2017 Predictive Analytics Symposium

Session 22, TensorFlow (workshop)

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Session 22: TensorFlow (workshop)

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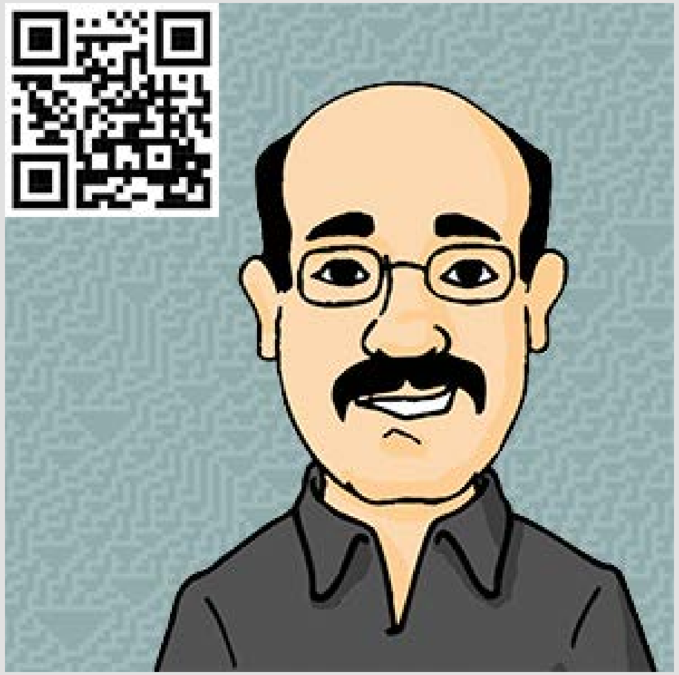


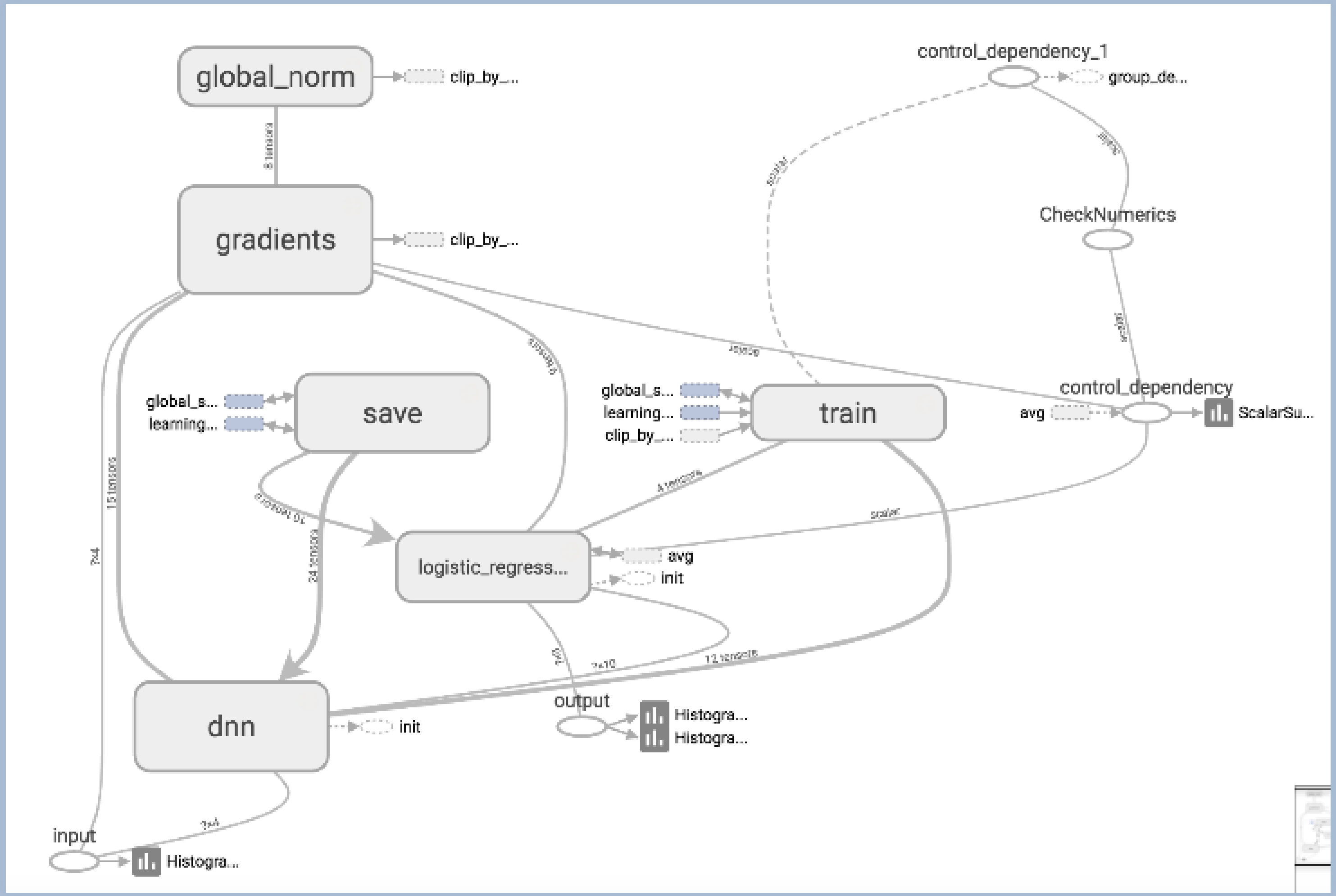
T81-558: Applications of Deep Learning

- **Course Website**: https://sites.wustl.edu/jeffheaton/t81-558/
- **Instructor Website:** https://sites.wustl.edu/jeffheaton/
- **Course Videos:** https://www.youtube.com/user/HeatonResearch

Presentation Outline

- TensorFlow as a Compute Graph/Engine
- Keras and TensorFlow
- Keras: Classification
- Keras: Regression
- Keras: Computer Vision and CNN
- Keras: Time Series and RNN
- GPU

TensorFlow as a Compute Graph/Engine



What are Tensors? Why are they flowing?

- Tensor of Rank 0 (or scaler) – simple variable
- Tensor of Rank 1 (or vector) – array/list
- Tensor of Rank 2 (or matrix) – 2D array
- Tensor of Rank 3 (or cube) – 3D array
- Tensor of Rank 4 (tesseract/hypercube) – 4D array
- Higher ranks (hypercube) – nD array

What is a Computation Graph?

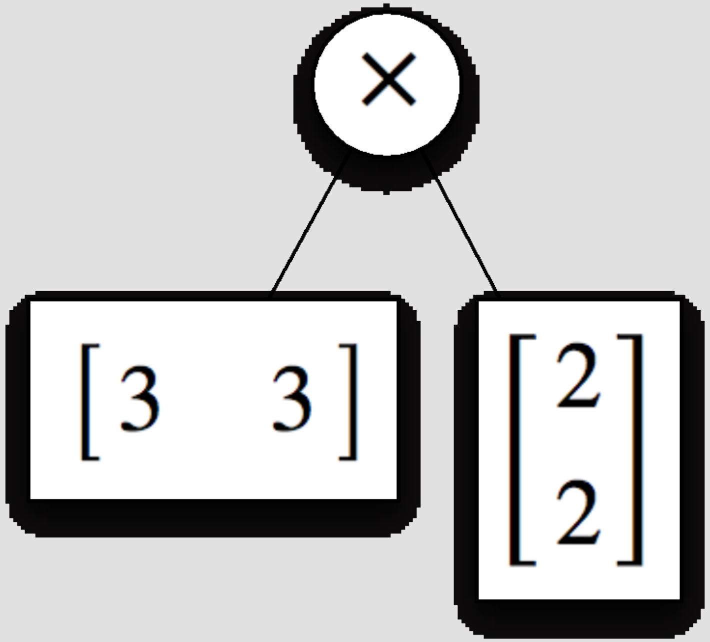
```
import tensorflow as tf

matrix1 = tf.constant([[3., 3.]])
matrix2 = tf.constant([[2.],[2.]])
product = tf.matmul(matrix1, matrix2)

with tf.Session() as sess:
   result = sess.run([product])

print(result)
```

$$\begin{bmatrix} 3 & 3 \end{bmatrix} \times \begin{bmatrix} 2 \\ 2 \end{bmatrix} = \begin{bmatrix} 3 \times 2 + 3 \times 2 \end{bmatrix} = \begin{bmatrix} 12 \end{bmatrix}$$



