Introduction to Deep Neural Networks

Finding lane lines by low-level image processing techniques

Introduction to TensorFlow

Traffic sign classification by TensorFlow

Introduction to Keras

Behavioral cloning

Accurate and efficient vehicle detection

Deep Learning for Self-Driving Cars

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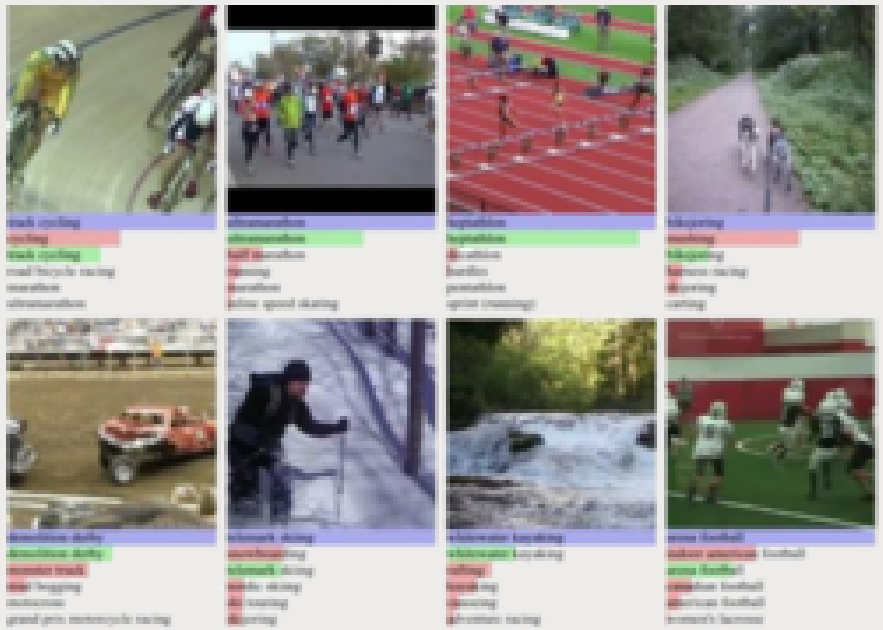
Applications of Deep Learning

- Image Classification: Labeling an image.



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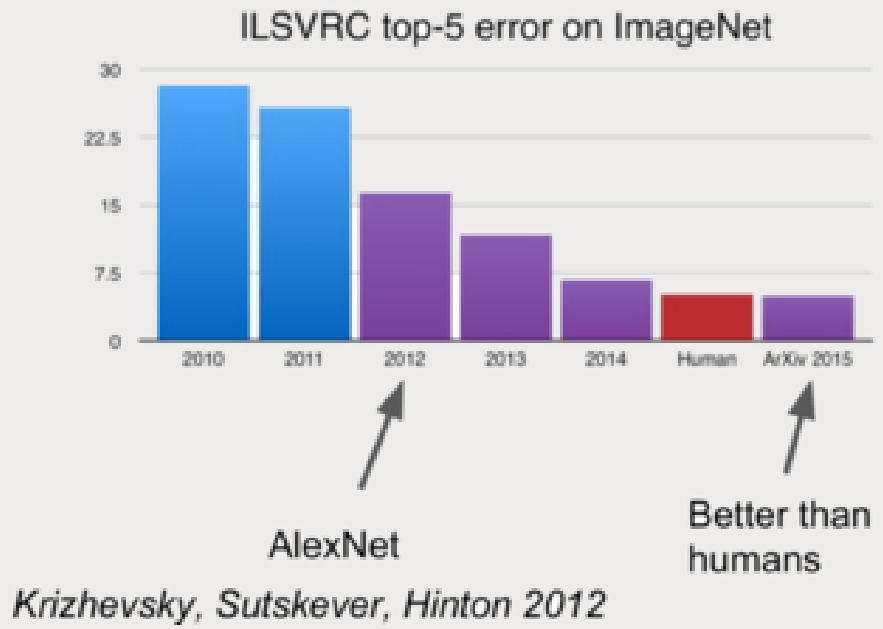

