CaffeLink

MNIST example

Requirements and Initialization

This example shows how to use CaffeLink to build, train and test LeNet. It relies on examples from Caffe, which can be found here.
Except for successfully build Caffe and CaffeLink, for this example MNIST data are also needed. Those can be obtained using script from Caffe:

```
cd $CAFFE_ROOT
./data/mnist/get_mnist.sh
./examples/mnist/create_mnist.sh
```

As is shown in MNIST example on Caffe web. This document is only concerned with CaffeLink, so for details regarding net design please refer to Caffe.

Caffe is a command line tool and it would be inefficient to somehow transmit all its output to *Mathematica*. So it is highly recommended to launch *Mathematica* session with terminal. CaffeLink also relies on stoud.

Initialize CaffeLink

The first think to do is load CaffeLink module and initialize it with path to `caffe.proto` protobuffer definition of all parameters Caffe uses.

In[1]:=

```
caffeDir = "/home/kerhy/fel-lin/caffe";
```

In[2]:=

```
Needs["CaffeLink`",FileNameJoin[{NotebookDirectory[],"../caffeLink.m"}]];
initCaffeLinkModule[FileNameJoin[{caffeDir,"src/caffe/proto/caffe.proto"}]];
```

Before training, testing etc. CaffeLink library must be initialized. That is: choose data type (double or float), computing mode (GPU or CPU) and device ID for GPU mode.

In[4]:=
```
initCaffeLink["UseDouble"→True,"UseGPU"→True,"GPUDevice"→0]
```

Out[4]=
```
True
```

Mode can be switched later, data type not.

Net

Building

A net is represented by its proto file. Path to or content of LeNet proto lenet_train_test.prototxt could be directly passed to CaffeLink, but it would be no fun. Functions `NewNet`, `AddLayer`, `SetNetParam` and `SetLayerParam` allow to gradually build the net. `GetNetParamString` then produces protobuffer string which is used to create net in CaffeLink.

This path should point to your mnist data set. Absolute path is recommended.

In[5]:=
```
mnistDir = FileNameJoin[{caffeDir,"examples/mnist/"}];
```

BuildLeNet

In[6]:=
```
netTrain =
    {"name"→"Net Train",{
        {
        "name"→"mnist","type"→"DATA","top"→{"data","label"},
        "source"→FileNameJoin[{mnistDir,"mnist_train_lmdb"}],
        "backend"→"LMDB","batch_size"→64,"scale"→0.00390625,"include.phase"→"TRAIN"
        },{
        "name"→"mnist","type"→"DATA","top"→{"data","label"},
        "source"→FileNameJoin[{mnistDir,"mnist_test_lmdb"}],
        "backend"→"LMDB","batch_size"→64,"scale"→0.00390625,"include.phase"→"TEST"
        },{
        "name"→"conv1","type"→"CONVOLUTION","bottom"→"data","top"→"conv1",
        "blobs_lr"→{1,2},"num_output"→20,"kernel_size"→5,"stride"→1,
        "weight_filler.type"→"xavier","bias_filler.type"→"constant"
```

```
        },{
        "name"→"pool1","type"→"POOLING","bottom"→"conv1","top"→"pool1",
        "pool"→"MAX","kernel_size"→2,"stride"→2
        },{
        "name"→"conv2","type"→"CONVOLUTION","bottom"→"pool1","top"→"conv2",
        "blobs_lr"→{1,2},"num_output"→50,"kernel_size"→5,"stride"→1,
        "weight_filler.type"→"xavier","bias_filler.type"→"constant"
        },{
        "name"→"pool2","type"→"POOLING","bottom"→"conv2","top"→"pool2",
        "pool"→"MAX","kernel_size"→2,"stride"→2
        },{
        "name"→"ip1","type"→"INNER_PRODUCT","bottom"→"pool2",
        "top"→"ip1","blobs_lr"→{1,2},"num_output"→500,
        "weight_filler.type"→"xavier","bias_filler.type"→"constant"
        },{
        "name"→"relu1","type"→"RELU","bottom"→"ip1","top"→"ip1"
        },{
        "name"→"ip2","type"→"INNER_PRODUCT","bottom"→"ip1",
        "top"→"ip2","blobs_lr"→{1,2},"num_output"→10,
        "weight_filler.type"→"xavier","bias_filler.type"→"constant"
        },{
        "name"→"accuracy","type"→"ACCURACY","bottom"→{"ip2","label"},
        "top"→"accuracy","include.phase"→"TEST"
        },{
        "name"→"loss","type"→"SOFTMAX_LOSS","bottom"→{"ip2","label"},"top"→"loss"
        }
    }
    };
```