Computation Graph with Variables

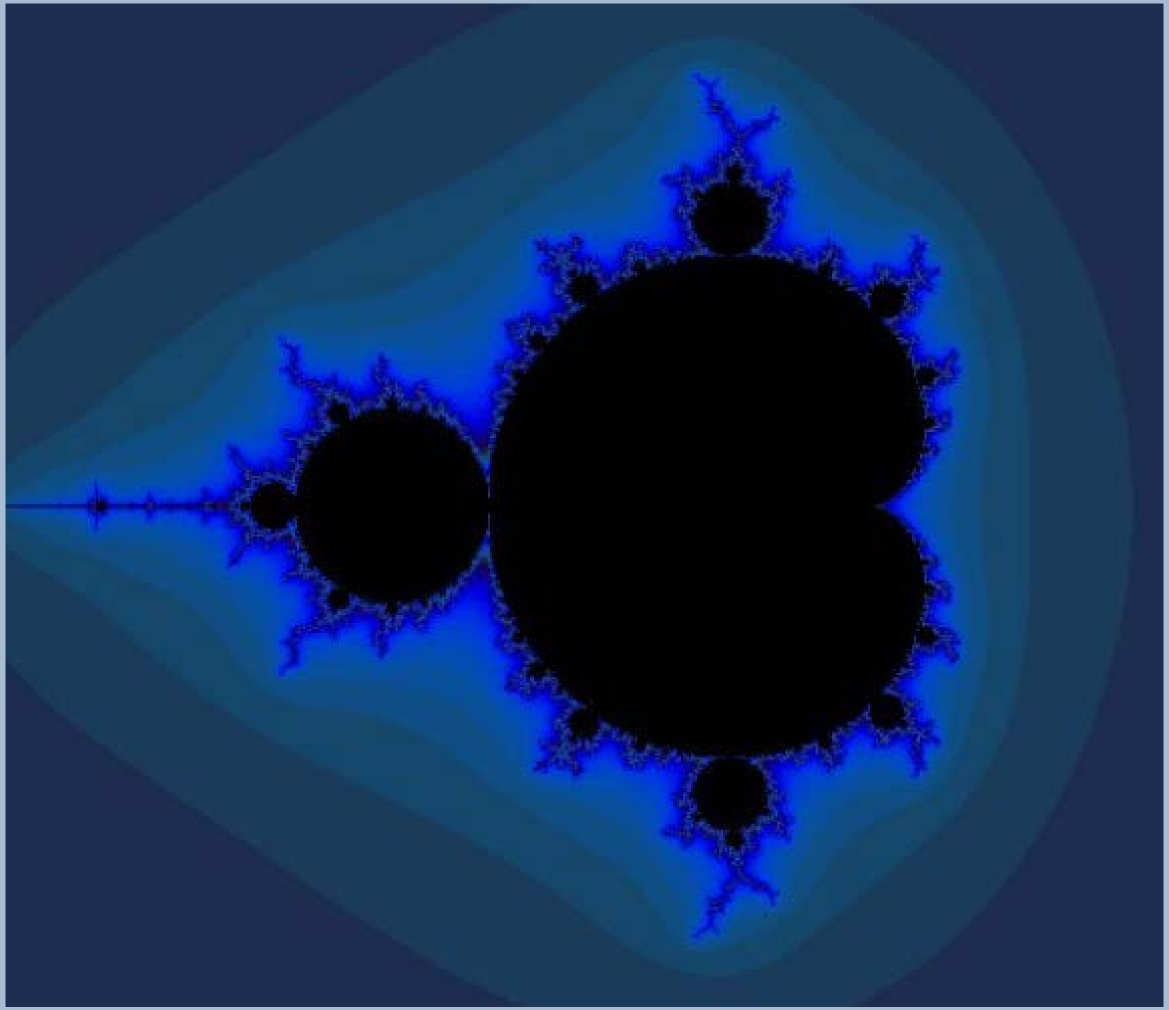
```
import tensorflow as tf
sess = tf.InteractiveSession()

x = tf.Variable([1.0, 2.0])
a = tf.constant([3.0, 3.0])
x.initializer.run()

sub = tf.subtract(x, a)
print(sub.eval())
# ==> [-2. -1.]

sess.run(x.assign([4.0, 6.0]))
print(sub.eval())
# ==> [1. 3.]
```

Computation Graph for Mandelbrot Set



Mandelbrot Set Review

- Some point *c* is a complex number with *x* as the real part, *y* as the imaginary part.

- $z_0 = 0$
- $z_1 = c$
- $z_2 = z_1^2 + c$
- ...
- $z_{n+1} = z_n^2 + c$

Mandelbrot Rendering in TensorFlow

```
xs = tf.constant(Z.astype(np.complex64))
zs = tf.Variable(xs)
ns = tf.Variable(tf.zeros_like(xs, tf.float32))
tf.global_variables_initializer().run()
# Compute the new values of z: z^2 + x
zs_ = zs*zs + xs
# Have we diverged with this new value?
not_diverged = tf.abs(zs_) < 4
step = tf.group(
  zs.assign(zs_),
  ns.assign_add(tf.cast(not_diverged, tf.float32))
  )
for i in range(200): step.run()
```

Keras and TensorFlow

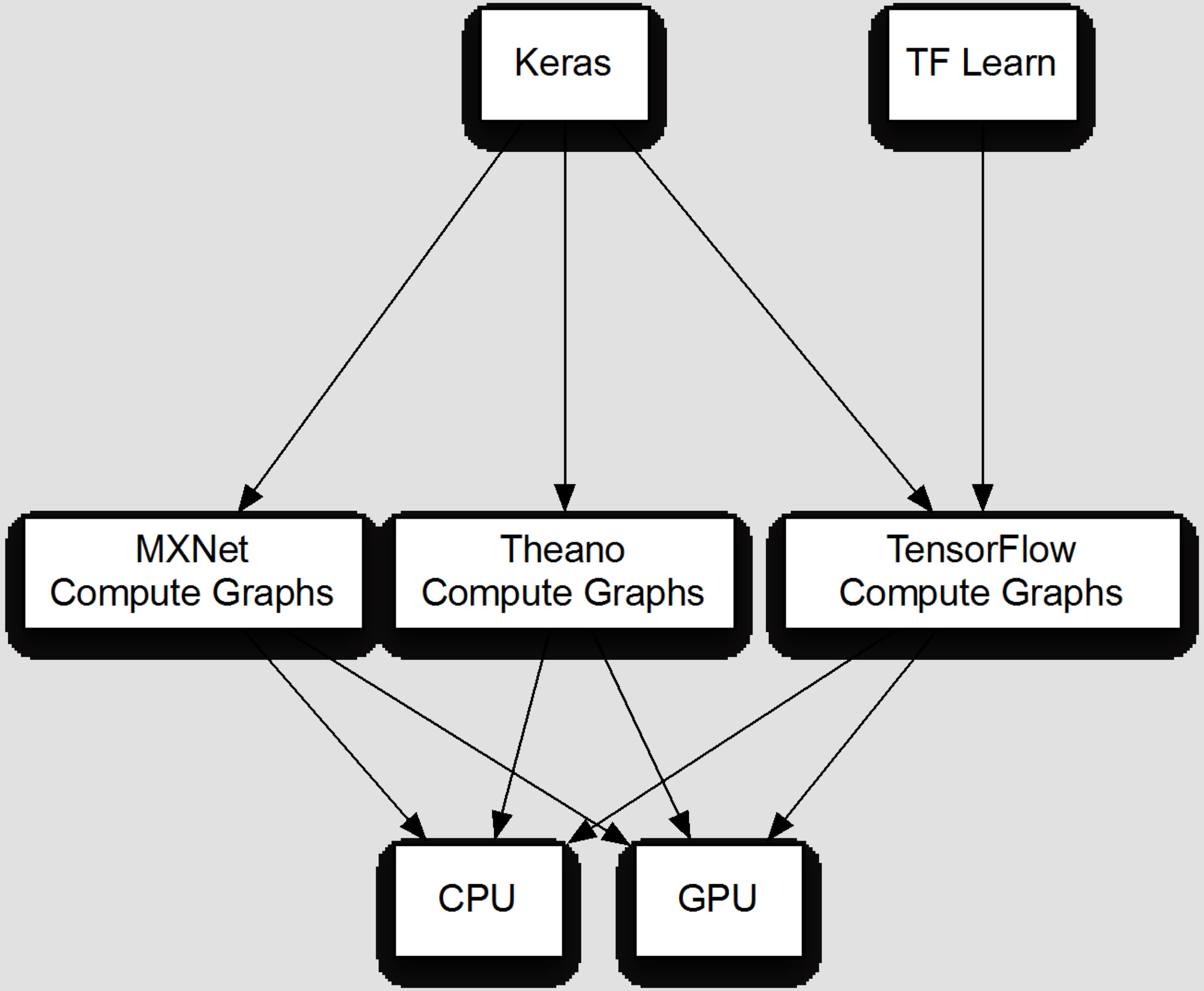
Tools Used in this Presentation

- Anaconda Python 3.6
- Google TensorFlow 1.2
- Keras 2.0.6
- Scikit-Learn
- Jupyter Notebooks

