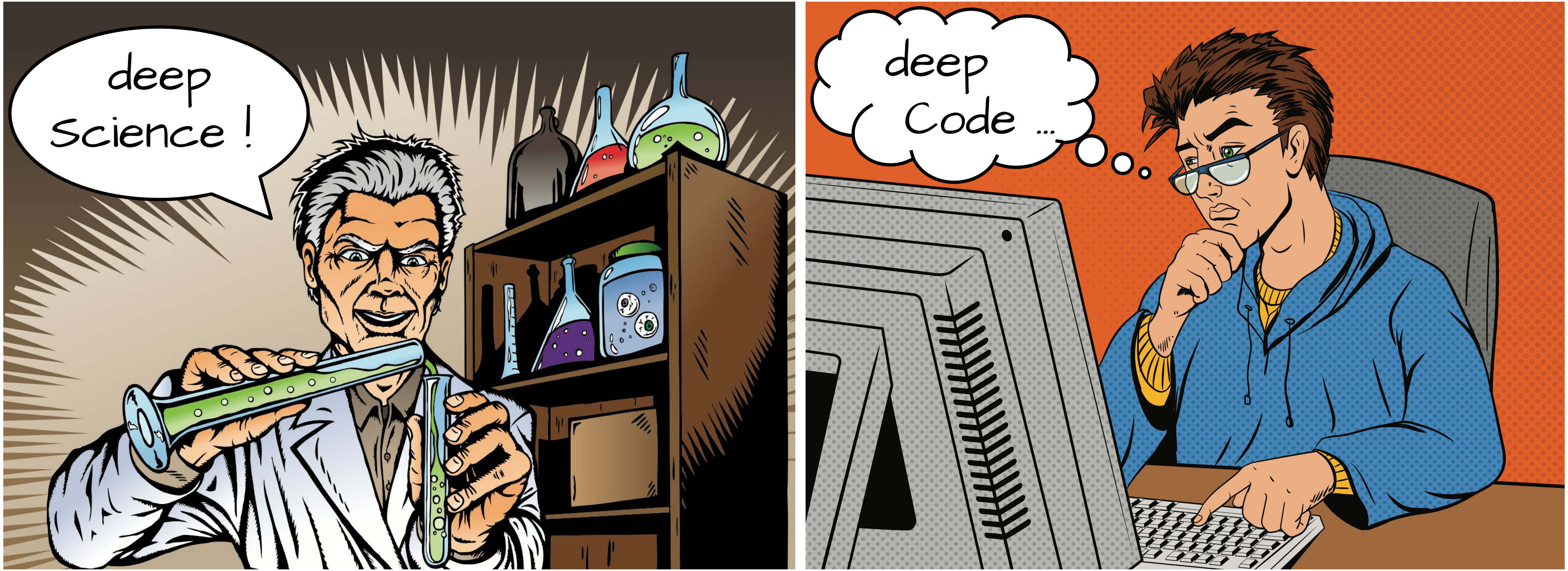
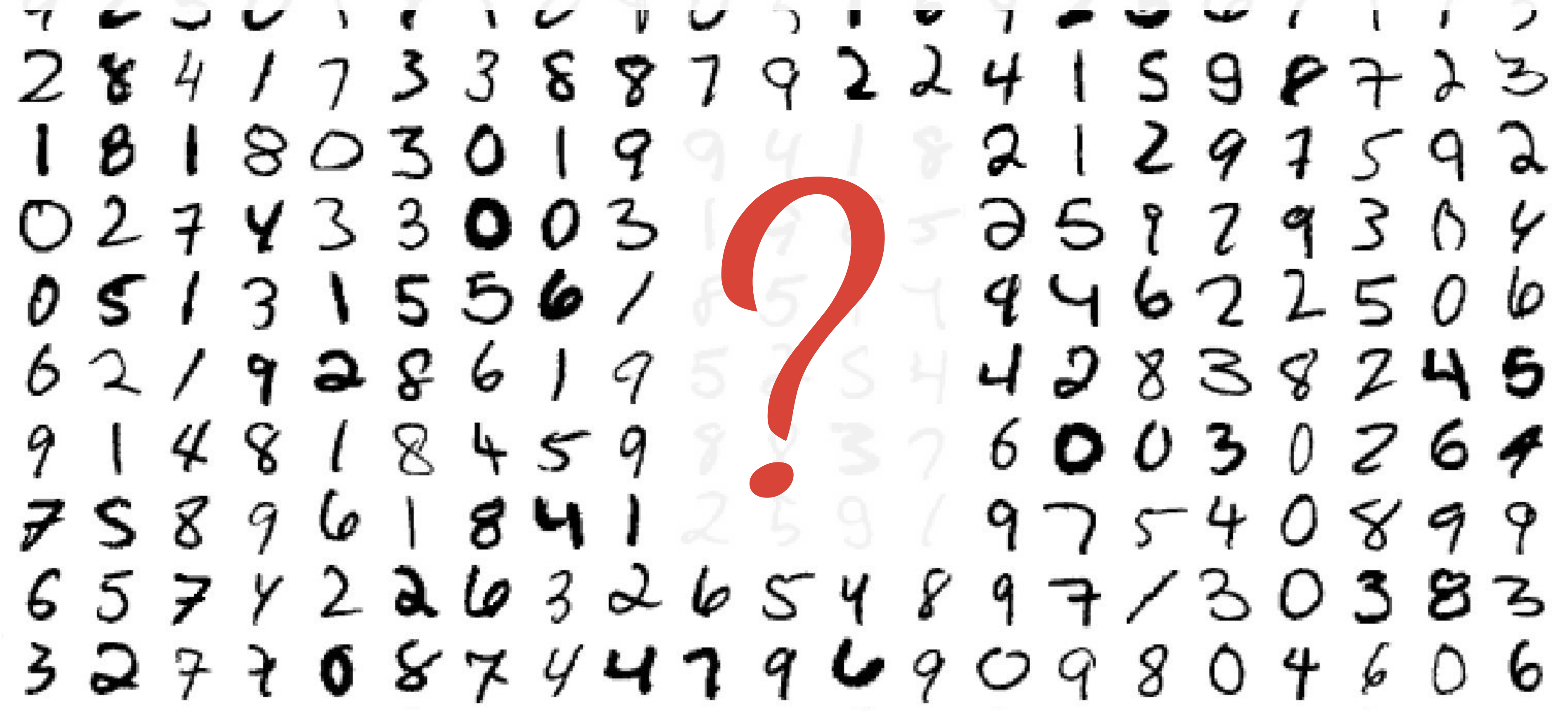
>TensorFlow and deep learning_

without a PhD

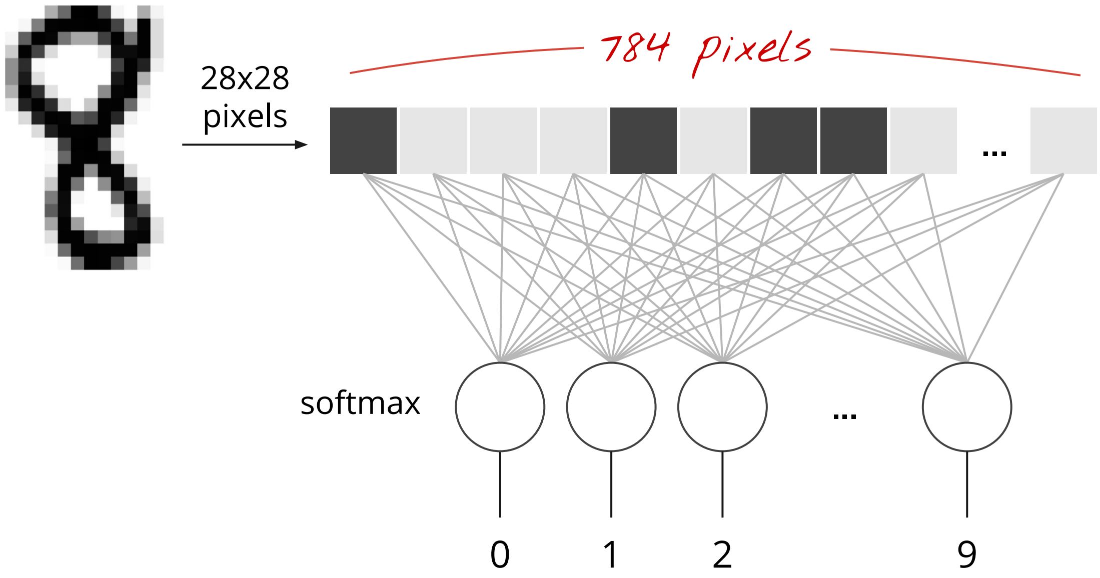


Hello World: handwritten digits classification - MNIST



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

Very simple model: softmax classification

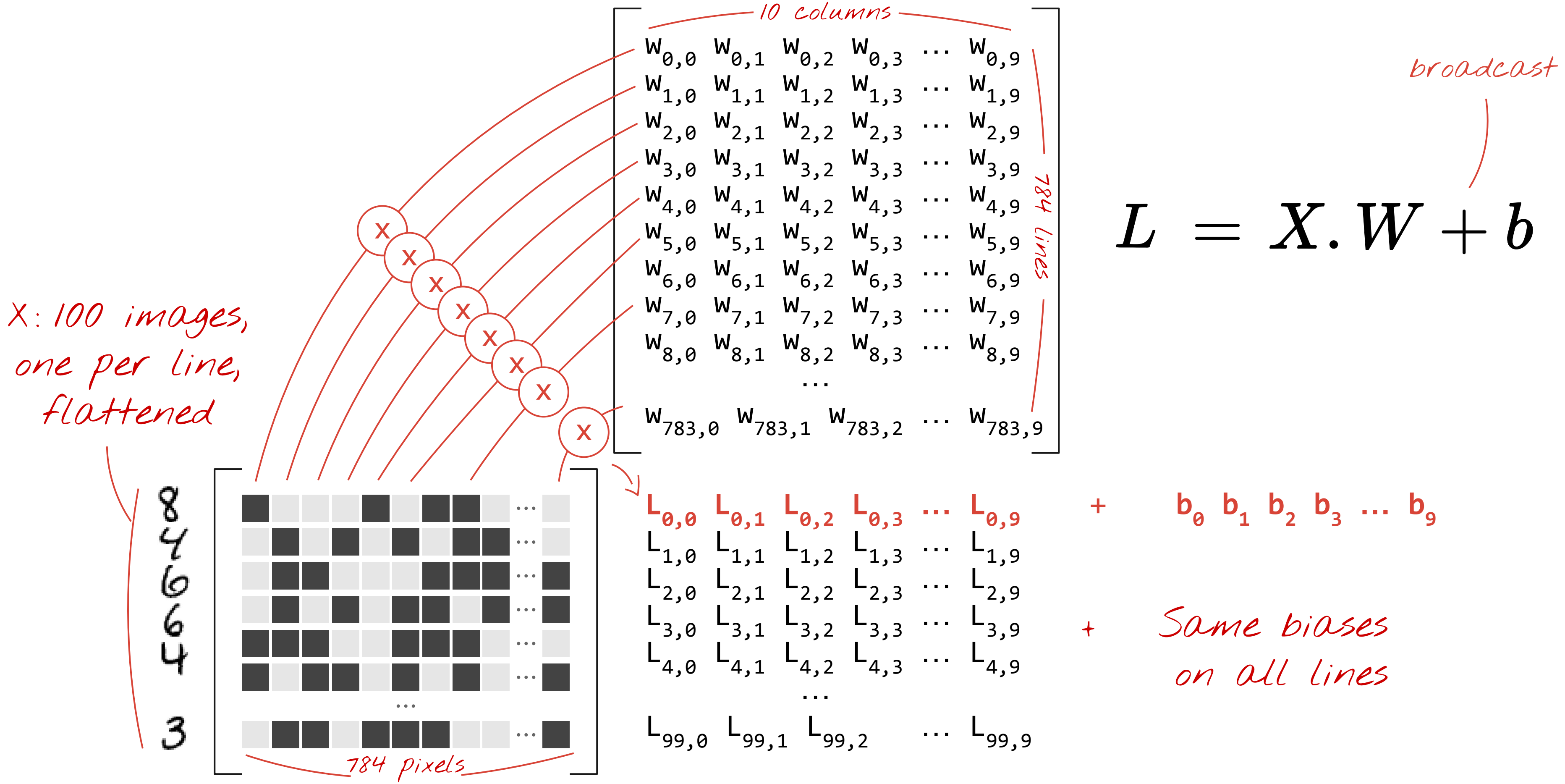


$$softmax(L_n) = \frac{e^{L_n}}{||e^L||}$$

weighted sum of all pixels + bias

neuron outputs

In matrix notation, 100 images at a time



Softmax, on a batch of images

Predictions

Y[100, 10]

Images

X[100, 748]

Weights

W[748,10]

Biases

b[10]

$$Y = softmax(X.W + b)$$

applied line by line

matrix multiply

broadcast on all lines

tensor shapes in [ ]

Now in TensorFlow (Python)

tensor shapes: X[100, 748] W[748,10] b[10]

