15-494/694: Cognitive Robotics

Dave Touretzky

Lecture 12:
Convolutional Neural Nets

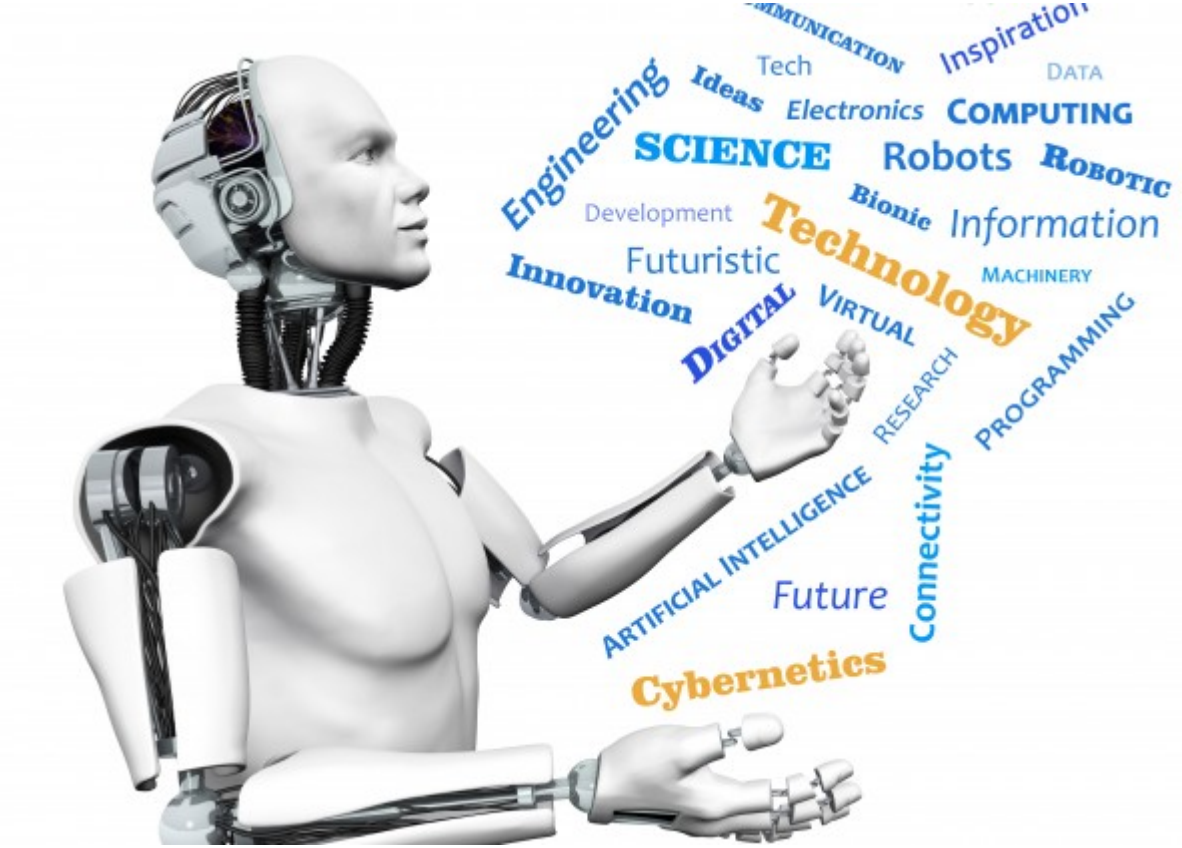
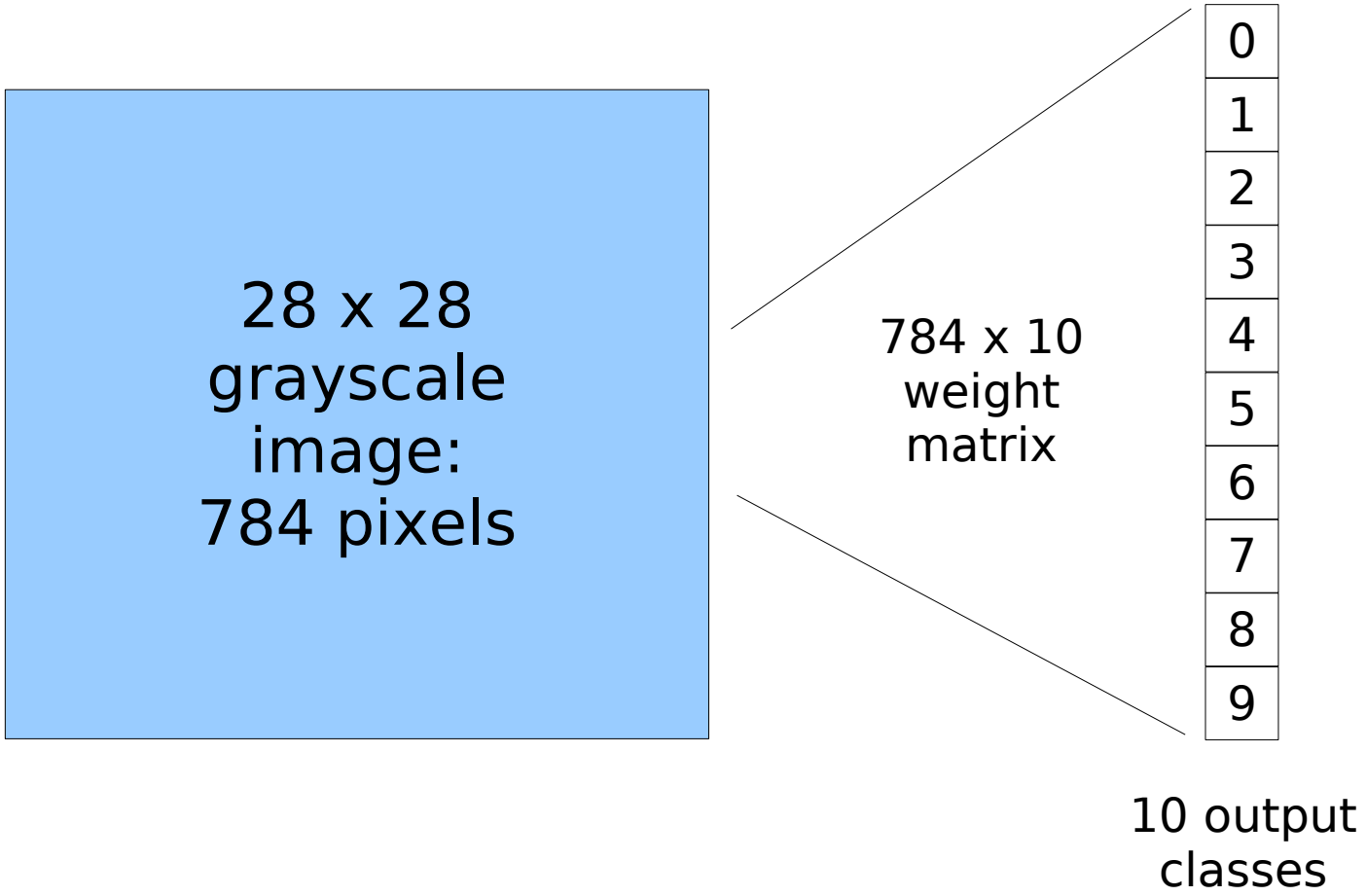