Installing These Tools

- Install Anaconda Python 3.6
- Then run the following:
  - conda install scipy
  - pip install sklearn
  - pip install pandas
  - pip install pandas-datareader
  - pip install matplotlib
  - pip install pillow
  - pip install requests
  - pip install h5py
  - pip install tensorflow==1.2.1
  - pip install keras==2.0.6

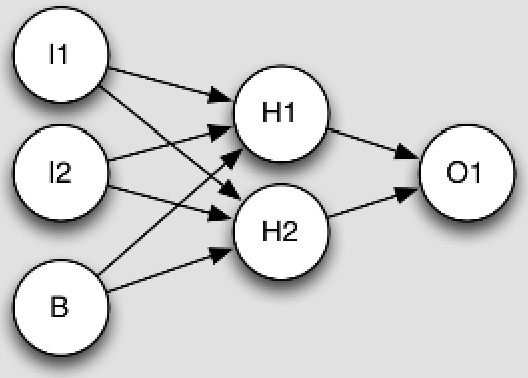
Keras and TensorFlow



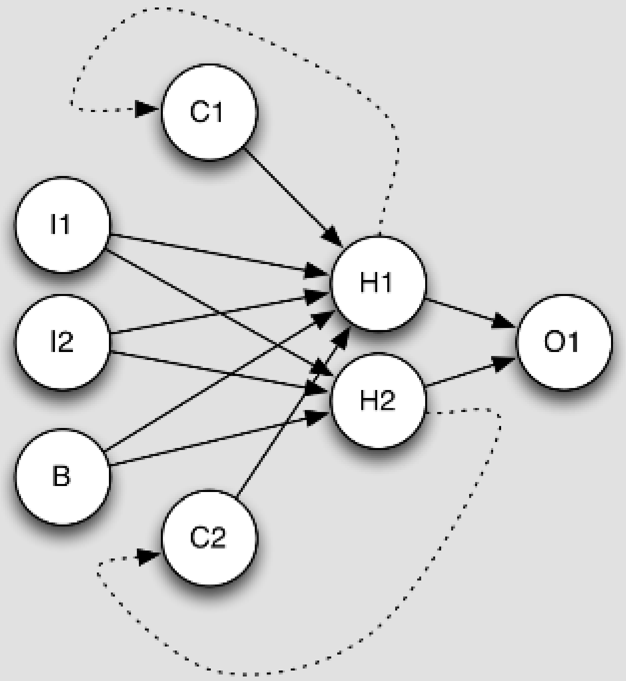
Anatomy of a Neural Network

- **Input Layer** – Maps inputs to the neural network.
- **Hidden Layer(s)** – Helps form prediction.
- **Output Layer** – Provides prediction based on inputs.
- **Context Layer** – Holds state between calls to the neural network for predictions.

Feedforward Neural Network



Recurrent Neural Network



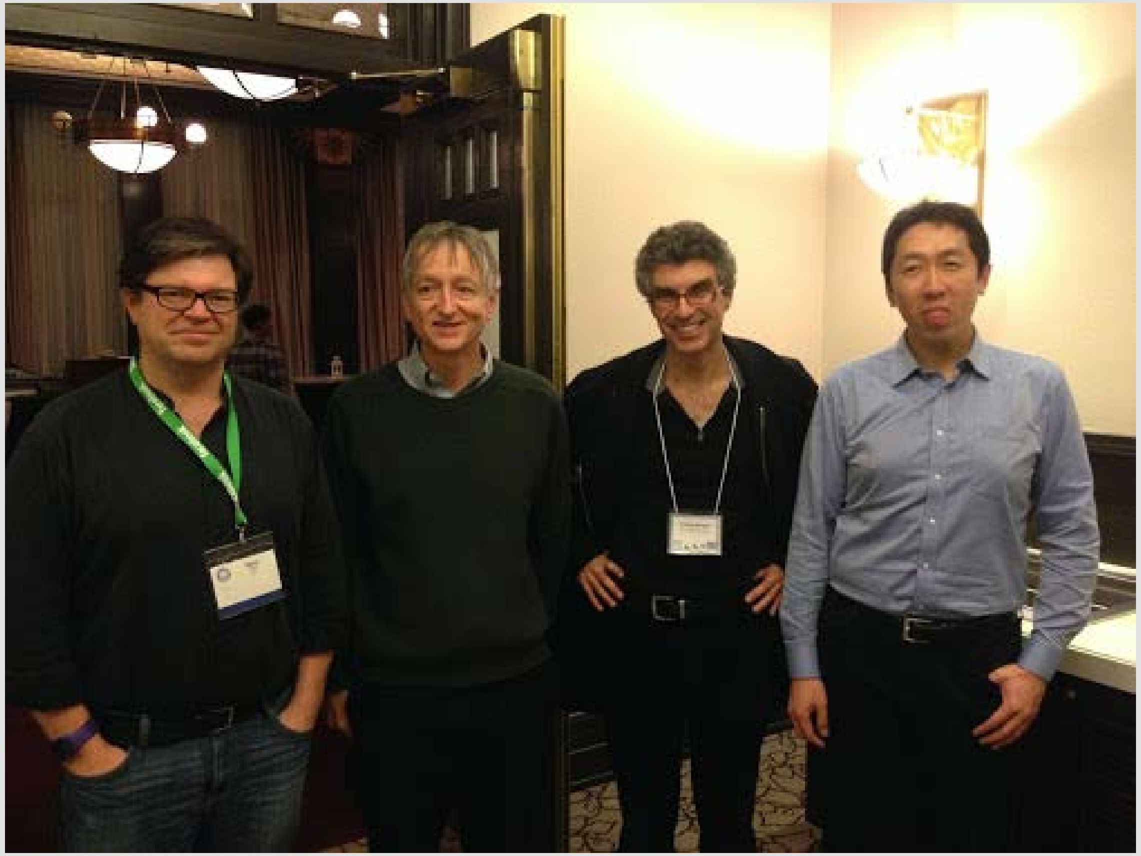
What is Deep Learning

- Deep learning is almost always applied to neural networks.
- A deep neural network has more than 2 hidden layers.
- Deep neural networks have existed as long as traditional neural networks.
  - We just did not have a way to train deep neural networks.
  - Hinton (et al.) introduced a means to train deep belief neural networks in 2006.
- Neural networks have risen three times and fallen twice in their history. Currently, they are on the rise.

The True Believers – Luminaries of Deep Learning

- From left to right:

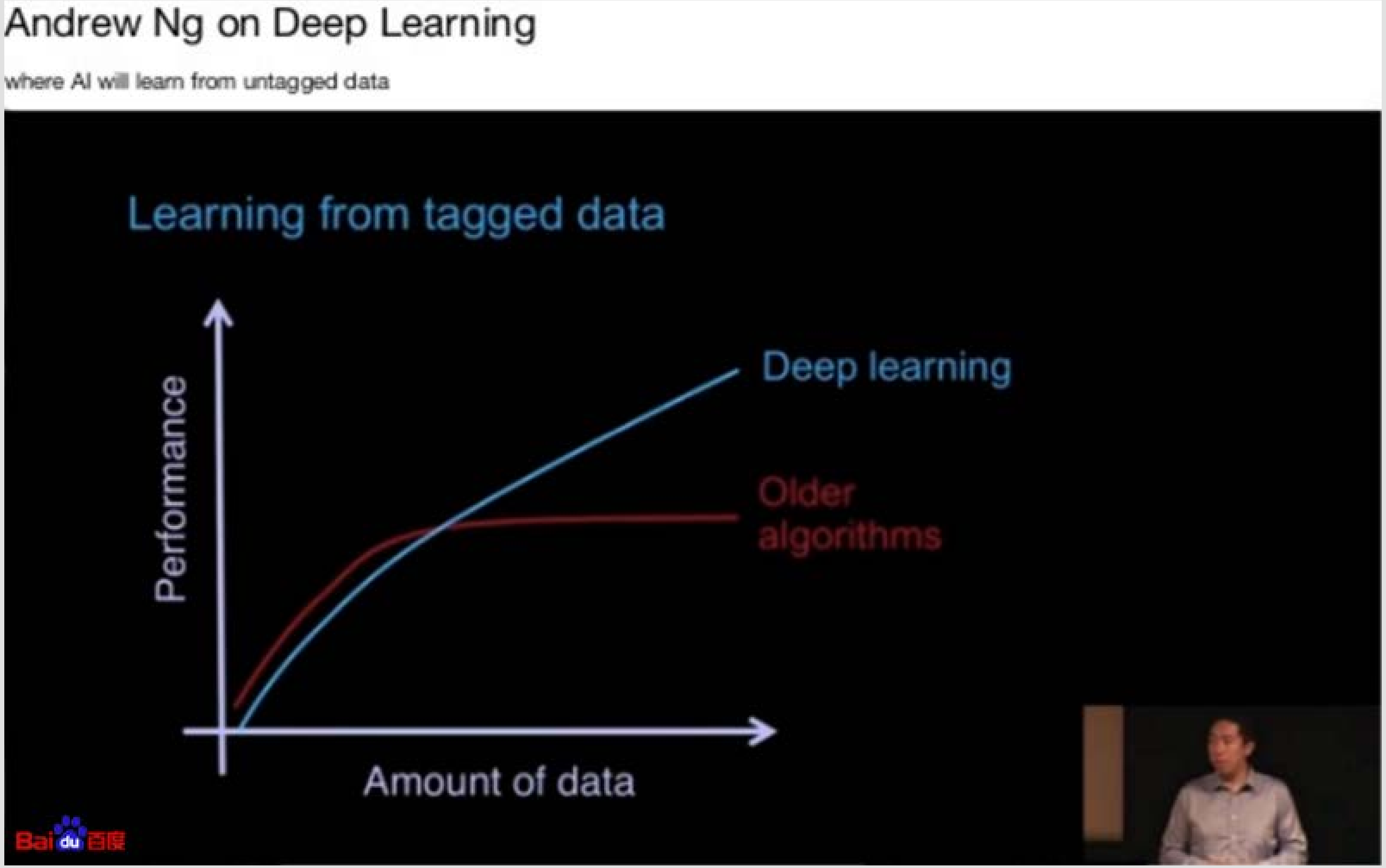
- Yann LeCun
- Geoffrey Hinton
- Yoshua Bengio
- Andrew Ng