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

matrix multiply

broadcast
on all lines

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

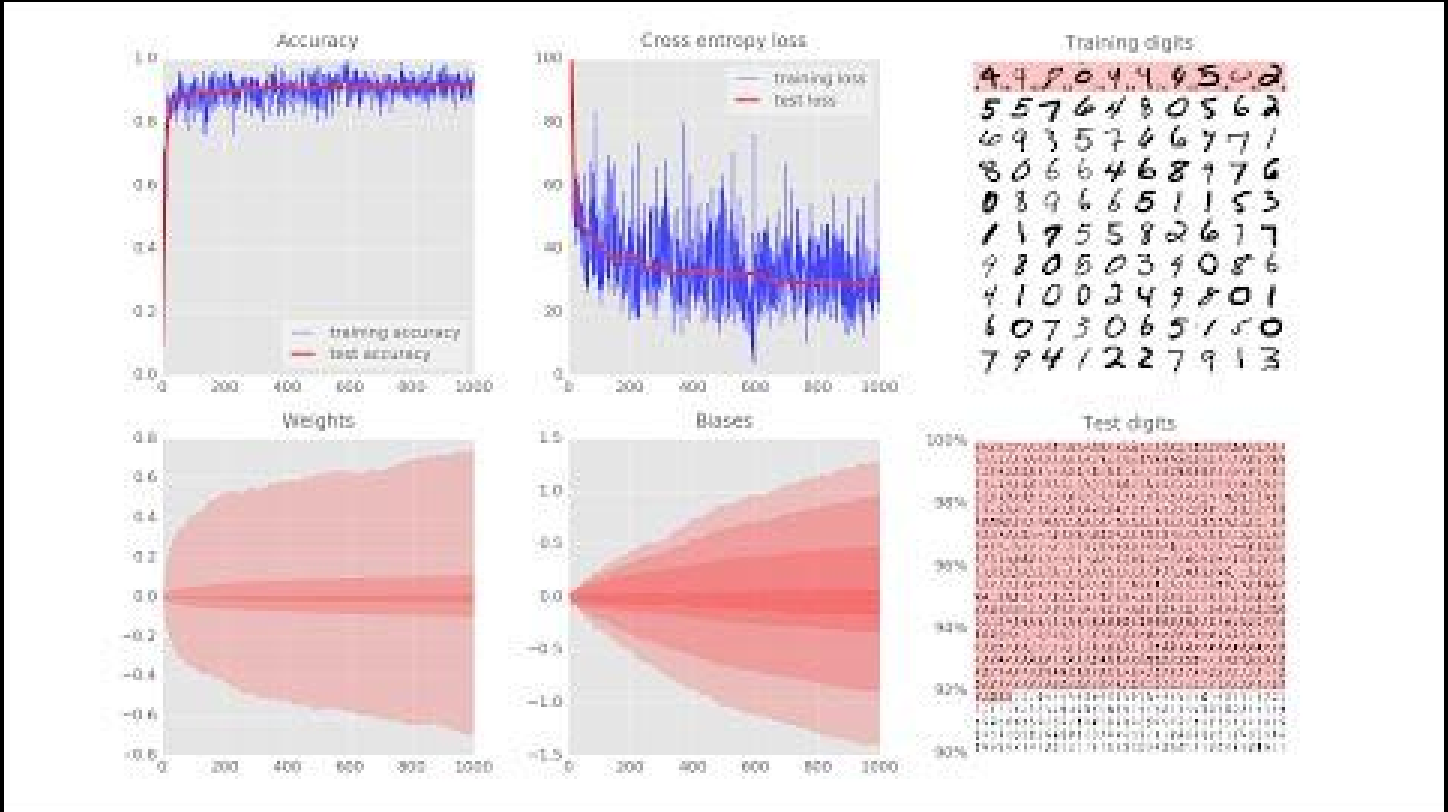
Cross entropy: $$-\sum Y'_i \cdot log(Y_i)$$

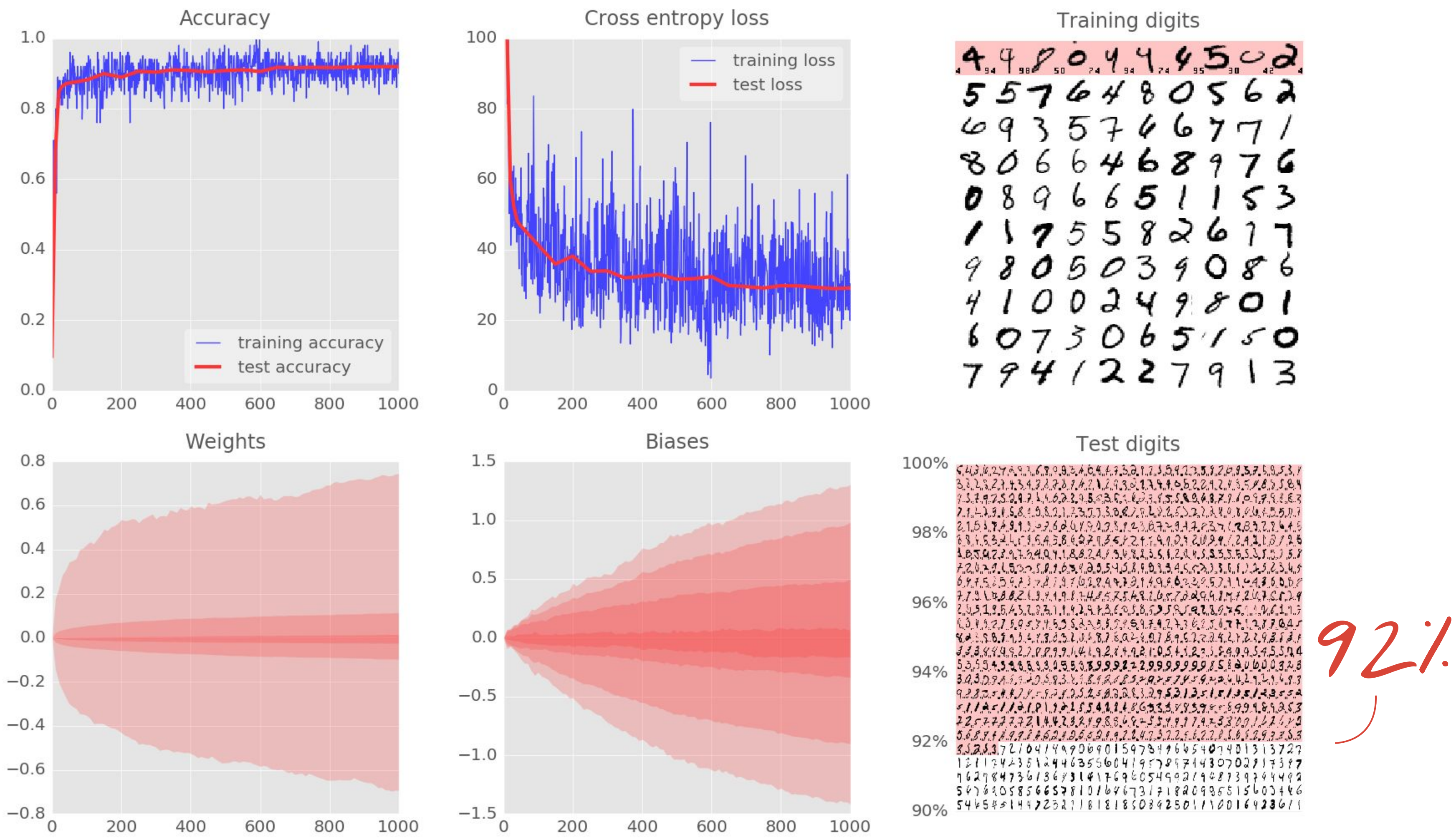
this is a "6"

computed probabilities

0.1	0.2	0.1	0.3	0.2	0.1	**0.9**	0.2	0.1	0.1
0	1	2	3	4	5	6	7	8	9

Demo


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



Accuracy
training accuracy
test accuracy
Cross entropy loss
training loss
test loss
Training digits
Weights
Biases
Test digits
100%
98%
96%
94%
92%
90%
92%

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 !

running a Tensorflow computation, feeding placeholders

```
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, It], feed=test_data)
```

Tip:
do this every 100 iterations

TensorFlow - full python code

initialisation

model

success metrics

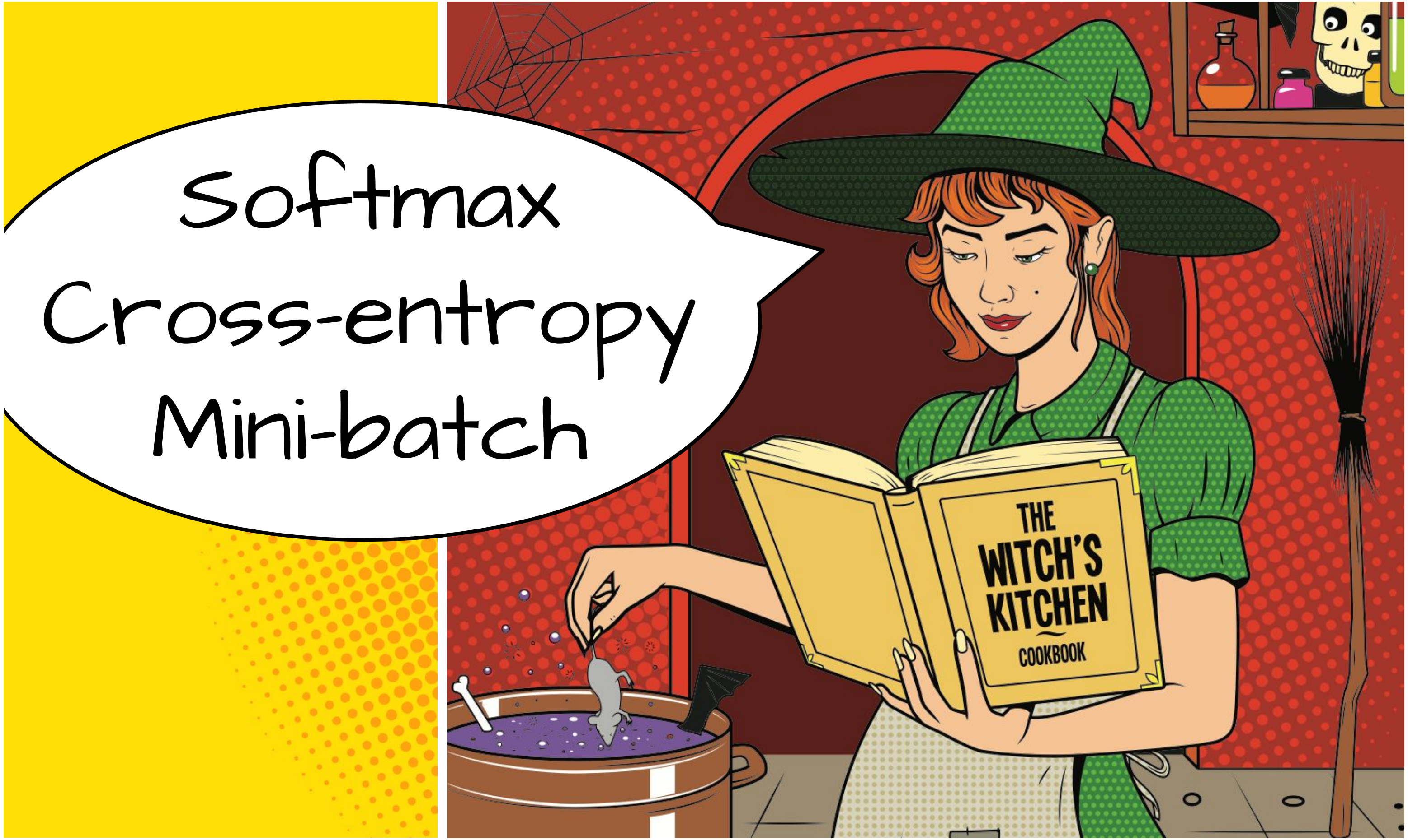
```
import tensorflow as tf

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

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

# 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

Run

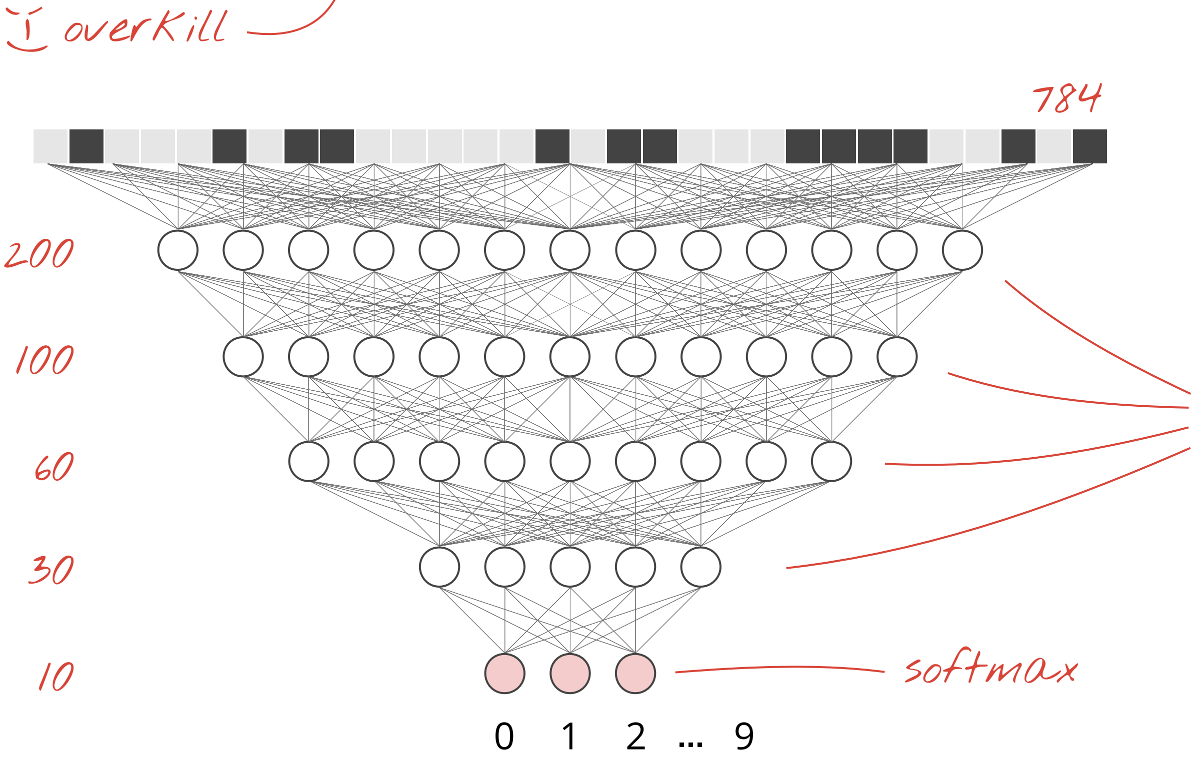
```
optimizer = tf.train.GradientDescentOptimizer(0.003)
train_step = optimizer.minimize(cross_entropy)

