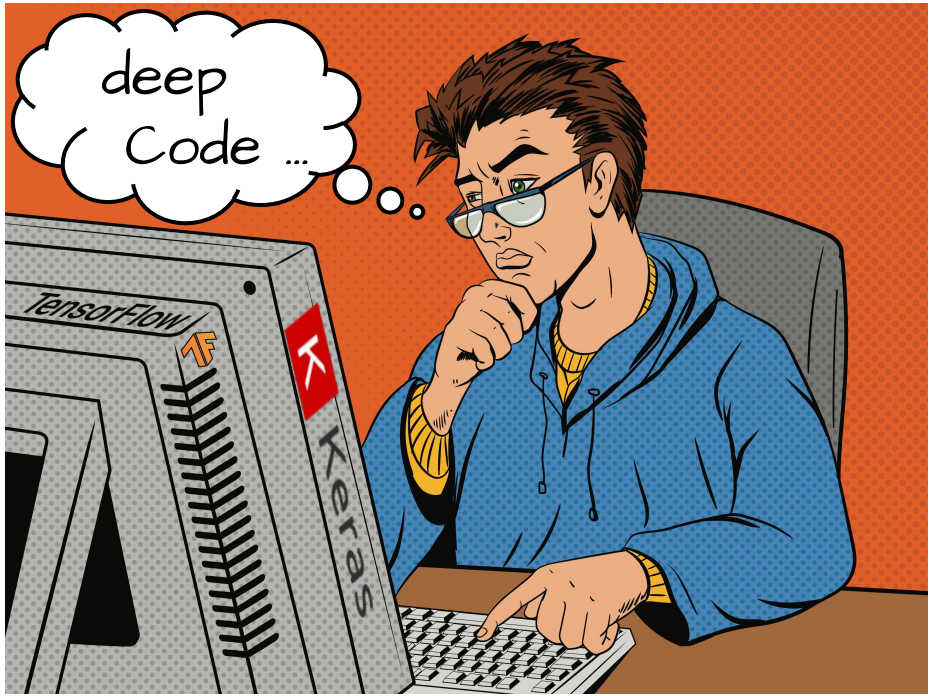
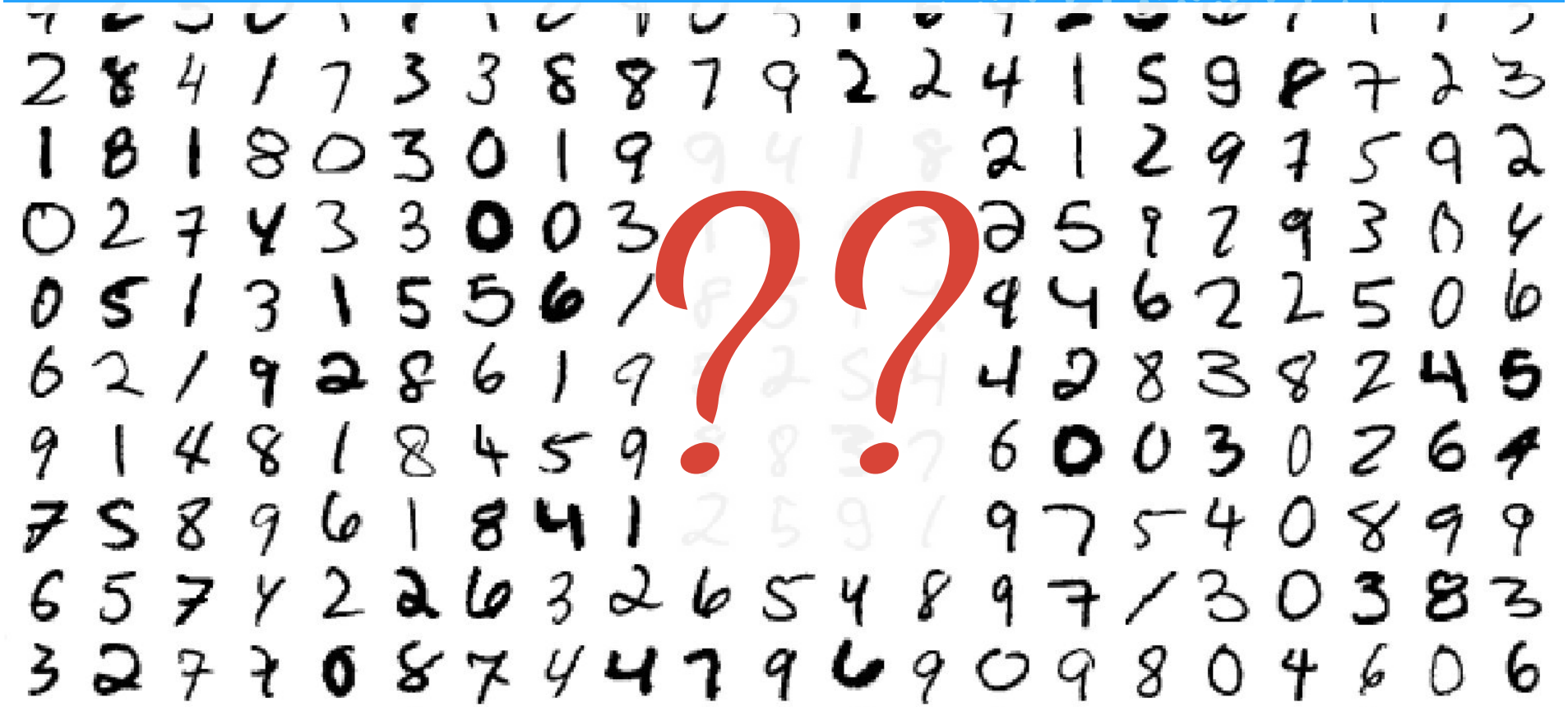
>Optimising Training of Neural Networks_



Recap till now

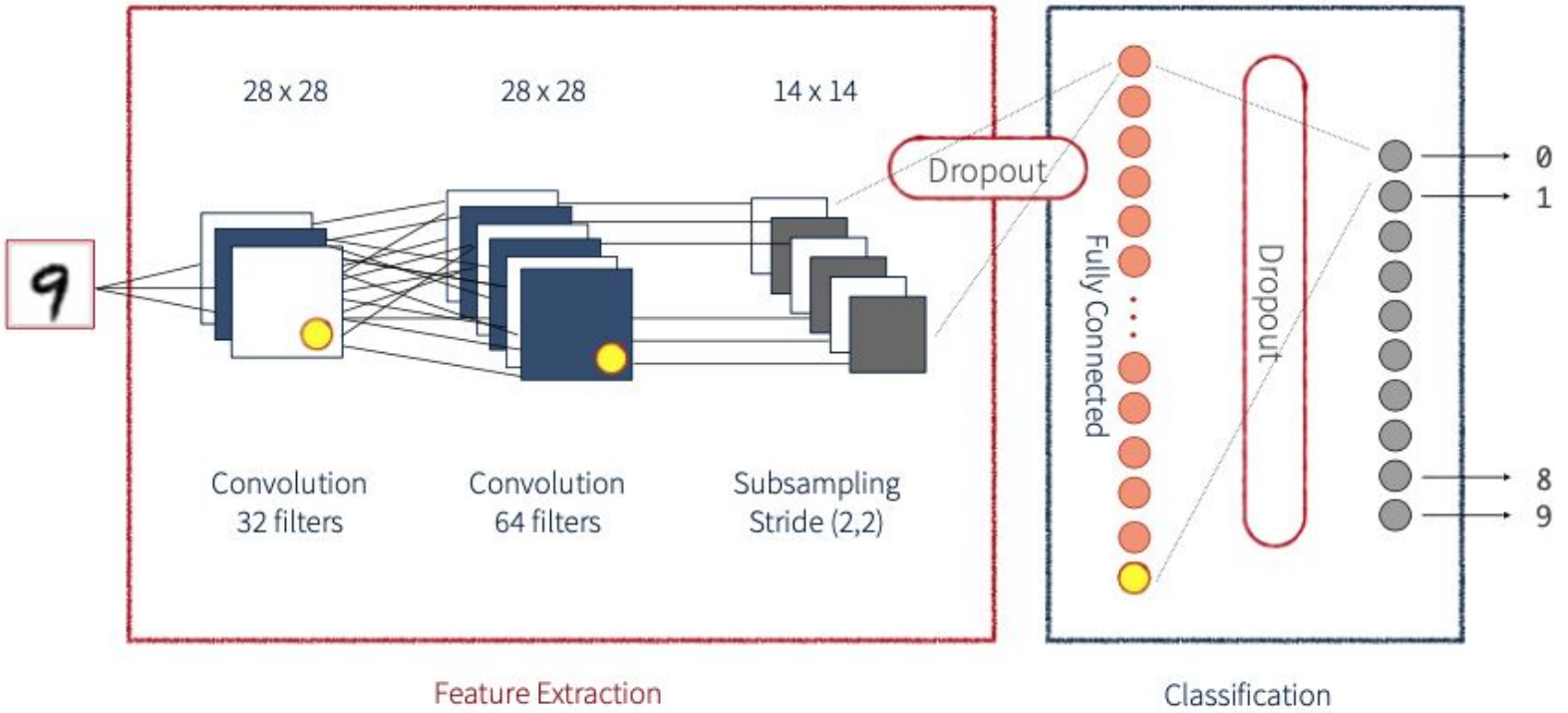
- Introduction to Neural Networks & its working
- Tensorflow framework
- Introduction to Neural Networks for Regression Problems
- Introduction to Neural Networks for Classification Problems
- Introduction to Hyperparameters (epochs, learning rate, batch size)
- Basics of optimization

Hello World: handwritten digits classification - MNIST

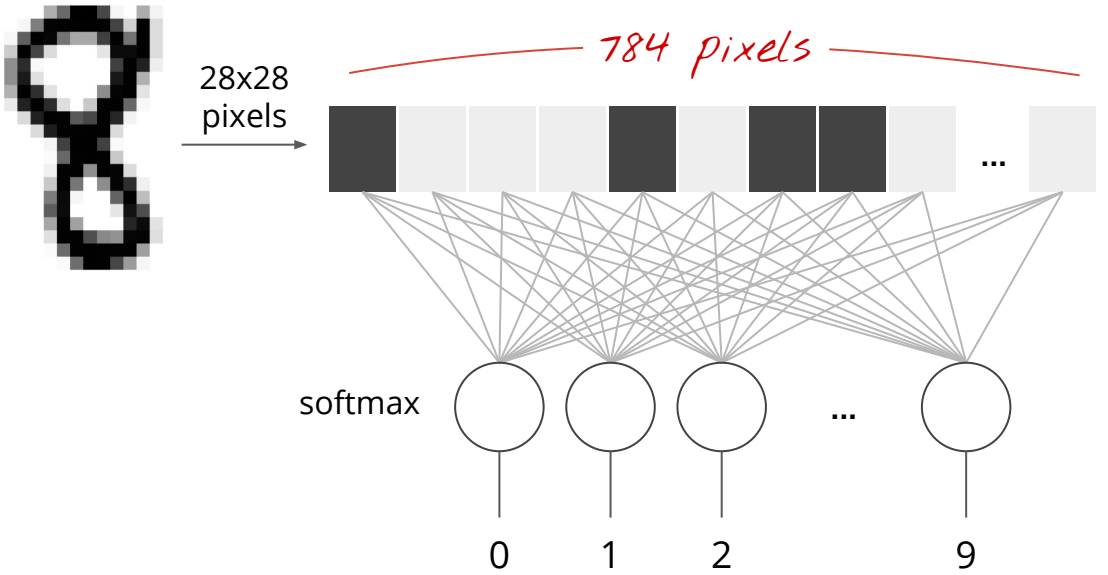


MNIST = Mixed National Institute of Standards and Technology - Download the dataset at http://yann.lecun.com/exdb/mnist/