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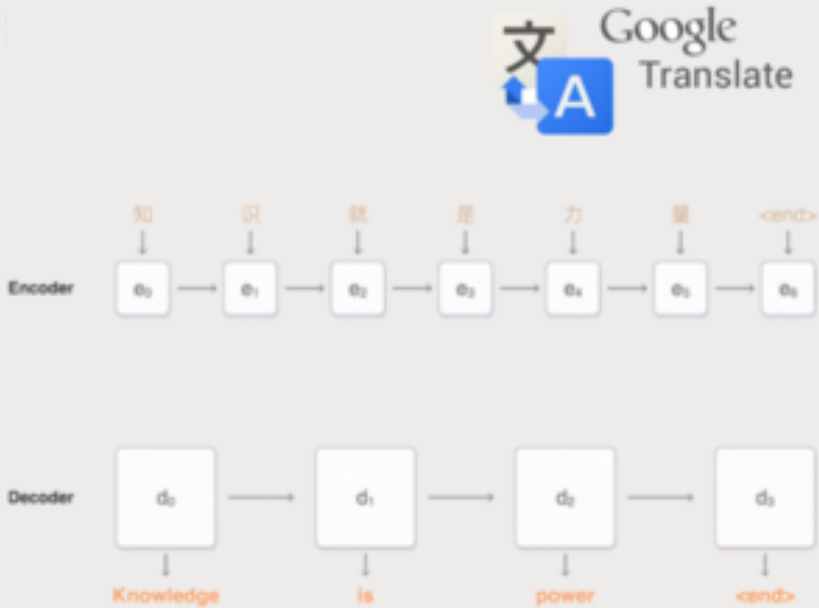
Applications of Deep Learning

- Machine Translation: Translating from one language to another.



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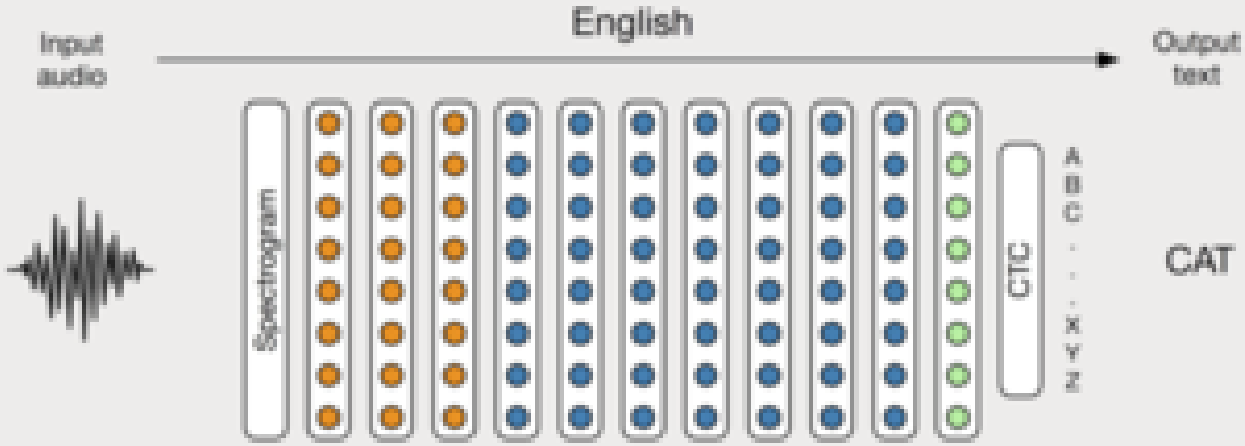
Applications of Deep Learning

- Speech Recognition: Conversion of speech to text.



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Applications of Deep Learning

- Game Playing: Deep Mind.