Why Use Deep Learning

- Deep neural networks often accomplish the same task as other models, such as:
  - Support Vector Machines
  - Random Forests
  - Gradient Boosted Machines
- For many problems deep learning will give a less accurate answer than the other models.
- However, for certain problems, deep neural networks perform considerably better than other models.

Why Deep Learning (high y-axis is good)



Supervised or Unsupervised?

Supervised Machine Learning

- Usually classification or regression.
- For an input, the correct output is provided.
- Examples of supervised learning:
  - Propensity to buy
  - Credit scoring

Unsupervised Machine Learning

- Usually clustering.
- Inputs analyzed without any specification of a correct output.
- Examples of unsupervised learning:
  - Clustering
  - Dimension reduction

Types of Machine Learning Algorithm

- **Clustering**: Group records together that have similar field values. For example, customers with common attributes in a propensity to buy model.
- **Regression**: Learn to predict a numeric outcome field, based on all of the other fields present in each record. For example, predict the amount of coverage a potential customer might buy.
- **Classification**: Learn to predict a non-numeric outcome field. For example, learn the type of policy an existing customer has a potential of buying next.

Application of Machine Learning Algorithm

	Predictive Modeling	Computer Vision	Time Series
Classification	• Intrusion Detection	• Face Recognition	• Buy, Sell, or Hold? • Intrusion Detection
Regression	• Normal Operating Levels	• Age Determination	• Tomorrow's opening stock price
Clustering	• Product Recommendation	• Design Recommendation	• Anomaly Detection

Problems that Deep Learning is Well Suited to

Sepal length	Sepal width	Petal length	Petal width	Species
5.1	3.5	1.4	0.2	*I. setosa*
4.9	3.0	1.4	0.2	*I. setosa*
4.7	3.2	1.3	0.2	*I. setosa*
4.6	3.1	1.5	0.2	*I. setosa*
5.0	3.6	1.4	0.2	*I. setosa*
5.4	3.9	1.7	0.4	*I. setosa*
4.6	3.4	1.4	0.3	*I. setosa*
5.0	3.4	1.5	0.2	*I. setosa*
4.4	2.9	1.4	0.2	*I. setosa*
4.9	3.1	1.5	0.1	*I. setosa*
5.4	3.7	1.5	0.2	*I. setosa*

Keras: Classification

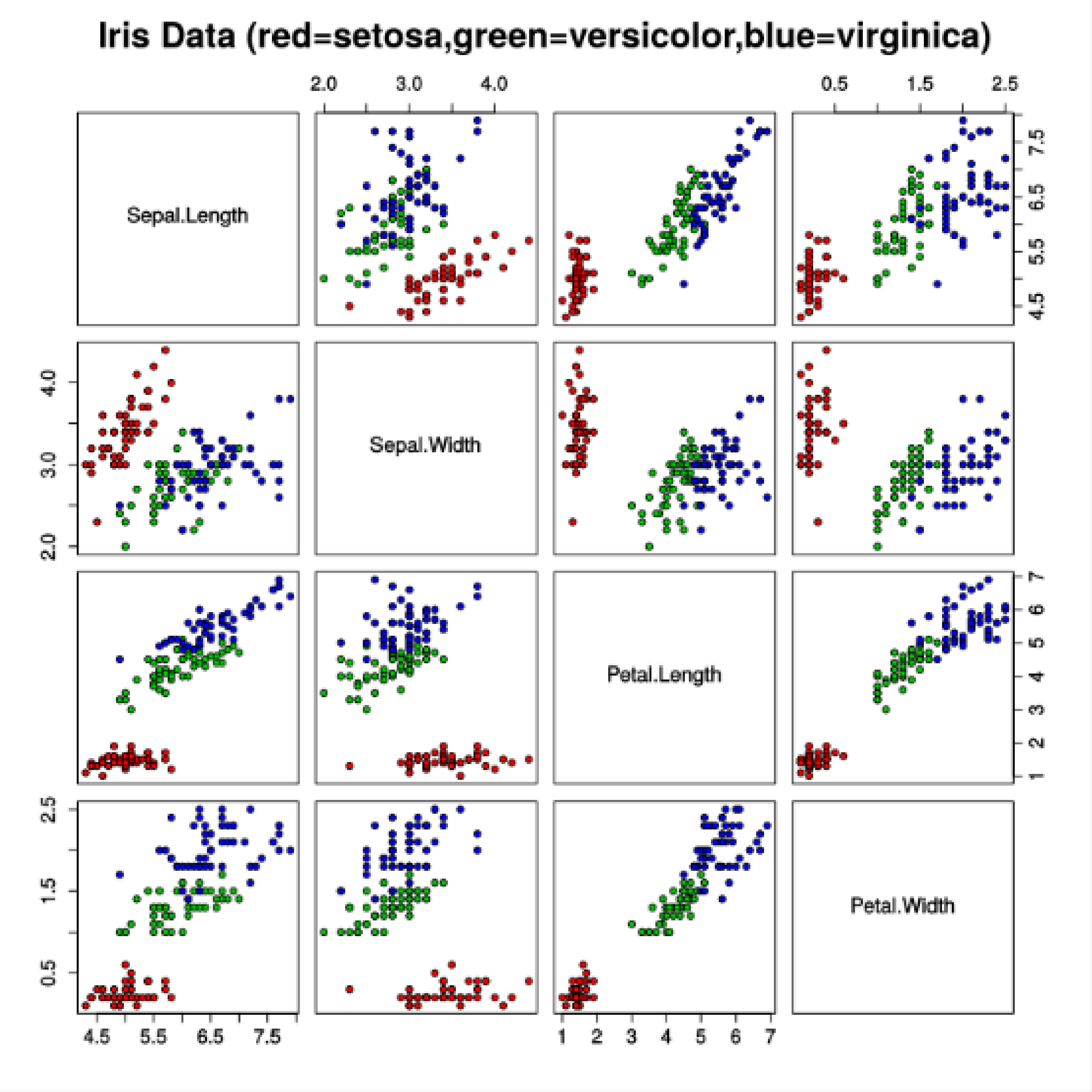
The Classic Iris Dataset

- Classic classification problem.
- 150 rows with 4 predictor columns.
- All 150 rows are labeled as a species of iris.
- Three different iris species.
- Created by Sir Ronald Fisher in 1936.
- Predictors:
  - Petal length
  - Petal width
  - Sepal length
  - Sepal width

The Classic Iris Dataset

sepal_length	sepal_width	petal_length	petal_width	class
5.1	3.5	1.4	0.2	Iris-setosa
7.0	3.2	4.7	1.4	Iris-versico
6.3	3.3	6.0	2.5	Iris-virginica
6.4	3.2	4.5	1.5	Iris-versicolor
5.8	2.7	5.1	1.9	Iris-virginica
4.9	3.0	1.4	0.2	Iris-setosa
…	…	…	…	…

Are the Iris Data Predictive?