Convolutional Neural Networks



Very simple model: softmax classification

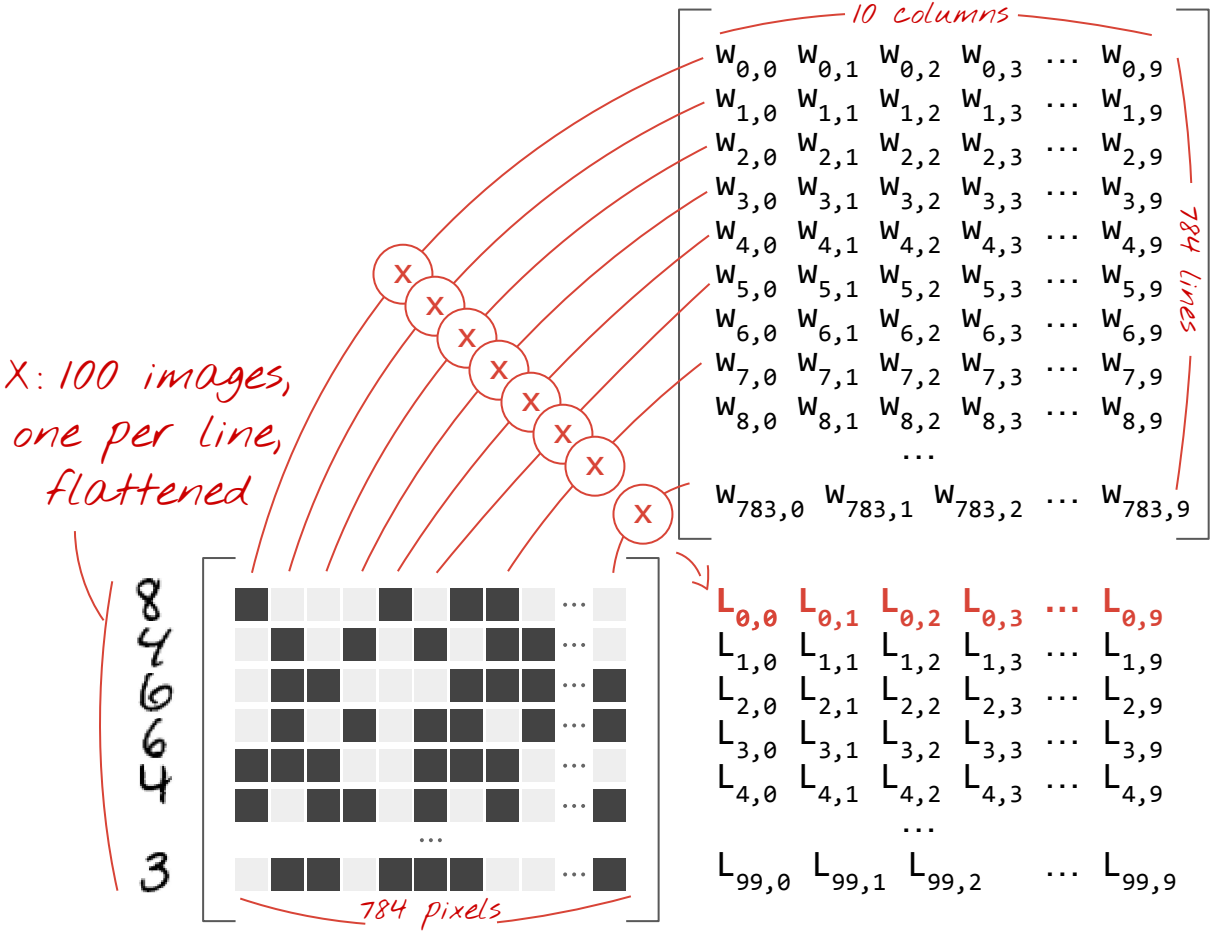


weighted sum of all pixels + bias

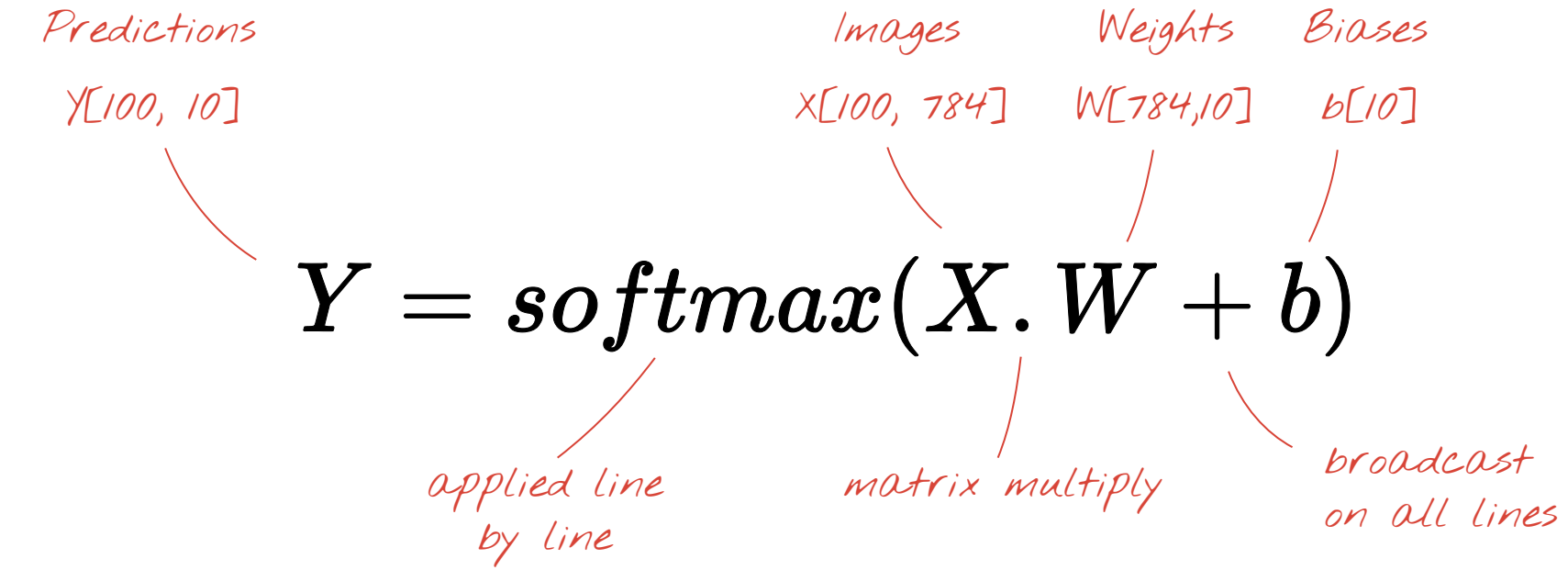
$$softmax(L_n) = \frac{e^{L_n}}{||e^{L}||}$$

neuron outputs

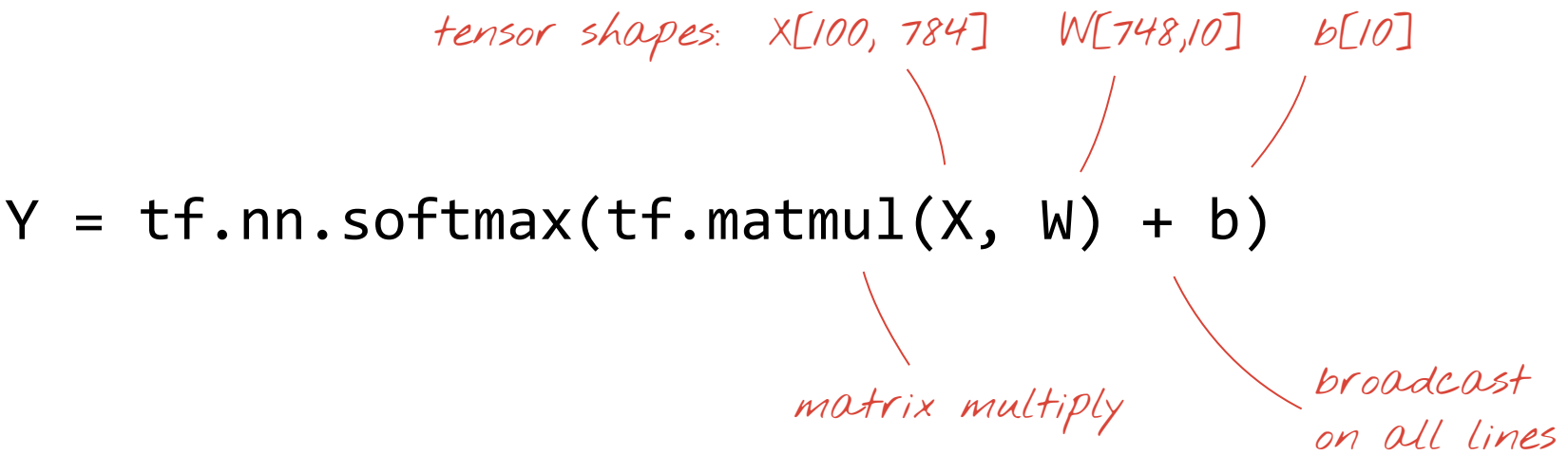
In matrix notation, 100 images at a time



Softmax, on a batch of images



Now in TensorFlow (Python)



Success ?

0	1	2	3	4	5	6	7	8	9
0	0	0	0	0	0	1	0	0	0

actual probabilities, "one-hot" encoded

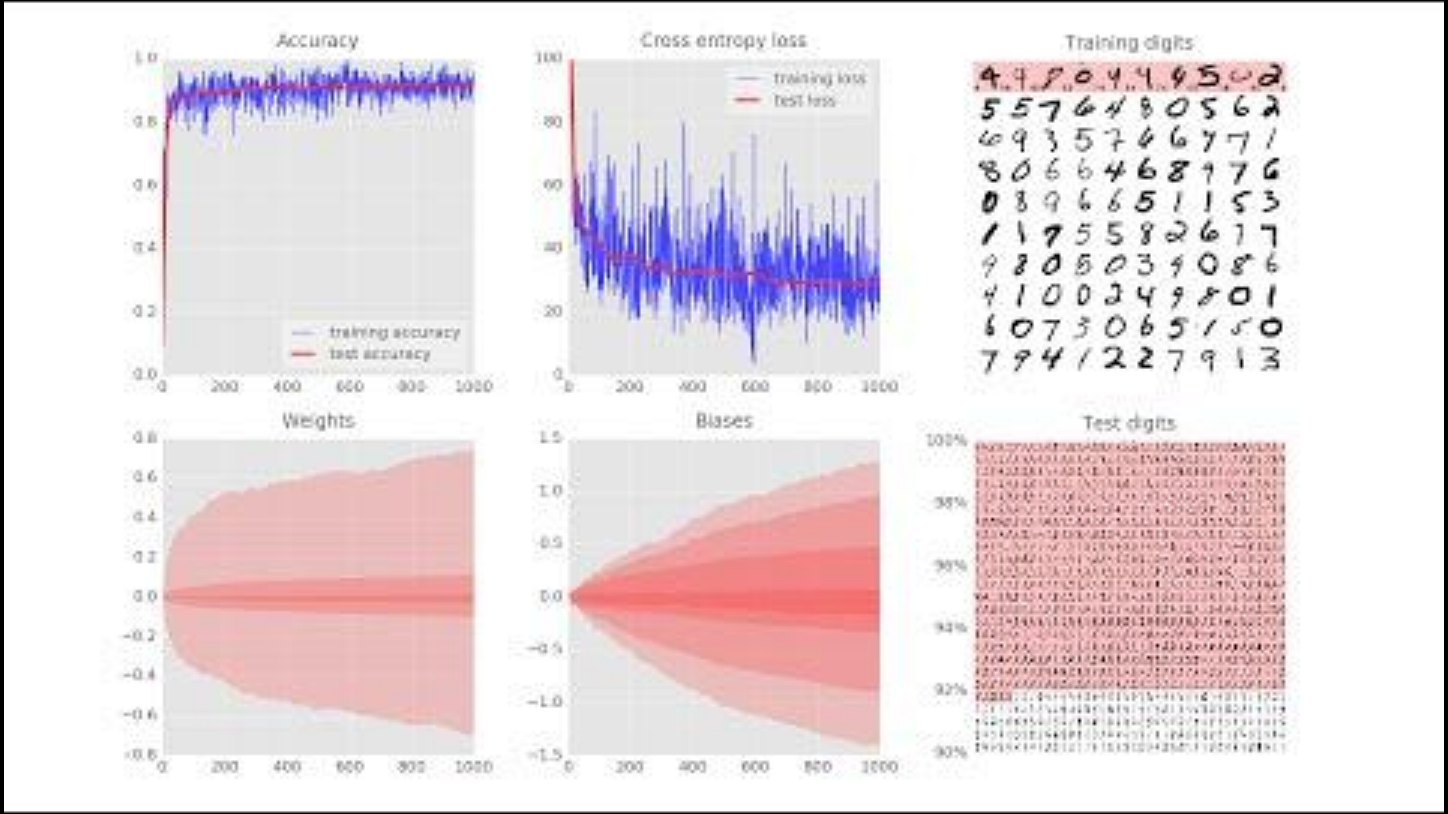
Cross entropy: $-\sum Y'_i . log(Y_i)$

computed probabilities

this is a "6"

0	1	2	3	4	5	6	7	8	9
.01	.03	.00	.04	.03	.05	0.8	.02	.01	.01

Demo


Accuracy
training accuracy
test accuracy
Cross entropy loss
training loss
test loss
Training digits
Weights
Biases
Test digits

TensorFlow - initialisation

```
import tensorflow as tf

X = tf.placeholder(tf.float32, [None, 28, 28, 1])
W = tf.Variable(tf.zeros([784, 10]))
b = tf.Variable(tf.zeros([10]))

init = tf.initialize_all_variables()
```

this will become the batch size, 100

28 x 28 grayscale images

Training = computing variables W and b

TensorFlow - success metrics

flattening images

```
# model
Y = tf.nn.softmax(tf.matmul(tf.reshape(X, [-1, 784]), W) + b)
# placeholder for correct answers
Y_ = tf.placeholder(tf.float32, [None, 10])
```

"one-hot" encoded

```
# loss function
cross_entropy = -tf.reduce_sum(Y_ * tf.log(Y))
```

"one-hot" decoding

```
# % of correct answers found in batch
is_correct = tf.equal(tf.argmax(Y,1), tf.argmax(Y_,1))
accuracy = tf.reduce_mean(tf.cast(is_correct, tf.float32))
```

TensorFlow - training

learning rate

```
optimizer = tf.train.GradientDescentOptimizer(0.003)
train_step = optimizer.minimize(cross_entropy)
```

loss function

TensorFlow - run !

```
sess = tf.Session()
sess.run(init)

for i in range(1000):
    # load batch of images and correct answers
    batch_X, batch_Y = mnist.train.next_batch(100)
    train_data={X: batch_X, Y_: batch_Y}

    # train
    sess.run(train_step, feed_dict=train_data)

    # success ?
    a,c = sess.run([accuracy, cross_entropy], feed_dict=train_data)

    # success on test data ?
    test_data={X: mnist.test.images, Y_: mnist.test.labels}
    a,c = sess.run([accuracy, cross_entropy], feed=test_data)
```

running a Tensorflow computation, feeding placeholders

Tip: do this every 100 iterations

TensorFlow - full python code

initialisation

```
import tensorflow as tf


X = tf.placeholder(tf.float32, [None, 28, 28, 1])
W = tf.Variable(tf.zeros([784, 10]))
b = tf.Variable(tf.zeros([10]))
init = tf.initialize_all_variables()
```

model

```
# model
Y=tf.nn.softmax(tf.matmul(tf.reshape(X,[-1, 784]), W) + b)

# placeholder for correct answers
Y_ = tf.placeholder(tf.float32, [None, 10])
```

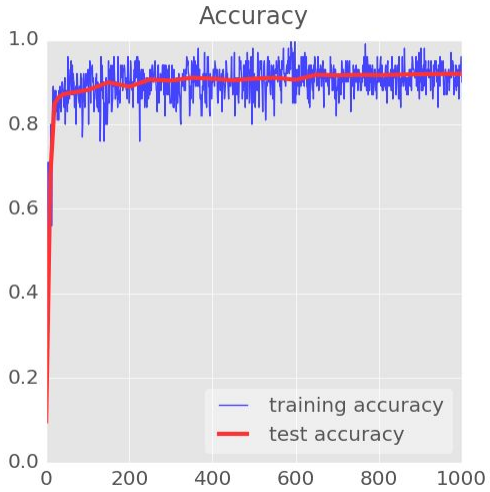
success metrics

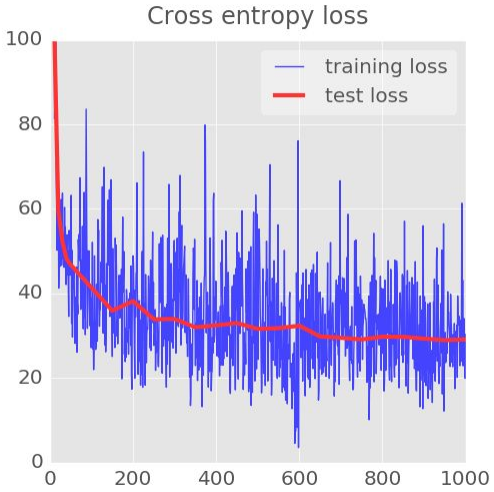
```
# loss function
cross_entropy = -tf.reduce_sum(Y_ * tf.log(Y))

# % of correct answers found in batch
is_correct = tf.equal(tf.argmax(Y,1), tf.argmax(Y_,1))
accuracy = tf.reduce_mean(tf.cast(is_correct,tf.float32))
```