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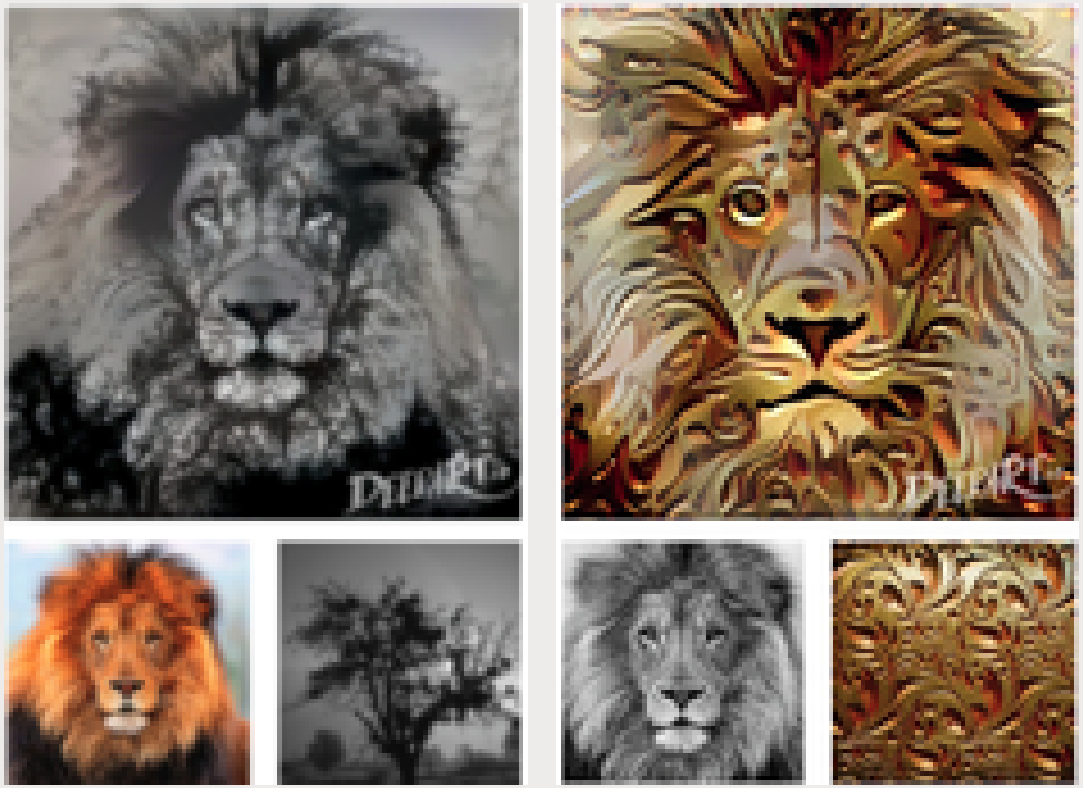
Applications of Deep Learning

Style transfer

- http://deepart.io/



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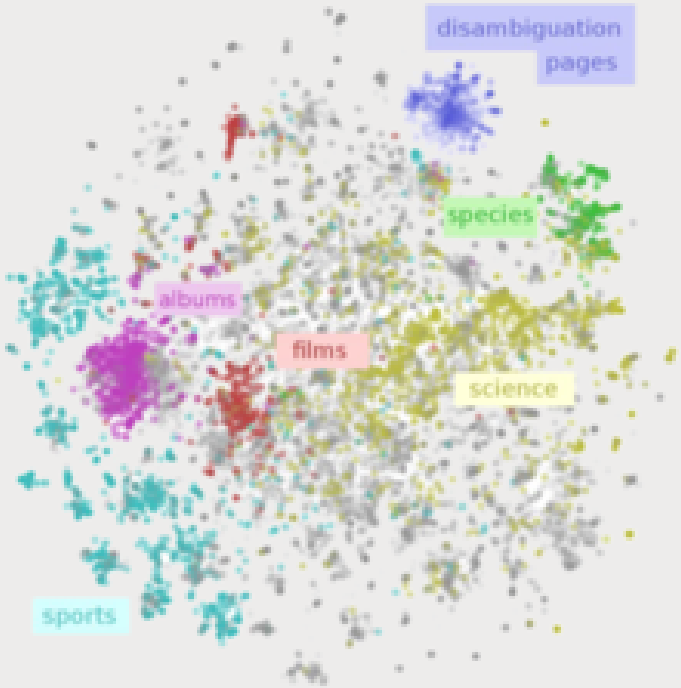
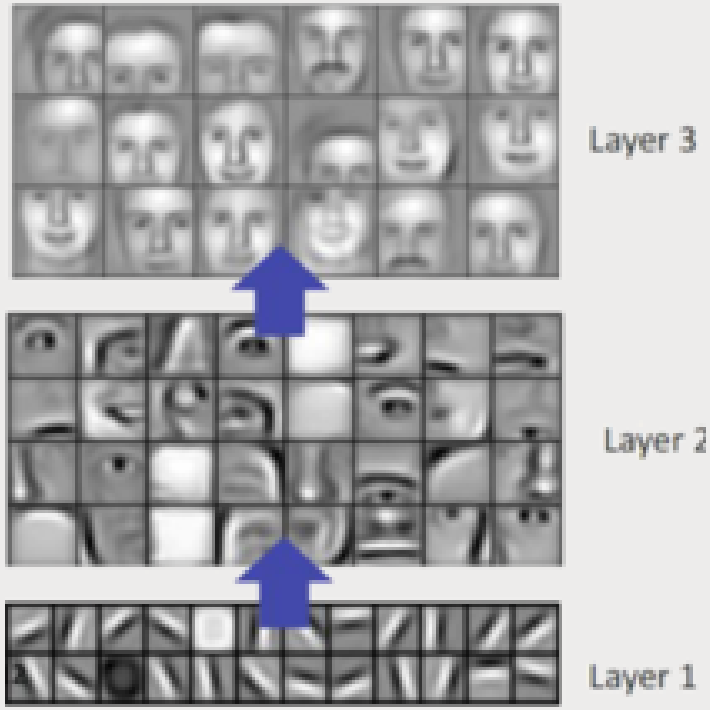
Why Deep Learning?