Image from http://www.futuristgerd.com/2015/09/10

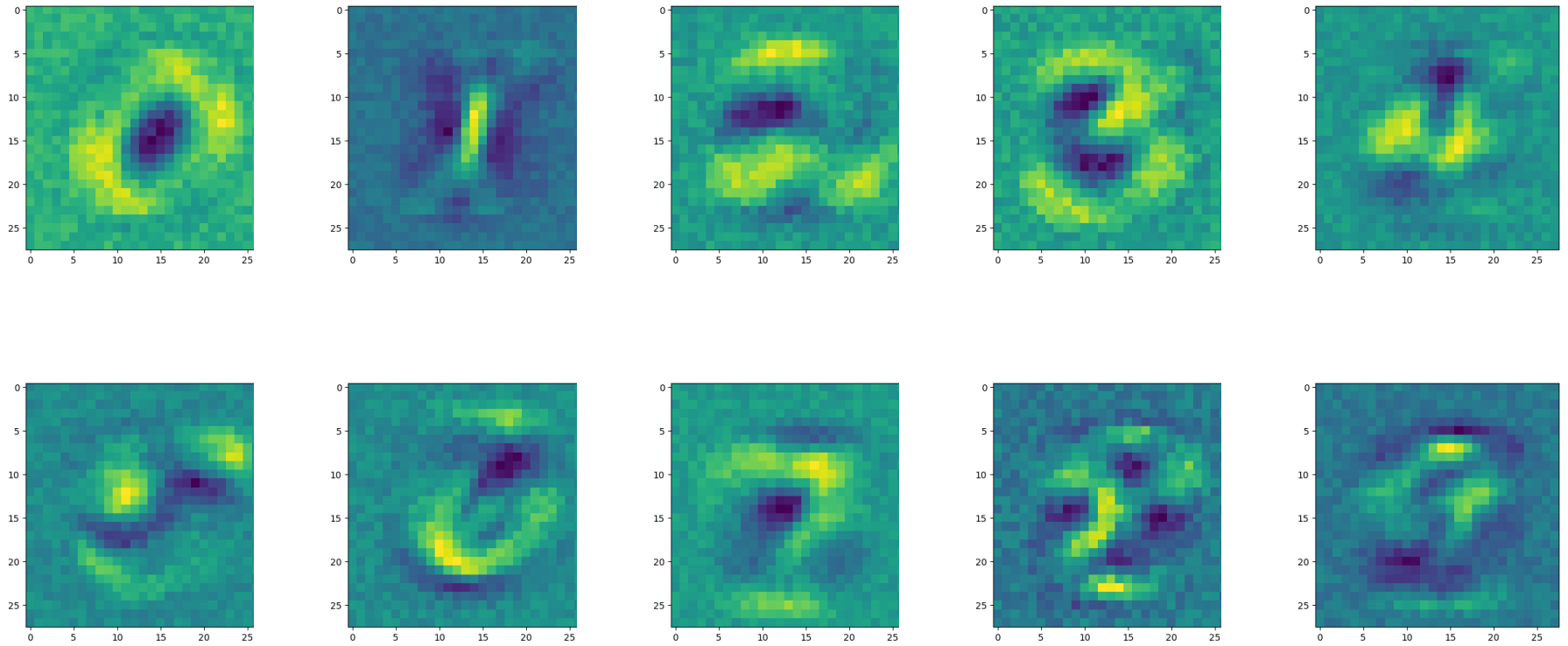
MNIST Dataset

- 60,000 labeled handwritten digits
- 28 x 28 pixel grayscale images

Recognition With a Linear Network



Learned Weights to Output Units

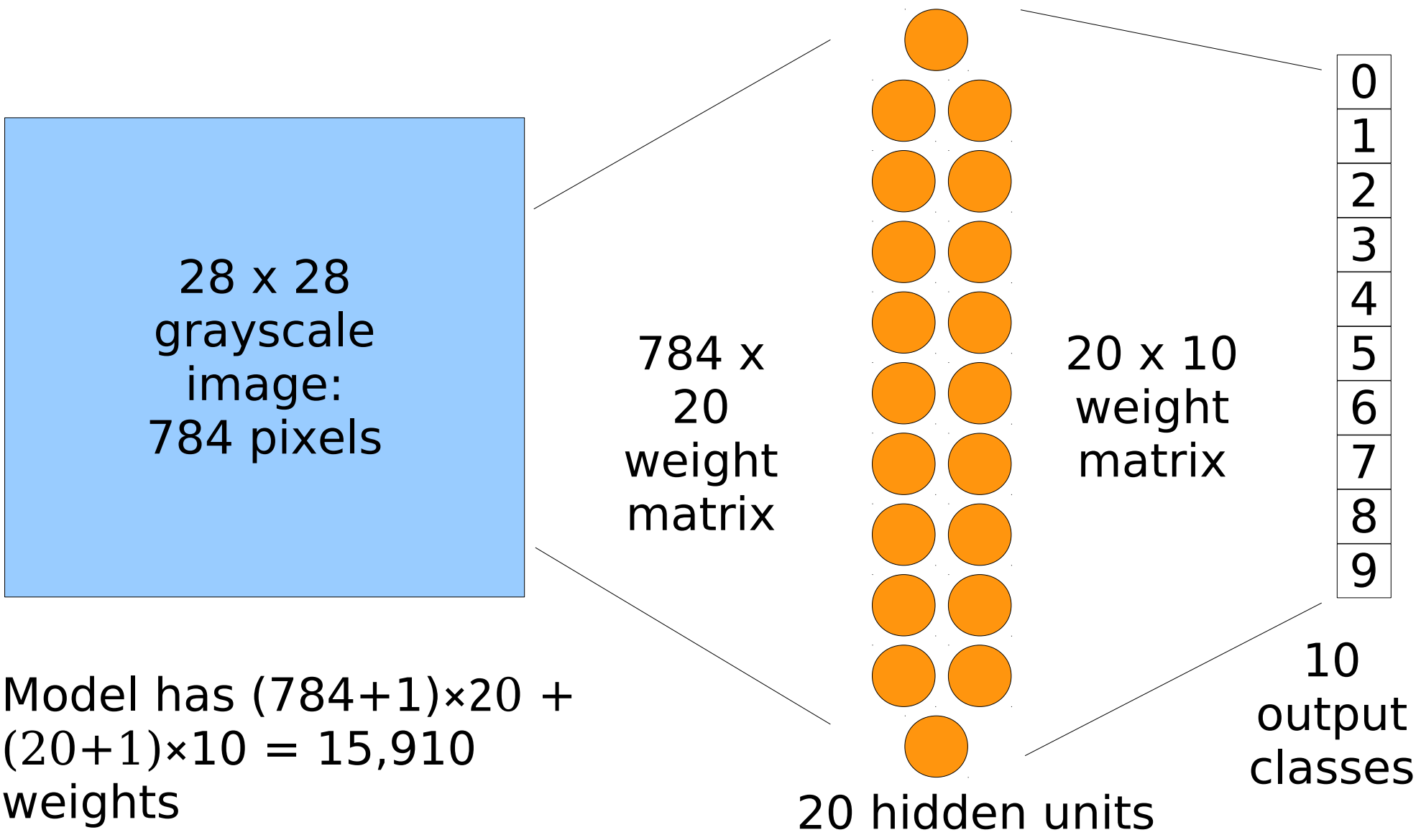


Training set performance: 89% correct.

Batch Size

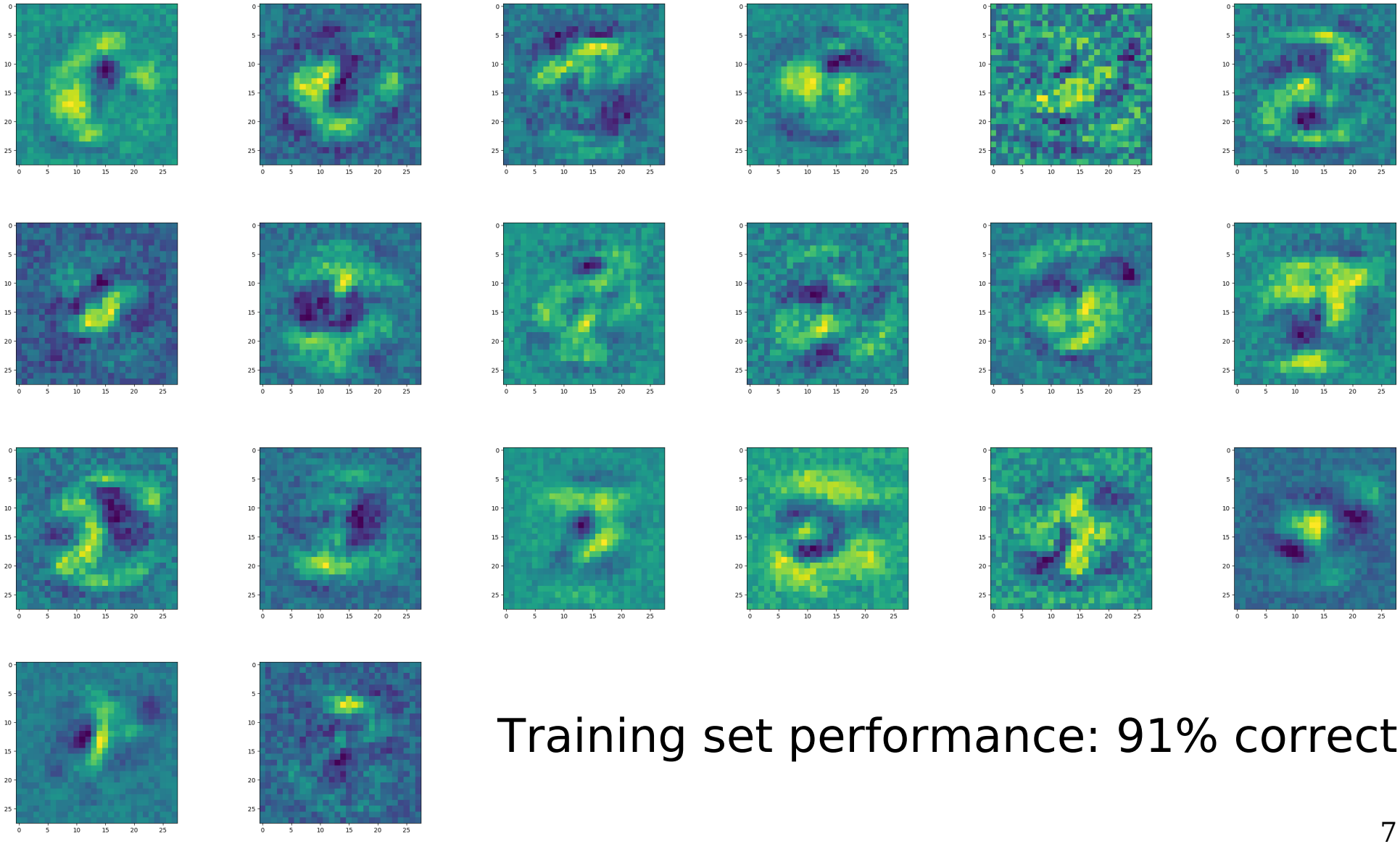
- An *epoch* is one pass through all the training data.
- With a large training set (60,000 images), we don't need to see all the training examples in order to estimate the error gradient.
- We set a batch size of 100 to indicate we want to do a weight update after every 100 training examples.
  - The examples need to be mixed together.
  - What if we trained on all the 2's first?