Keras Classification: Load and Train/Test Split

```
path = "./data/"

filename = os.path.join(path,"iris.csv")
df = pd.read_csv(filename,na_values=['NA','?'])

species = encode_text_index(df,"species")
x,y = to_xy(df,"species")

# Split into train/test
x_train, x_test, y_train, y_test = train_test_split(
    x, y, test_size=0.25, random_state=42)
```

Keras Classification: Build NN and Fit

```
model = Sequential()
model.add(Dense(10, input_dim=x.shape[1],
kernel_initializer='normal', activation='relu'))
model.add(Dense(1, kernel_initializer='normal'))
model.add(Dense(y.shape[1],activation='softmax'))
model.compile(loss='categorical_crossentropy', optimizer='adam')
monitor = EarlyStopping(monitor='val_loss', min_delta=1e-3,
patience=5, verbose=1, mode='auto')

model.fit(x,y,validation_data=(x_test,y_test),callbacks=[monitor],ve
rbose=2,epochs=1000)
```

Keras Classification: Build NN and Fit

```
# Evaluate success using accuracy
# raw probabilities to chosen class (highest probability)
pred = model.predict(x_test)

pred = np.argmax(pred,axis=1)

y_compare = np.argmax(y_test,axis=1)
score = metrics.accuracy_score(y_compare, pred)
print("Accuracy score: {}".format(score))
```

Keras: Regression

Predict a Car’s Miles Per Gallon (MPG)

- Classic regression problem.
- Target: mpg
- Predictors:
  - cylinders
  - displacement
  - horsepower
  - weight
  - acceleration
  - year
  - origin
  - name

Predict a Car’s Miles Per Gallon (MPG)

mpg	cylinders	displacement	horsepower	weight	acceleration	year	origin	name
18	8	307	130	3504	12	70	1	chevrolet chevelle malibu
15	8	350	165	3693	11.5	70	1	buick skylark 320
18	8	318	150	3436	11	70	1	plymouth satellite
16	8	304	150	3433	12	70	1	amc rebel sst
17	8	302	140	3449	10.5	70	1	ford torino
15	8	429	198	4341	10	70	1	ford galaxie 500
14	8	454	220	4354	9	70	1	chevrolet impala

Regression Models - MPG

- Models such as GBM or Neural Network can predict the MPG to around +/-2.7 accuracy.
- Result of regression can be given in equation form (though not as accurate as a model):

$$mpg = 0.002\left(acc + \frac{1}{3}(-dsp - 1) - wgt\right) + 29.6$$

Keras Regression: Load and Train/Test Split

```
path = "./data/"

filename_read = os.path.join(path,"auto-mpg.csv")
df = pd.read_csv(filename_read,na_values=['NA','?'])

cars = df['name']
df.drop('name',1,inplace=True)
missing_median(df, 'horsepower')
x,y = to_xy(df,"mpg")
```

Keras Regression: Build and Fit

```
model = Sequential()
model.add(Dense(10, input_dim=x.shape[1],
kernel_initializer='normal', activation='relu'))
model.add(Dense(1, kernel_initializer='normal'))
model.compile(loss='mean_squared_error', optimizer='adam')
monitor = EarlyStopping(monitor='val_loss', min_delta=1e-3,
patience=5, verbose=1, mode='auto')
model.fit(x,y,validation_data=(x_test,y_test),callbacks=[monitor],ve
rbose=2,epochs=1000)
```

Keras Regression: Predict and Evaluate

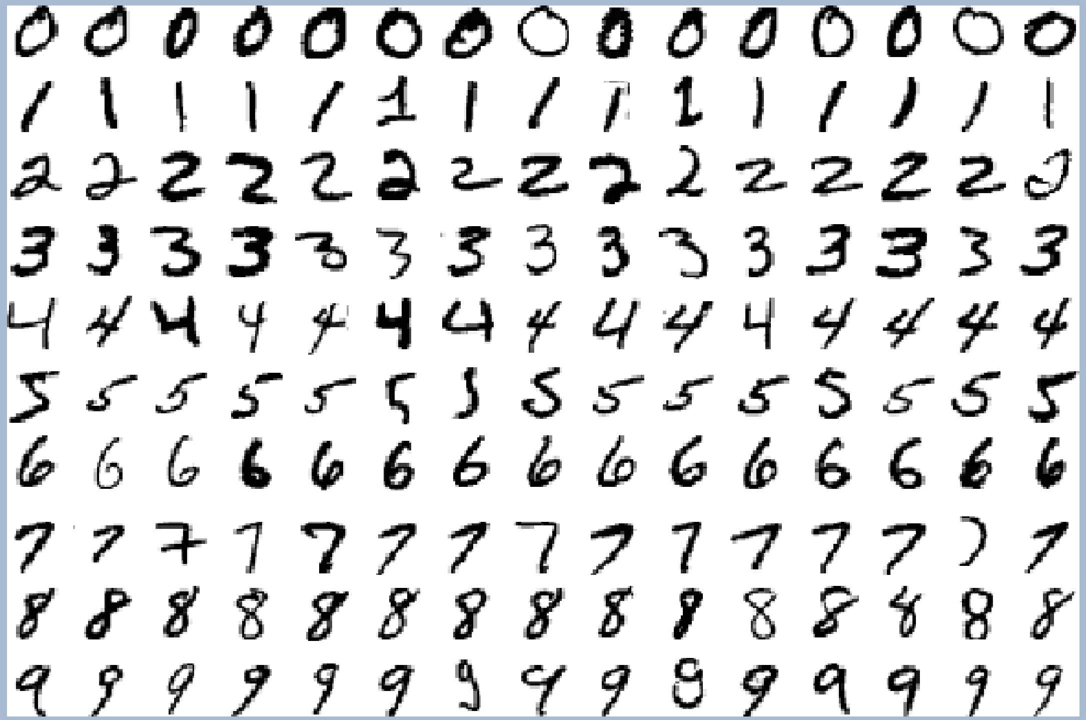
```
# Predict
pred = model.predict(x_test)

# Measure RMSE error.  RMSE is common for regression.
score = np.sqrt(metrics.mean_squared_error(pred,y_test))
print("Final score (RMSE): {}".format(score))
```

Preparing Data for Predictive Modeling is Hard

- The iris and MPG datasets are nicely formatted.
- Real world data is a complex mix of XML, JSON, textual formats, binary formats, and web service accessed content (the variety V in “Big Data”).
- More complex security data will be presented later in this talk.