- Hand-Engineered Features vs. Leanred Features.





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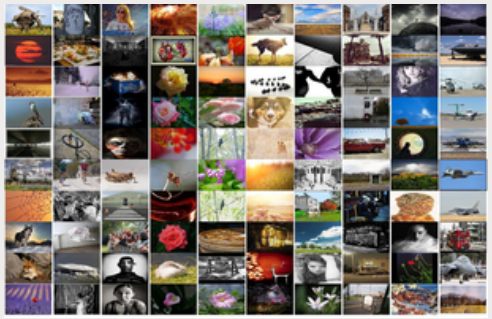
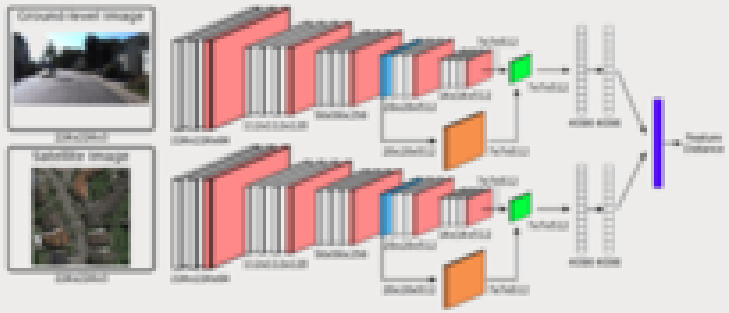
Why Now?

- Large Datasets.
- GPU Hardware Advances + Price Decreases
- Improved Techniques





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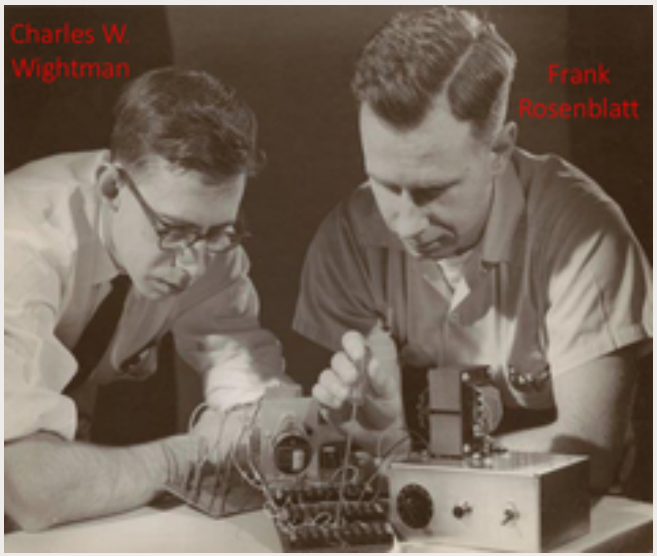
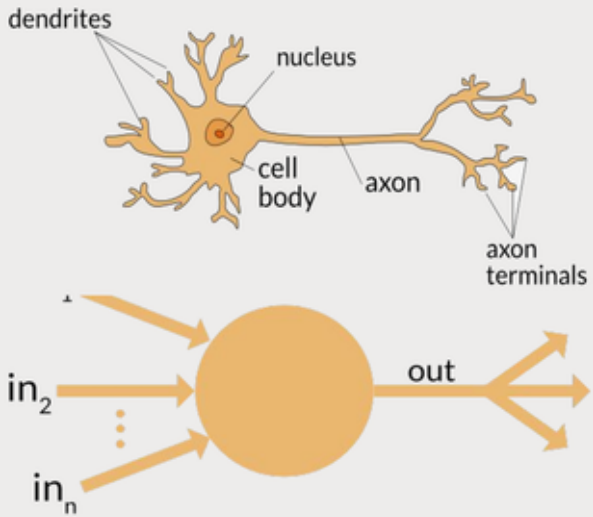
The Perceptron

- Invented in 1954 by Frank Rosenblatt.
- Inspired by neurobiology.