Resulting string is equal to content of lenet_train_test.prototxt.

In[7]:=

```
netParam = getParamString[newNet[netTrain]]
```

Out[7]=

```
name: "Net Train"
layers {
  top: "data"
  top: "label"
  name: "mnist"
  type: DATA
```

```
    include {
      phase: TRAIN
    }
    transform_param {
      scale: 0.00390625
    }
    data_param {
      source: "/home/kerhy/fel-lin/caffe/examples/mnist/mnist_train_lmdb"
      batch_size: 64
      backend: LMDB
    }
  }
  layers {
    top: "data"
    top: "label"
    name: "mnist"
    type: DATA
    include {
      phase: TEST
    }
    transform_param {
      scale: 0.00390625
    }
    data_param {
      source: "/home/kerhy/fel-lin/caffe/examples/mnist/mnist_test_lmdb"
      batch_size: 64
      backend: LMDB
    }
  }
  layers {
    bottom: "data"
    top: "conv1"
    name: "conv1"
    type: CONVOLUTION
    blobs_lr: 1
```

```
  blobs_lr: 2
  convolution_param {
    num_output: 20
    kernel_size: 5
    stride: 1
    weight_filler {
      type: "xavier"
    }
    bias_filler {
      type: "constant"
    }
  }
}
layers {
  bottom: "conv1"
  top: "pool1"
  name: "pool1"
  type: POOLING
  pooling_param {
    pool: MAX
    kernel_size: 2
    stride: 2
  }
}
layers {
  bottom: "pool1"
  top: "conv2"
  name: "conv2"
  type: CONVOLUTION
  blobs_lr: 1
  blobs_lr: 2
  convolution_param {
    num_output: 50
    kernel_size: 5
    stride: 1
```

```
      weight_filler {
        type: "xavier"
      }
      bias_filler {
        type: "constant"
      }
    }
  }
  layers {
    bottom: "conv2"
    top: "pool2"
    name: "pool2"
    type: POOLING
    pooling_param {
      pool: MAX
      kernel_size: 2
      stride: 2
    }
  }
  layers {
    bottom: "pool2"
    top: "ip1"
    name: "ip1"
    type: INNER_PRODUCT
    blobs_lr: 1
    blobs_lr: 2
    inner_product_param {
      num_output: 500
      weight_filler {
        type: "xavier"
      }
      bias_filler {
        type: "constant"
      }
    }
```

```
}
layers {
  bottom: "ip1"
  top: "ip1"
  name: "relu1"
  type: RELU
}
layers {
  bottom: "ip1"
  top: "ip2"
  name: "ip2"
  type: INNER_PRODUCT
  blobs_lr: 1
  blobs_lr: 2
  inner_product_param {
    num_output: 10
    weight_filler {
      type: "xavier"
    }
    bias_filler {
      type: "constant"
    }
  }
}
layers {
  bottom: "ip2"
  bottom: "label"
  top: "accuracy"
  name: "accuracy"
  type: ACCURACY
  include {
    phase: TEST
  }
}
layers {
```

```
  bottom: "ip2"
  bottom: "label"
  top: "loss"
  name: "loss"
  type: SOFTMAX_LOSS
}
```

Notes

- Repeating parameters can be set with array:

  “top”→{“data”,”label”}

  resulting in:

  ```
  top: “data”
  top: “label”
  ```

- Parameters with the same name but in different block must be specified with the block name as well:

  ”weight_filler.type”→”xavier”

  ”bias_filler.type”→”constant”

  gives:

  ```
  weight_filler {
      type: “xavier”
  }
  bias_filler {
      type: “constant”
  }
  ```

  This holds even if only one of these is used.