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)
```

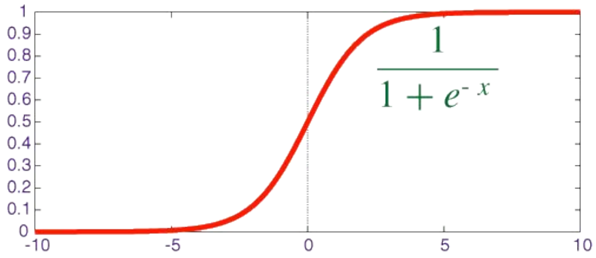
Cookbook


Softmax
Cross-entropy
Mini-batch
THE WITCH'S KITCHEN
COOKBOOK


Go deep!

Let's try 5 fully-connected layers !





TensorFlow - initialisation

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

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]))
```

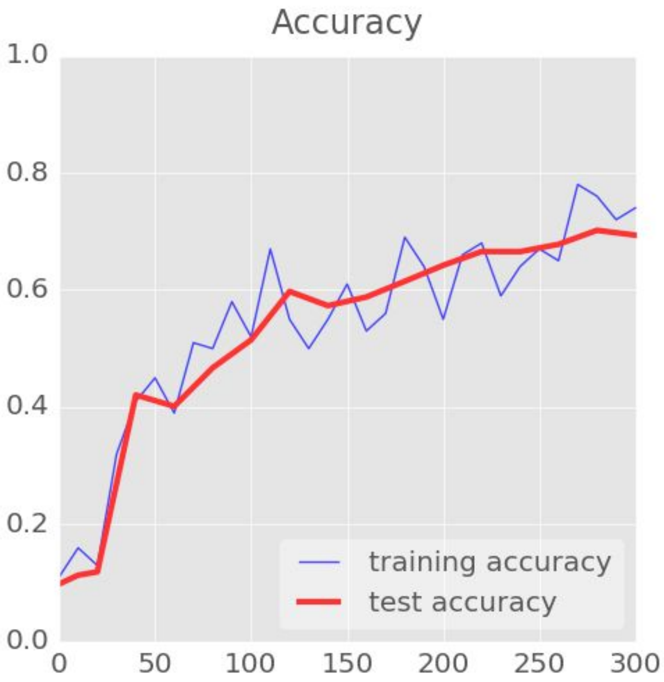
weights initialised with random values

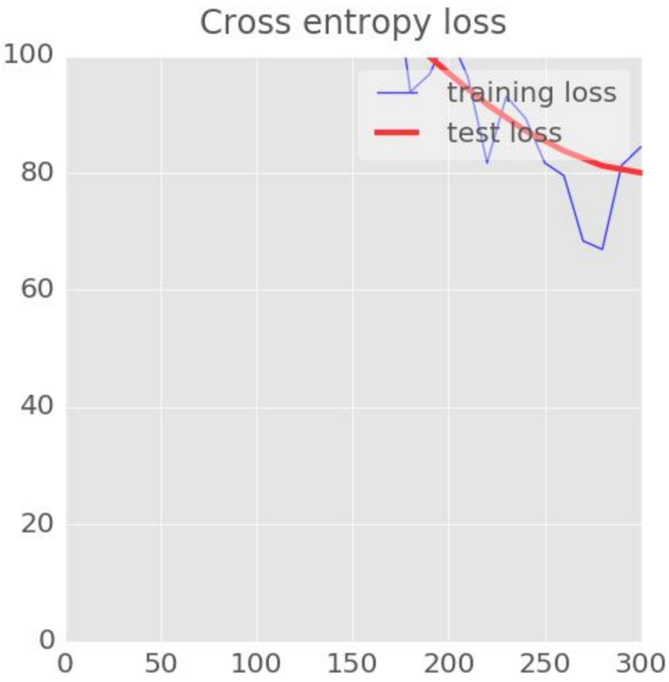
TensorFlow - the model

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)
```

Demo - slow start ?

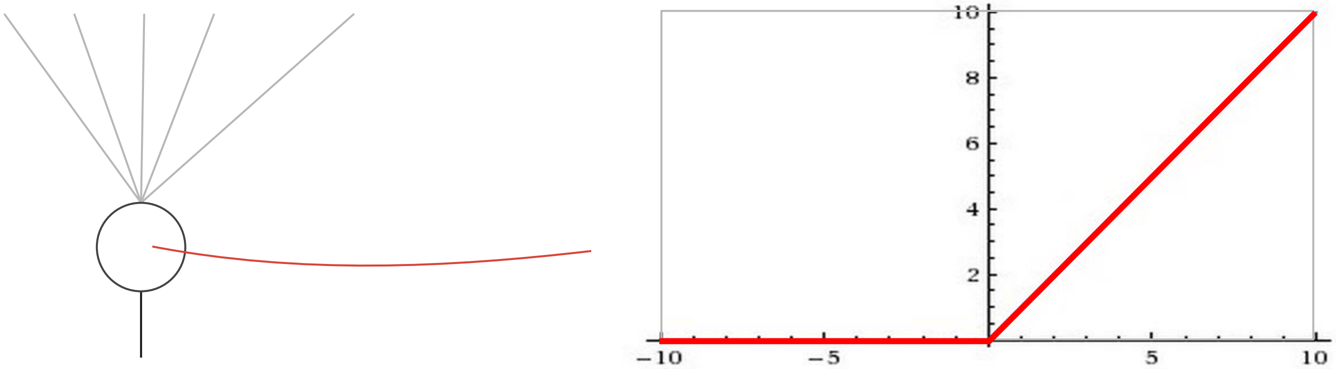





Relu !

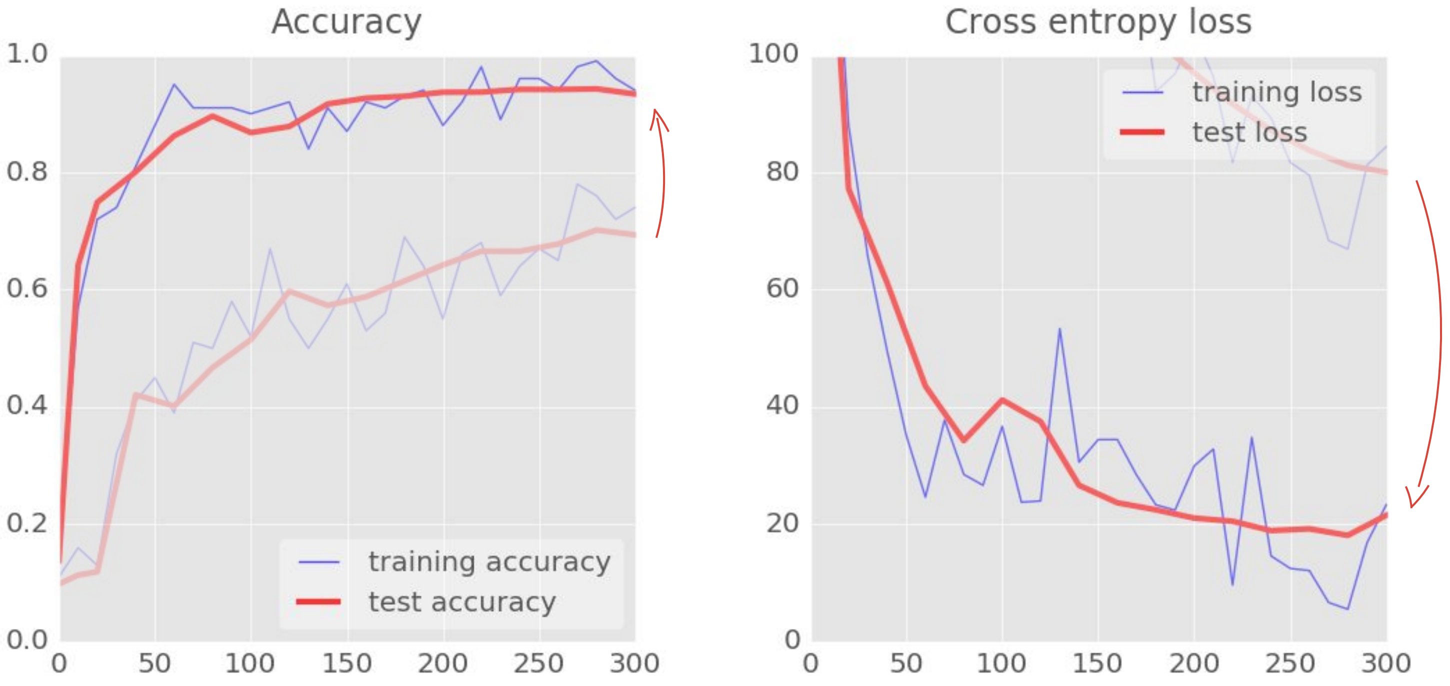
RELU

RELU = Rectified Linear Unit

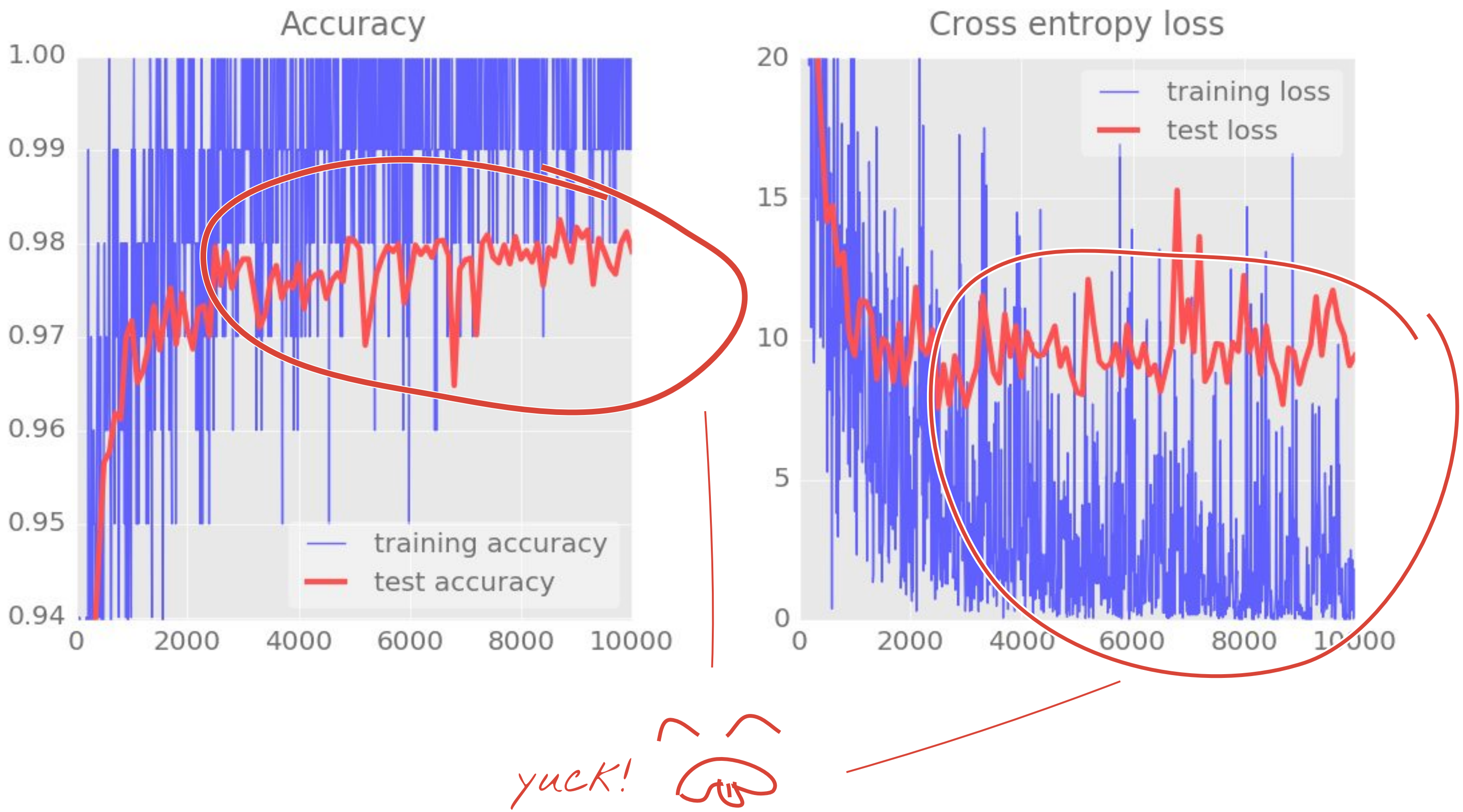