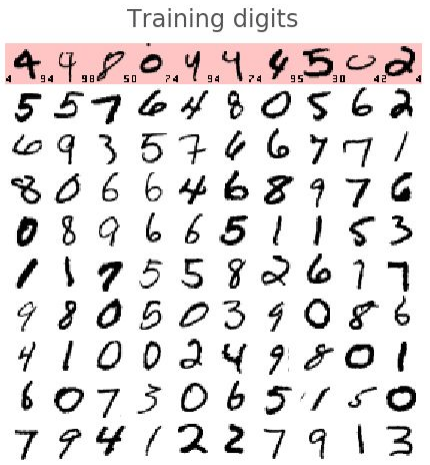
training step

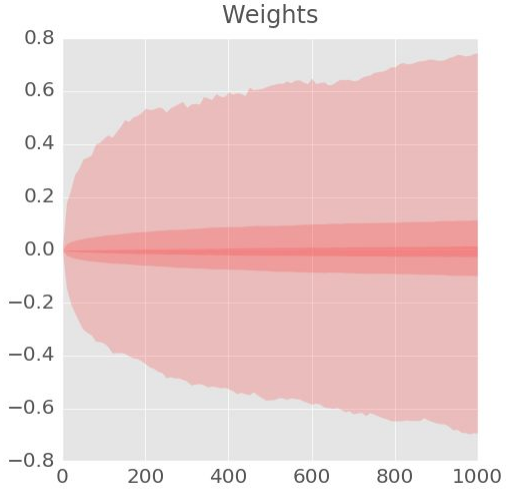
```
optimizer = tf.train.GradientDescentOptimizer(0.003)
train_step = optimizer.minimize(cross_entropy)


sess = tf.Session()
sess.run(init)

for i in range(10000):
      # load batch of images and correct answers
      batch_X, batch_Y = mnist.train.next_batch(100)
      train_data={X: batch_X, Y_: batch_Y}

      # train
      sess.run(train_step, feed_dict=train_data)

      # success ? add code to print it
      a,c = sess.run([accuracy, cross_entropy], feed=train_data)

      # success on test data ?
      test_data={X:mnist.test.images, Y_:mnist.test.labels}
      a,c = sess.run([accuracy, cross_entropy], feed=test_data)
```

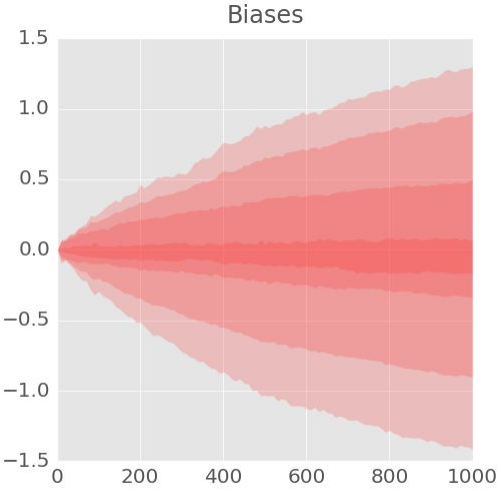
Run

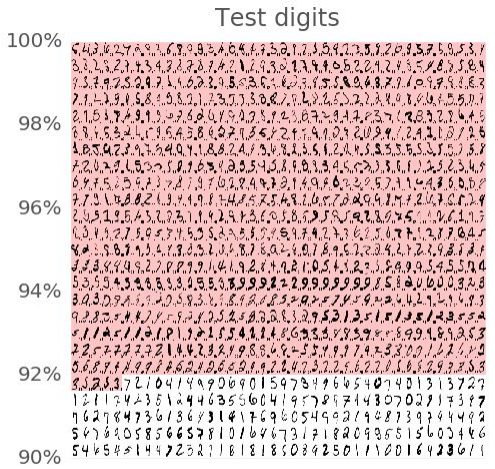

Accuracy
training accuracy
test accuracy


Cross entropy loss
training loss
test loss


Training digits


Weights


Biases

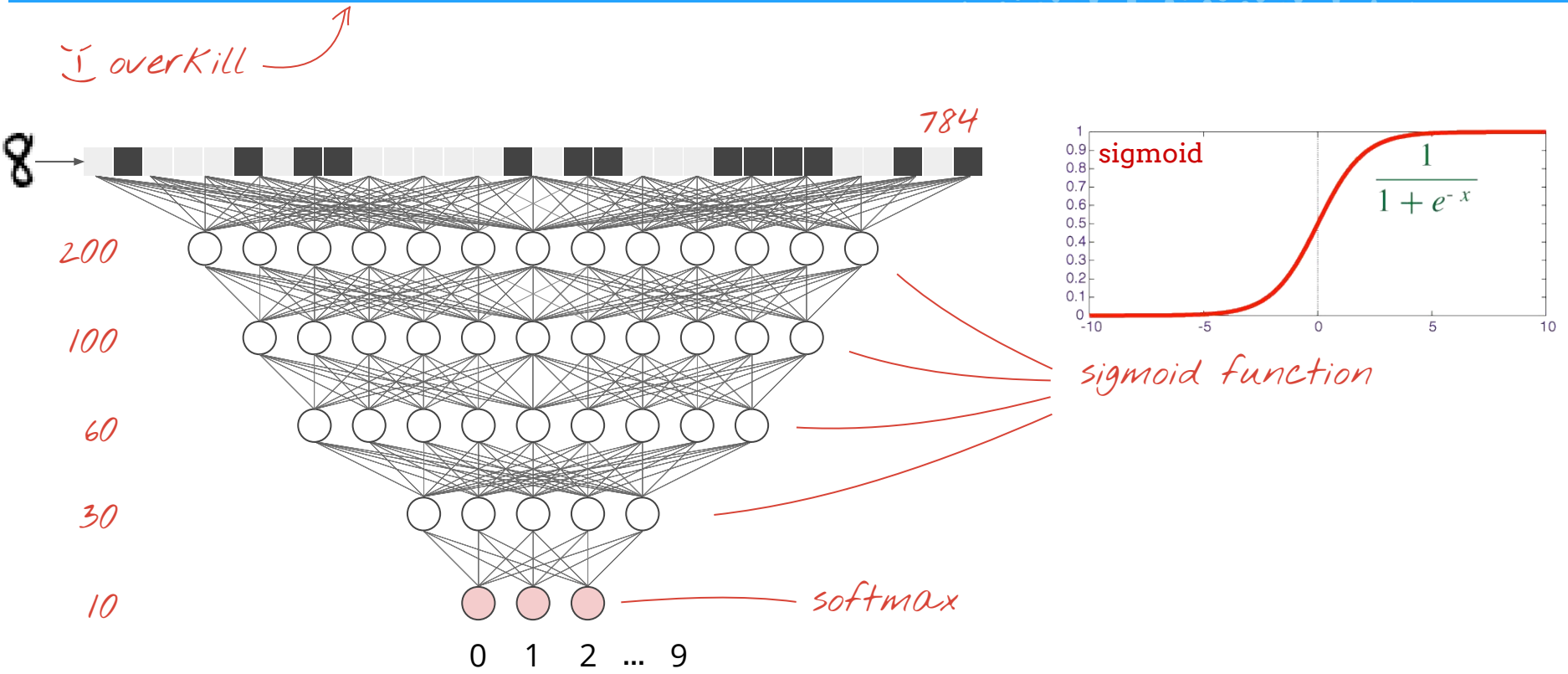

Test digits

92%

Softmax
Cross-entropy
Mini-batch


Go deep !

Let's try 5 fully-connected layers !



TensorFlow - initialisation

```
K = 200
L = 100
M = 60
N = 30
```

weights initialised with random values

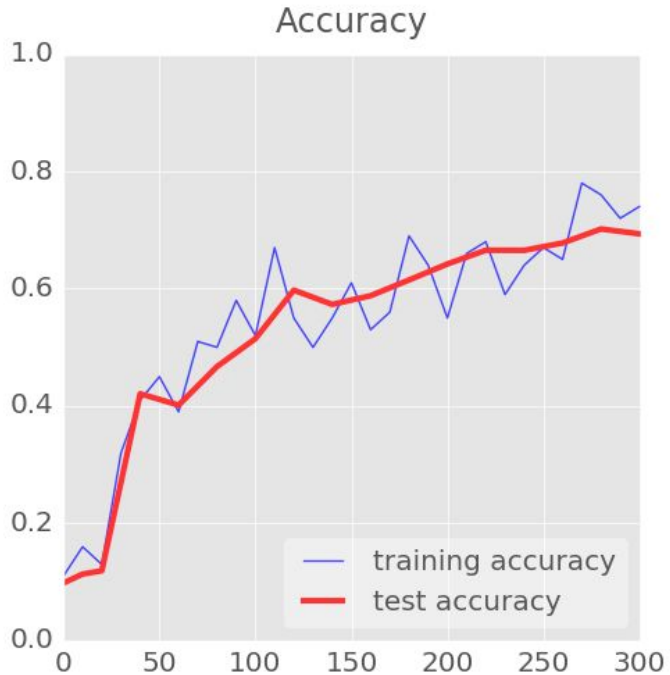
```
W1 = tf.Variable(tf.truncated_normal([28*28, K] ,stddev=0.1))
B1 = tf.Variable(tf.zeros([K]))

W2 = tf.Variable(tf.truncated_normal([K, L], stddev=0.1))
B2 = tf.Variable(tf.zeros([L]))

W3 = tf.Variable(tf.truncated_normal([L, M], stddev=0.1))
B3 = tf.Variable(tf.zeros([M]))
W4 = tf.Variable(tf.truncated_normal([M, N], stddev=0.1))
B4 = tf.Variable(tf.zeros([N]))
W5 = tf.Variable(tf.truncated_normal([N, 10], stddev=0.1))
B5 = tf.Variable(tf.zeros([10]))
```

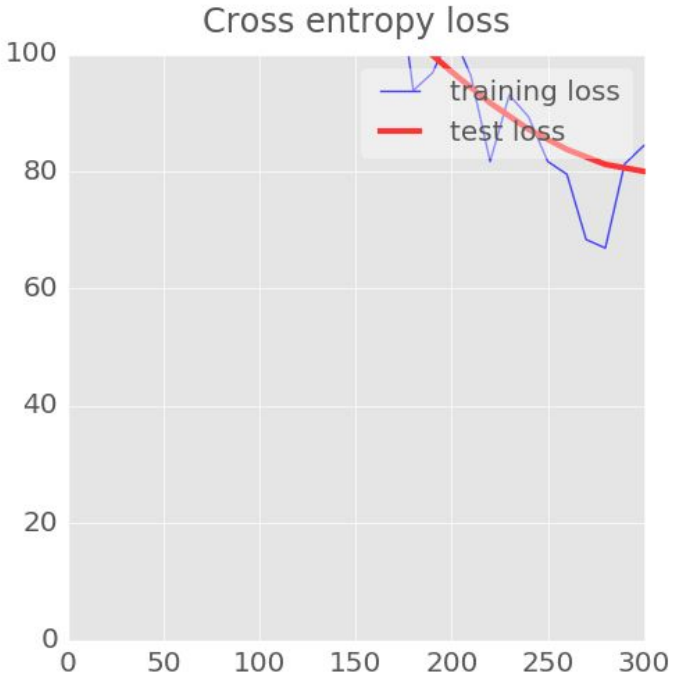
TensorFlow - the model

weights and biases

```
X = tf.reshape(X, [-1, 28*28])

Y1 = tf.nn.sigmoid(tf.matmul(X, W1) + B1)
Y2 = tf.nn.sigmoid(tf.matmul(Y1, W2) + B2)
Y3 = tf.nn.sigmoid(tf.matmul(Y2, W3) + B3)
Y4 = tf.nn.sigmoid(tf.matmul(Y3, W4) + B4)
Y = tf.nn.softmax(tf.matmul(Y4, W5) + B5)
```

slow start ?

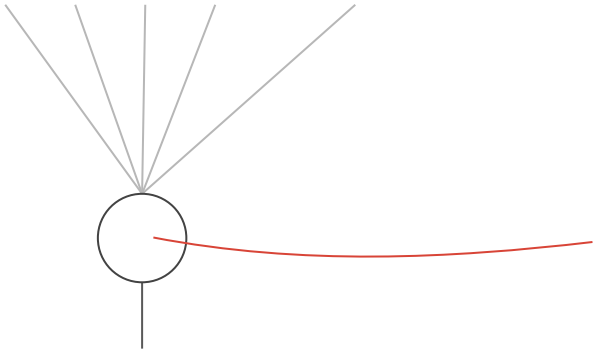

Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
training accuracy
test accuracy

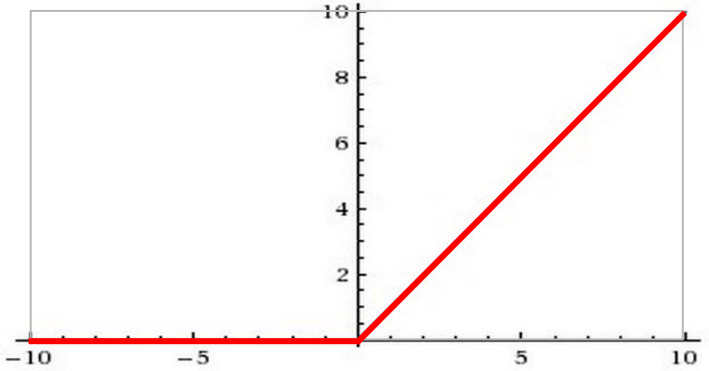

Cross entropy loss
100
80
60
40
20
0
0
50
100
150
200
250
300
training loss
test loss


Relu !