Adding A Hidden Layer



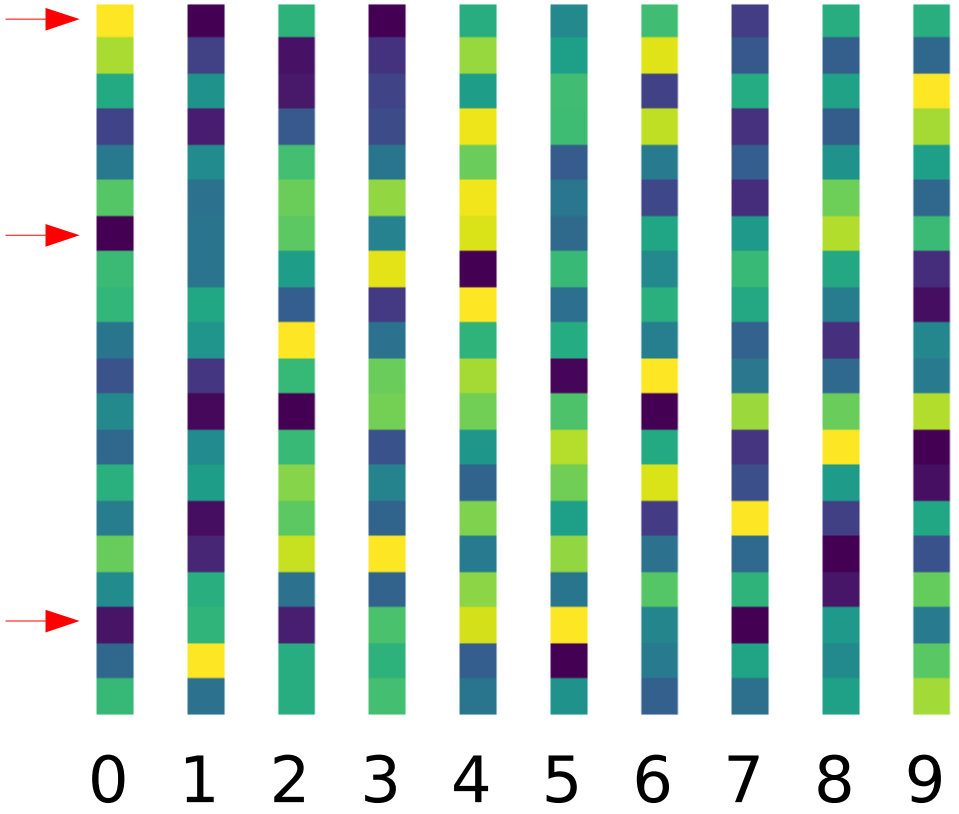
Model has (784+1)×20 + (20+1)×10 = 15,910 weights

Learned Weights to Hidden Units



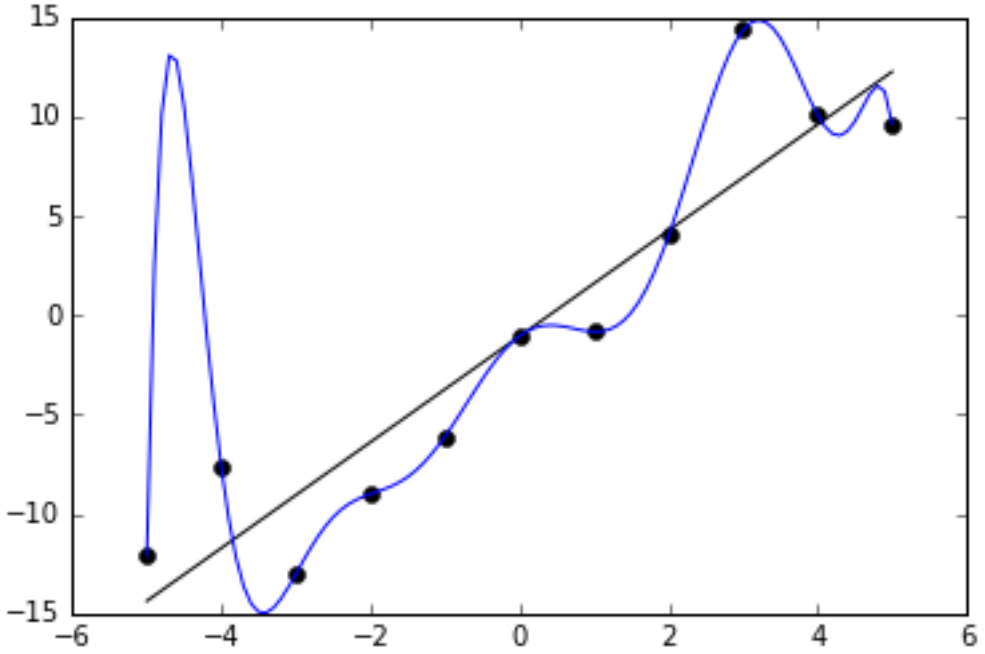
Training set performance: 91% correct.

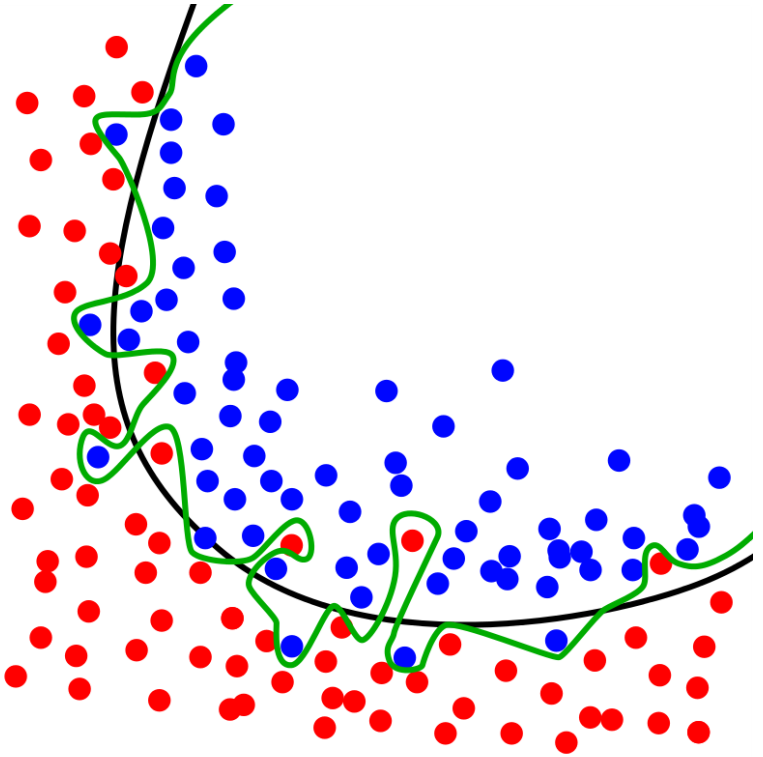
Learned Weights to Output Units



Training set performance: 91% correct.

