prototxt

...
I0911 13:31:32.394986  5078 layer_factory.hpp:74] Creating layer images
I0911 13:31:32.395014  5078 net.cpp:90] Creating Layer images
I0911 13:31:32.395026  5078 net.cpp:368] images -> data
I0911 13:31:32.395061  5078 net.cpp:368] images -> label
I0911 13:31:32.395078  5078 net.cpp:120] Setting up images
I0911 13:31:32.395531  5078 db_lmdb.cpp:22] Opened lmdb db/training
I0911 13:31:32.395733  5078 data_layer.cpp:52] output data size: 256,1,65,65
I0911 13:31:32.396944  5078 net.cpp:127] Top shape: 256 1 65 65 (1081600)
I0911 13:31:32.396968  5078 net.cpp:127] Top shape: 256 (256)
I0911 13:31:32.396981  5078 layer_factory.hpp:74] Creating layer conv1
I0911 13:31:32.397017  5078 net.cpp:90] Creating Layer conv1
I0911 13:31:32.397027  5078 net.cpp:410] conv1 <- data
I0911 13:31:32.397049  5078 net.cpp:368] conv1 -> conv1
I0911 13:31:32.397069  5078 net.cpp:120] Setting up conv1
I0911 13:31:32.441848  5078 net.cpp:127] Top shape: 256 48 60 60 (44236800)
I0911 13:31:32.441915  5078 layer_factory.hpp:74] Creating layer nonlin1
I0911 13:31:32.441941  5078 net.cpp:90] Creating Layer nonlin1
I0911 13:31:32.441956  5078 net.cpp:410] nonlin1 <- conv1
I0911 13:31:32.441977  5078 net.cpp:357] nonlin1 -> conv1 (in-place)
I0911 13:31:32.441994  5078 net.cpp:120] Setting up nonlin1
I0911 13:31:32.442090  5078 net.cpp:127] Top shape: 256 48 60 60 (44236800)
...
```

Running caffe

```
...
I0911 13:31:32.453774  5078 solver.cpp:294] Iteration 0, Testing net (#0)
I0911 13:31:36.487558  5078 solver.cpp:343]     Test net output #0: accuracy = 0.463281
I0911 13:31:36.487620  5078 solver.cpp:343]     Test net output #1: loss = 0.699408 (* 1 = 0.699408 loss)
I0911 13:31:36.531695  5078 solver.cpp:214] Iteration 0, loss = 0.681241
I0911 13:31:36.531749  5078 solver.cpp:229]     Train net output #0: loss = 0.681241 (* 1 = 0.681241 loss)
I0911 13:31:36.531764  5078 solver.cpp:486] Iteration 0, lr = 0.01
I0911 13:31:50.624618  5078 solver.cpp:214] Iteration 100, loss = 0.37712
I0911 13:31:50.624673  5078 solver.cpp:229]     Train net output #0: loss = 0.408127 (* 1 = 0.408127 loss)
I0911 13:31:50.624686  5078 solver.cpp:486] Iteration 100, lr = 0.01
I0911 13:32:04.677295  5078 solver.cpp:214] Iteration 200, loss = 0.315125
I0911 13:32:04.677389  5078 solver.cpp:229]     Train net output #0: loss = 0.278361 (* 1 = 0.278361 loss)
I0911 13:32:04.677403  5078 solver.cpp:486] Iteration 200, lr = 0.01
...
I0911 13:33:57.053082  5078 solver.cpp:361] Snapshotting to models/nfbia_iter_1000.caffemodel
I0911 13:33:57.055656  5078 solver.cpp:369] Snapshotting solver state to models/nfbia_iter_1000.solverstate
I0911 13:33:57.056545  5078 solver.cpp:294] Iteration 1000, Testing net (#0)
I0911 13:34:01.060945  5078 solver.cpp:343]     Test net output #0: accuracy = 0.922148
I0911 13:34:01.061064  5078 solver.cpp:343]     Test net output #1: loss = 0.206845 (* 1 = 0.206845 loss)
...
```

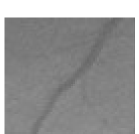
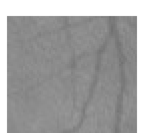
DRIVE



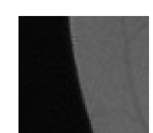
- 40 images of the retina with ground truth vessel segmentation
- 20 training, 20 testing
  - First 14 training images used for <u>training</u>
  - Last 6 training images used for <u>validation</u>
- We want to do pixel classification

Preprocessing and data augmentation

- Preprocessing
  - Average the 3 RGB color channels to obtain a grayscale image
  - Retina mask
- Data augmentation
  - From each image sample (with replacement) 300K samples of size 65x65 pixels
  - Random rotation between 0 and 2π
  - Label “1” if the central pixel belongs to a vessel, “0” otherwise
    - 4.2M training samples, 1.8M validation samples
    - Only ~12% of the training samples are positive





DRIVE notebook

- Now, let's look at the notebook with the DRIVE example...