RELU

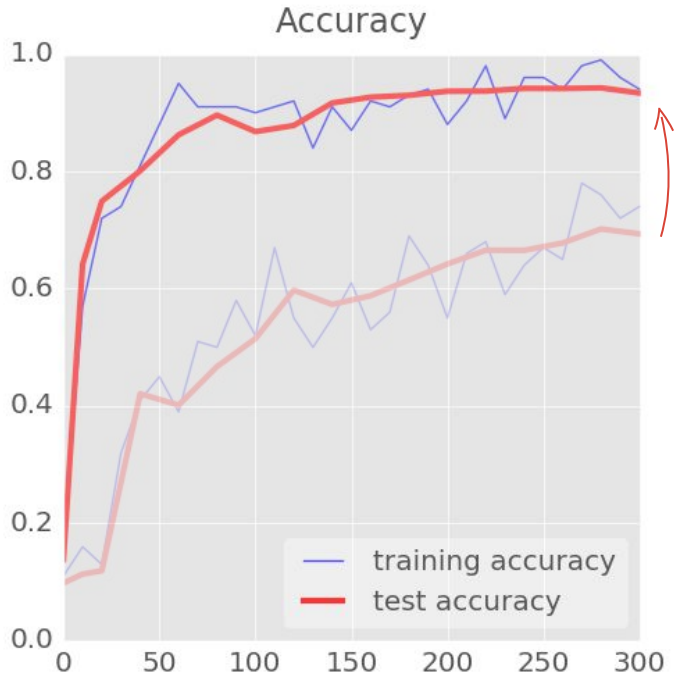
RELU = Rectified Linear Unit

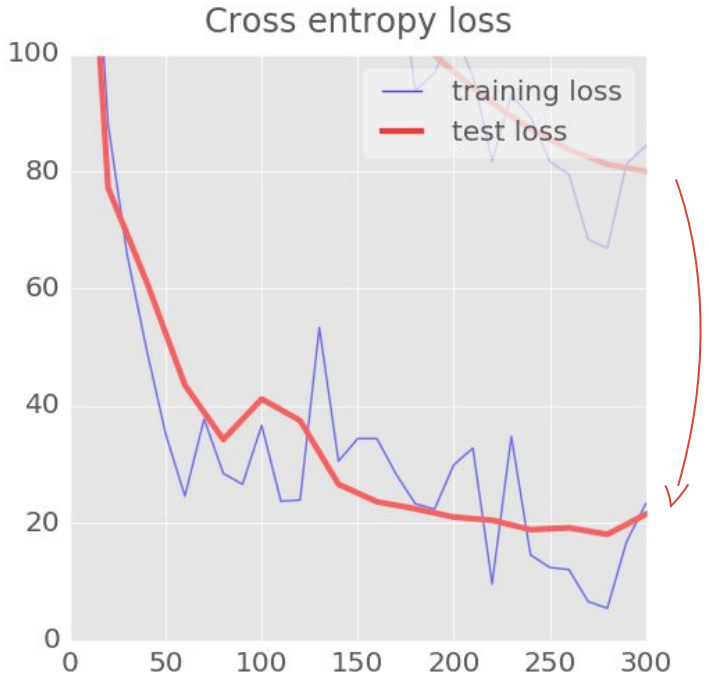




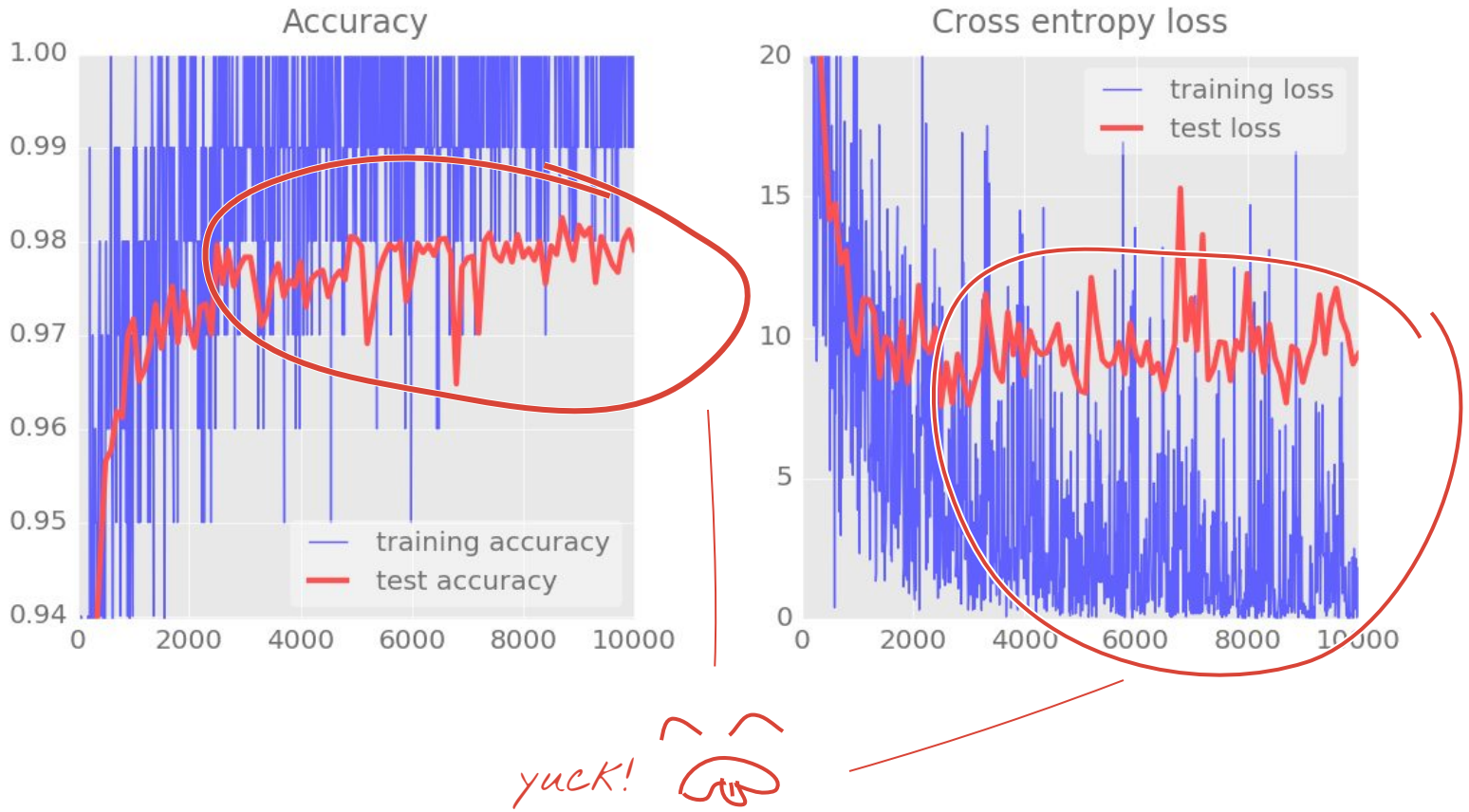

```
Y = tf.nn.relu(tf.matmul(X, W) + b)
```

RELU


Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
training accuracy
test accuracy

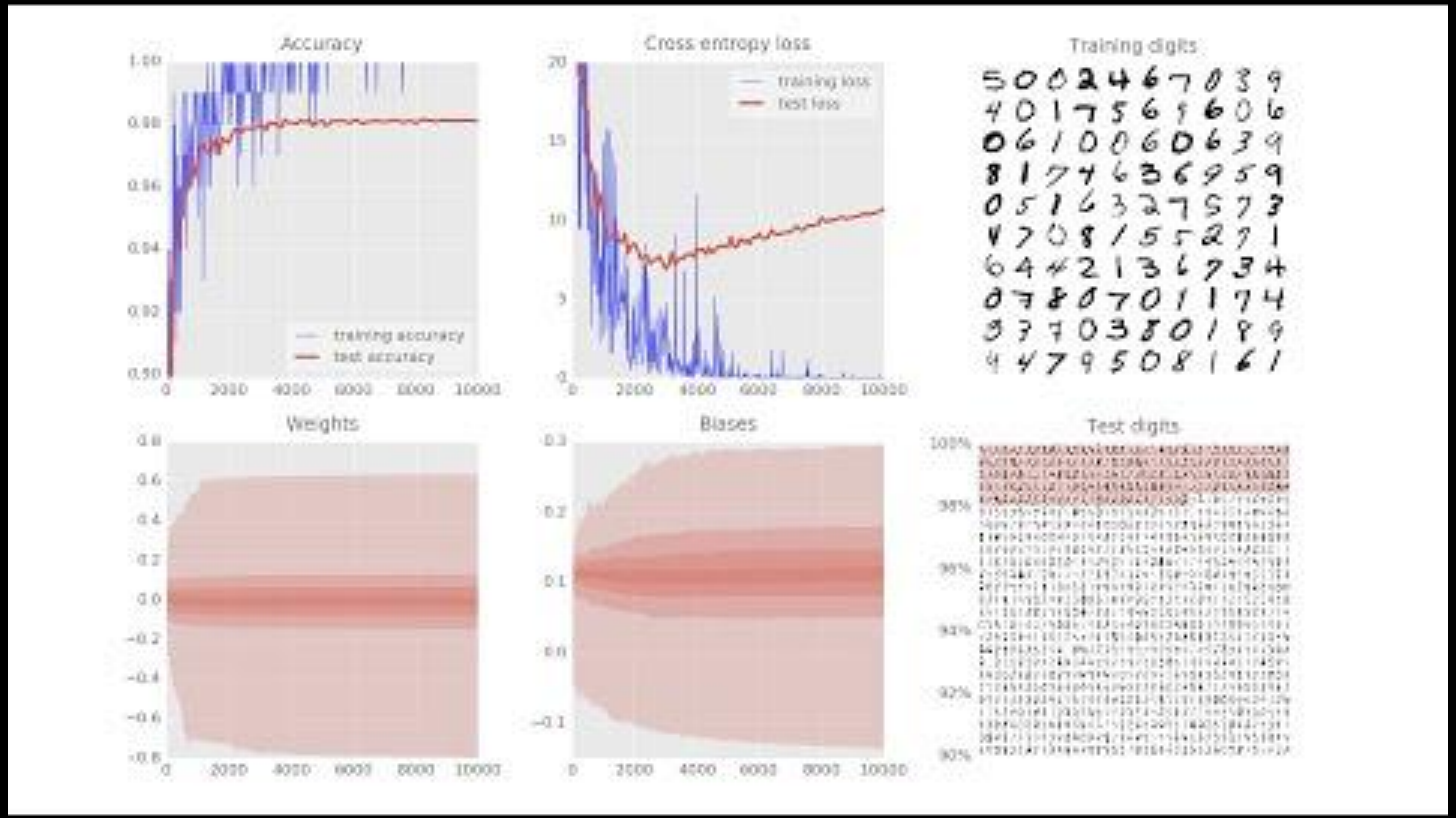

Cross entropy loss
100
80
60
40
20
0
0
50
100
150
200
250
300
training loss
test loss

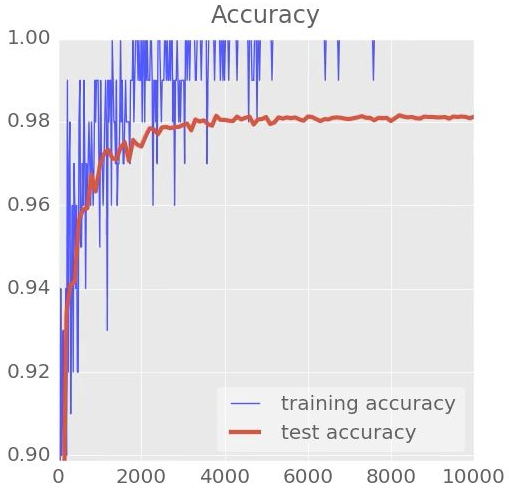
Demo - noisy accuracy curve ?

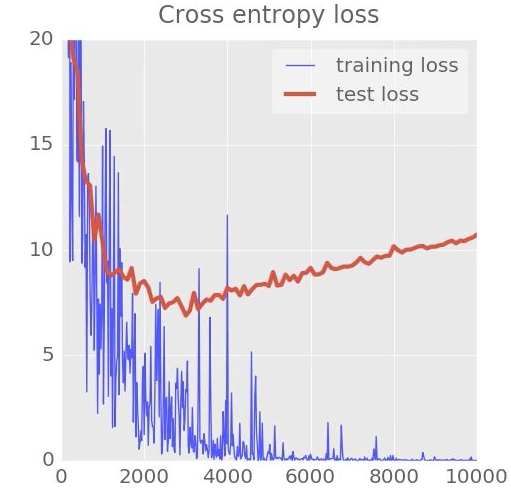


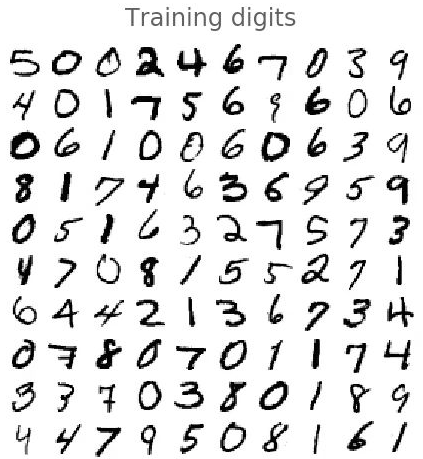
Slow down...