Overfitting



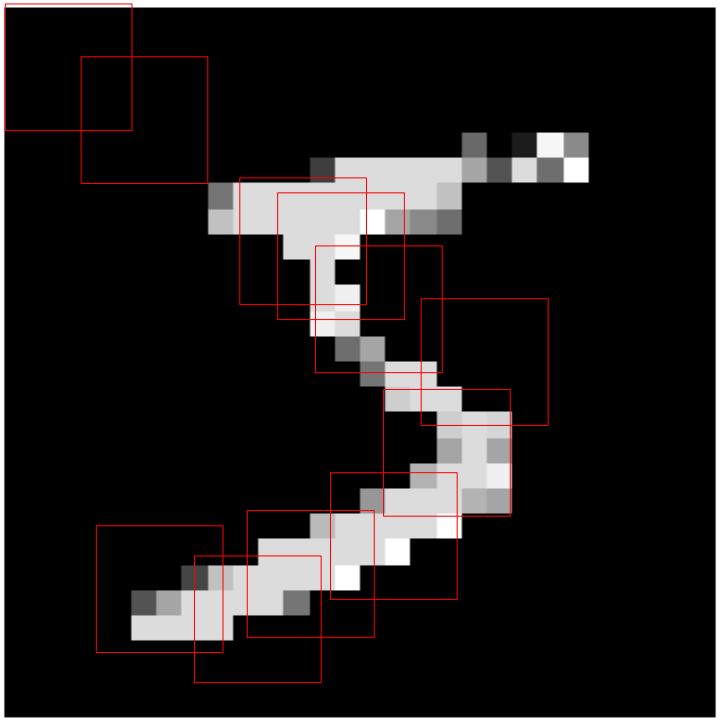


How to Avoid Overfitting

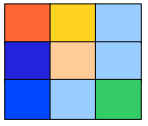
- Increase the size of the training set.
- Reduce the number of parameters:
  - Fewer hidden units
  - Shared weights (convolutional network)
- Regularization: penalize large weights to encourage making more weights be zero.
- Dropout: randomly disable some fraction of the connections on every iteration.
- Early stopping:
  - Maintain a separate cross-validation set
  - Stop training when the cv error rises

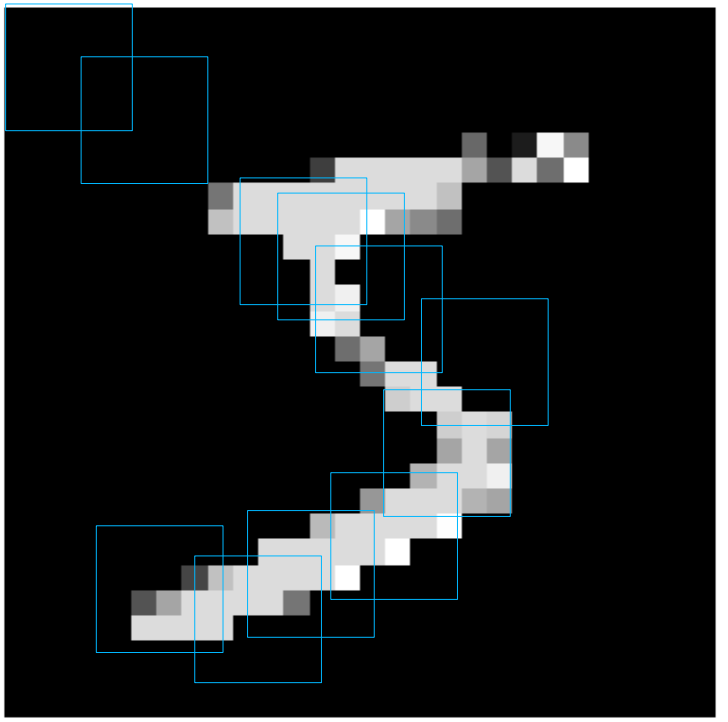
Convolutional Neural Networks

- Learn small (3x3 or 5x5) feature detectors or *kernels* that can be applied anywhere in the image.



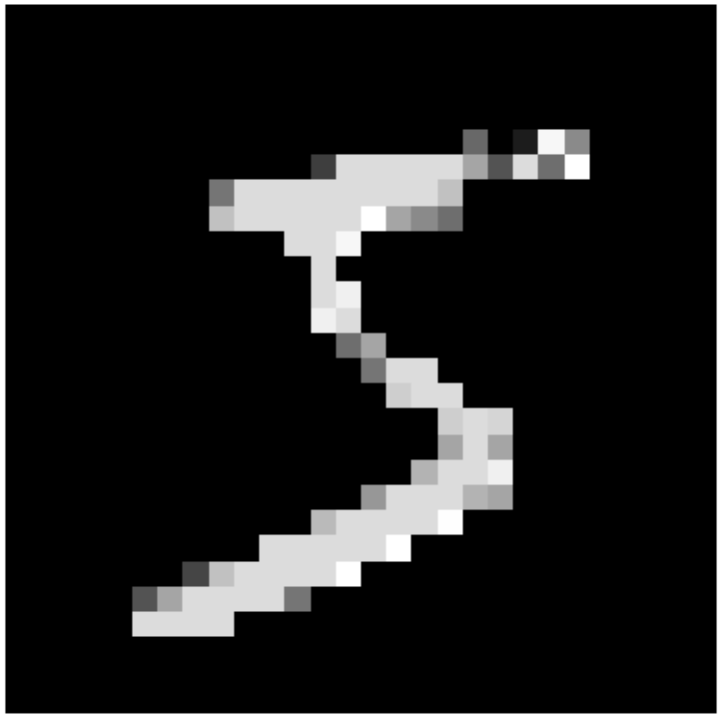
Feature 1:



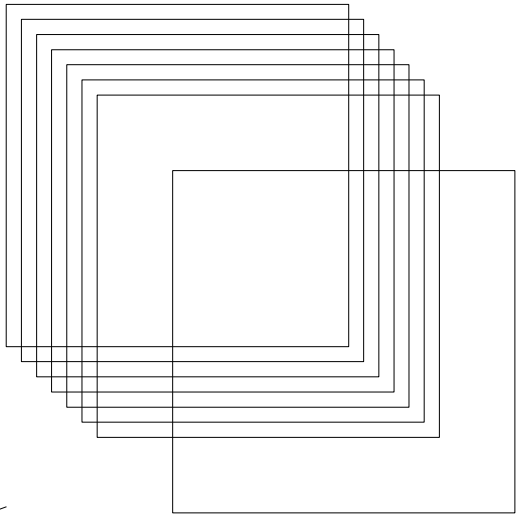


Feature 2:

Feature Maps



28 x 28 image

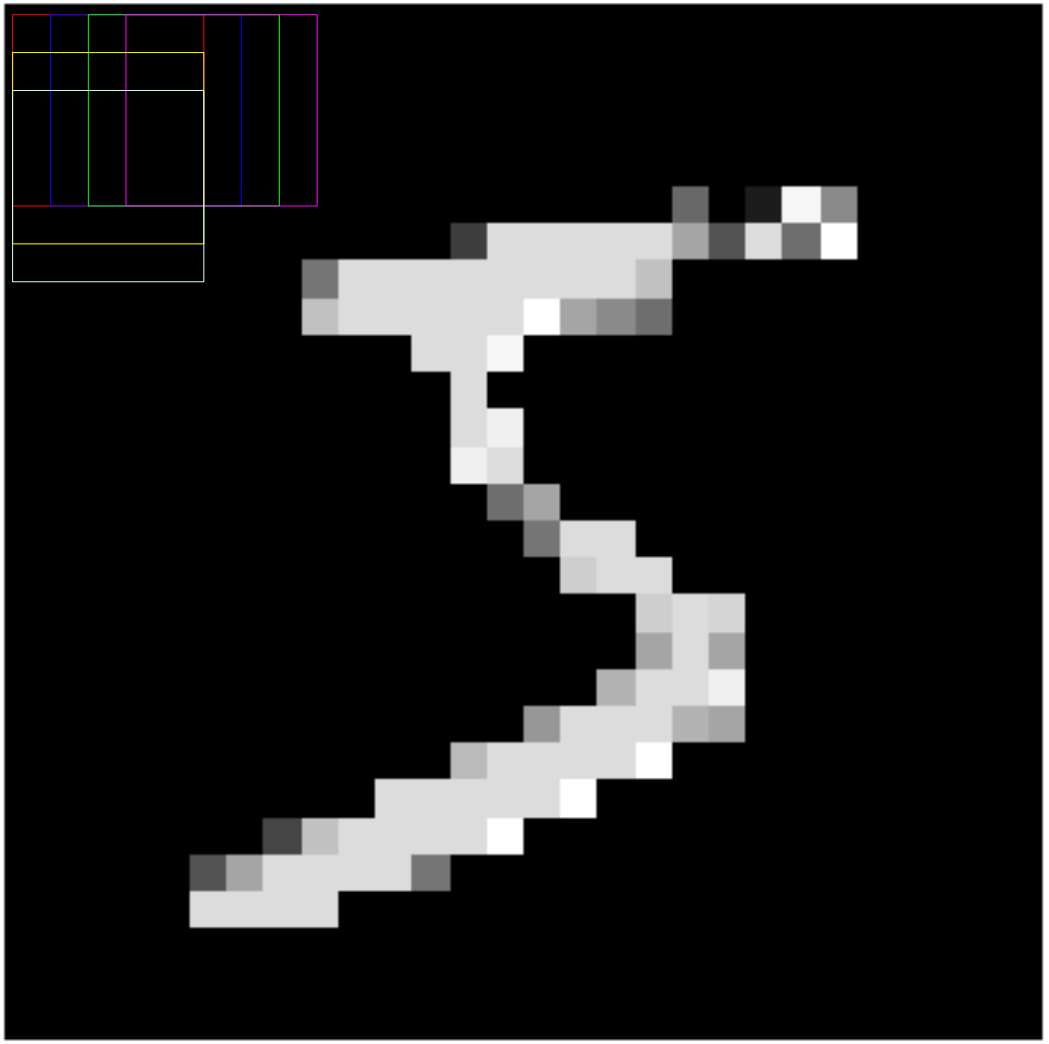


32 kernels
5x5 pixels
stride 1
padding 1

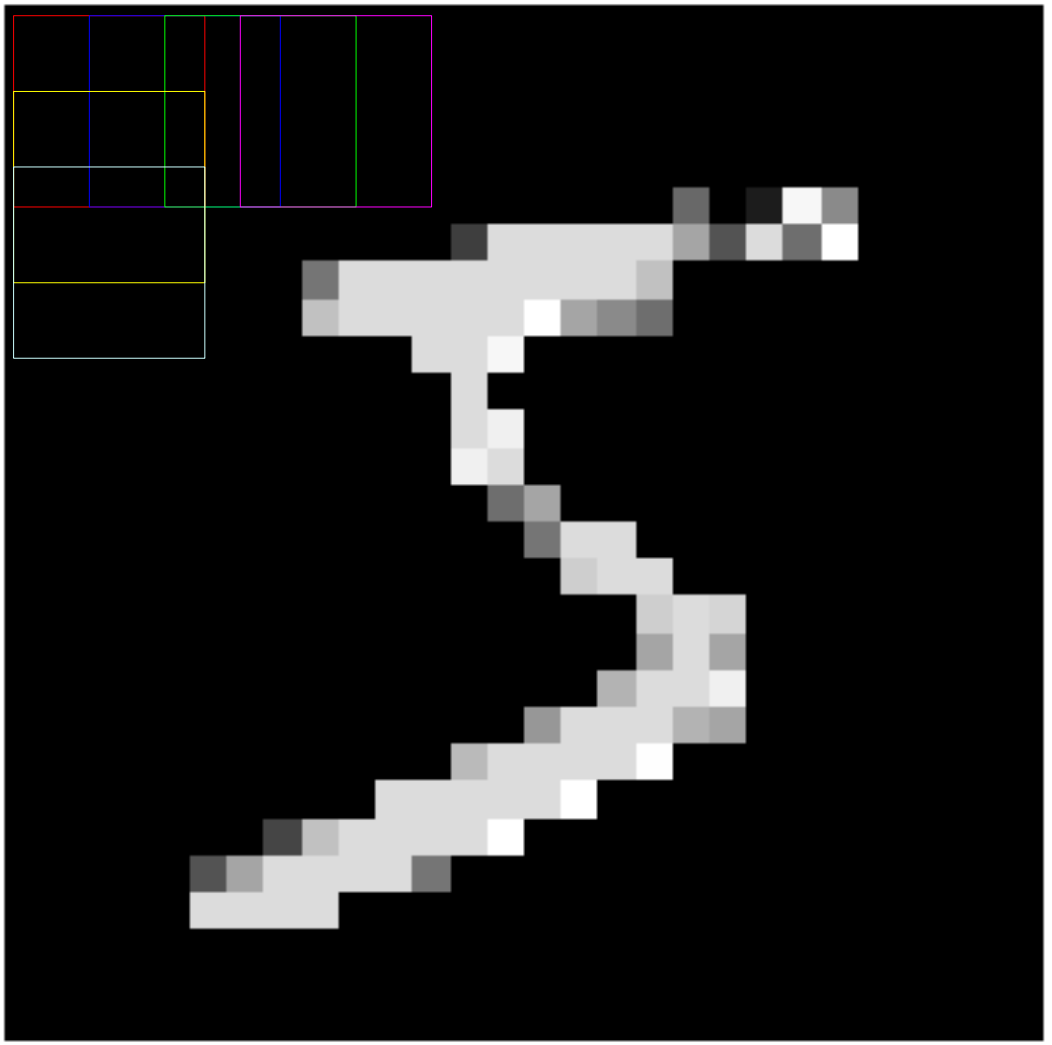
32 feature maps
26 x 26

weights = 32 x (5x5+1) = 832 (small!)
connections = 32 x (26x26) x (5x5+1) = 562,432