Training

Before training a solver must be defined. This can be done in a similar way to building net, or an existing file can be used.

Definesolver

In[8]:=

```
solver = newSolver[{
    "solver_type"→"SGD","test_iter"→100,"test_interval"→500,
    "base_lr"→0.01,"momentum"→0.9,"weight_decay"→0.0005,
    "lr_policy"→"inv","gamma"→0.0001,"power"→0.75,
    "display"→100,"max_iter"→1000,"snapshot"→1000,
    "snapshot_prefix"→StringJoin[NotebookDirectory[],"snaps/lenet"]
}];
solverParam = getParamString[solver]
```

Out[9]=

```
test_iter: 100
test_interval: 500
base_lr: 0.01
display: 100
max_iter: 1000
lr_policy: "inv"
gamma: 0.0001
power: 0.75
momentum: 0.9
weight_decay: 0.0005
snapshot: 1000
snapshot_prefix:
  "/home/kerhy/NetBeansProjects/caffeLink/module/demo/snaps/lenet"
solver_type: SGD
```

Create snapshot directory:

In[10]:=

```
CreateDirectory[FileNameJoin[{NotebookDirectory[],"snaps/"}]];
```

Add net Definition to solver.

In[11]:=

```
trainParam = solverAddNetParam[solverParam,netParam];
```

Notes

- Either double check relative paths or simply use absolute. All directories must exist. Be careful especially with source path in DATA layers. Current working directory can be printed in console with `printWorkingPath`.

In[12]:=
```
printWorkingPath[]
```

- Parameter `"solver_mode"` overrides mode set with `initCaffeLink`.

Train LeNet

New net can be trained with functions `trainNetString` and `trainNetFile`. The first expects solver parameters in a string, the second expects path pointing to a file with parameters. Both do the same. Training progress is printed to console.

```
trainNetString[trainParam]
```

Testing

Net testing requires a net and net parameters, referred by Caffe as deploy proto. The main difference between deploy and training proto is in input definition, the rest can be the same.

DeployLeNet

In[13]:=

```
netDeploy =
    {"name"→"Net Deploy","input"→"data","input_dim"→{10,1,28,28},{
        {
        "name"→"conv1","type"→"CONVOLUTION","bottom"→"data","top"→"conv1",
        "blobs_lr"→{1,2},"num_output"→20,"kernel_size"→5,"stride"→1,
        "weight_filler.type"→"xavier","bias_filler.type"→"constant"
        },{
        "name"→"pool1","type"→"POOLING","bottom"→"conv1","top"→"pool1",
        "pool"→"MAX","kernel_size"→2,"stride"→2
        },{
        "name"→"conv2","type"→"CONVOLUTION","bottom"→"pool1","top"→"conv2",
        "blobs_lr"→{1,2},"num_output"→50,"kernel_size"→5,"stride"→1,
        "weight_filler.type"→"xavier","bias_filler.type"→"constant"
        },{
        "name"→"pool2","type"→"POOLING","bottom"→"conv2","top"→"pool2",
        "pool"→"MAX","kernel_size"→2,"stride"→2
        },{
        "name"→"ip1","type"→"INNER_PRODUCT","bottom"→"pool2","top"→"ip1",
        "blobs_lr"→{1,2},"num_output"→500,
        "weight_filler.type"→"xavier","bias_filler.type"→"constant"
        },{
        "name"→"relu1","type"→"RELU","bottom"→"ip1","top"→"ip1"
        },{
        "name"→"ip2","type"→"INNER_PRODUCT","bottom"→"ip1","top"→"ip2",
        "blobs_lr"→{1,2},"num_output"→10,
        "weight_filler.type"→"xavier","bias_filler.type"→"constant"
        },{
        "name"→"prob","type"→"SOFTMAX","bottom"→"ip2","top"→"prob"
        }
    }
    };
```