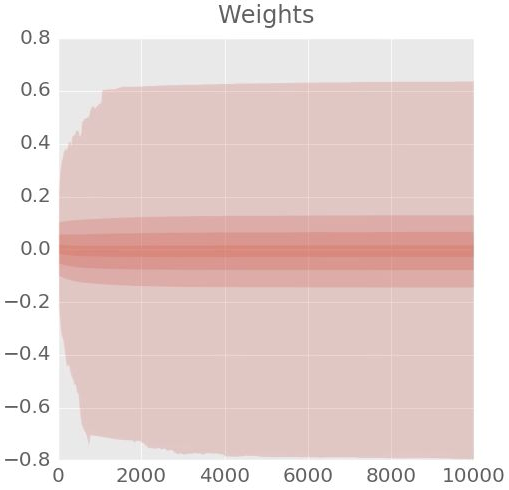
Demo

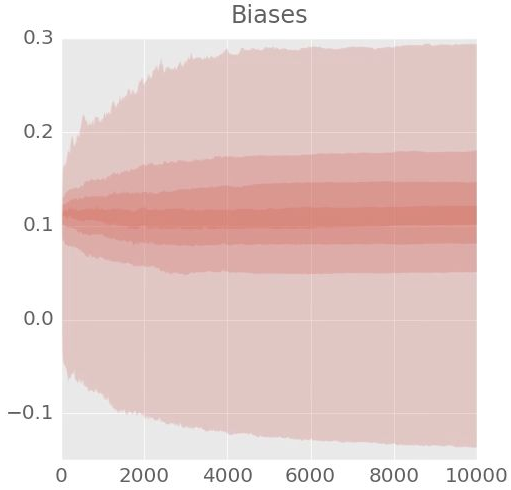

Accuracy
training accuracy
test accuracy
Cross entropy loss
training loss
test loss
Training digits
Weights
Biases
Test digits

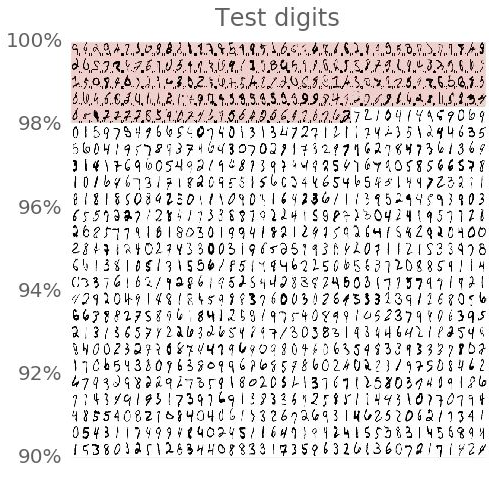

Accuracy
1.00
0.98
0.96
0.94
0.92
0.90
0
2000
4000
6000
8000
10000
training accuracy
test accuracy


Cross entropy loss
20
15
10
5
0
2000
4000
6000
8000
10000
training loss
test loss

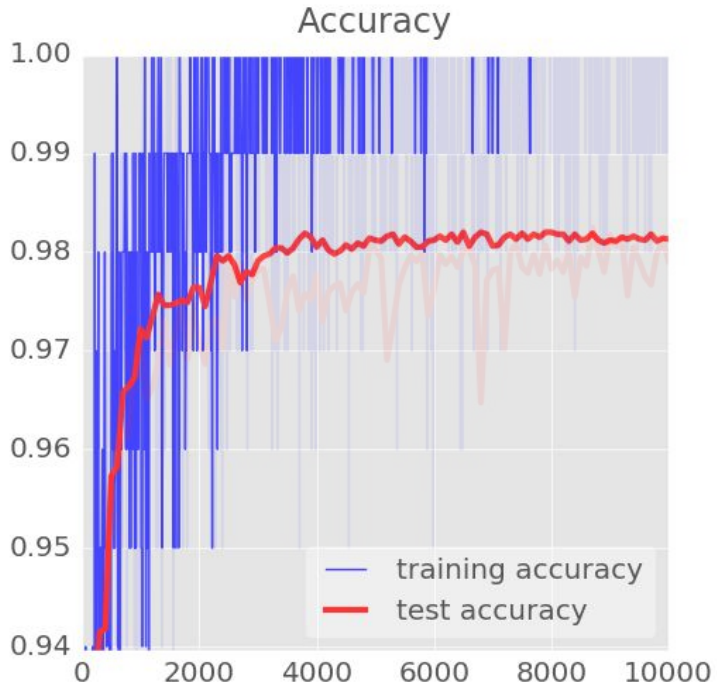

Training digits

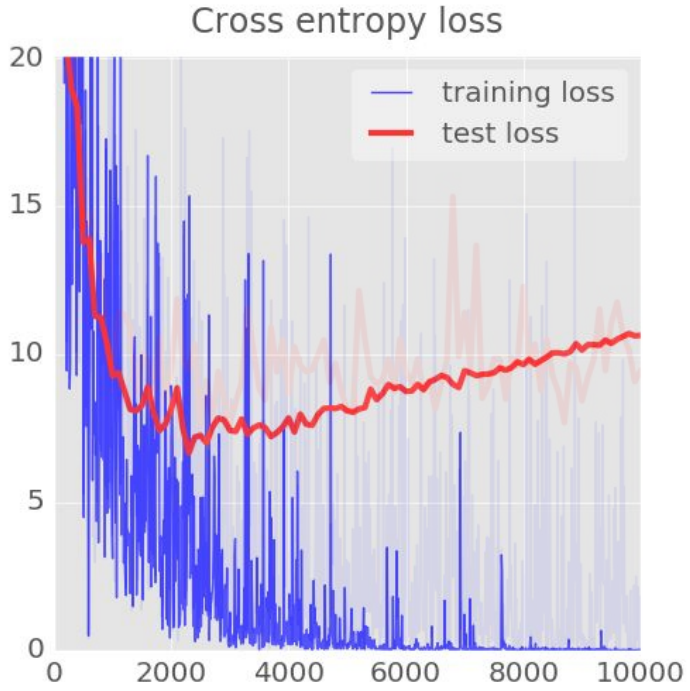

Weights
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0
2000
4000
6000
8000
10000


Biases
0.3
0.2
0.1
0.0
−0.1
0
2000
4000
6000
8000
10000


Test digits
100%
98%
96%
94%
92%
90%
98%

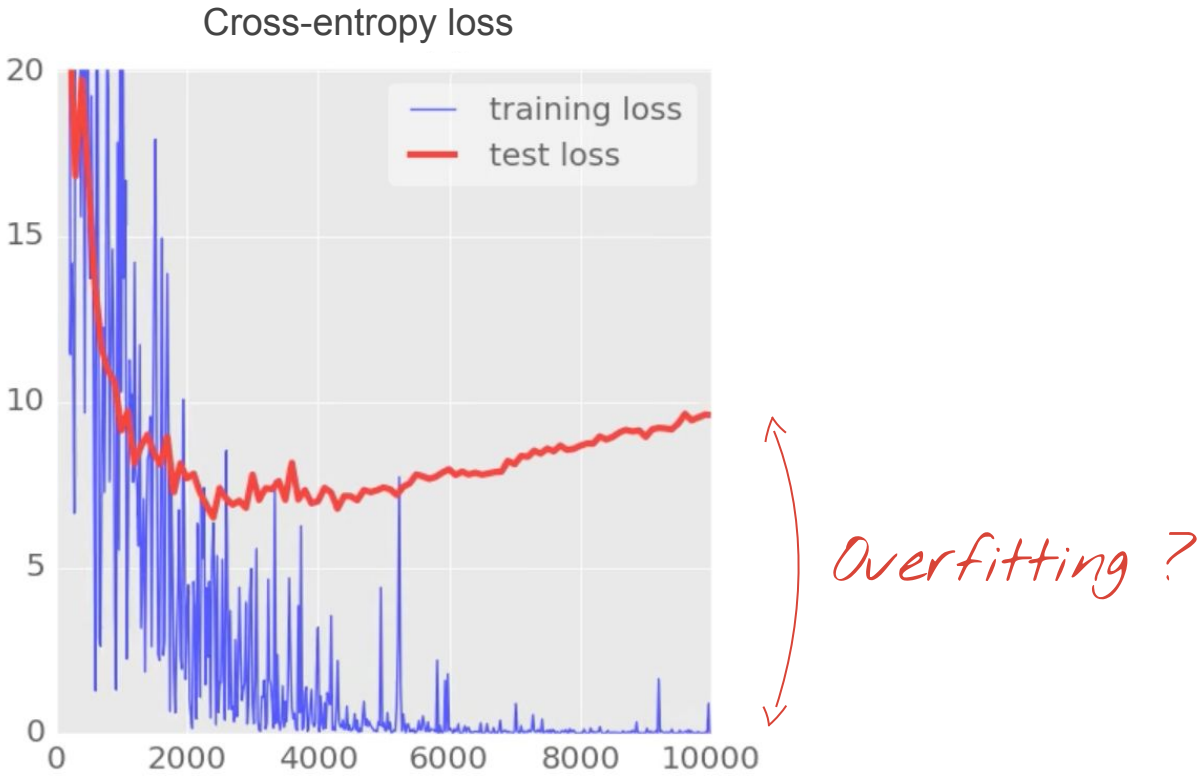
Learning rate decay

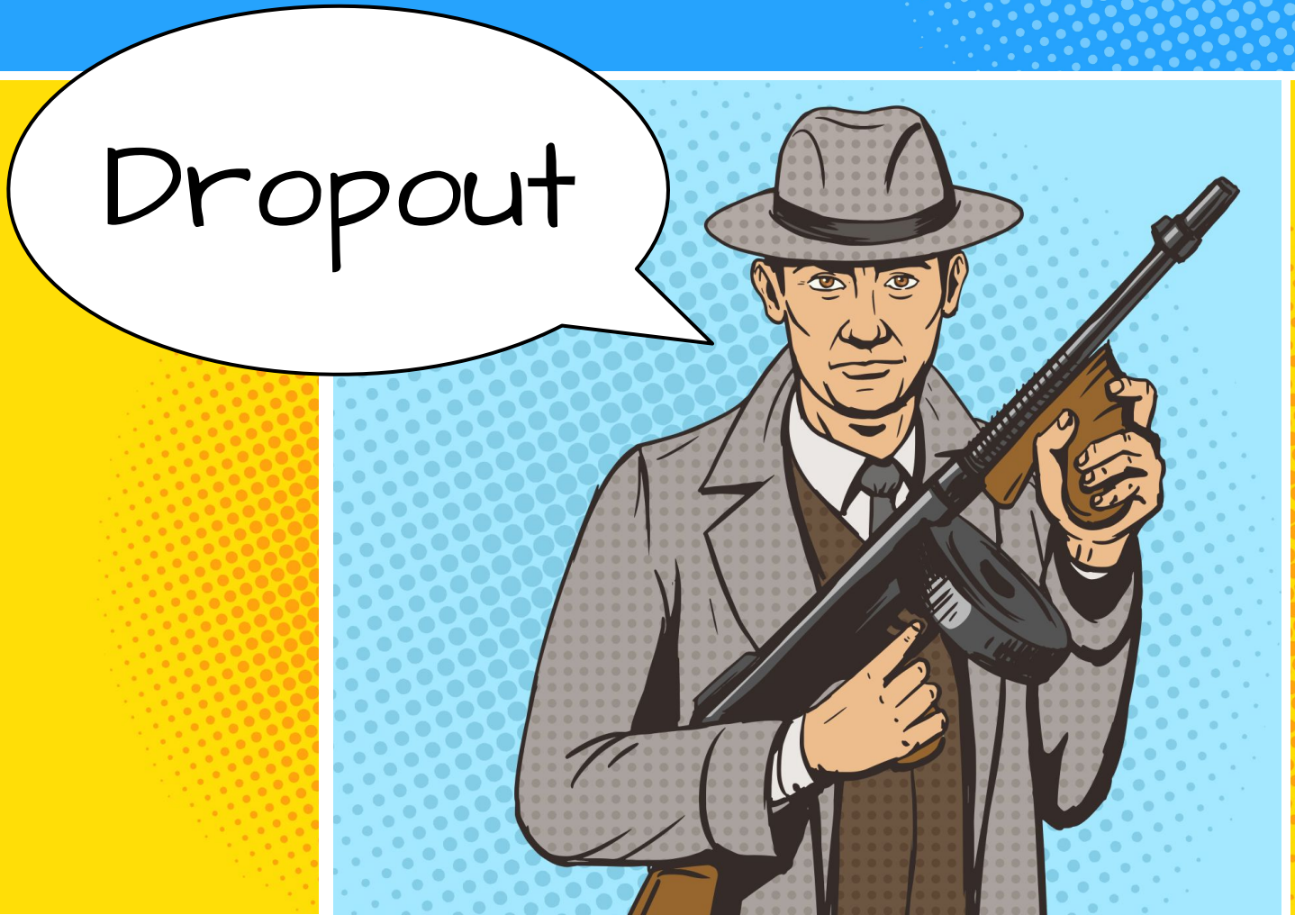




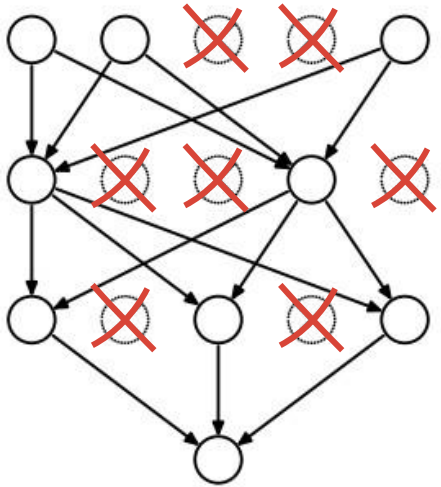
Learning rate 0.003 at start then dropping exponentially to 0.0001