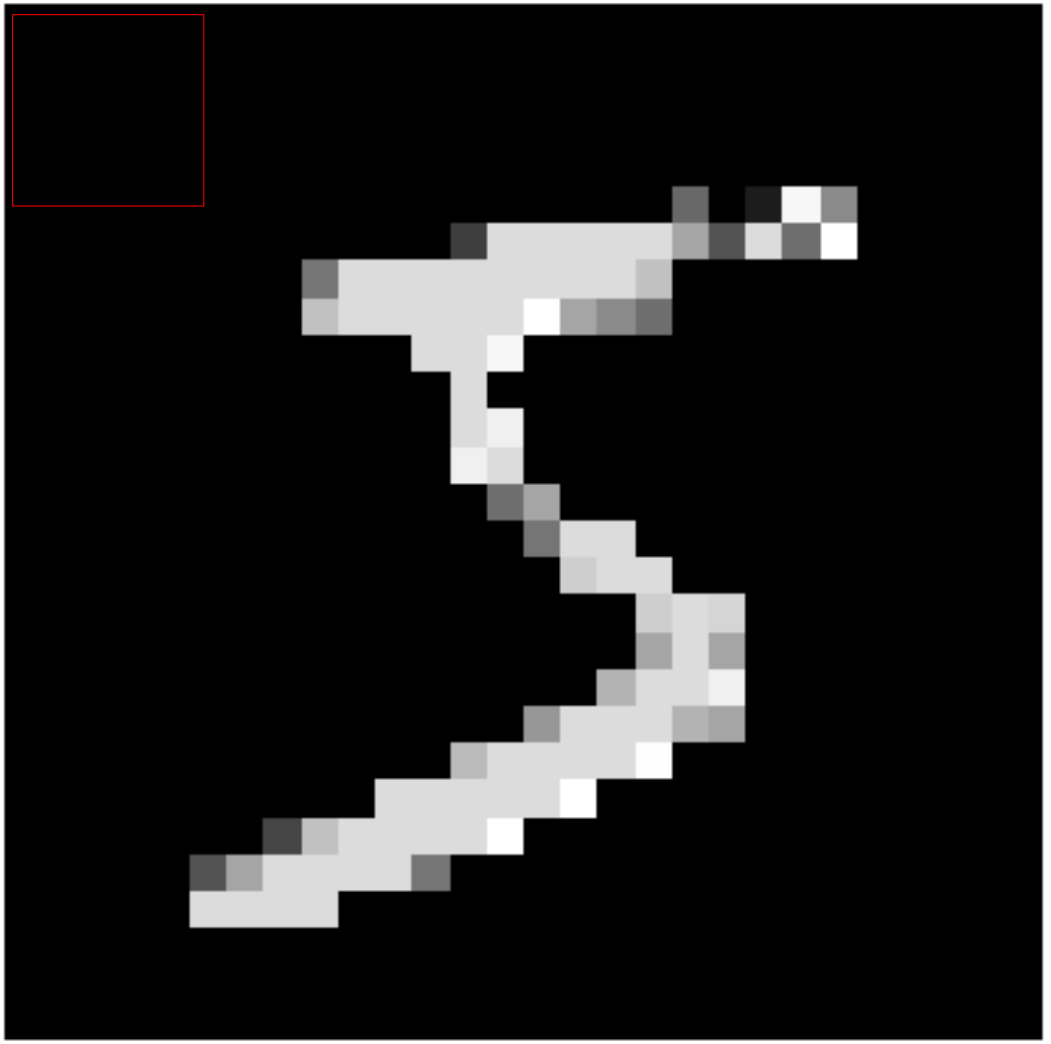
Stride 1



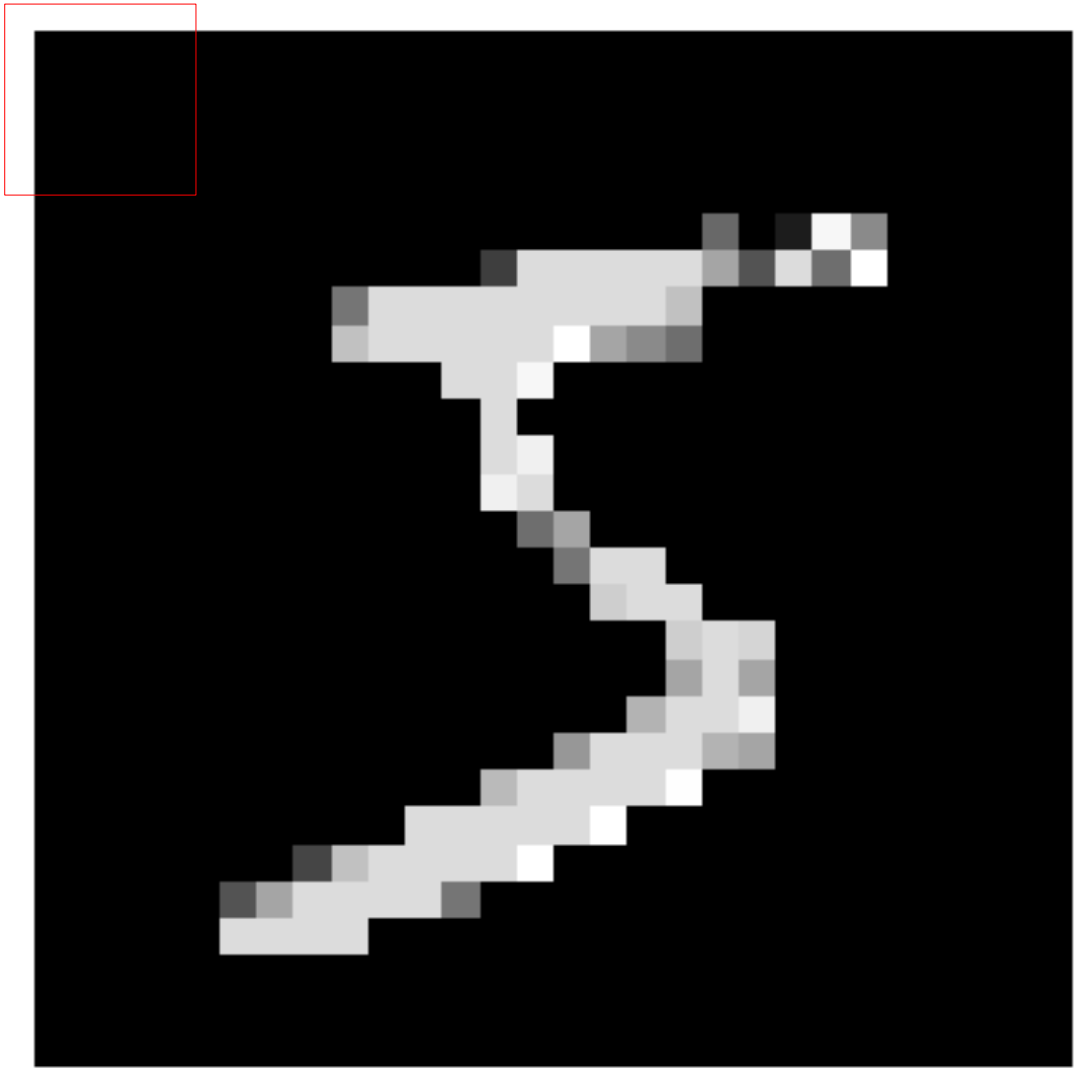
Stride 2



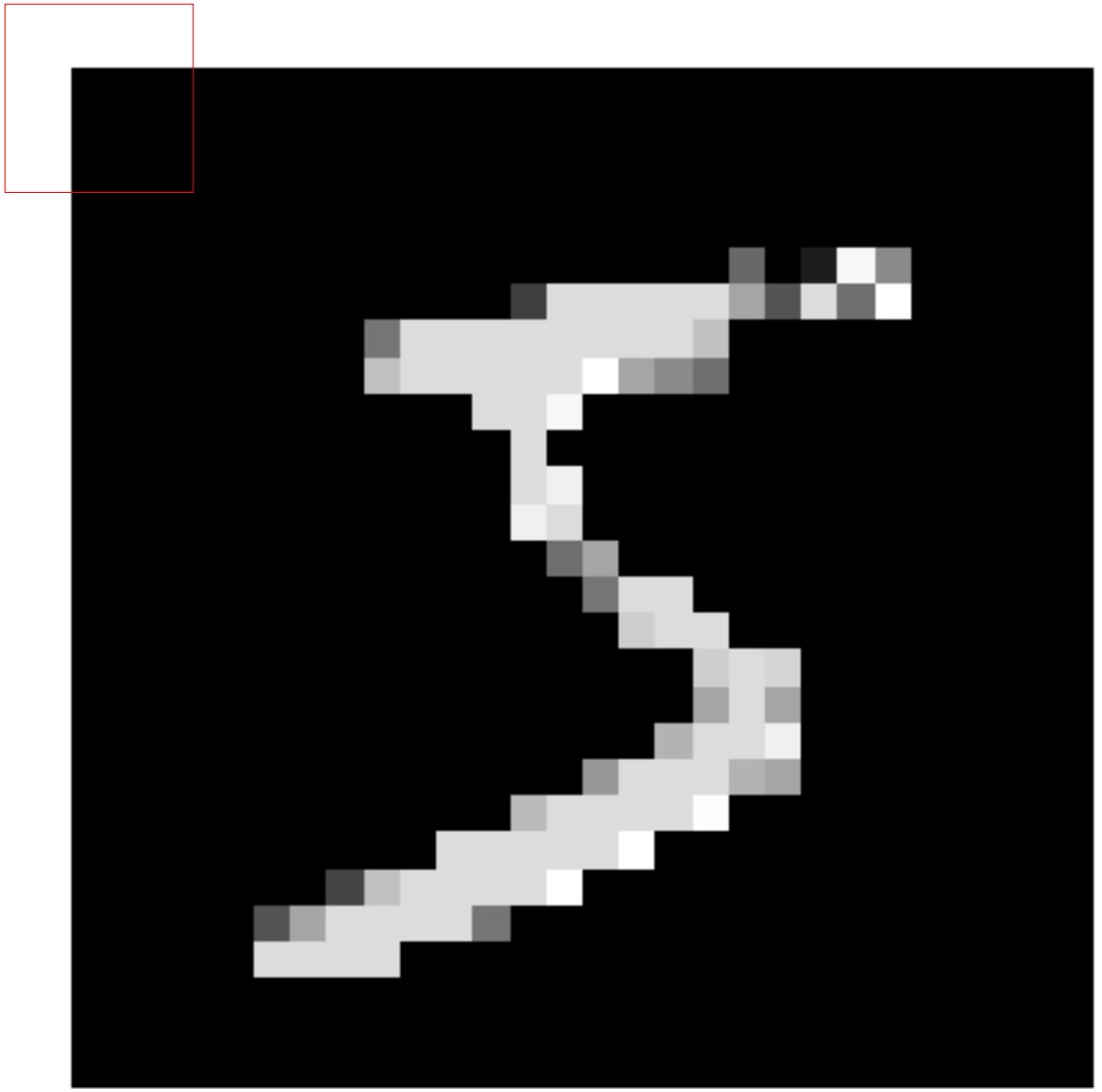
First Kernel: Padding 0



First Kernel: Padding 1

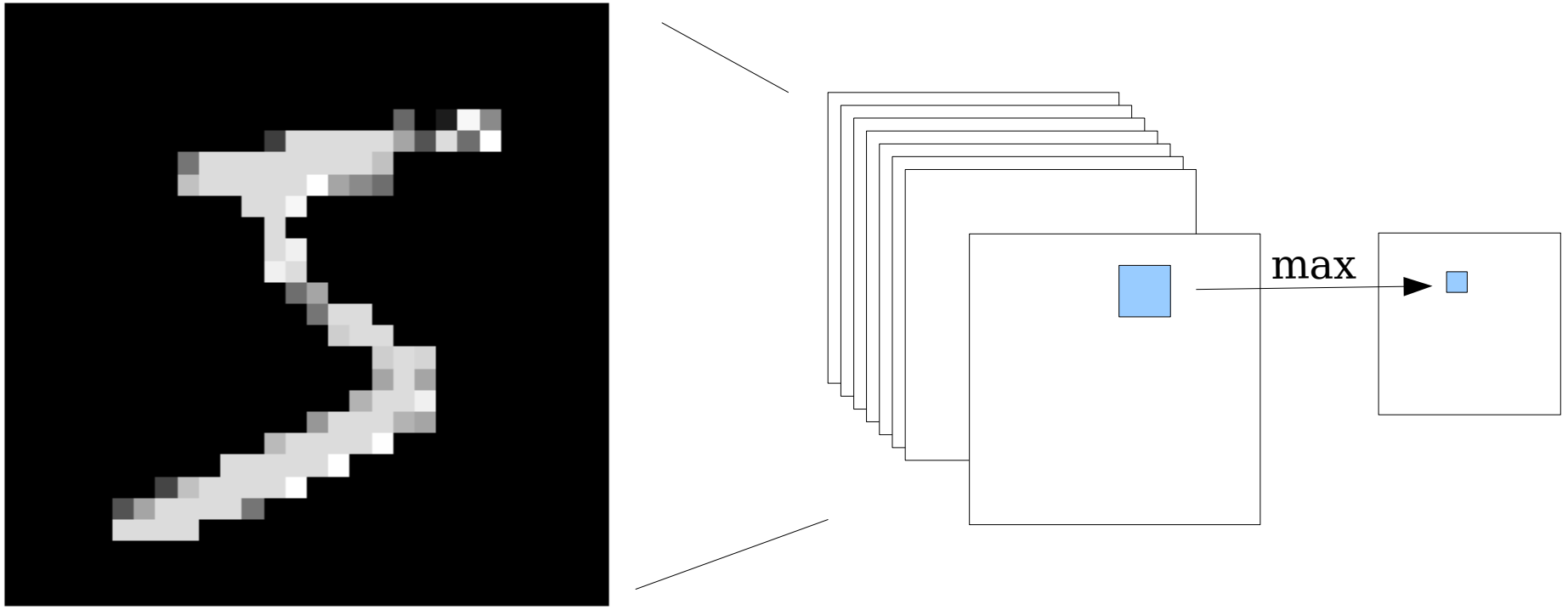


First Kernel: Padding 2



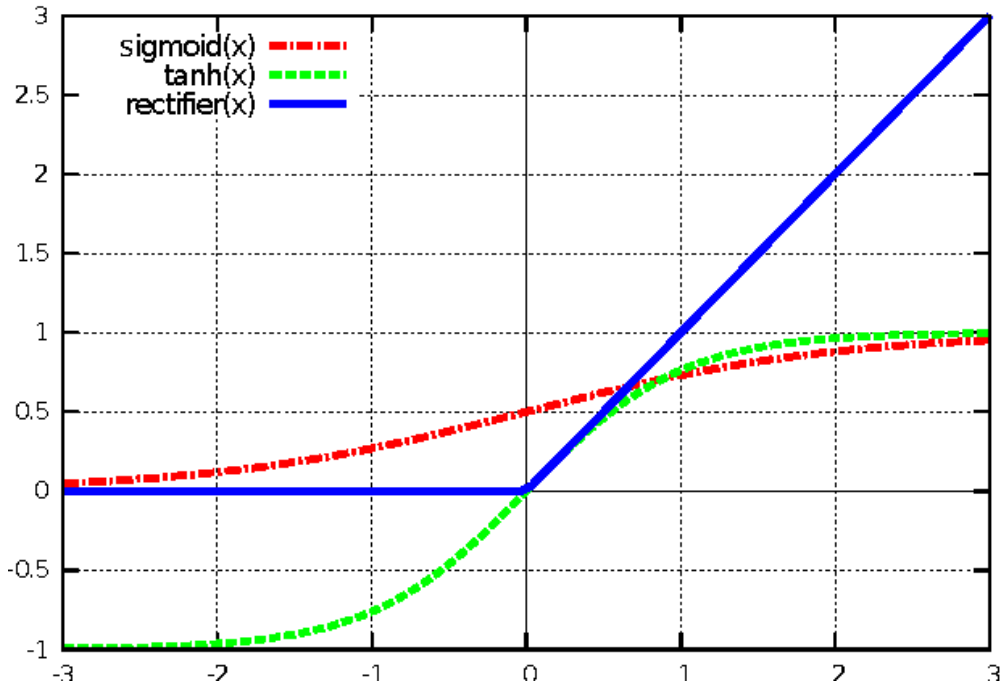
Max Pooling

- We might not care exactly where a feature appears in the image.
- Downsampling by max pooling reduces the number of units and connections.



Choice of Activation Function

- Sigmoid and tanh were popular early on:



- Now it's more common to use ReLU: Rectified Linear Unit. $g(x) = \max(x,0)$
  - Derivative doesn't go to zero for large x.

Choice of Loss Function

- Mean Squared Error is a general loss function but not always the best to use.

$$E = \frac{1}{2}\sum_{p}\left(d^{p}-y^{p}\right)^{2}$$

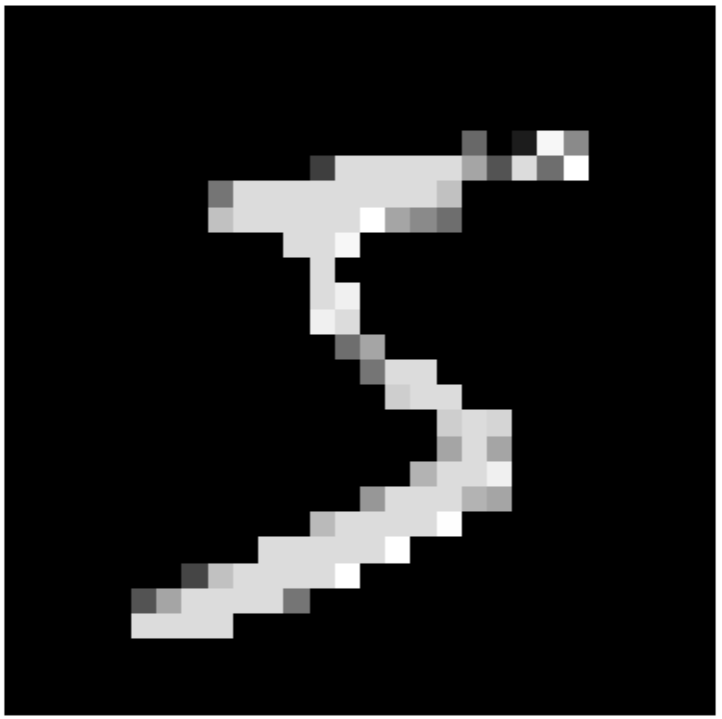