```
Y = tf.nn.relu(tf.matmul(X, W) + b)
```

RELU

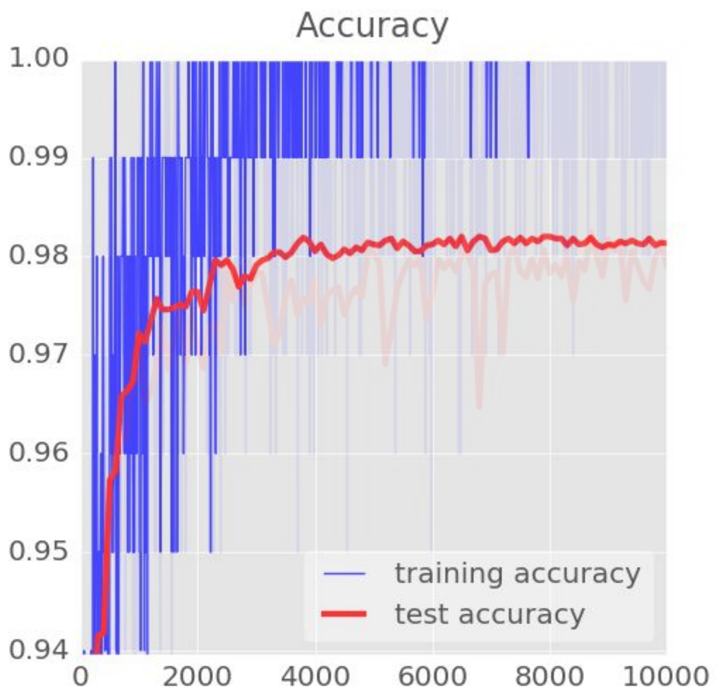

Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
training accuracy
test accuracy
Cross entropy loss
100
80
60
40
20
0
0
50
100
150
200
250
300
training loss
test loss

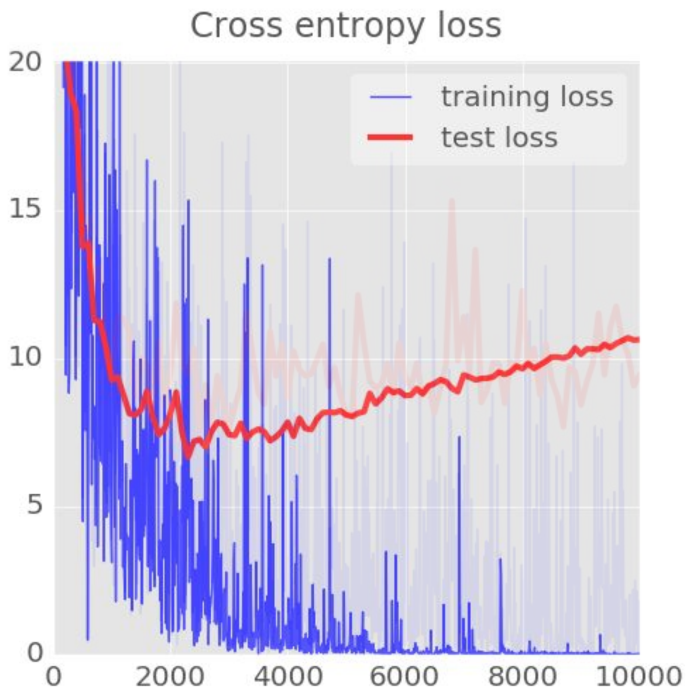
Demo - noisy accuracy curve ?



Slow down...

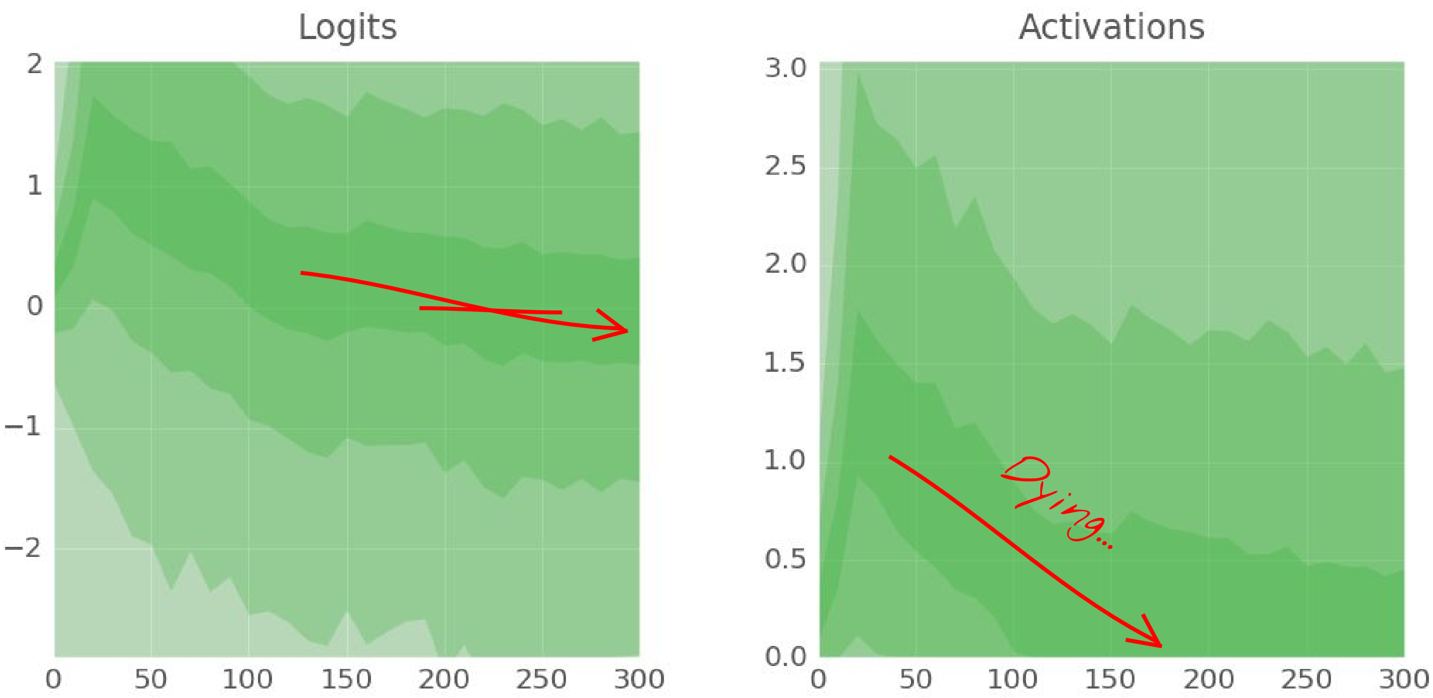
Learning rate decay

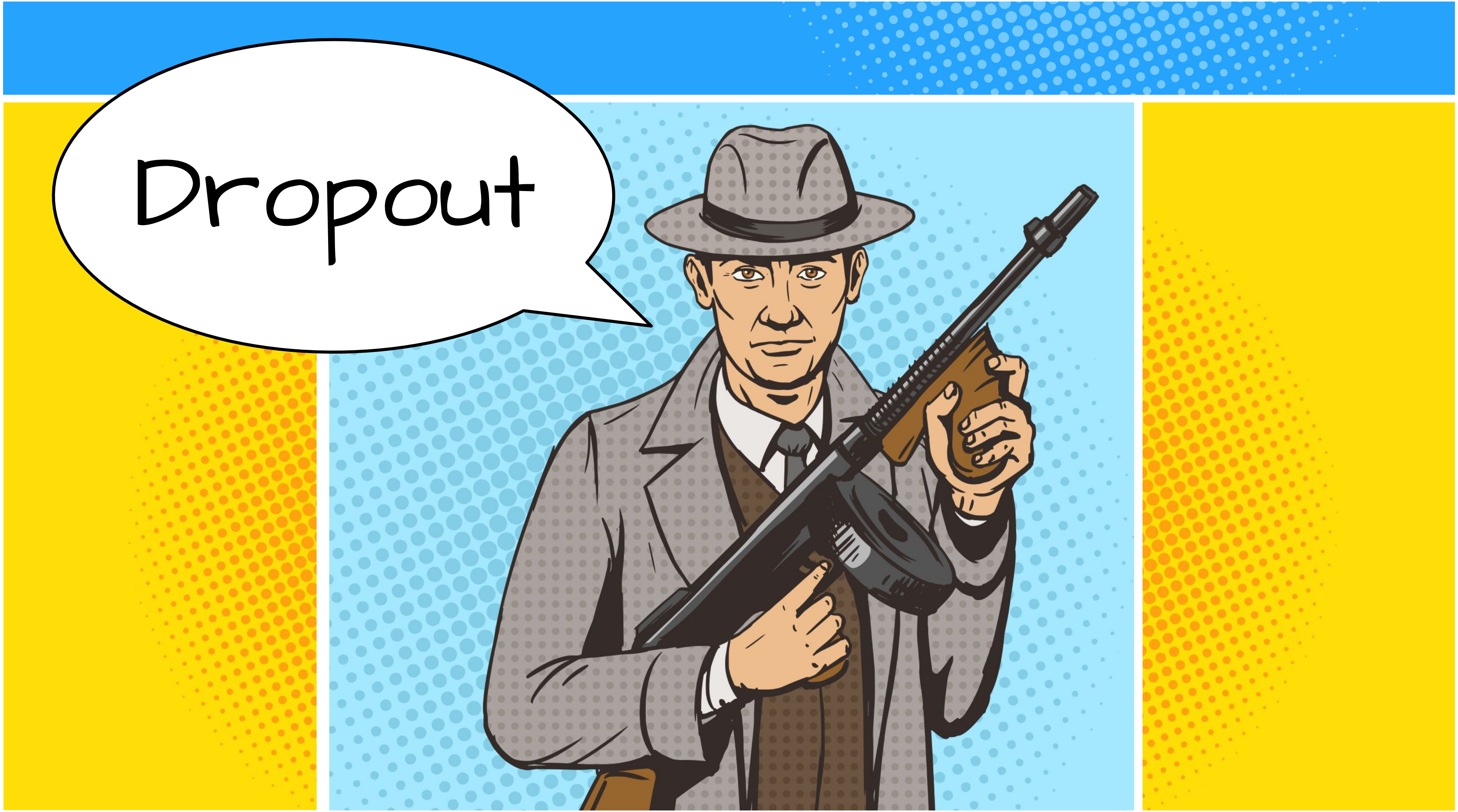




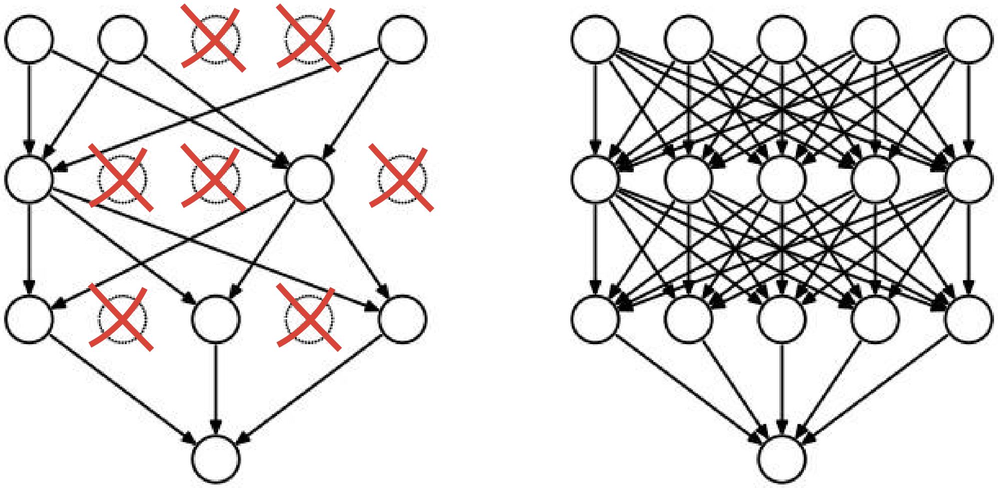
Learning rate 0.003 at start then dropping exponentially to 0.0001

Demo - dying neurons



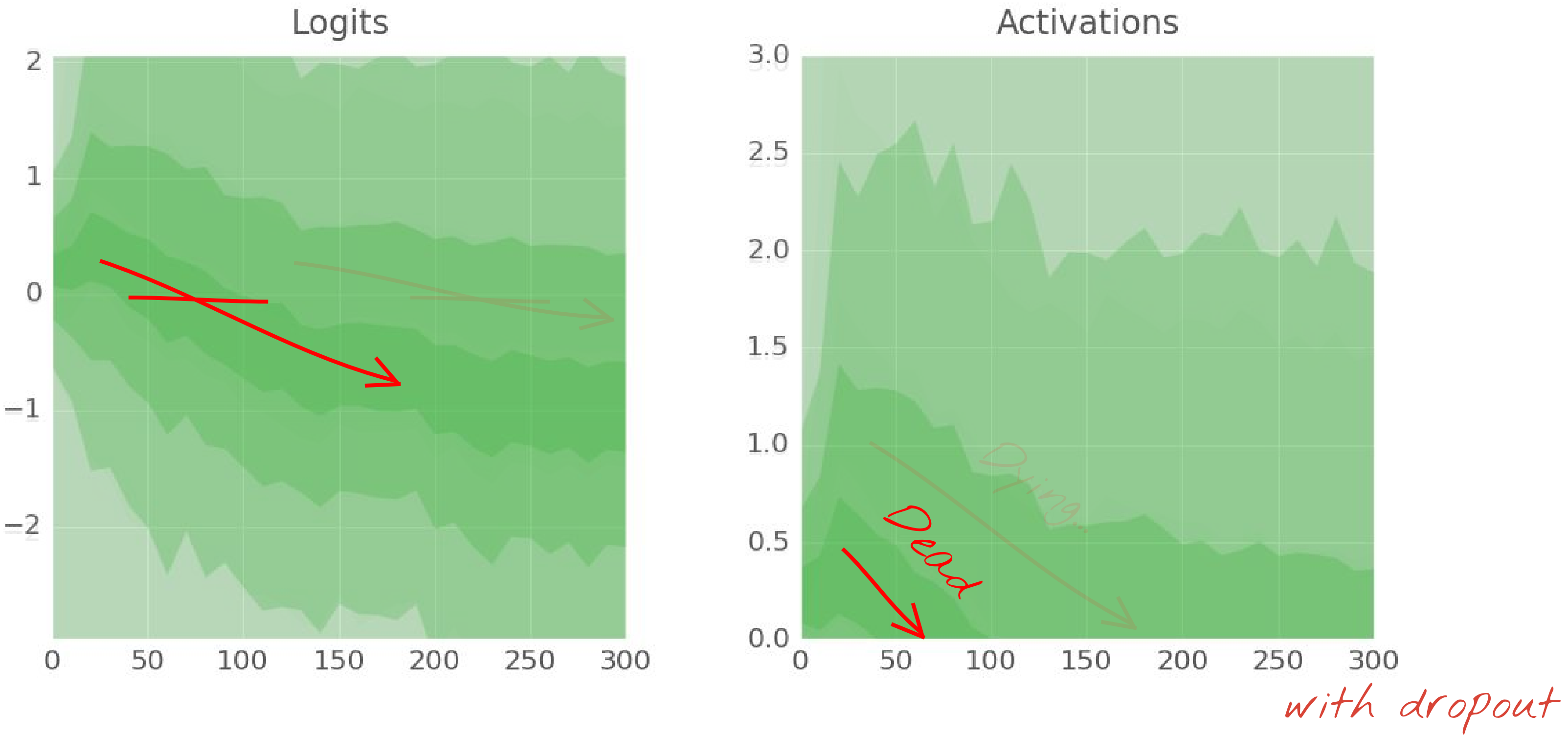

Dropout

Dropout



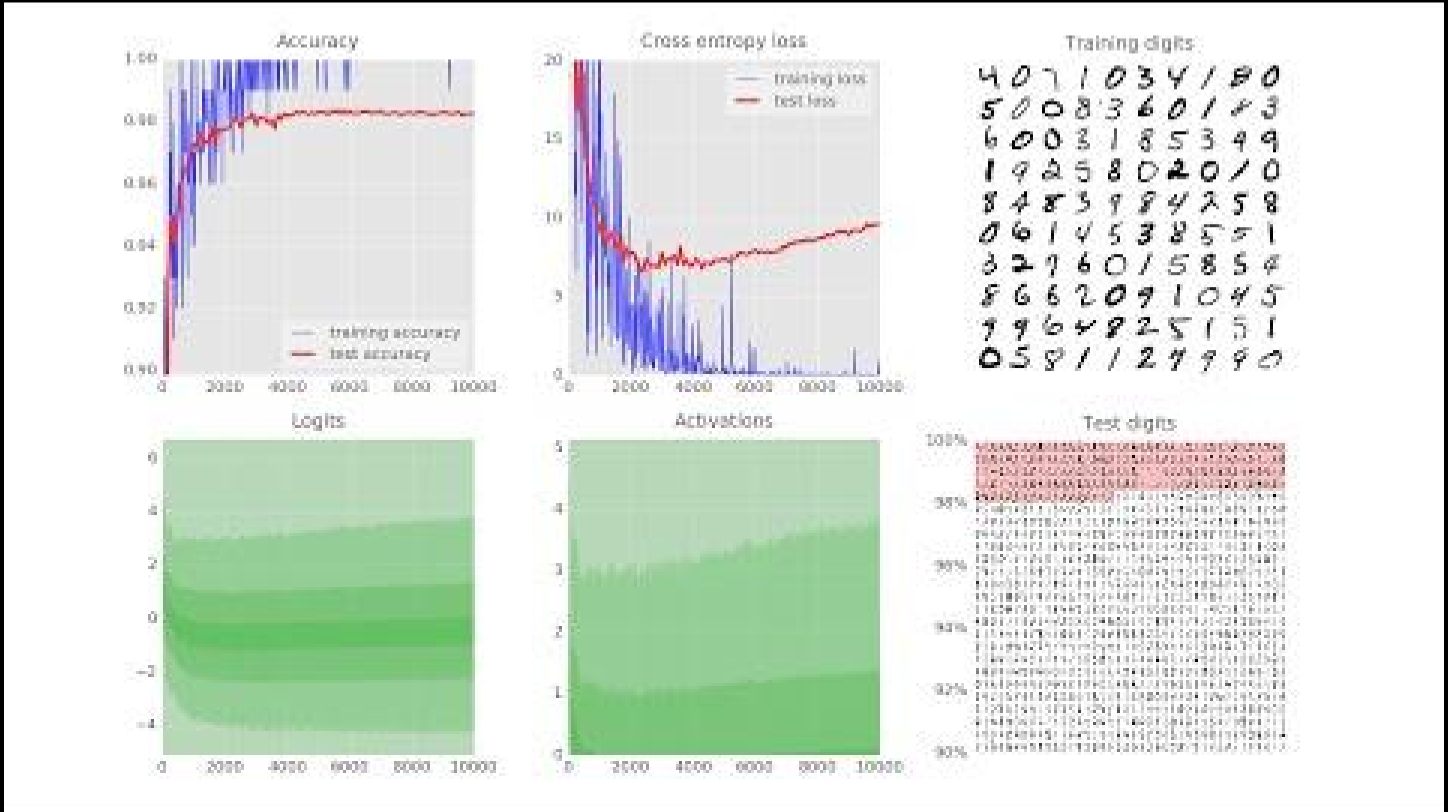