Overfitting

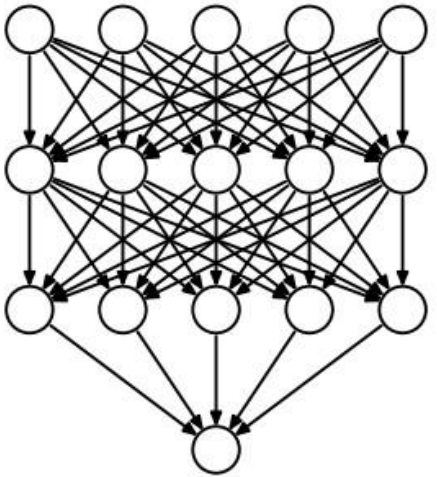



Dropout

Dropout



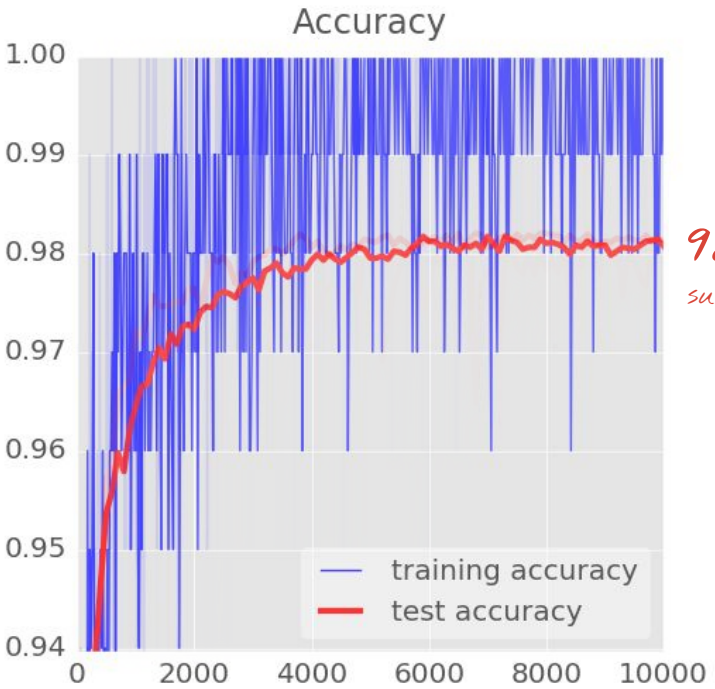
TRAINING
rate=0.5



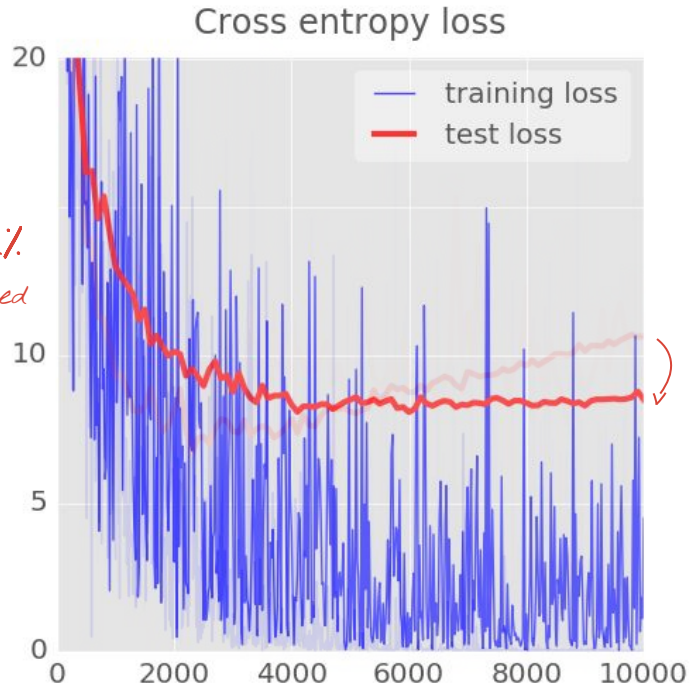
EVALUATION
rate=0

```
pkeep =
tf.placeholder(tf.float32)

Yf = tf.nn.relu(tf.matmul(X, W) + B)
Y  = tf.nn.dropout(Yf, pkeep)
```

All the party tricks

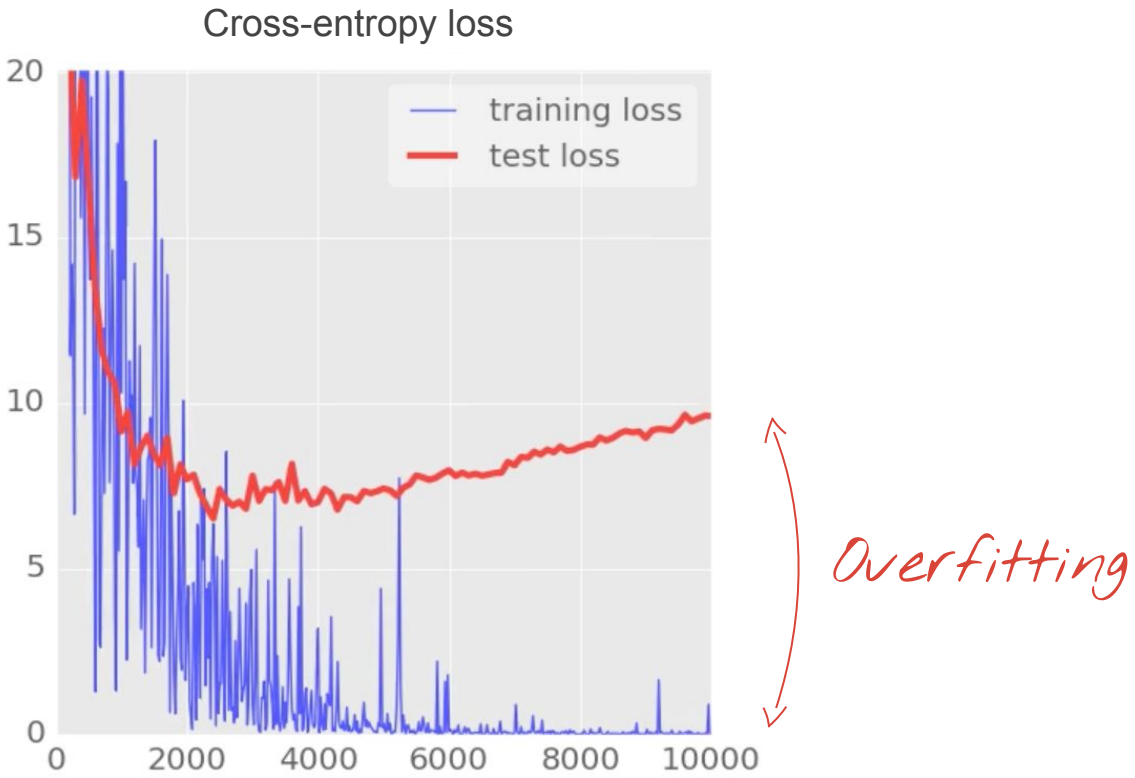


98.2%
sustained



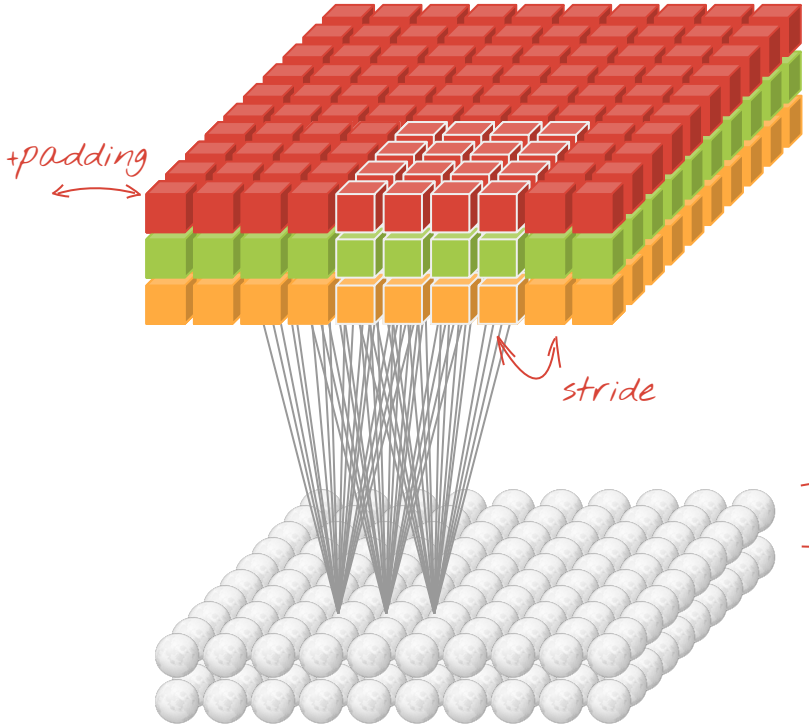
RELU, decaying learning rate 0.003 -> 0.0001 and dropout 0.75

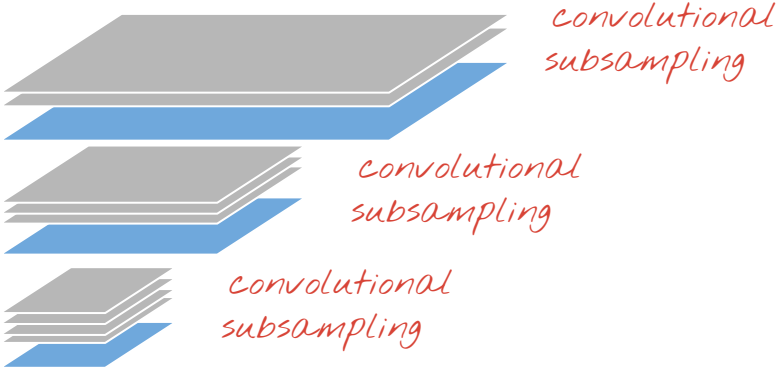
Overfitting




Overfitting
?!?
Too many
neurons
Not
enough
DATA
BAD
Network

Convolutional layer





$W_1[4, 4, 3]$

$W_2[4, 4, 3]$

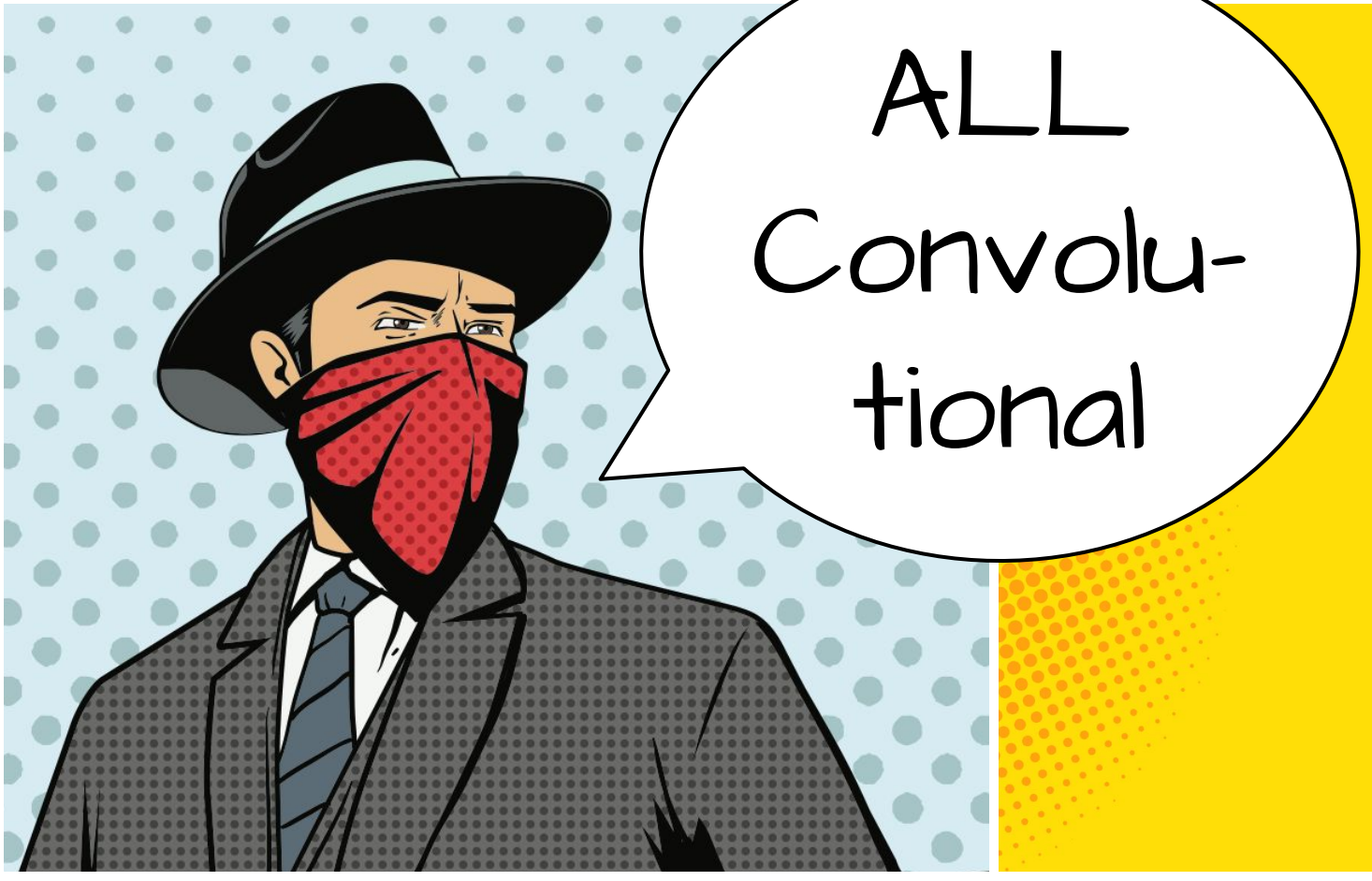
$W[4, 4, 3, 2]$

filter size

input channels

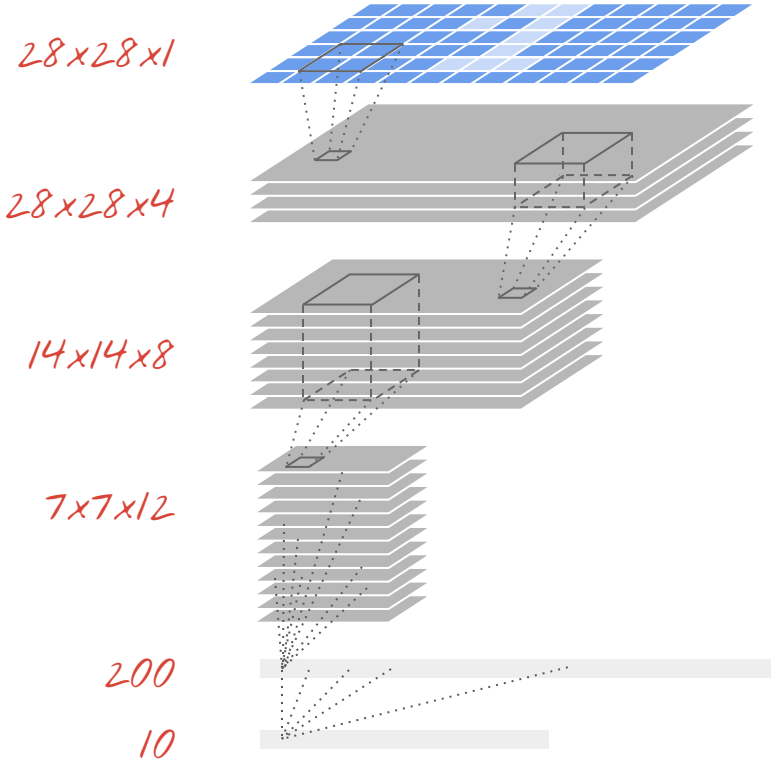
output channels

Hacker's tip



Convolutional neural network

+ biases on all layers



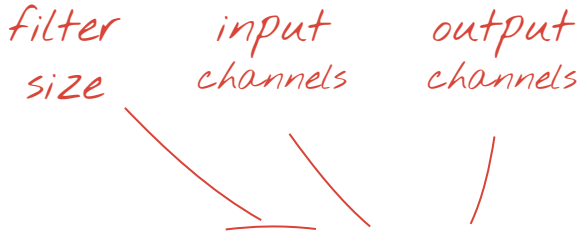
convolutional layer, 4 channels
W1[5, 5, 1, 4] stride 1

convolutional layer, 8 channels
W2[4, 4, 4, 8] stride 2

convolutional layer, 12 channels
W3[4, 4, 8, 12] stride 2

fully connected layer W4[7x7x12, 200]
softmax readout layer W5[200, 10]