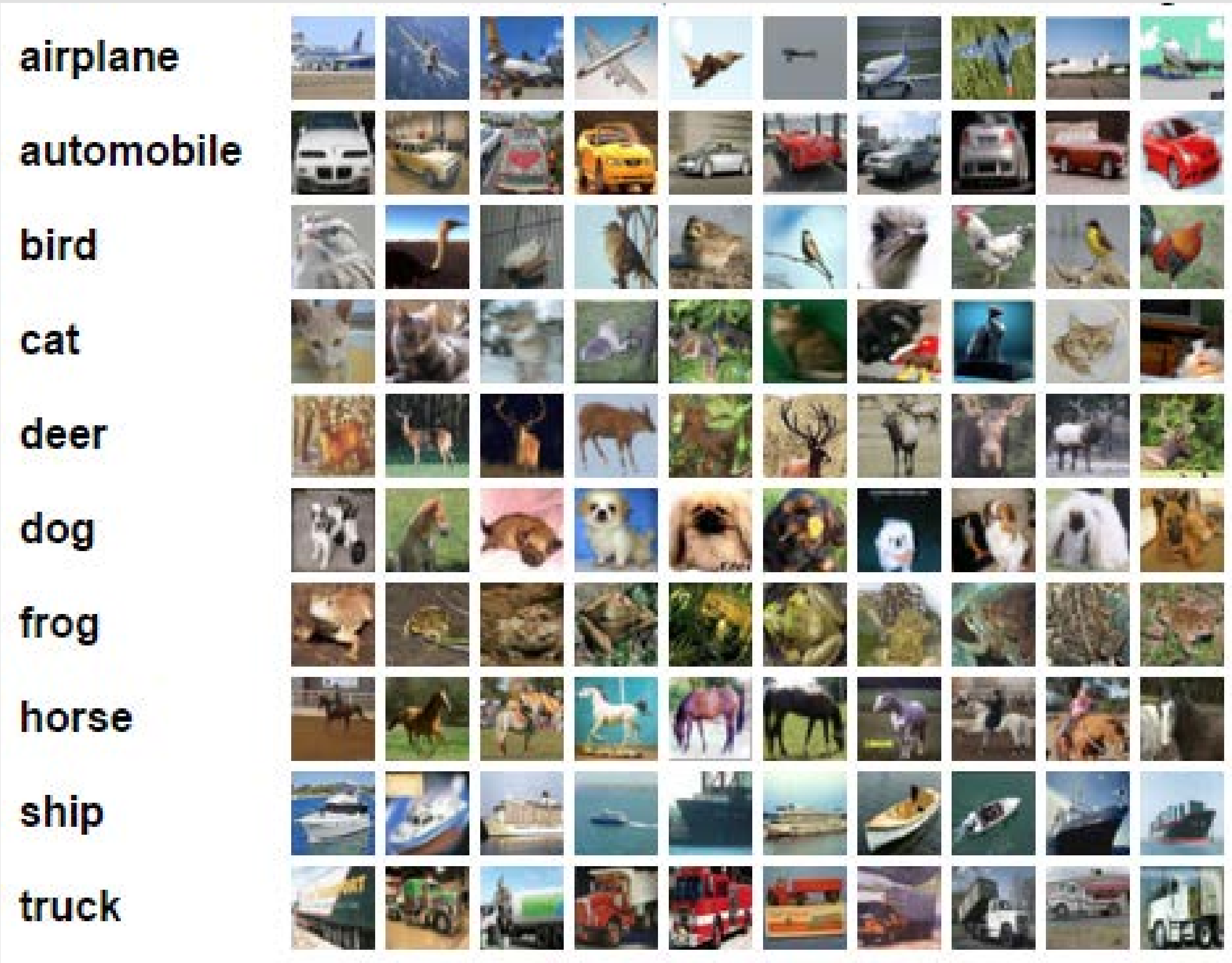
Keras: Computer Vision and CNN



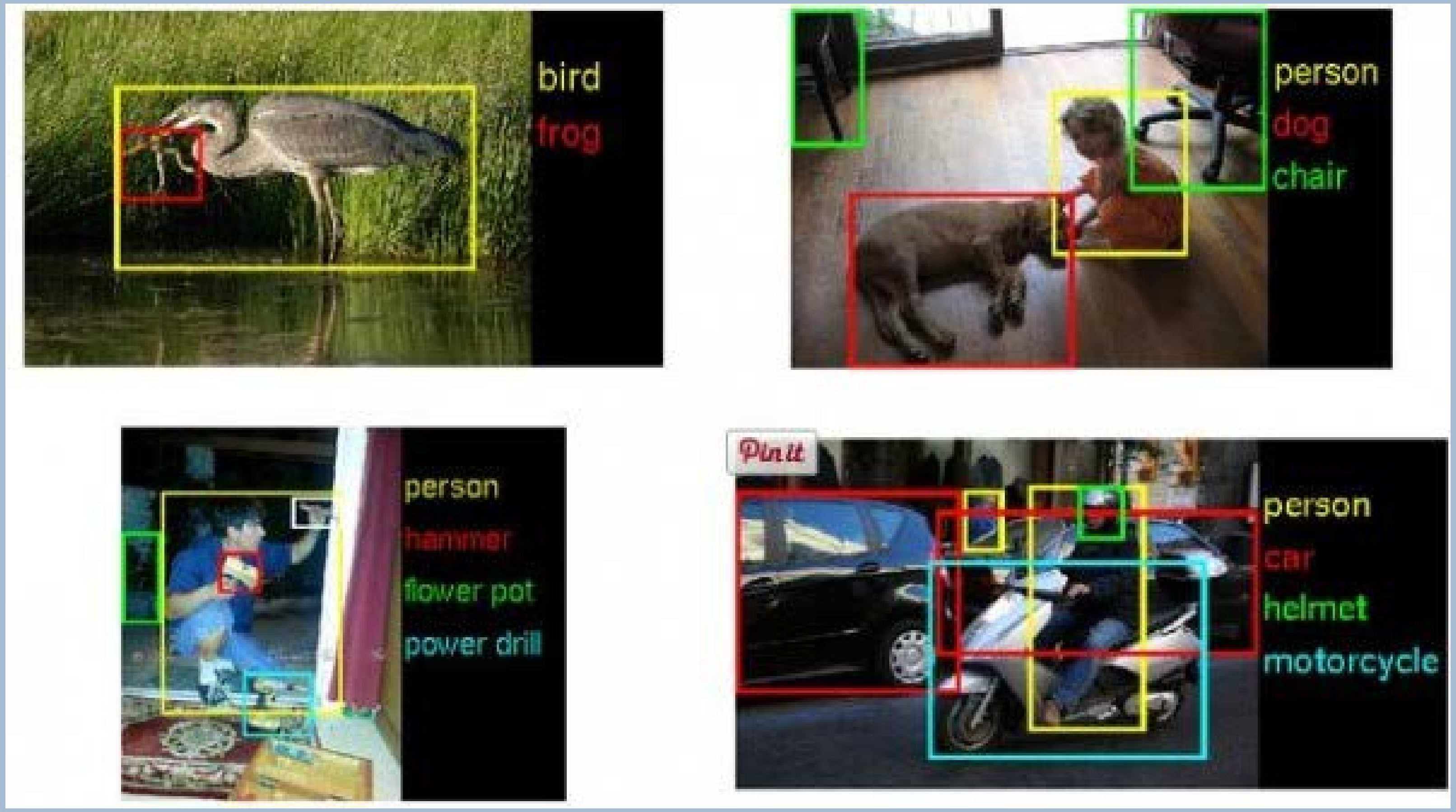
Predicting Images: What is Different?

- We will usually use classification, though regression is still an option.
- The input to the neural network is now 3D (height, width, color).
- Data are not transformed, no zscores or dummy variables.
- Processing time is usually much longer.
- We now have different layer types: dense layers (just like before), convolution layers and max pooling layers.
- Data will no longer arrive as CSV files. TensorFlow provides some utilities for going directly from image to the input of a neural network.

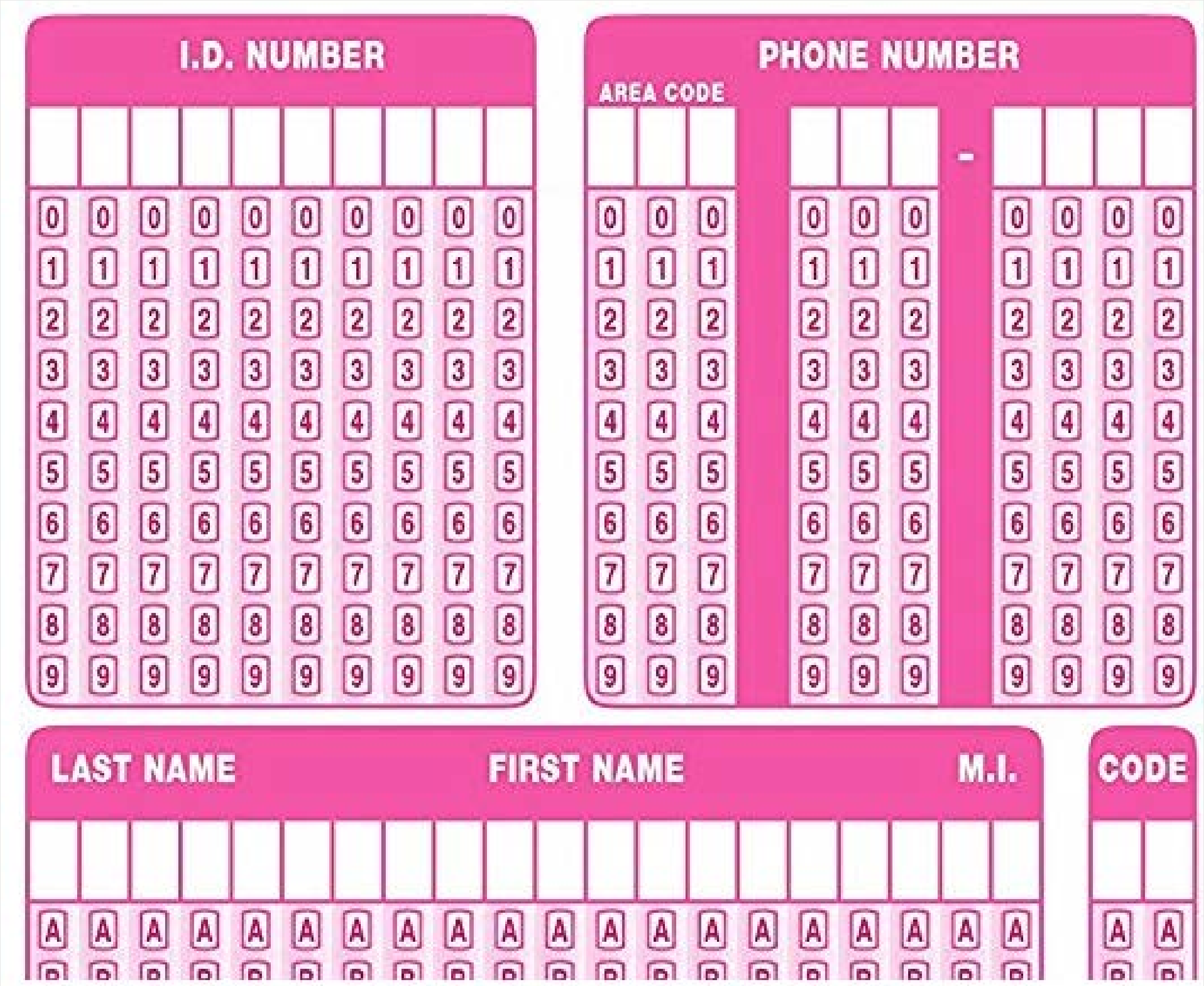
Sources of Image Data: CIFAR10 and CIFAR100