```
pkeep =
tf.placeholder(tf.float32)

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

Dropout

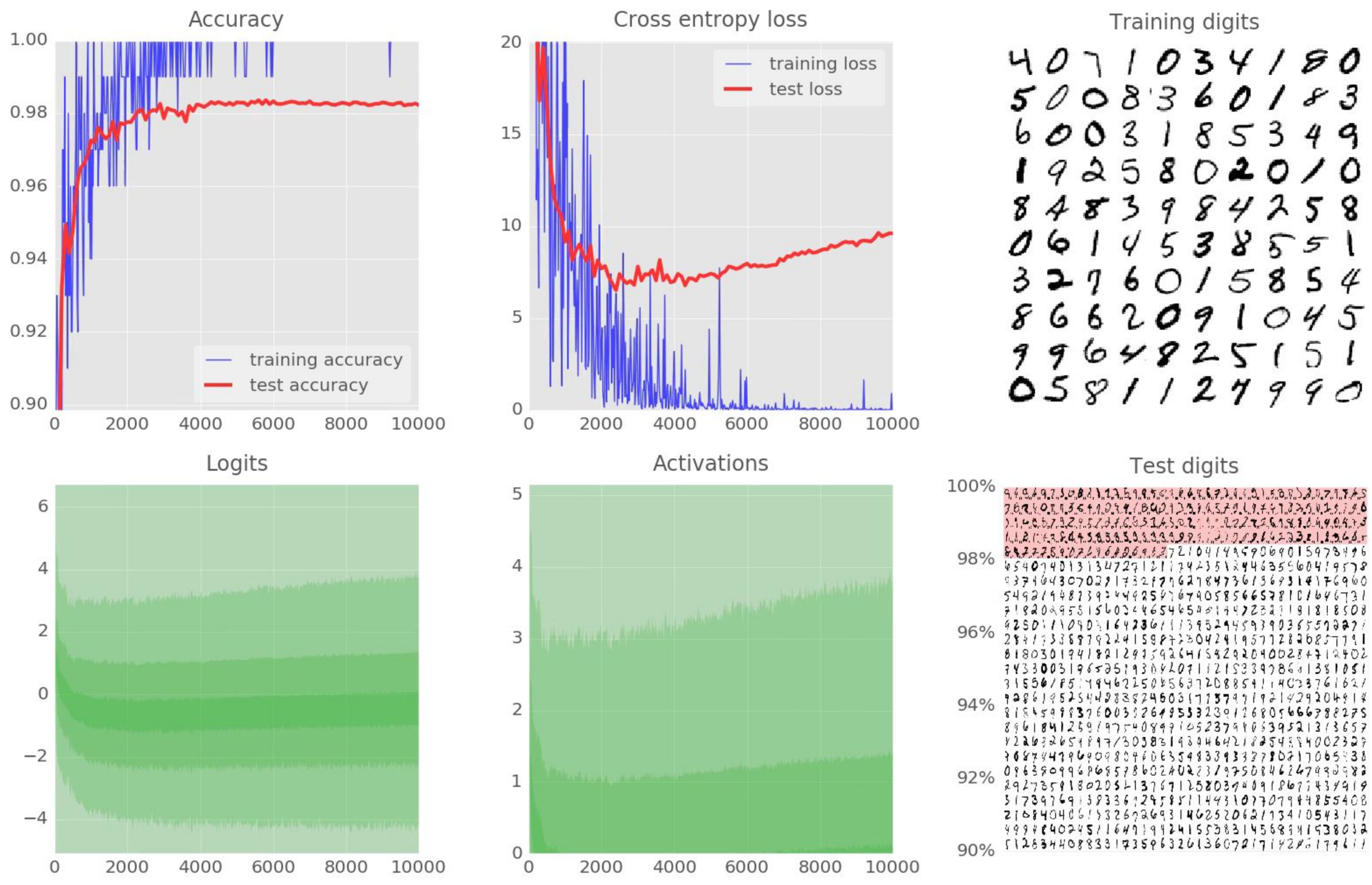


Logits
2
1
0
−1
−2
0
50
100
150
200
250
300
Activations
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
Dead
Dying...
with dropout