- If desired outputs are probabilities (values between 0 and 1), use cross-entropy instead. Heavily penalizes <u>really</u> wrong outputs.

$$E = \sum_{p} -d^{p}\log\left(y^{p}\right)-\left(1-d^{p}\right)\log\left(1-y^{p}\right)$$

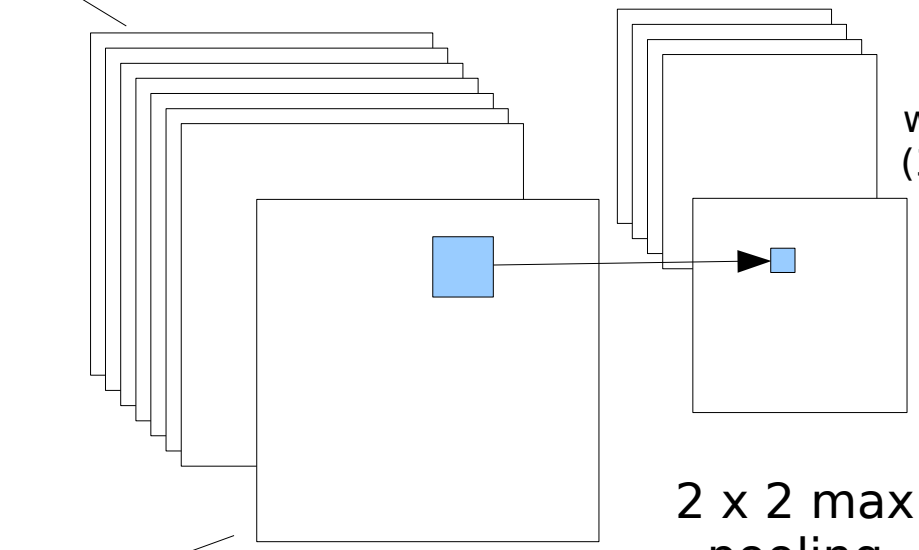
Batch Normalization

- We want the activity patterns in each layer to have nice statistical properties (mean and variance) because this helps speed up learning.
- But each weight update changes the statistical distribution.
- Solution: “batch normalization”, a trick for making the distributions more uniform.
- Built in to PyTorch.

MNIST With A CNN



28 x 28 image



32 kernels 5x5 pixels
stride 1
padding 2
ReLU nonlinearity
image maps 28 x 28
batch normalization

2 x 2 max
pooling

32 image maps
14 x 14

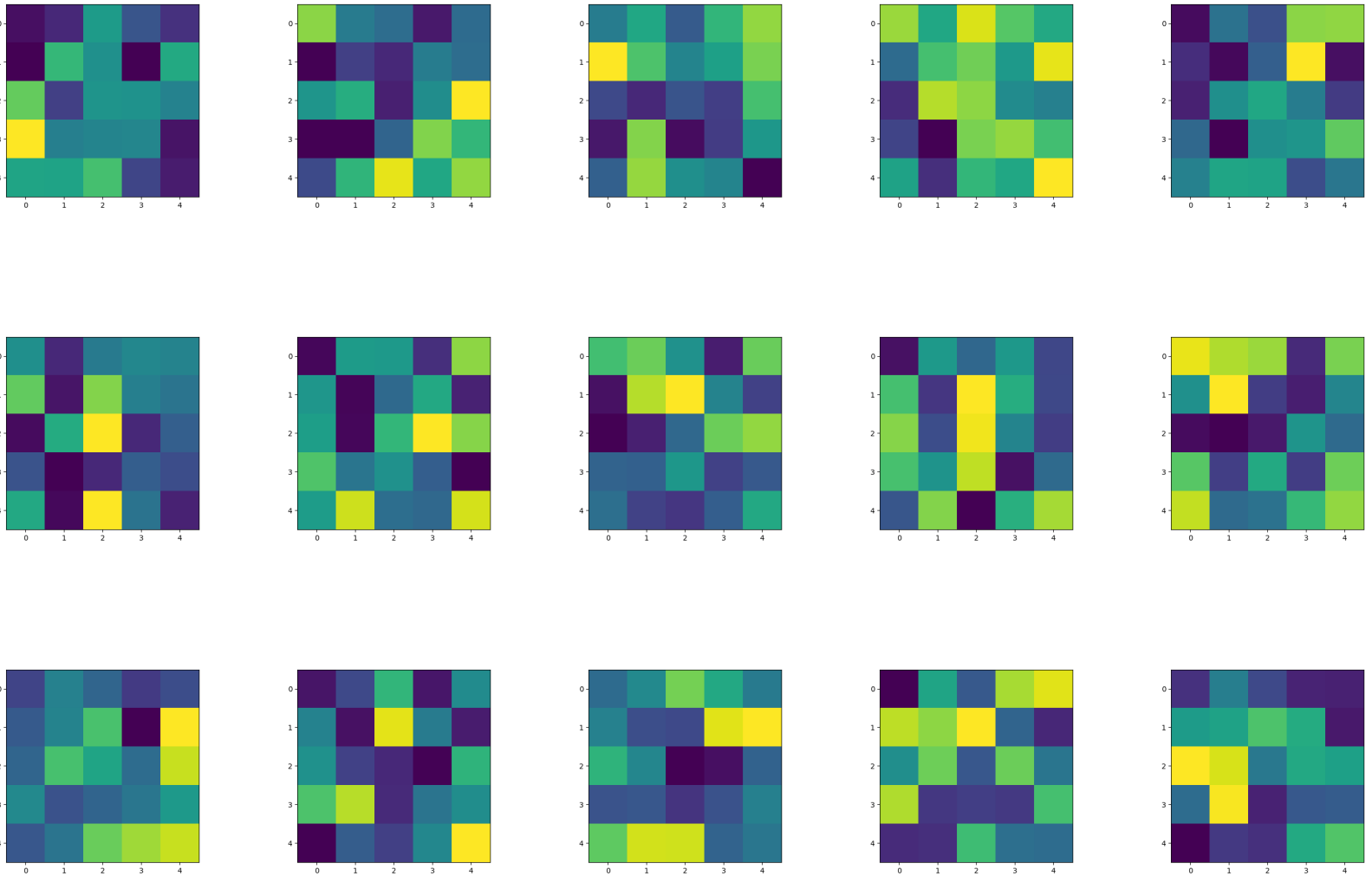
fully
connected
weight matrix
(32*14*14+1)
x 10