In[14]:=

```
netDeployParam = getParamString[newNet[netDeploy]]
```

Out[14]=

```
name: "Net Deploy"
input: "data"
```

```
input_dim: 10
input_dim: 1
input_dim: 28
input_dim: 28
layers {
  bottom: "data"
  top: "conv1"
  name: "conv1"
  type: CONVOLUTION
  blobs_lr: 1
  blobs_lr: 2
  convolution_param {
    num_output: 20
    kernel_size: 5
    stride: 1
    weight_filler {
      type: "xavier"
    }
    bias_filler {
      type: "constant"
    }
  }
}
layers {
  bottom: "conv1"
  top: "pool1"
  name: "pool1"
  type: POOLING
  pooling_param {
    pool: MAX
    kernel_size: 2
    stride: 2
  }
}
layers {
```

```
  bottom: "pool1"
  top: "conv2"
  name: "conv2"
  type: CONVOLUTION
  blobs_lr: 1
  blobs_lr: 2
  convolution_param {
    num_output: 50
    kernel_size: 5
    stride: 1
    weight_filler {
      type: "xavier"
    }
    bias_filler {
      type: "constant"
    }
  }
}
layers {
  bottom: "conv2"
  top: "pool2"
  name: "pool2"
  type: POOLING
  pooling_param {
    pool: MAX
    kernel_size: 2
    stride: 2
  }
}
layers {
  bottom: "pool2"
  top: "ip1"
  name: "ip1"
  type: INNER_PRODUCT
  blobs_lr: 1
```

```
  blobs_lr: 2
  inner_product_param {
    num_output: 500
    weight_filler {
      type: "xavier"
    }
    bias_filler {
      type: "constant"
    }
  }
}
layers {
  bottom: "ip1"
  top: "ip1"
  name: "relu1"
  type: RELU
}
layers {
  bottom: "ip1"
  top: "ip2"
  name: "ip2"
  type: INNER_PRODUCT
  blobs_lr: 1
  blobs_lr: 2
  inner_product_param {
    num_output: 10
    weight_filler {
      type: "xavier"
    }
    bias_filler {
      type: "constant"
    }
  }
}
layers {
```

```
  bottom: "ip2"
  top: "prob"
  name: "prob"
  type: SOFTMAX
}
```

Test LeNet

- Tested net must be prepared at first. Caffe allocates memory and creates net topology based on given deploy proto. Preparation is done either from string with `prepareNetString` or from file path using `prepareNetFile`.

```
prepareNetString[netDeployParam]
```

Net info can be printed (to console) with `printNetInfo`.

```
printNetInfo[]
```

- After preparation, any net data with the same topology can be loaded.

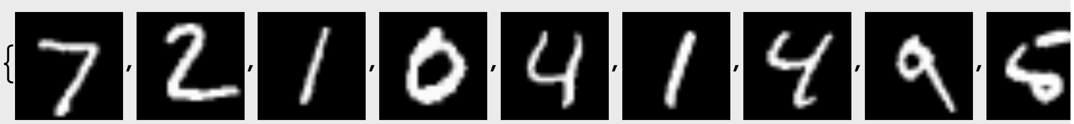
```
loadNet[FileNameJoin[{NotebookDirectory[],"snaps/lenet_iter_1000.caffemodel"}]]
```

That also allows extracting learned parameters (weights, filters, etc.).

- Insertion of data to be tested is necessary only if there is no DATA layer in the deploy proto.

In[15]:=

```
inputImgs = {
```



```
input = Flatten[Map[ImageData[#]&,inputImgs,1]];
```

```
setInput[input]
```