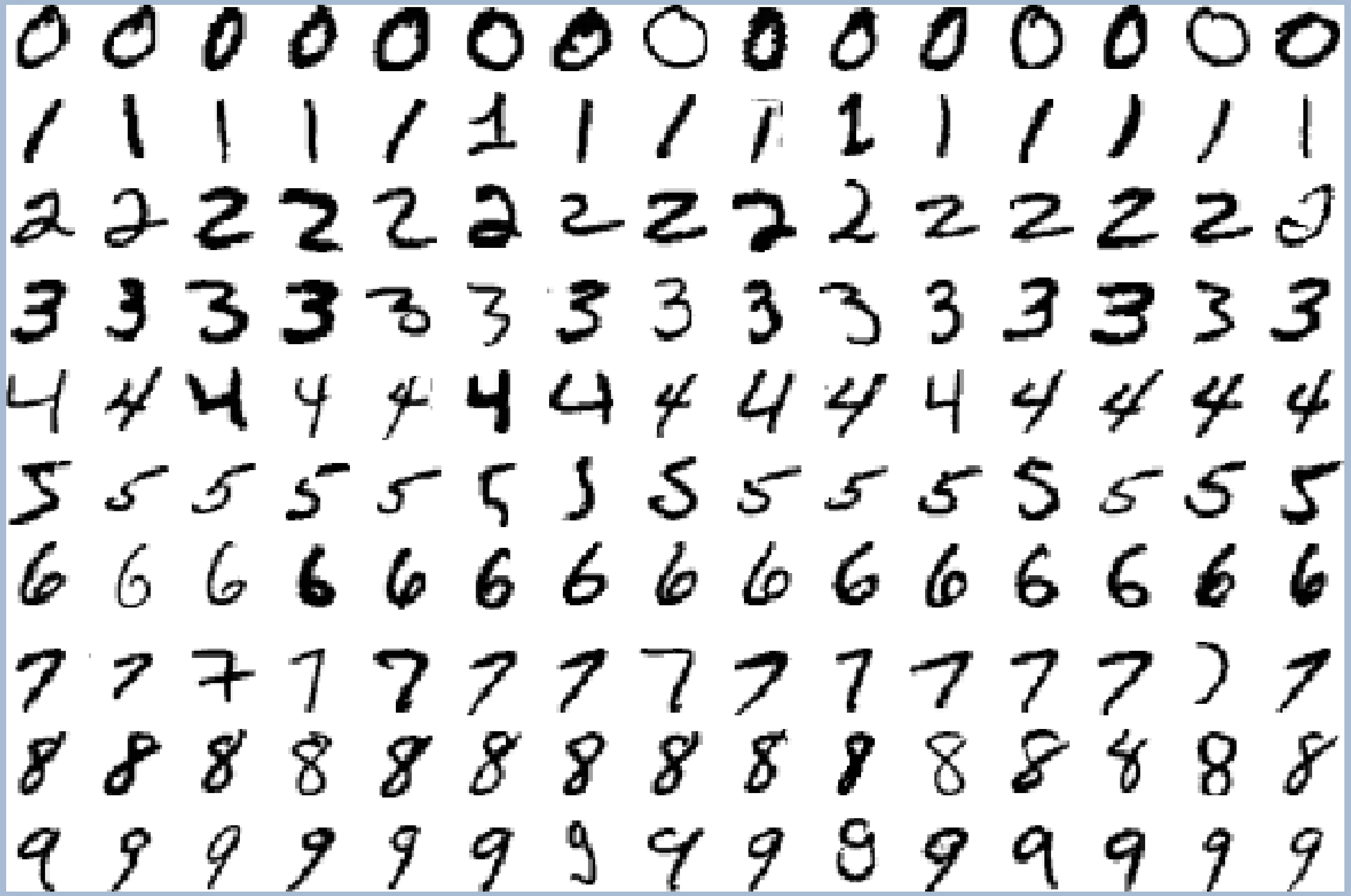
Sources of Image Data: ImageNet



Sources of Training Data: The MNIST Data Set

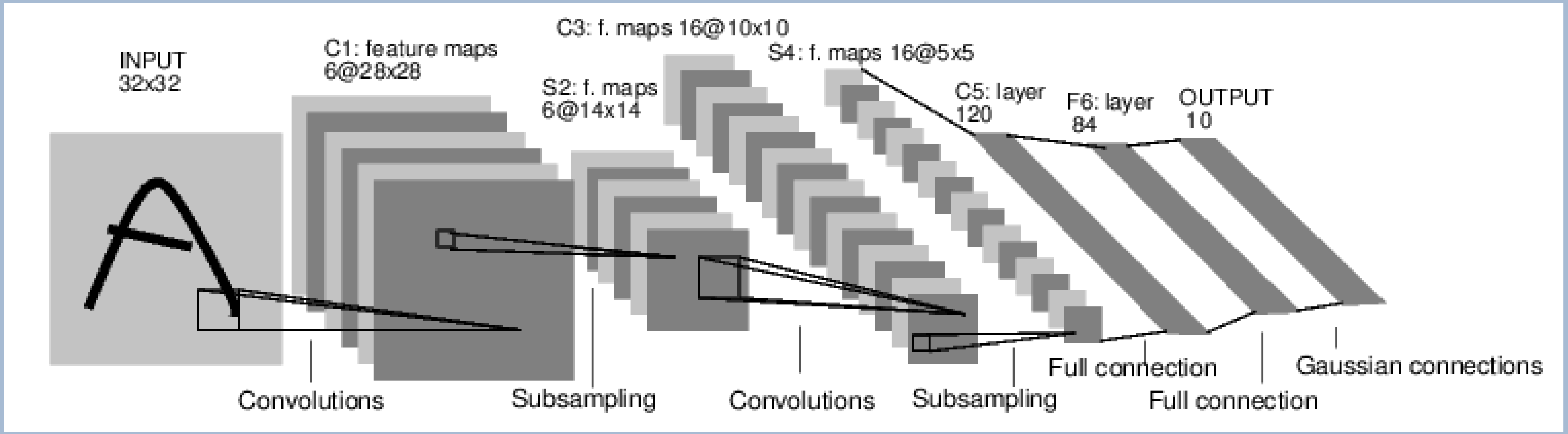


Recognizing Digits



Convolutional Neural Networks (CNN)

A LeNET-5/CNN Network (LeCun, 1998)



Dense Layers - Fully connected layers.
Convolution Layers - Used to scan across images.
Max Pooling Layers - Used to downsample images.
Dropout Layer - Used to add regularization.

Loading the Digits

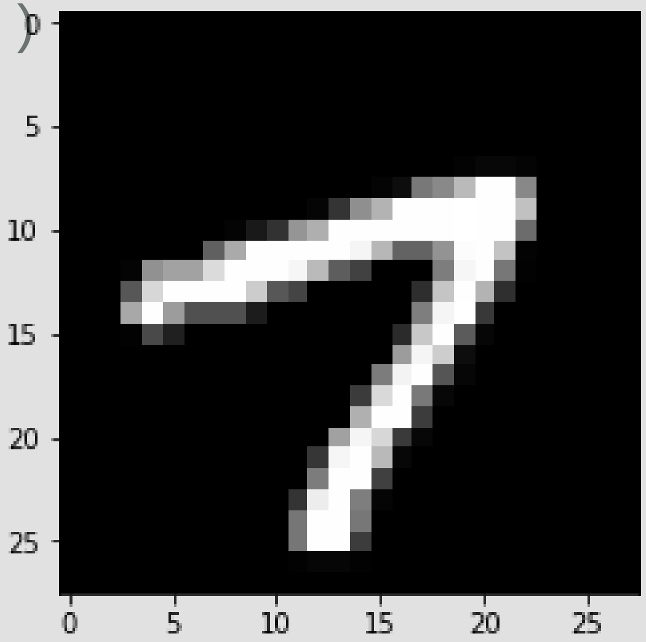
```
(x_train, y_train), (x_test, y_test) = mnist.load_data()
print("Shape of x_train: {}".format(x_train.shape))
print("Shape of y_train: {}".format(y_train.shape))
print()
print("Shape of x_test: {}".format(x_test.shape))
print("Shape of y_test: {}".format(y_test.shape))
```

```
➔Shape of x_train: (60000, 28, 28)
➔Shape of y_train: (60000,)

➔Shape of x_test: (10000, 28, 28)
➔Shape of y_test: (10000,)
```

Display a Digit

```
%matplotlib inline
import matplotlib.pyplot as plt
import numpy as np
digit = 101 # Change to choose new digit
a = x_train[digit]
plt.imshow(a, cmap='gray', interpolation='nearest')
print("Image (#{}): Which is digit '{}'".
format(digit,y_train[digit]))
```