Demo

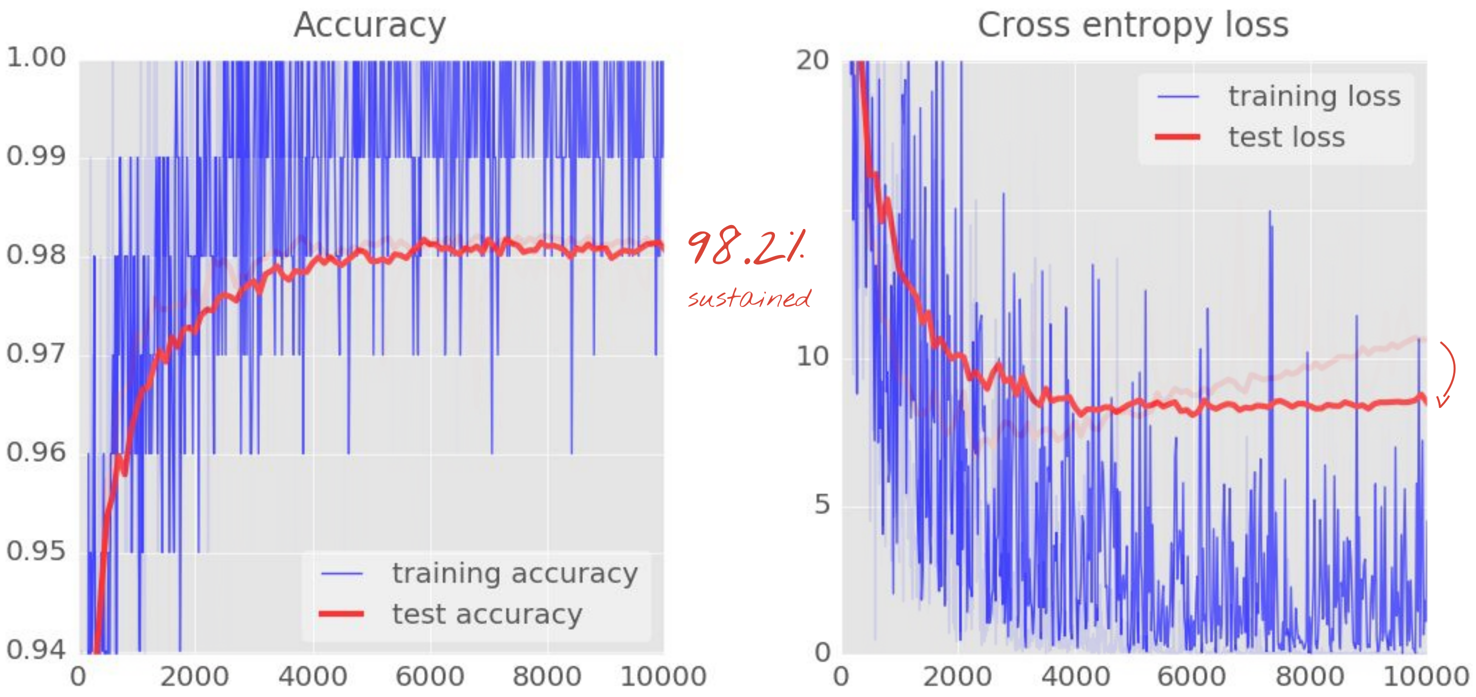


Accuracy
training accuracy
test accuracy
Cross entropy loss
training loss
test loss
Training digits
Logits
Activations
Test digits


Accuracy
training accuracy
test accuracy
Cross entropy loss
training loss
test loss
Training digits
Logits
Activations
Test digits
100%
98%
96%
94%
92%
90%

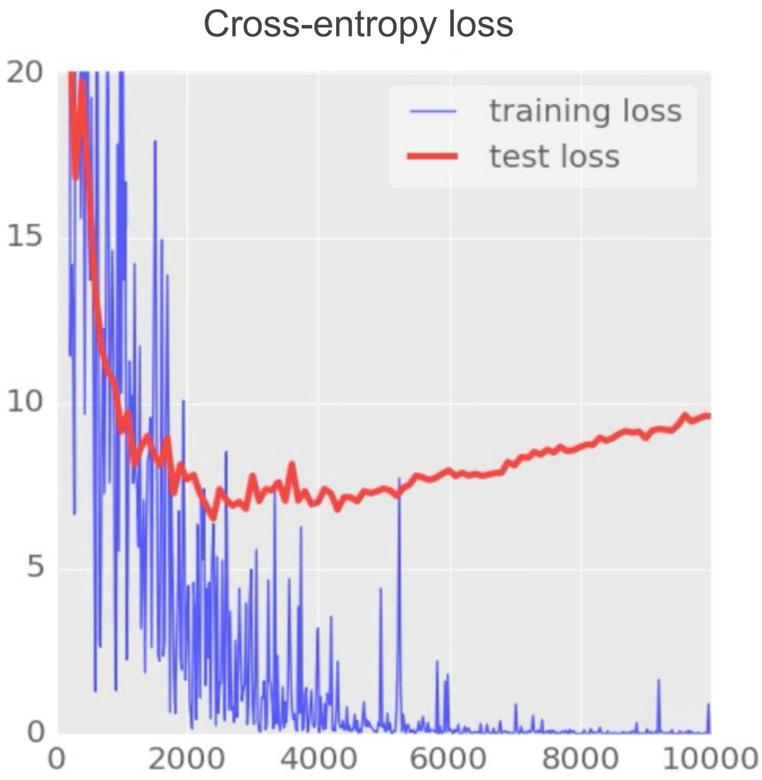
98%

All the party tricks



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

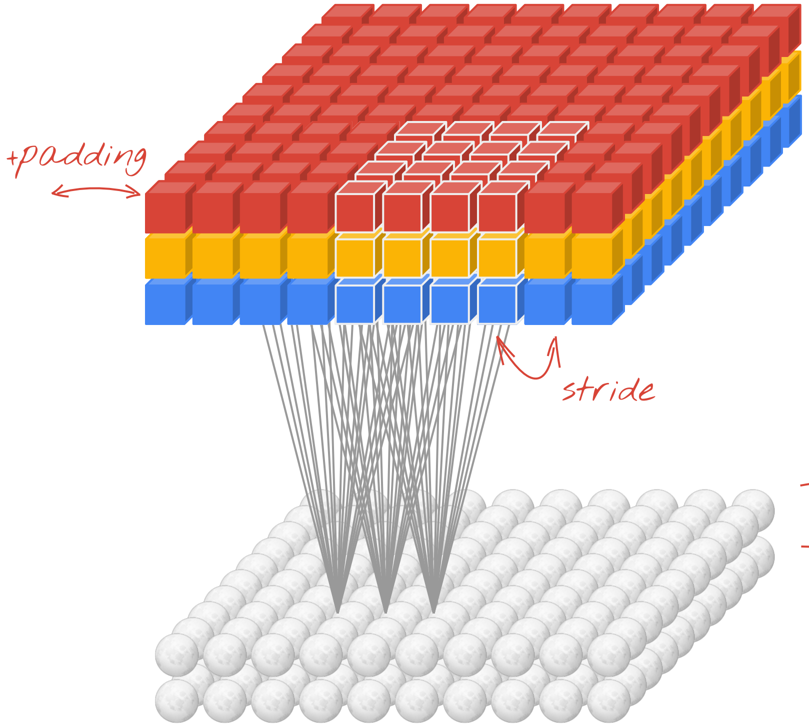
Overfitting

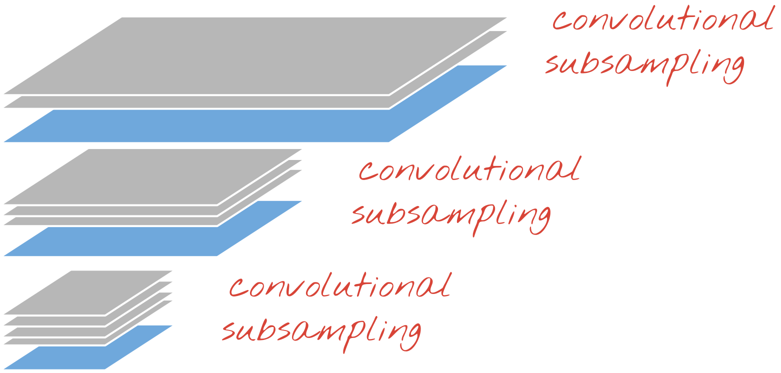


Overfitting


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

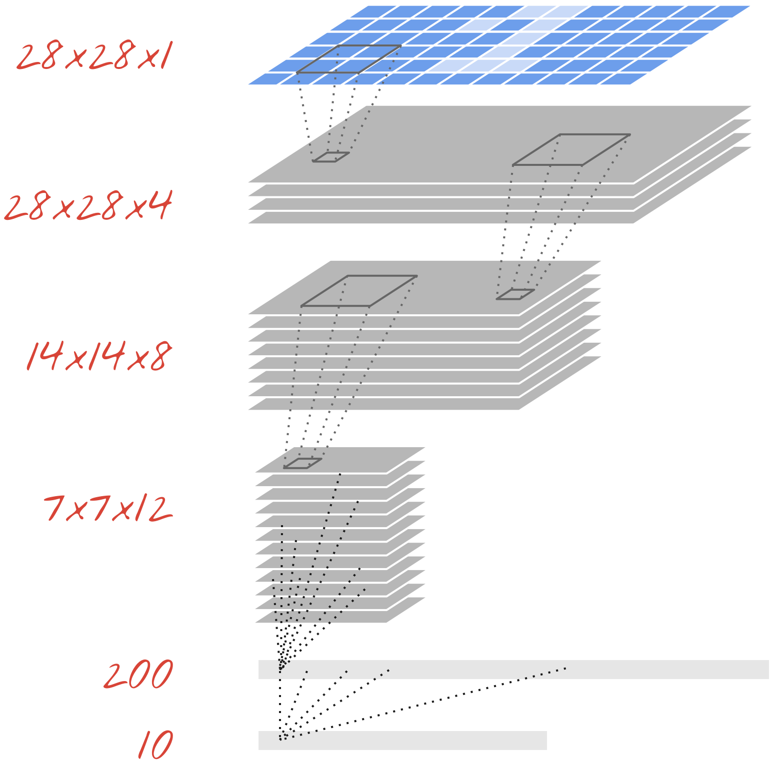
input channels

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

filter size

input channels

output channels

```
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

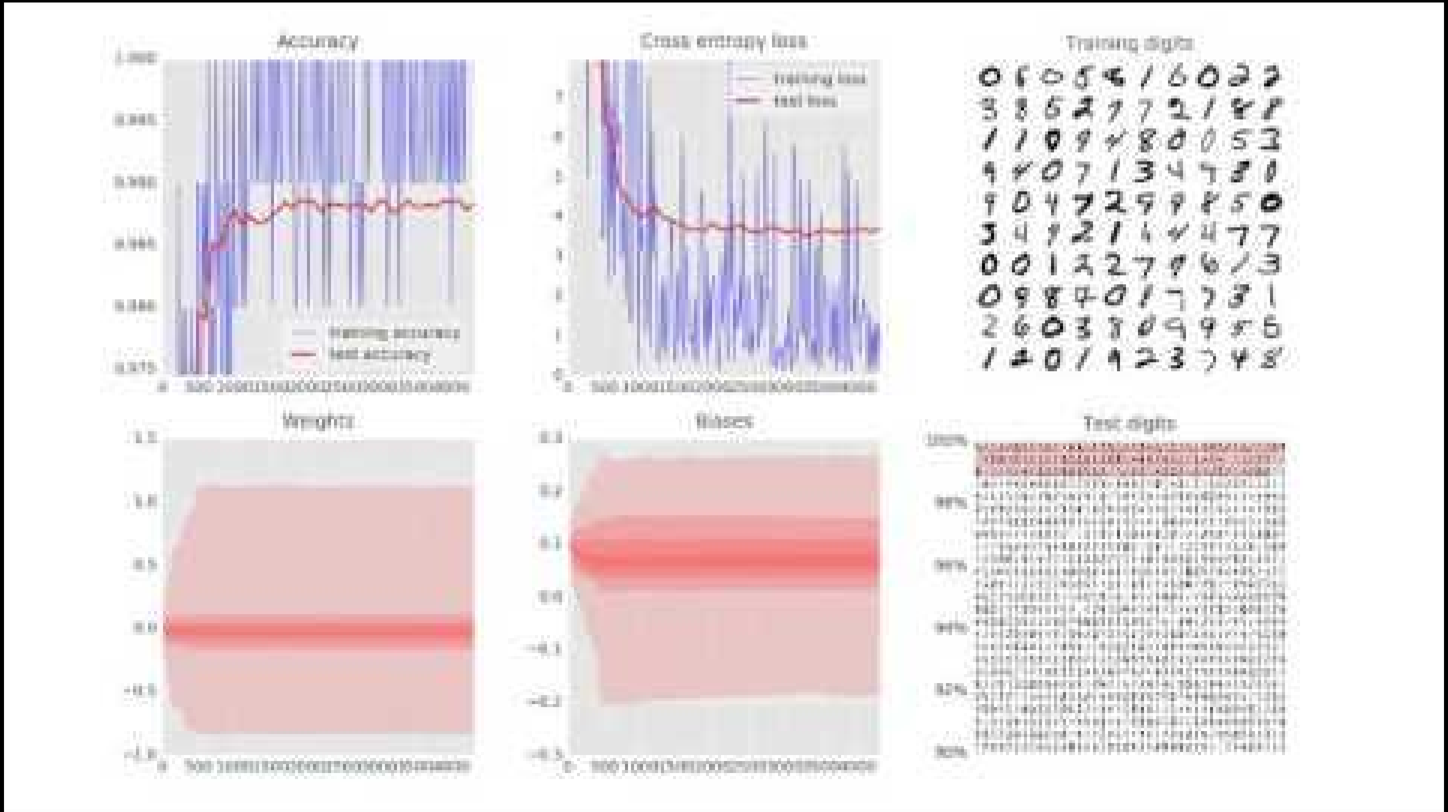
```
Y1 = tf.nn.relu(tf.nn.conv2d(X, W1, strides=[1, 1, 1, 1], padding='SAME') + B1)
Y2 = tf.nn.relu(tf.nn.conv2d(Y1, W2, strides=[1, 2, 2, 1], padding='SAME') + B2)
Y3 = tf.nn.relu(tf.nn.conv2d(Y2, W3, strides=[1, 2, 2, 1], padding='SAME') + B3)