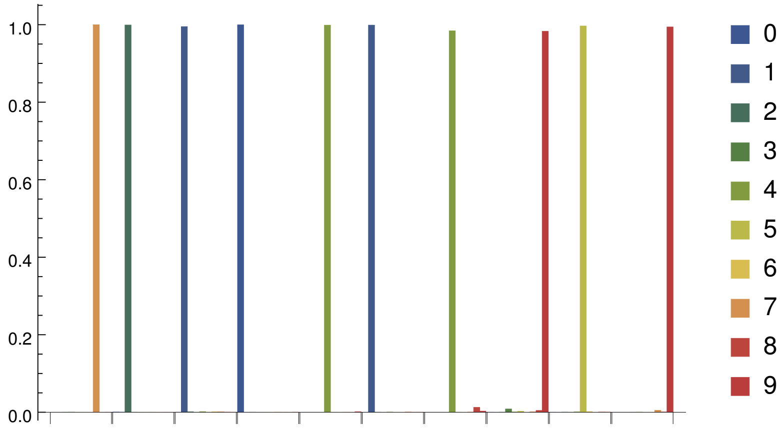
- This runs the test.

```
evaluateNet[]
```

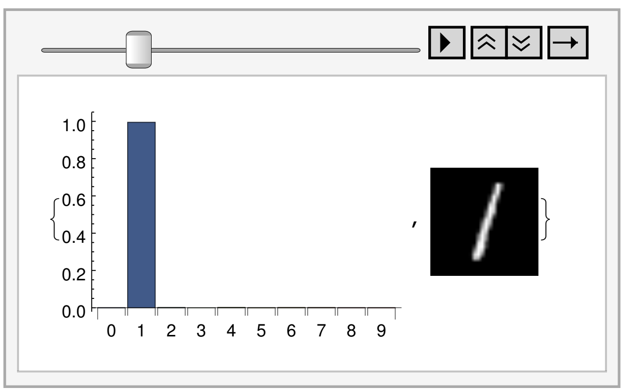
Result can be obtained from top blob of the last layer.

```
result = getTopBlob["prob"];
```

```
res = ArrayReshape[result,{10,10}];
leg = Range[10]-1;
BarChart[res,ChartLegends→leg,ChartStyle→"DarkRainbow"]
resList = Map[BarChart[#,ChartStyle→"DarkRainbow",ChartLabels→leg]&,res,1];
resList = ArrayReshape[Riffle[resList,inputImgs],{10,2}];
```




```
ListAnimate[resList,0.25]
```



Fine tuning

For fine tuning, functions `trainNetWeightsString` or `trainNetWeightsFile` can be used. These two functions takes solver parameters from string or file and start training a new net with weights initialized from given net data.

```
trainNetWeightsString[trainParam,
    FileNameJoin[{NotebookDirectory[],"snaps/lenet_iter_1000.caffemodel"}]
]
```

Extracting features and net surgery

Functions `getParamBlob`, `getTopBlob` and `getBottomBlob` allow inspection of all blobs in net. In combination with `setParamBlob` weights can be easily copied to another layer or to completely different net.

As shown in test section, this loads net, inserts input and tests it.

```
prepareNetString[netDeployParam]
loadNet[FileNameJoin[{NotebookDirectory[],"snaps/lenet_iter_1000.caffemodel"}]]
setInput[input]
evaluateNet[]
printNetInfo[]
```

Surgery

For example, copying filters from layer `conv1` to `conv2` can be done like this:

```
filters = getParamBlob[0]; (* 0th layer: conv1, 0th par. blob: filters, 20x1x5x5 *)
filters2 = getParamBlob["conv2"];(* 2th layer: conv2, 0th par. blob: filters, 50x20x5x5 *
filters2[[1;;Length[filters]]] = filters;
setParamBlob[filters2,2,0];
```

Now each of 20 channels in the first filter of `conv2` is the same as one of 20 filters in `conv1`.
That could of course breaks the whole net. Anyway, altered net can be exported back to Caffe format with `exportNet`.

```
exportNet[FileNameJoin[{NotebookDirectory[],"snaps/lenet_edited.caffemodel"}]]
```

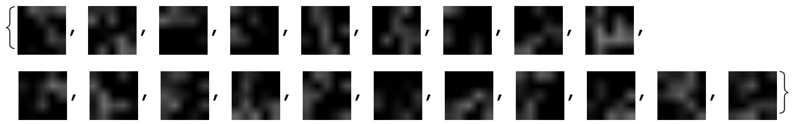
Visualization

In short: get parameters, separate and reshape them and then render.