Tensorflow - initialisation




```
K=4
L=8
M=12

W1 = tf.Variable(tf.truncated_normal([5, 5, 1, K] ,stddev=0.1))
B1 = tf.Variable(tf.ones([K])/10)
W2 = tf.Variable(tf.truncated_normal([5, 5, K, L] ,stddev=0.1))
B2 = tf.Variable(tf.ones([L])/10)
W3 = tf.Variable(tf.truncated_normal([4, 4, L, M] ,stddev=0.1))
B3 = tf.Variable(tf.ones([M])/10)

N=200

W4 = tf.Variable(tf.truncated_normal([7*7*M, N] ,stddev=0.1))
B4 = tf.Variable(tf.ones([N])/10)
W5 = tf.Variable(tf.truncated_normal([N, 10] ,stddev=0.1))
B5 = tf.Variable(tf.zeros([10])/10)
```

weights initialised with random values

Tensorflow - the model

input image batch
X[100, 28, 28, 1]

weights

stride

biases

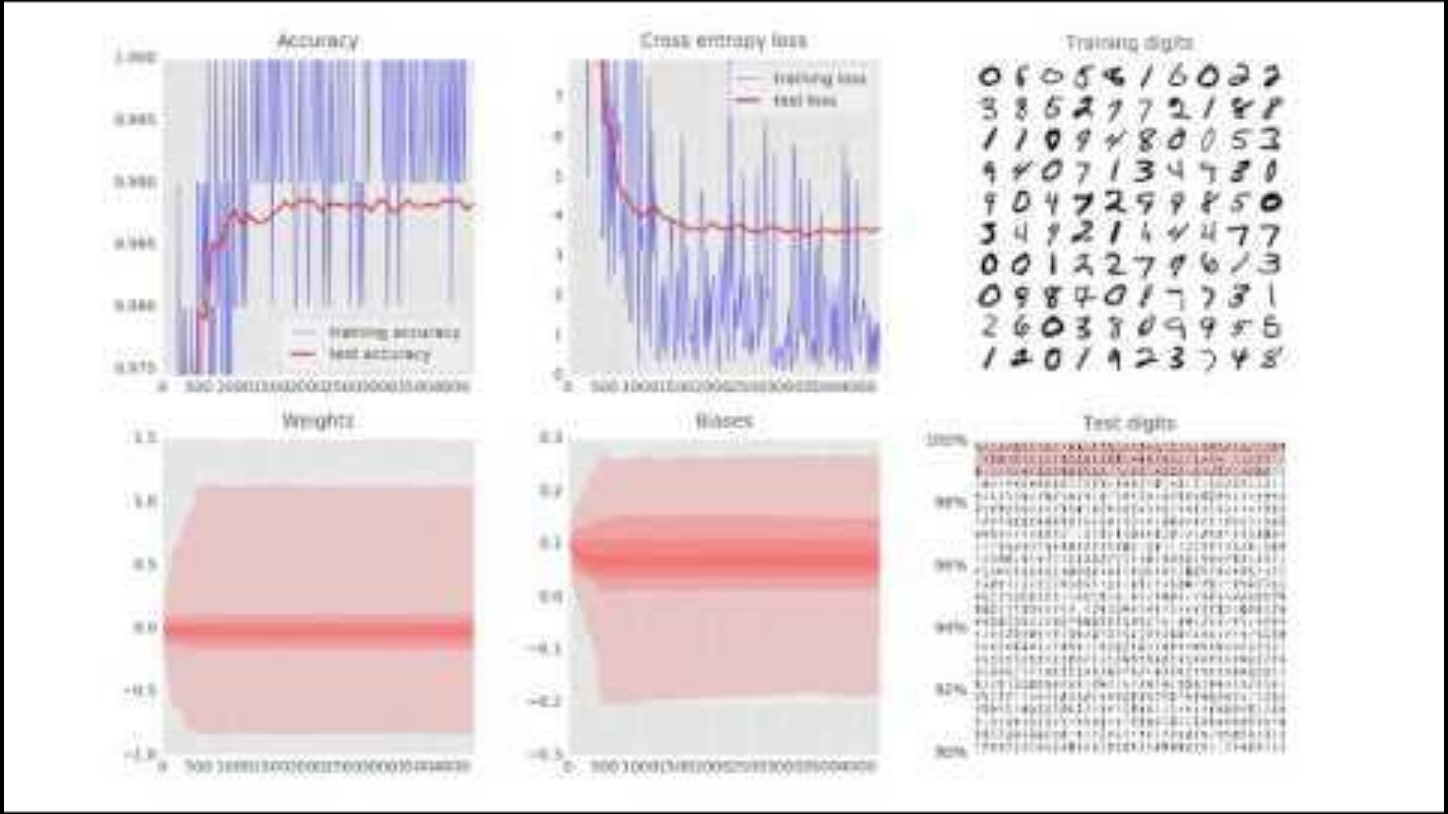
```
Y1 = tf.nn.relu(tf.nn.conv2d(X, W1, strides=[1, 1, 1, 1], padding='SAME') + B1)
Y2 = tf.nn.relu(tf.nn.conv2d(Y1, W2, strides=[1, 2, 2, 1], padding='SAME') + B2)
Y3 = tf.nn.relu(tf.nn.conv2d(Y2, W3, strides=[1, 2, 2, 1], padding='SAME') + B3)

YY = tf.reshape(Y3, shape=[-1, 7 * 7 * M])

Y4 = tf.nn.relu(tf.matmul(YY, W4) + B4)
Y  = tf.nn.softmax(tf.matmul(Y4, W5) + B5)
```

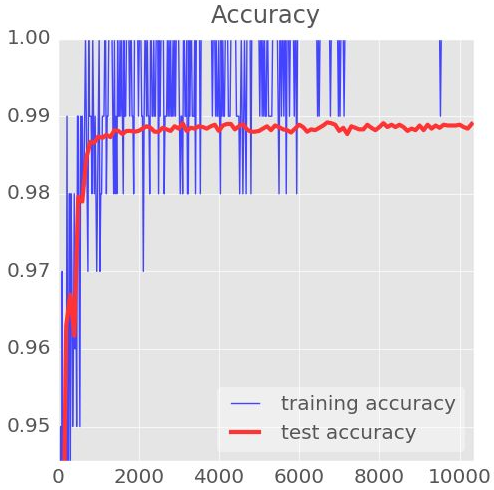
flatten all values for fully connected layer

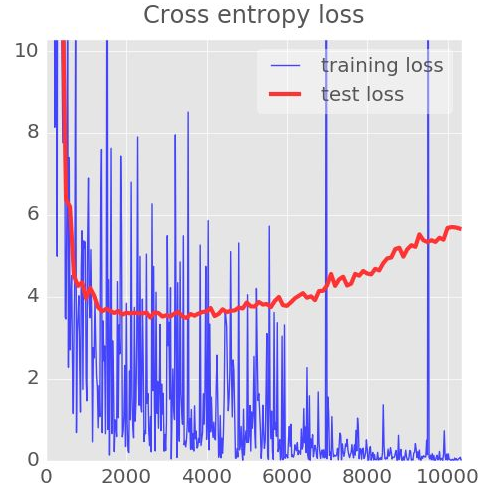
Y3 [100, 7, 7, 12]

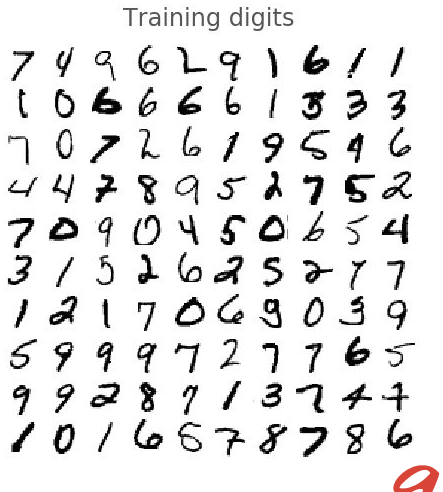
YY [100, 7x7x12]

Demo

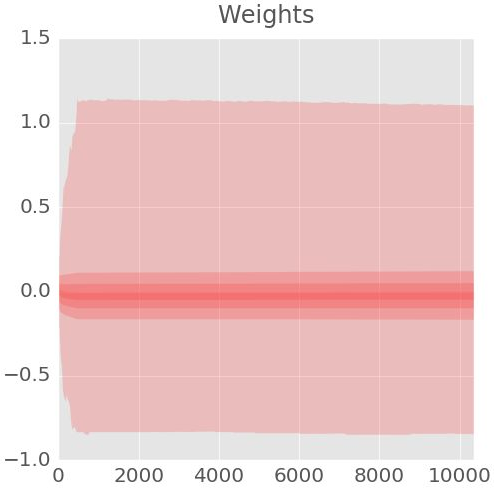

Accuracy
training accuracy
test accuracy
Cross entropy loss
training loss
test loss
Training digits
Weights
Biases
Test digits

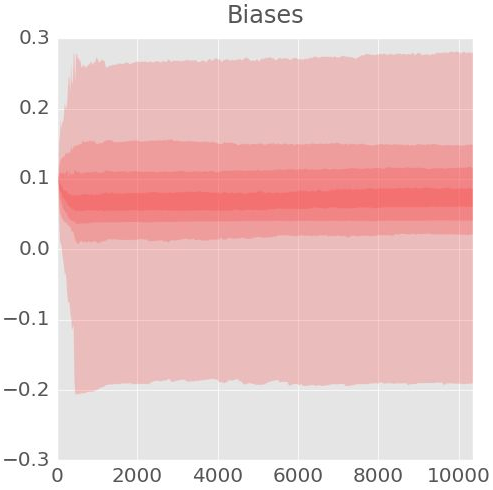

Accuracy
1.00
0.99
0.98
0.97
0.96
0.95
0
2000
4000
6000
8000
10000
training accuracy
test accuracy

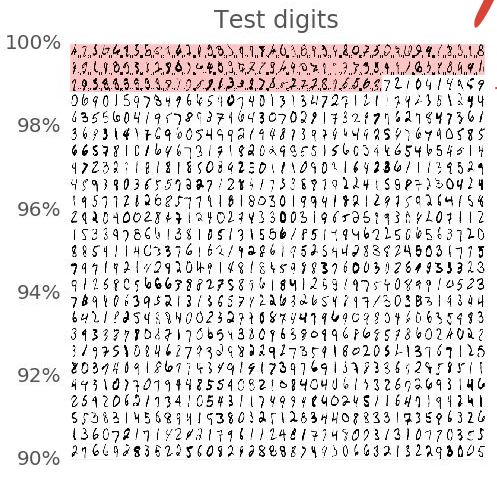

Cross entropy loss
10
8
6
4
2
0
0
2000
4000
6000
8000
10000
training loss
test loss


Training digits

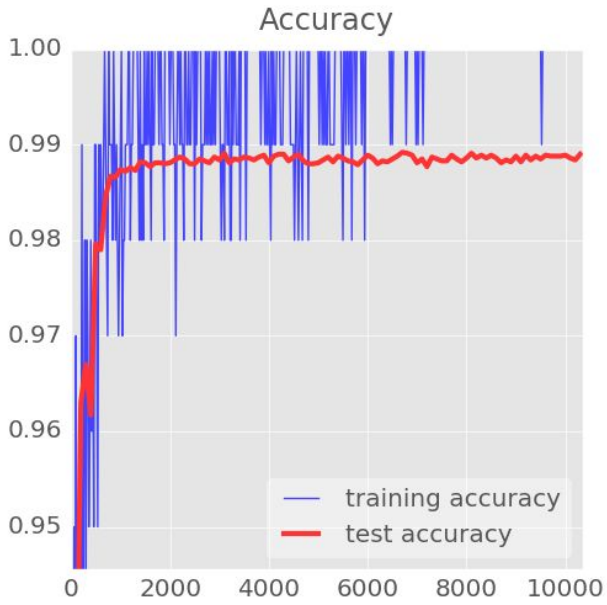
98.9%

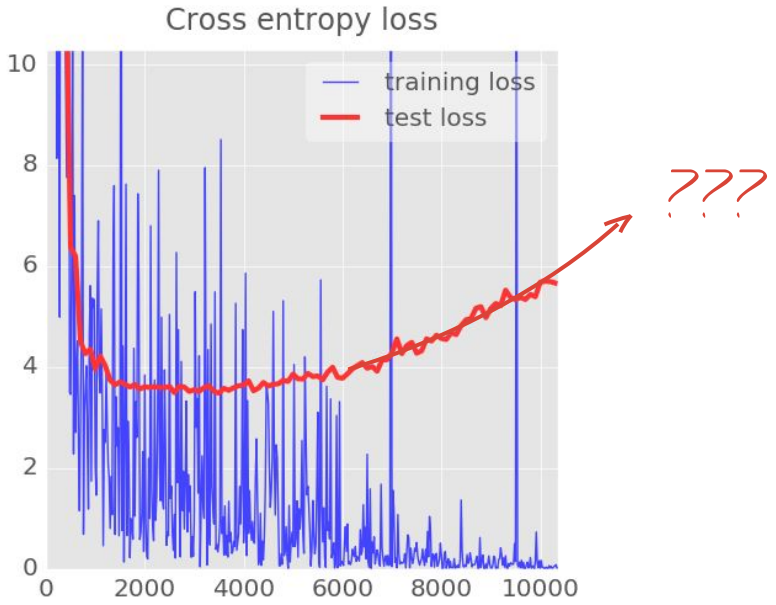

Weights
1.5
1.0
0.5
0.0
−0.5
−1.0
0
2000
4000
6000
8000
10000


Biases
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0
2000
4000
6000
8000
10000