Cross-
entropy
loss
function

parameters = 63,626
How many connections?

Accuracy on training set: 98.3%

Sample Learned Kernels

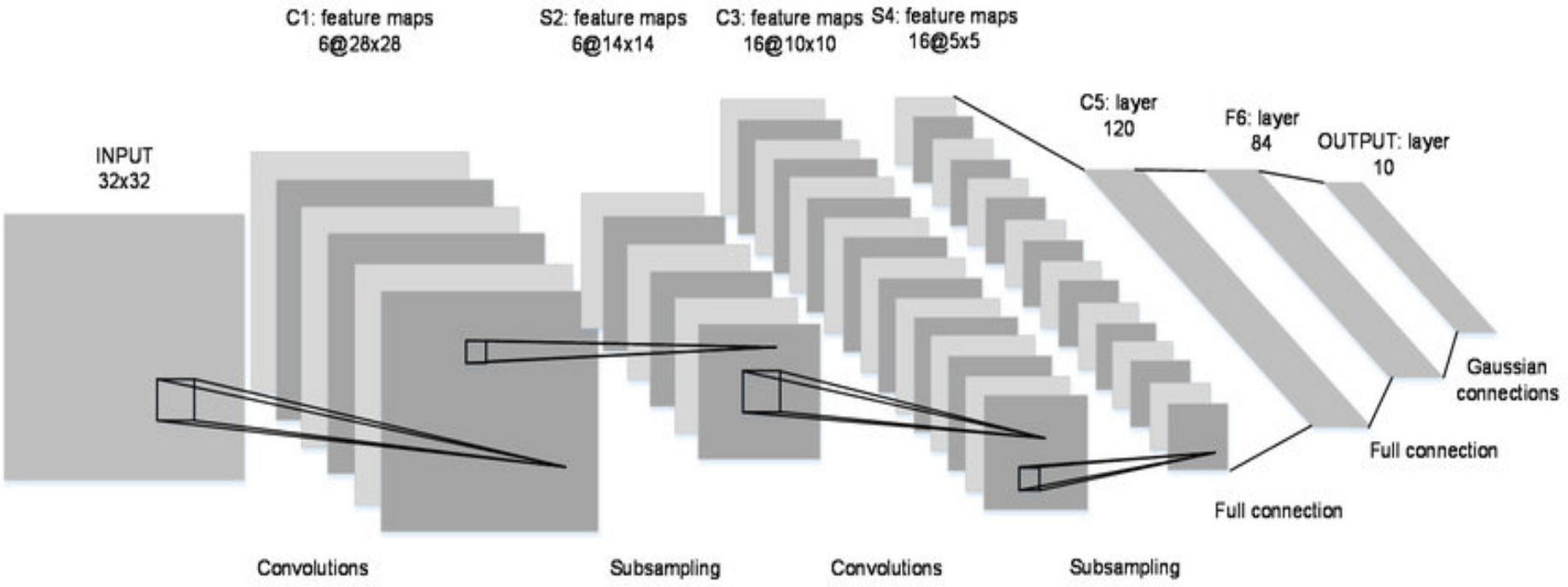


Deep Neural Networks

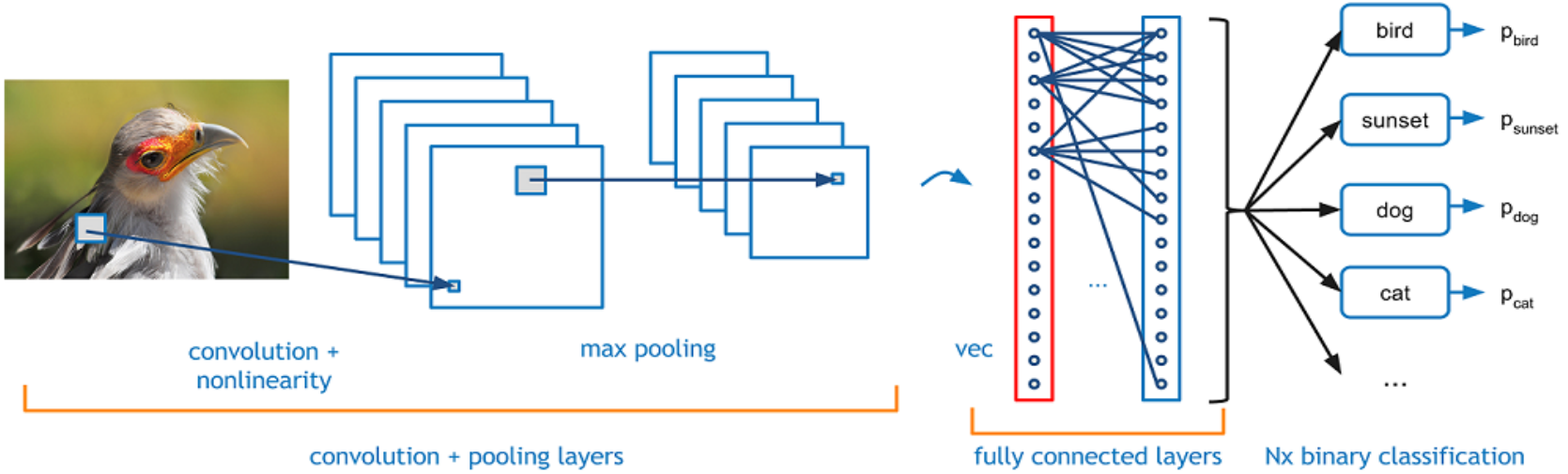
- For really hard problems (e.g., object recognition on color images) we may need many layers.
- Series of convolutional and max pooling layers, followed by some fully connected layers.
  - LeNet had 10 layers.
  - Inception V1 had 27 layers.
  - ResNet has 100 layers.
- GPUs required for training.

LeNet (Yann LuCun, 1990s)

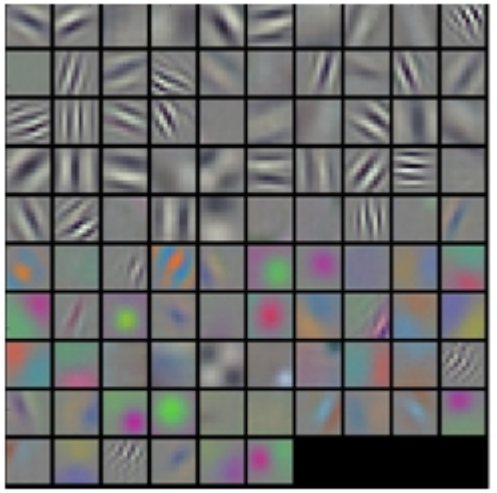
- Handwritten digit recognition



Object Recognition CNN



https://adeshpande3.github.io/A-Beginner%27s-Guide-To-Understanding-Convolutional-Neural-Networks/



Visualizations of filters

PyTorch

- Python package for tensor manipulation and vectorized computations, including neural net learning.
  - Replacement for numpy
  - Optimized for GPUs
- Tensors are multi-dimensional arrays, similar to numpy's ndarray structure.
- Code can run on either CPU or GPU.