- Layer `conv1` - filters

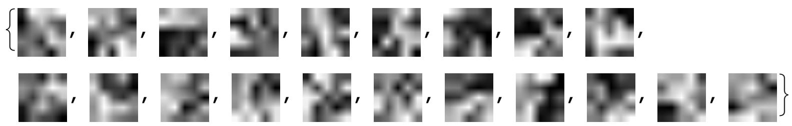
```
par = getParamBlob["conv1"]; (* 0th layer: conv1, 0th par. blob - filters *)
```

```
filters = ArrayReshape[par,{20,5,5}]; (* conv1 has 20 filters, 5x5 *)
fImgs = Map[Image[#,Magnification→5]&,filters,1]
```



Mapping image data to range 0,1 might be useful.

```
filters = Map[(#-Min[#])/(Max[#]-Min[#])&,filters,1];
fImgs = Map[Image[#,Magnification→5]&,filters,1]
```

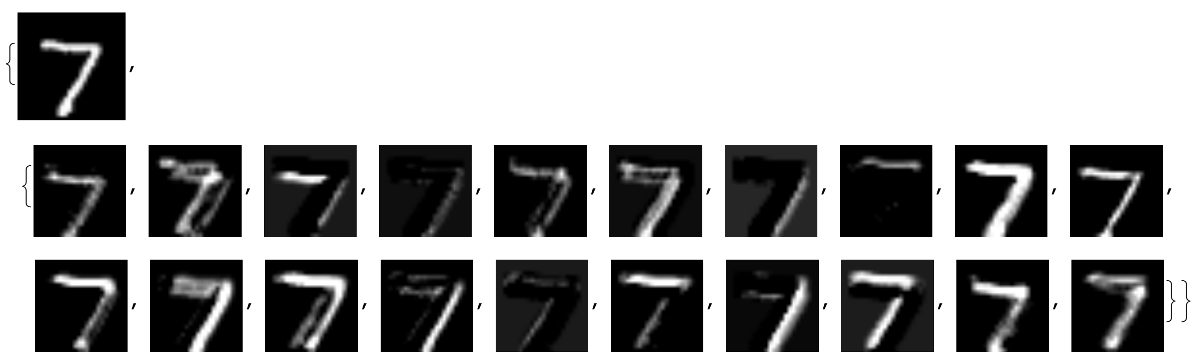


- Layer `conv1` - features

```
in = getBottomBlob[0,0];
out = getTopBlob[0,0];
```

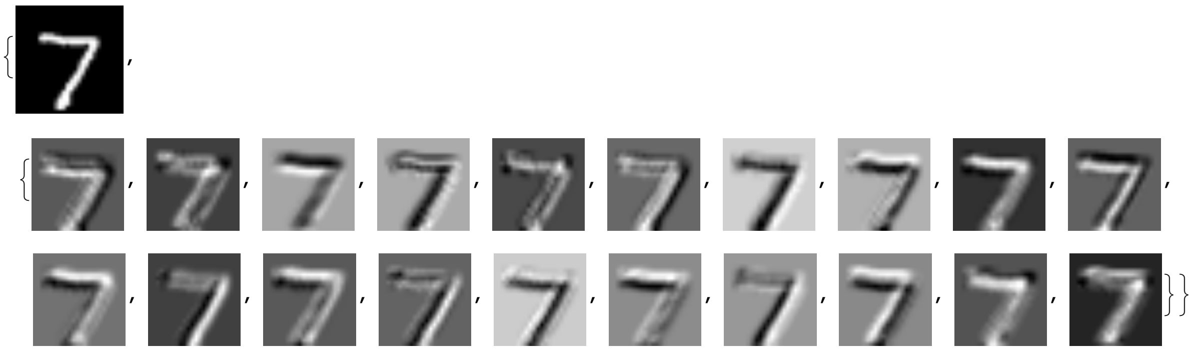
This shows one input image and result after convolution (20 filters).

```
imgi = 1; (* test image index, 1 - 10 *)
inImg = ArrayReshape[in,{10,28,28}][[imgi]];
outImgs = ArrayReshape[out,{10,20,24,24}][[imgi]];
{Image[inImg,Magnification→2],
Map[Image[#,Magnification→2]&,outImgs,1]}
```