Test digits
100%
98%
96%
94%
92%
90%

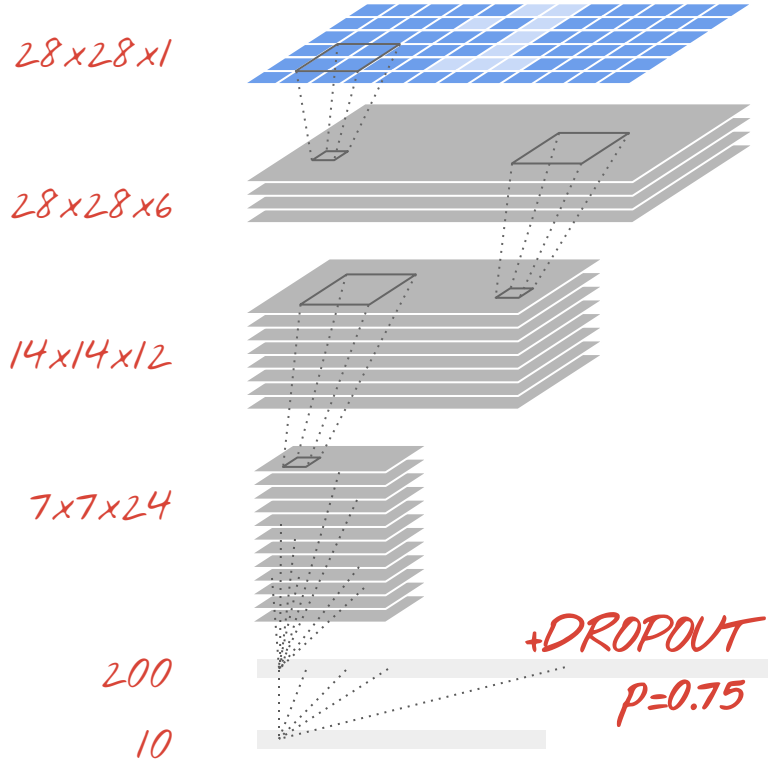
WTFH ???


Accuracy
1.00
0.99
0.98
0.97
0.96
0.95
0
2000
4000
6000
8000
10000
training accuracy
test accuracy


Cross entropy loss
10
8
6
4
2
0
0
2000
4000
6000
8000
10000
training loss
test loss
???

Bigger convolutional network + dropout

+ biases on all layers



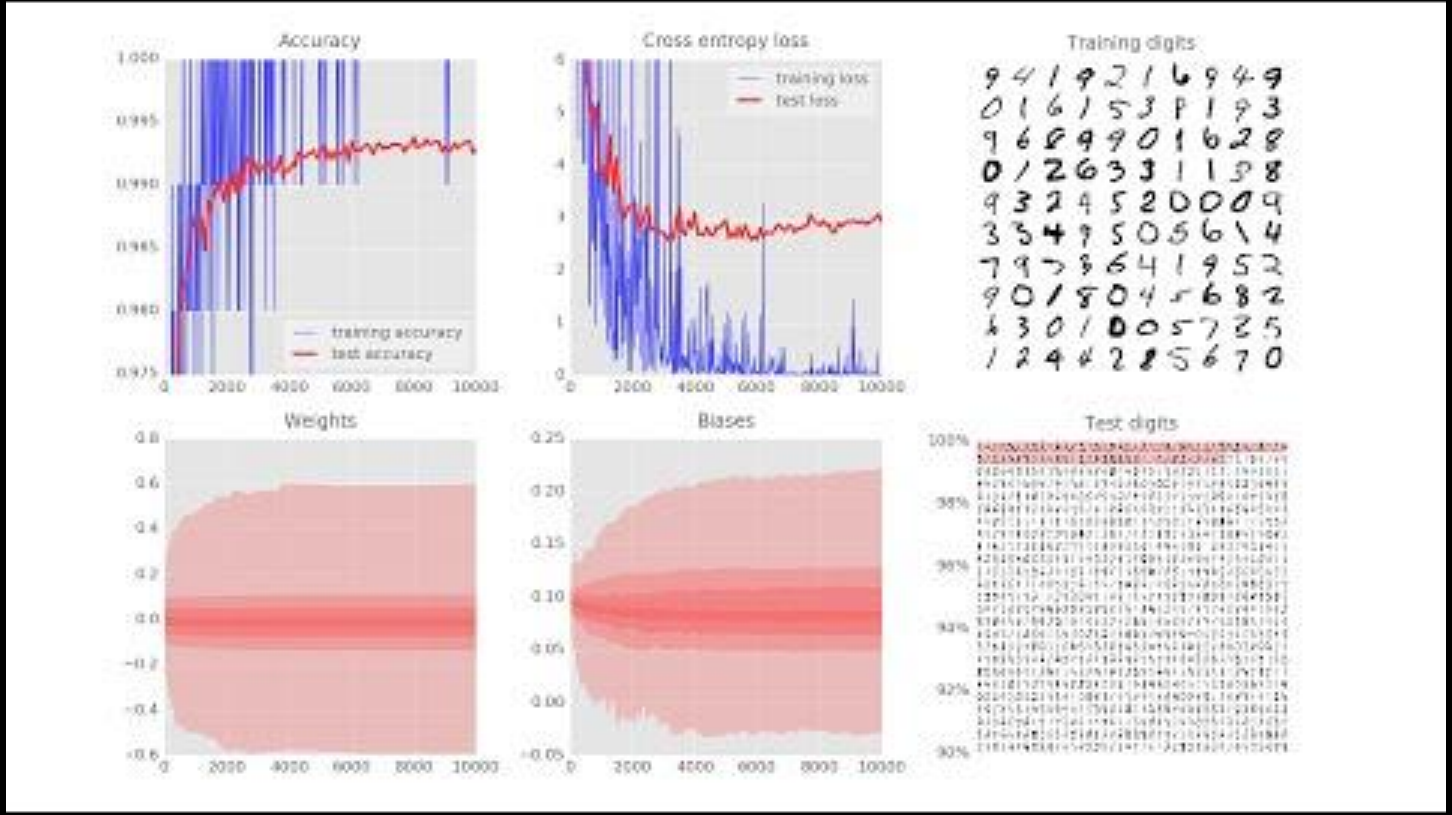
convolutional layer, **6 channels**
W1[**6**, **6**, 1, 6] stride 1

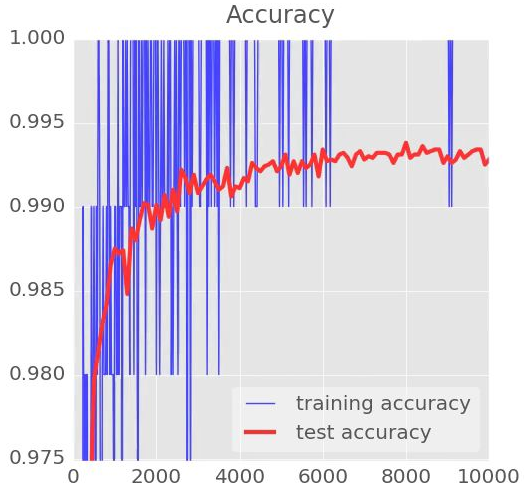
convolutional layer, **12 channels**
W2[**5**, **5**, 6, 12] stride 2

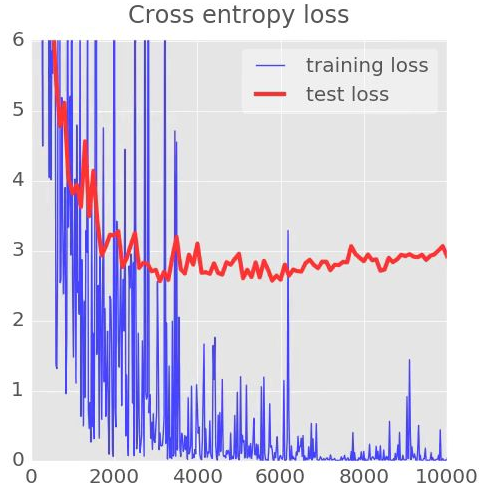
convolutional layer, **24 channels**
W3[**4**, **4**, 12, 24] stride 2

fully connected layer W4[7x7x24, 200]
softmax readout layer W5[200, 10]

Demo

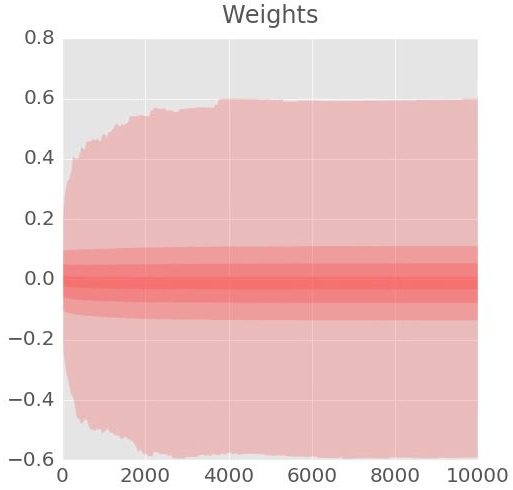

Accuracy
training accuracy
test accuracy
Cross entropy loss
training loss
test loss
Training digits
Weights
Biases
Test digits

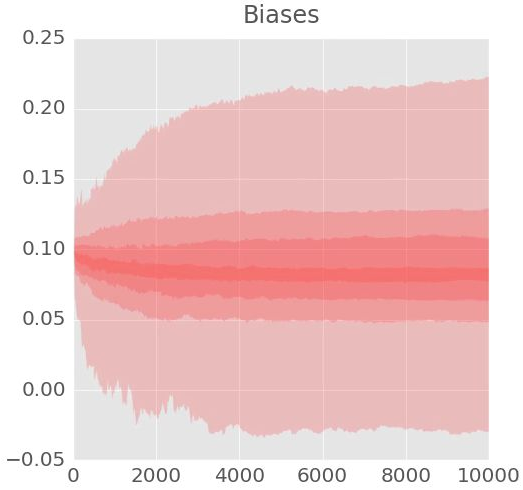

Accuracy
1.000
0.995
0.990
0.985
0.980
0.975
0
2000
4000
6000
8000
10000
training accuracy
test accuracy

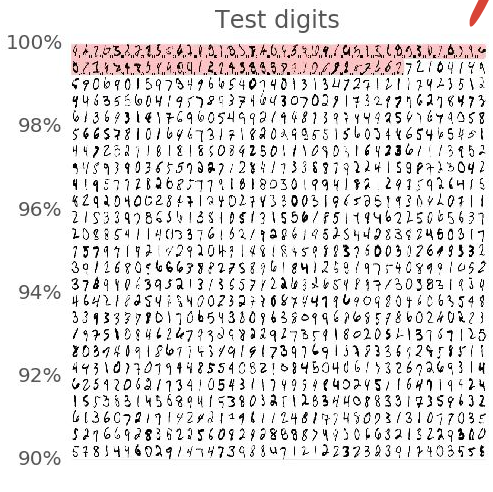

Cross entropy loss
6
5
4
3
2
1
0
2000
4000
6000
8000
10000
training loss
test loss


Training digits

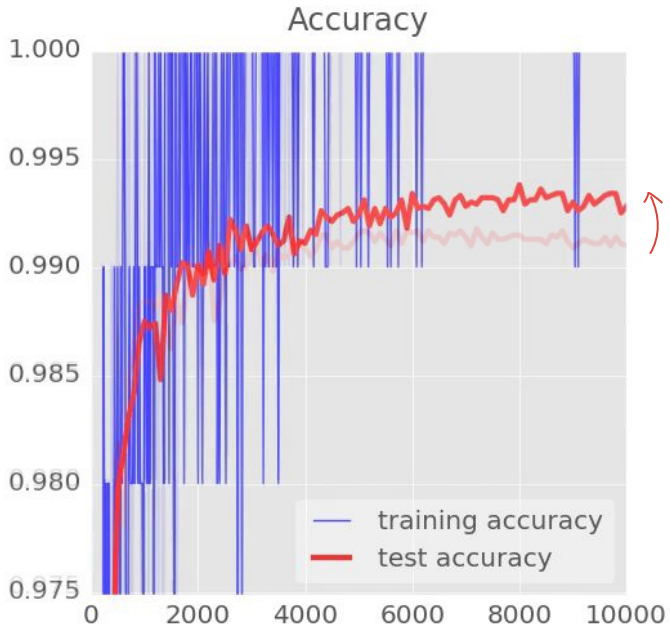
99.3%

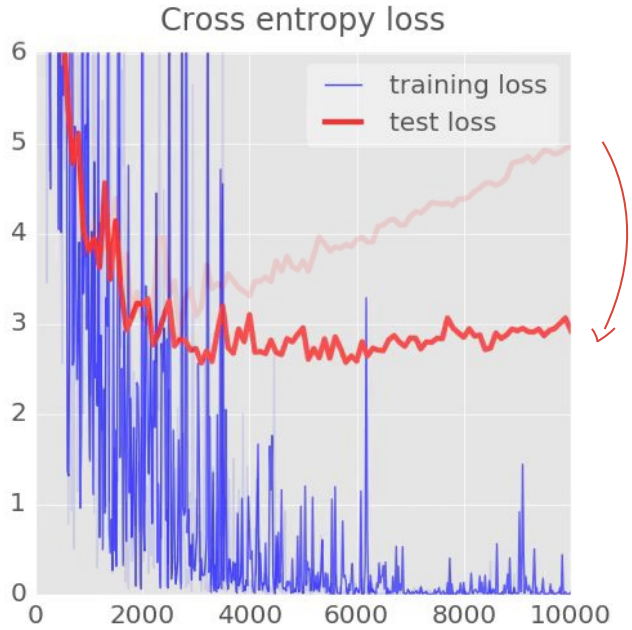

Weights
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0
2000
4000
6000
8000
10000


Biases
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
0
2000
4000
6000
8000
10000


Test digits
100%
98%
96%
94%
92%
90%

YEAH !





with dropout

Slides Downloadable Link

https://docs.google.com/presentation/d/1B_ft3b1oLluOAOO2HzsvLwbN8fn1PzF4Kx44LF8P4Q0/edit?usp=sharing