Build the CNN Network

```
model = Sequential()
model.add(Conv2D(32, kernel_size=(3, 3),
                 activation='relu',
                 input_shape=input_shape))
model.add(Conv2D(64, (3, 3), activation='relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.25))
model.add(Flatten())
model.add(Dense(128, activation='relu'))
model.add(Dropout(0.5))
model.add(Dense(num_classes, activation='softmax'))
model.compile(loss=keras.losses.categorical_crossentropy,
              optimizer=keras.optimizers.Adadelta(),
              metrics=['accuracy'])
```

Fit and Evaluate

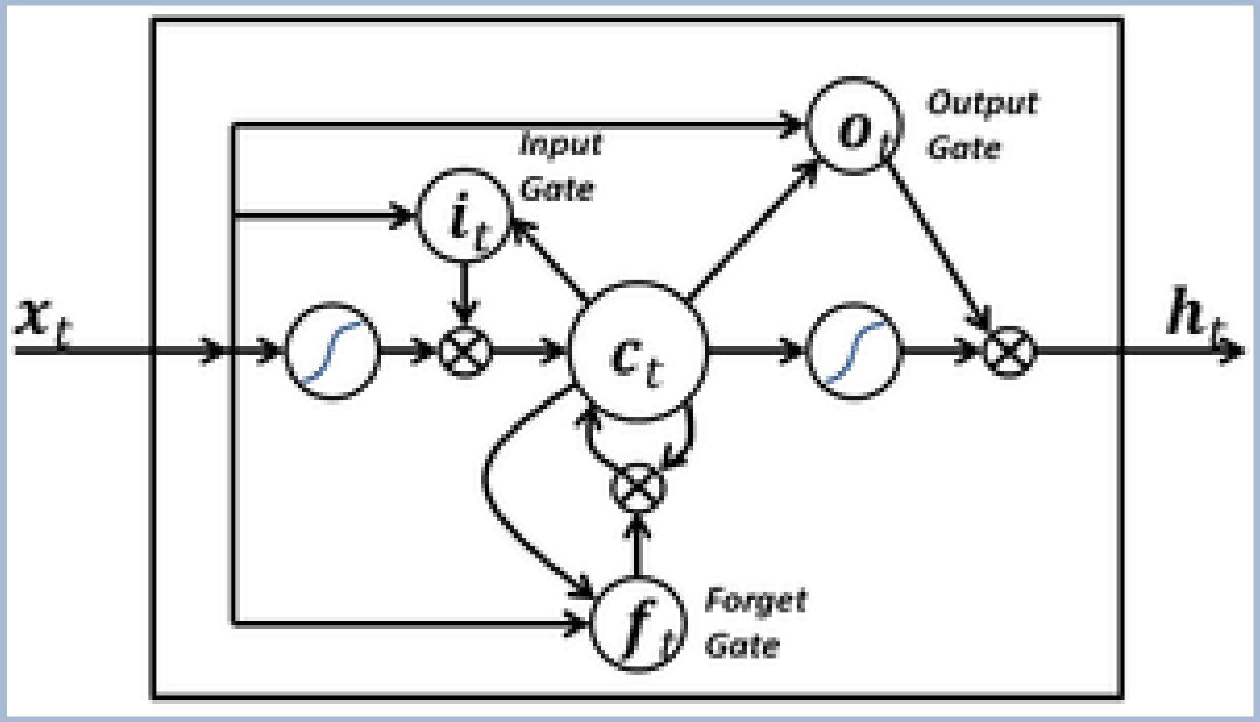
```
model.fit(x_train, y_train,
          batch_size=batch_size,
          epochs=epochs,
          verbose=2,
          validation_data=(x_test, y_test))
score = model.evaluate(x_test, y_test, verbose=0)
print('Test loss: {}'.format(score[0]))
print('Test accuracy: {}'.format(score[1]))
```

➔Test loss: 0.03047790436172363

➔Test accuracy: 0.9902

➔Elapsed time: 1:30:40.79 **(for CPU, approx 30 min GPU)**

Keras: Time Series and RNN

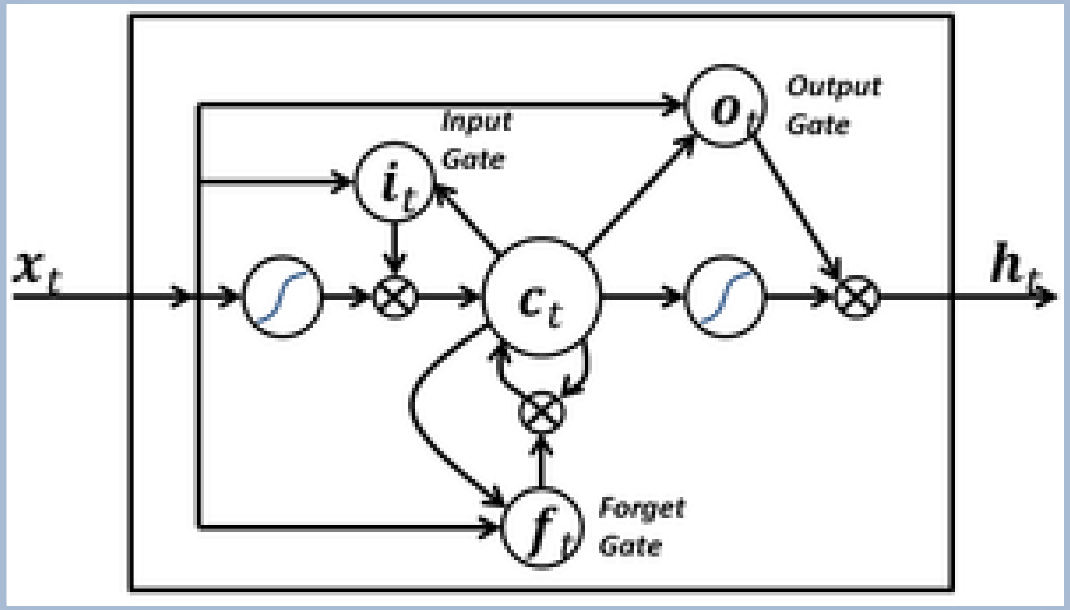


How is a RNN Different?

- RNN = Recurrent Neural Network.
- LSTM = Long Short Term Memory.
- Most models will always produce the same output for the same input.
- Previous input does not matter to a non-recurrent neural network.
- To convert today’s temperature from Fahrenheit to Celsius, the value of yesterdays temperature does not matter.
- To predict tomorrow’s closing price for a stock you need more than just today’s price.
- To determine if a packet is part of an attack, previous packets must be considered.

How do LSTM’s Work?

- The LSTM units in a deep neural network are short-term memory.
- This short term memory is governed by 3 gates:
  - Input Gate: When do we remember?
  - Output Gate: When do we act?
  - Forget Gate: When do we forget?



Sample Recurrent Data: Stock Price & Volume

```
x = [
    [[32,1383],[41,2928],[39,8823],[20,1252],[15,1532]],
    [[35,8272],[32,1383],[41,2928],[39,8823],[20,1252]],
    [[37,2738],[35,8272],[32,1383],[41,2928],[39,8823]],
    [[34,2845],[37,2738],[35,8272],[32,1383],[41,2928]],
    [[32,2345],[34,2845],[37,2738],[35,8272],[32,1383]],
]
y = [
    1,
    -1,
    0,
    -1,
    1
]
```

LSTM Example

```
max_features = 4 # 0,1,2,3 (total of 4)
x = [
    [[0],[1],[1],[0],[0],[0]],
    [[0],[0],[0],[2],[2],[0]],
    [[0],[0],[0],[0],[3],[3]],
    [[0],[2],[2],[0],[0],[0]],
    [[0],[0],[3],[3],[0],[0]],
    [[0],[0],[0],[0],[1],[1]]
]
x = np.array(x,dtype=np.float32)
y = np.array([1,2,3,2,3,1],dtype=np.int32)
```

Build a LSTM

```
model = Sequential()
model.add(LSTM(128, dropout=0.2, recurrent_dropout=0.2,
input_dim=1))
model.add(Dense(4, activation='sigmoid'))

model.compile(loss='binary_crossentropy',
              optimizer='adam',
              metrics=['accuracy'])
```

Test the LSTM

```
def runit(model, inp):
    inp = np.array(inp,dtype=np.float32)
    pred = model.predict(inp)
    return np.argmax(pred[0])

print( runit( model, [[[0],[0],[0],[0],[3],[3]]] ))

➔3

print( runit( model, [[[4],[4],[0],[0],[0],[0]]] ))

➔4
```

GPU’s and Deep Learning

Low Level GPU Frameworks

- CUDA

  CUDA is NVidia's low-level GPGPU framework.

- OpenCL

  An open framework supporting CPU’s, GPU’s and other devices. Managed by the Khronos Group.

Thank you!

- Jeff Heaton
- http://www.jeffheaton.com