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

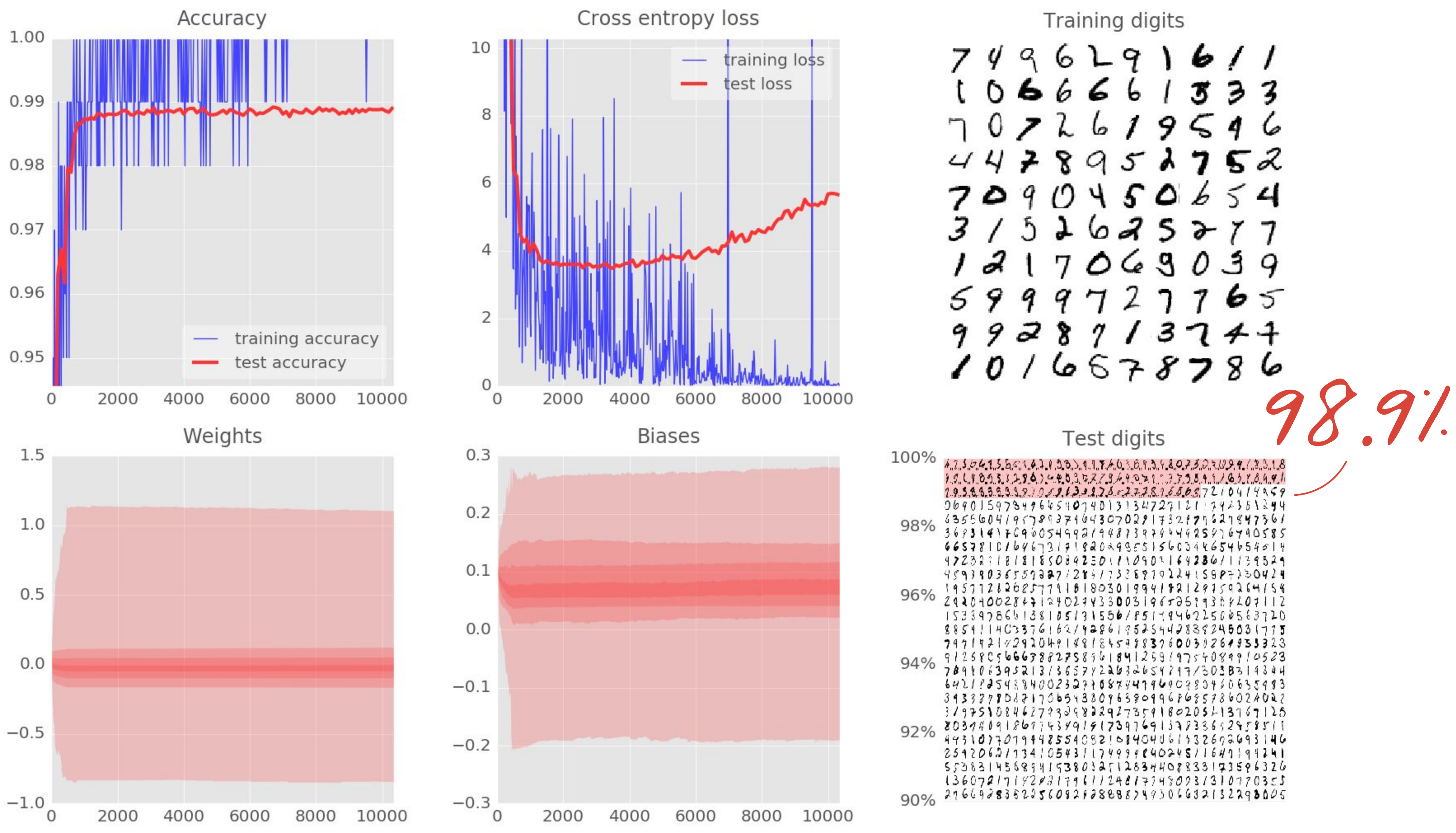
Y3 [100, 7, 7, 12]

YY [100, 7x7x12]

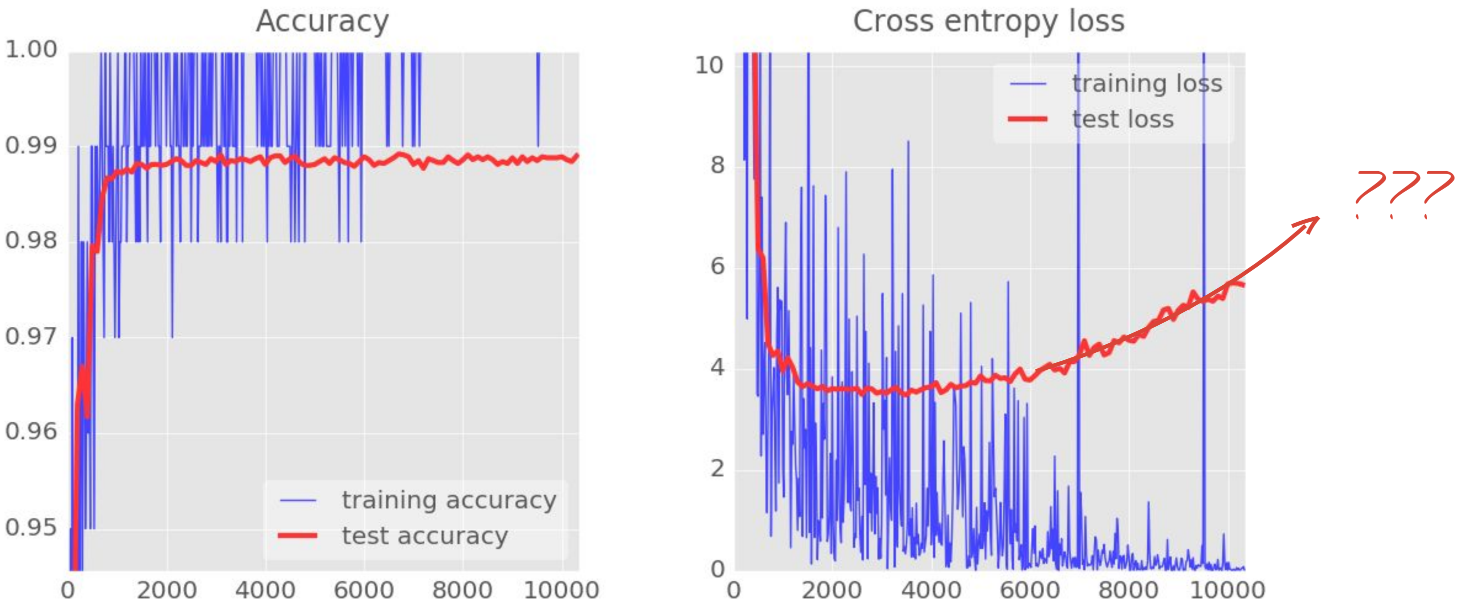
Demo



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

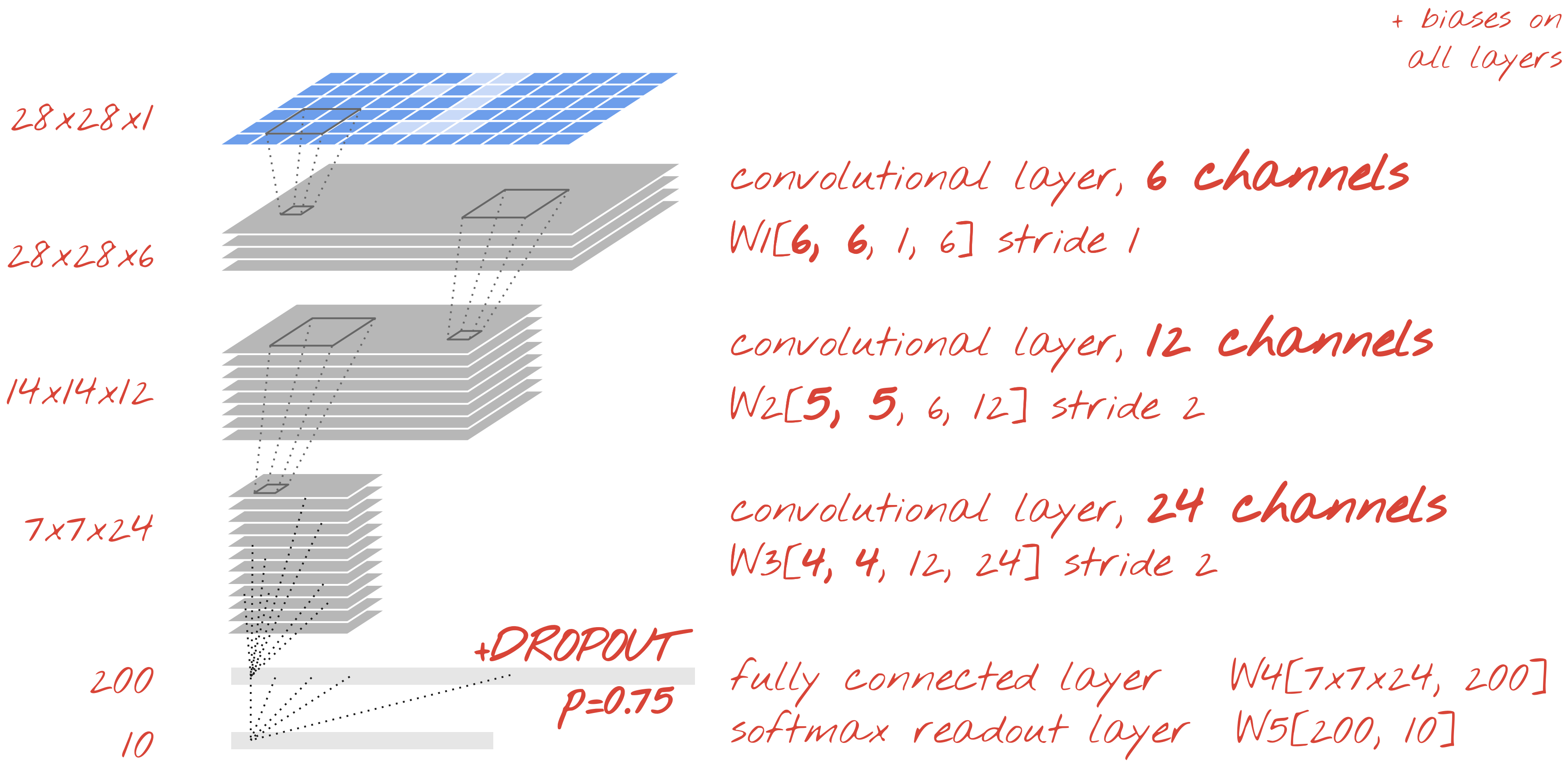

Accuracy
training accuracy
test accuracy
Cross entropy loss
training loss
test loss
Training digits
98.9%
Weights
Biases
Test digits

WT~~F~~H ???