The same in range 0, 1 :

```
outImgs = Map[(#-Min[#])/(Max[#]-Min[#])&,outImgs,1];
{Image[inImg,Magnification→2],
Map[Image[#,Magnification→2]&,outImgs,1]}
```

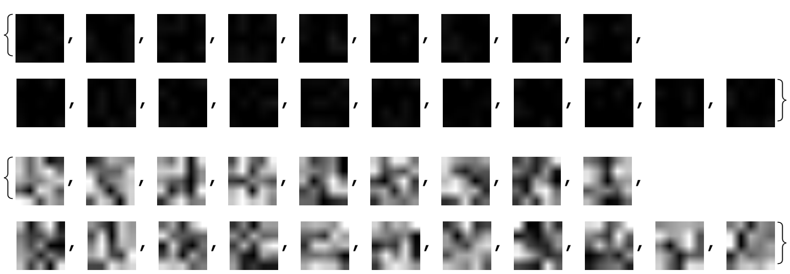


- Layer `conv2` - filters

```
par = getParamBlob["conv2"]; (* 2th layer: conv2, 0th par. blob - filters *)
```

This show 20 channels of the first filter.

```
filters = ArrayReshape[par,{20,5,5}]; (* conv2 has 50 filterst with 20 channels each, 5x5
Map[Image[#,Magnification→5]&,filters,1]
filters = Map[(#-Min[#])/(Max[#]-Min[#])&,filters,1];
Map[Image[#,Magnification→5]&,filters,1]
```

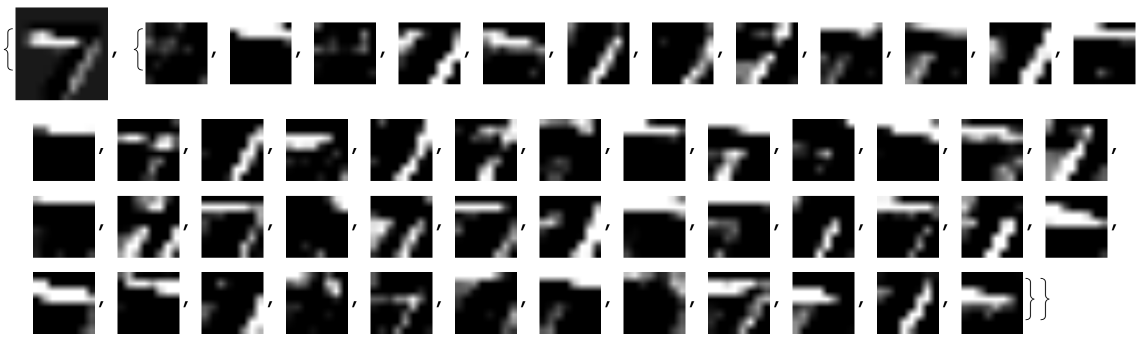


- Layer `conv2` - features

```
in = getBottomBlob["conv2"];
out = getTopBlob["conv2"];
```

This shows one input image and result after convolution (50 filters).

```
imgi = 1; (* test image index, 1 - 10 *)
imgfi = 3; (* conv1 filter index, 1 - 20 *)
inImg = ArrayReshape[in,{10,20,12,12}][[imgi,imgfi]];
outImgs = ArrayReshape[out,{10,50,8,8}][[imgi]];
{Image[inImg,Magnification→4],
Map[Image[#,Magnification→4]&,outImgs,1]}
```



The same in range 0, 1 :

```
outImgs = Map[(#-Min[#])/(Max[#]-Min[#])&,outImgs,1];
inImg = Map[(#-Min[#])/(Max[#]-Min[#])&,{inImg},1][[1]];
{Image[inImg,Magnification→4],
Map[Image[#,Magnification→4]&,outImgs,1]}
```