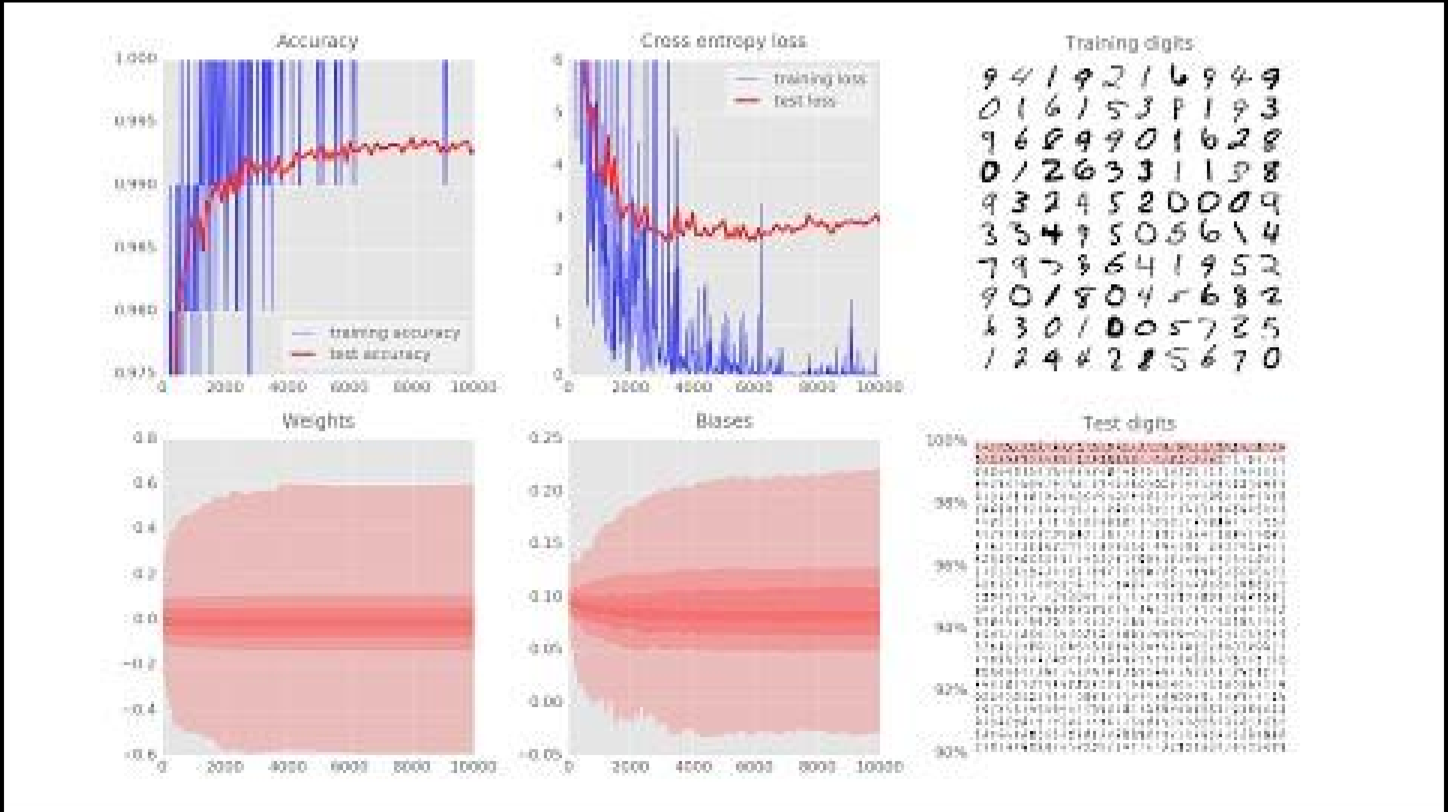


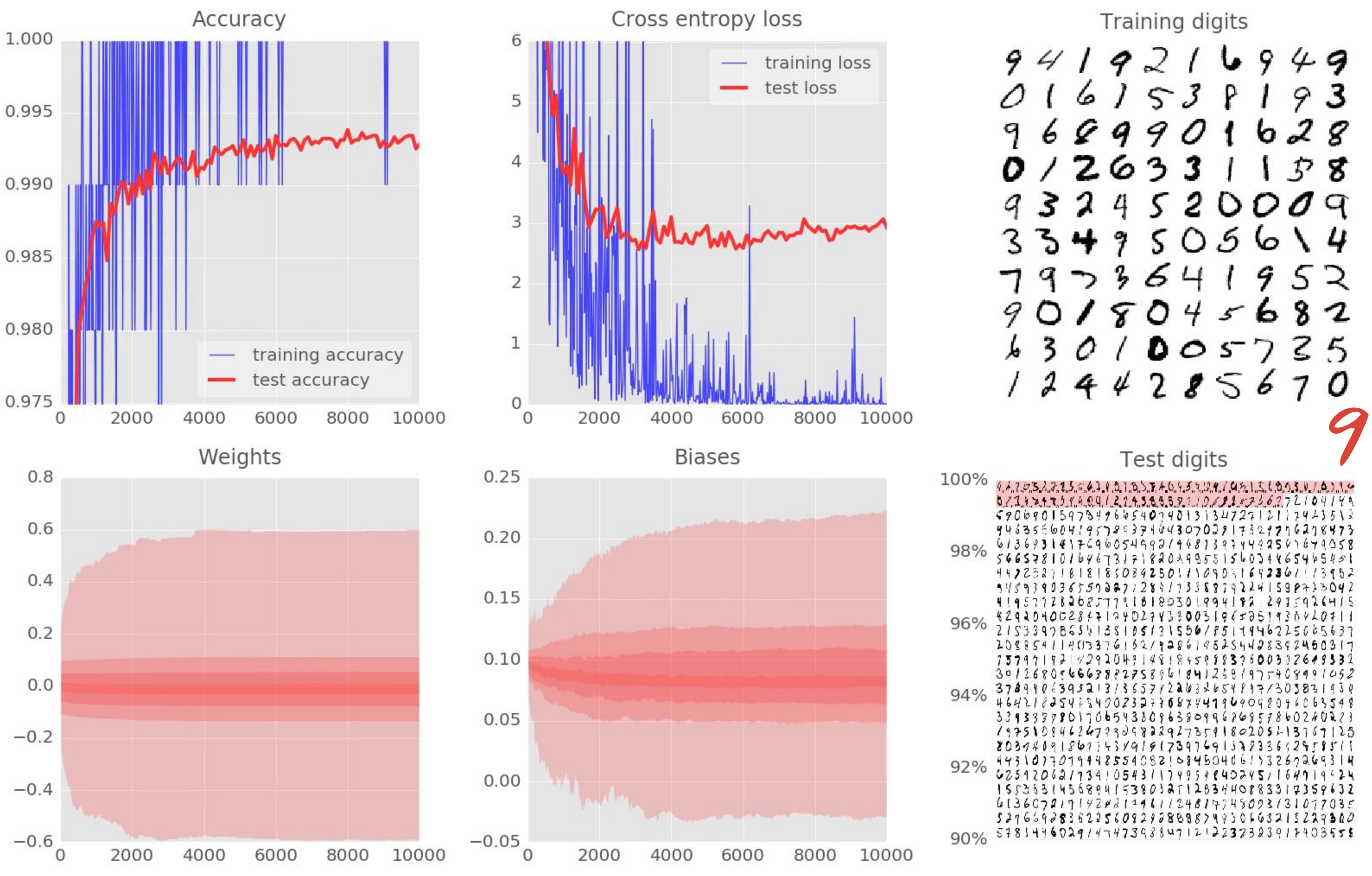
Accuracy
1.00
0.99
0.98
0.97
0.96
0.95
0
2000
4000
6000
8000
10000
training accuracy
test accuracy
Cross entropy loss
10
8
6
4
2
0
0
2000
4000
6000
8000
10000
training loss
test loss
???

Bigger convolutional network + dropout



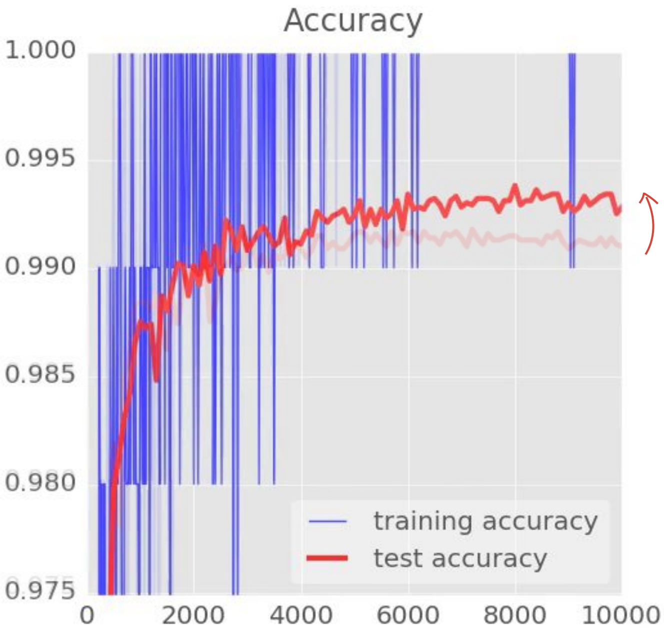
Demo

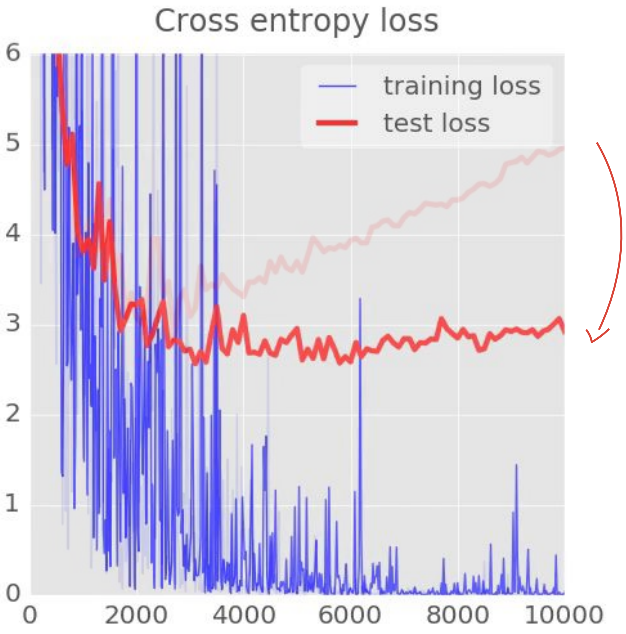

Accuracy
training accuracy
test accuracy
Cross entropy loss
training loss
test loss
Training digits
Weights
Biases
Test digits


Accuracy
training accuracy
test accuracy
Cross entropy loss
training loss
test loss
Training digits
Weights
Biases
Test digits
100%
98%
96%
94%
92%
90%

99.3%

YEAH !



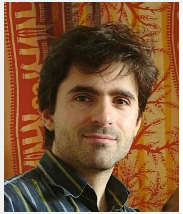


with dropout


Learning rate decay
THE WITCH'S KITCHEN COOKBOOK
Relu !
Dropout
Softmax Cross-entropy Mini-batch
Go deep
ALL Convolu-tional
Overfitting ?!?
Too many neurons
BAD Network
Not enough DATA

Have fun !

TensorFlow
tensorflow.org



Martin Görner
Google Developer relations
@martin_gorner
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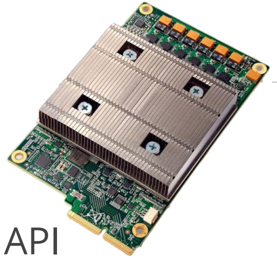
Google Cloud Platform - cloud.google.com

Cloud ML ALPHA
your TensorFlow models trained in Google's cloud, fast.



Pre-trained models:

Cloud Vision API

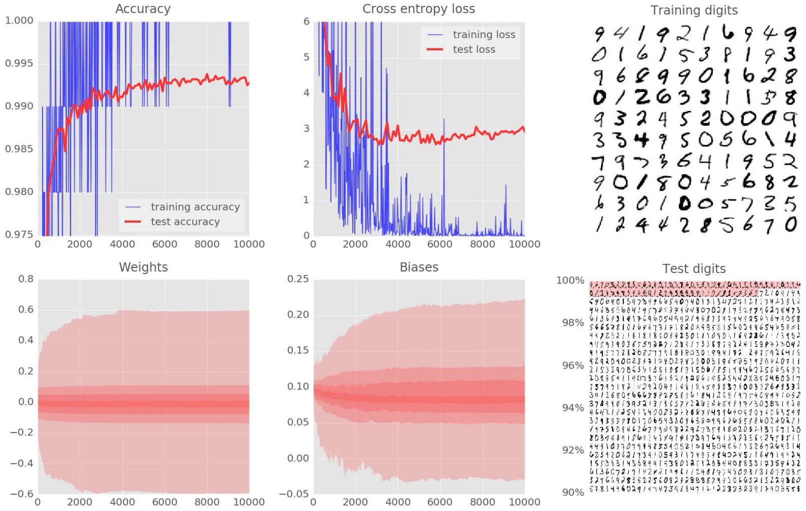
Cloud Speech API ALPHA

Google Translate API

All code snippets are on GitHub:
github.com/martin-gorner/tensorflow-mnist-tutorial

This presentation:
goo.gl/pHeXe7

Workshop




```
Keyboard shortcuts for the
visualisation GUI:

1 ......... display 1st graph only
2 ......... display 2nd graph only
3 ......... display 3rd graph only
4 ......... display 4th graph only
5 ......... display 5th graph only
6 ......... display 6th graph only
7 ......... display graphs 1 and 2
8 ......... display graphs 4 and 5
9 ......... display graphs 3 and 6
ESC or 0 .. back to displaying all graphs

SPACE ..... pause/resume
O ......... box zoom mode (then use mouse)
H ......... reset all zooms
Ctrl-S .... save current image
```

Workshop

Starter code and solutions:
github.com/martin-gorner/tensorflow-mnist-tutorial

1. Theory (sit back and listen)

Softmax classifier, mini-batch, cross-entropy and how to implement them in Tensorflow (slides 1-14)

2. Practice

Open file: `mnist_1.0_softmax.py`
Run it, play with the visualisations (see instructions on previous slide), read and understand the code as well as the basic structure of a Tensorflow program.

3. Theory (sit back and listen)

Hidden layers, sigmoid activation function (slides 16-19)

4. Practice

Start from the file you have and add one or two hidden layers. Use [`cross_entropy_with_logits`]() to avoid numerical instabilities with `log(0)`.

Solution in: `mnist_2.0_five_layers_sigmoid.py`

5. Theory (sit back and listen)

The neural network toolbox: RELUs, learning rate decay, dropout, overfitting (slides 20-35)

6. Practice

Replace all your sigmoids with RELUs. Test. Then add learning rate decay from 0.003 to 0.0001 using the formula `lr = lrmin+(lrmax-lrmin)*exp(-i/2000)`.

Solution in: `mnist_2.1_five_layers_relu_lrdecay.py`

7. Practice (if time allows)

Add dropout on all layers using a value between 0.5 and 0.8 for pkeep.

Solution in: `mnist_2.2_five_layers_relu_lrdecay_dropout.py`

8. Theory (sit back and listen)

Convolutional networks (slides 36-42)

9. Practice

Replace your model with a convolutional network, without dropout.

Solution in: `mnist_3.0_convolutional.py`

10. Practice (if time allows)

Try a bigger neural network (good hyperparameters on slide 44) and add dropout on the last layer.

Solution in: `mnist_3.0_convolutional_bigger_dropout.py`