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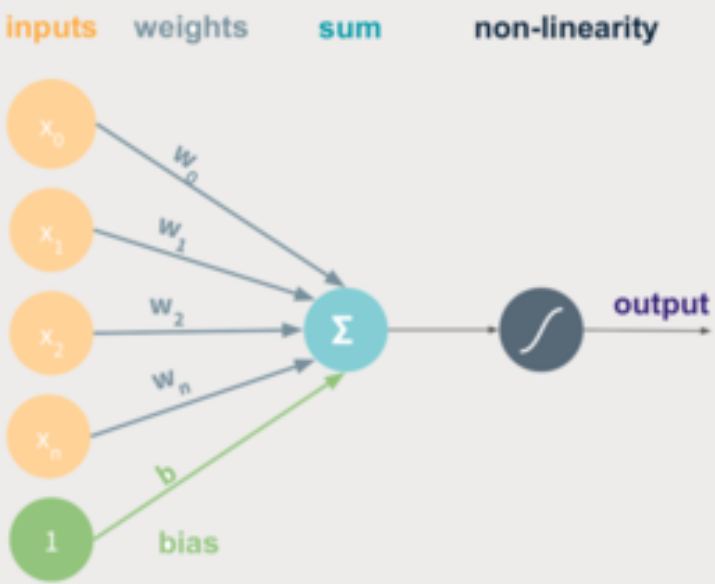
The Perceptron Forward Pass

- Inputs are multiplied by weights.
- A bias is added.
- The activation function is applied.



$$output = g(XW + b)$$

$$g(a) = \sigma(a) = \frac{1}{1 + e^{-a}}$$

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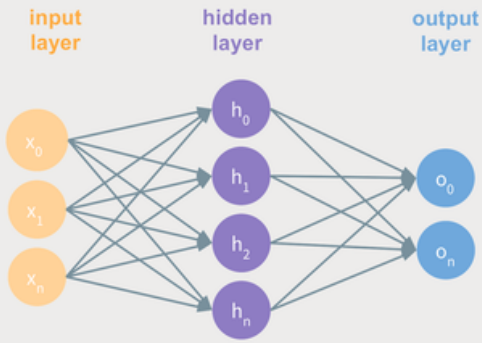
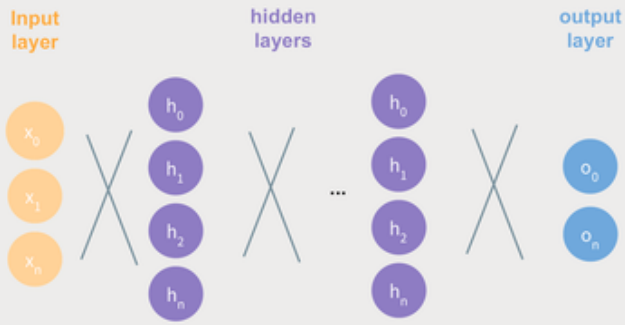
Multi-Layer & Deep Neural Networks

- A perceptron can have more than one output.
- A multi-layer perceptron has at least one hidden layer.
- Adding more hidden layers results in a deep neural network.





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Deep Convolutional Neural Networks (CNNs)

- CNNs have repetitive blocks of neurons that are applied across space (for images) or time (for audio signals etc).
- For images, these blocks of neurons can be interpreted as 2D convolutional kernels.
- For speech, they can be seen as the 1D convolutional kernels applied across time-windows.
- At training time, the weights for these repeated blocks are shared.
- The reason for choosing this special structure, is to exploit spatial or temporal invariance in recognition.

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Regular neural networks vs. CNNs

- Convolutional neural networks (CNNs) are a biologically-inspired variation of the multilayer perceptrons (MLPs).
- Neurons in CNNs share weights unlike in MLPs where each neuron has a separate weight vector.
- Convolutional neural networks employ a weight sharing strategy that leads to a significant reduction in the number of parameters that have to be learned.

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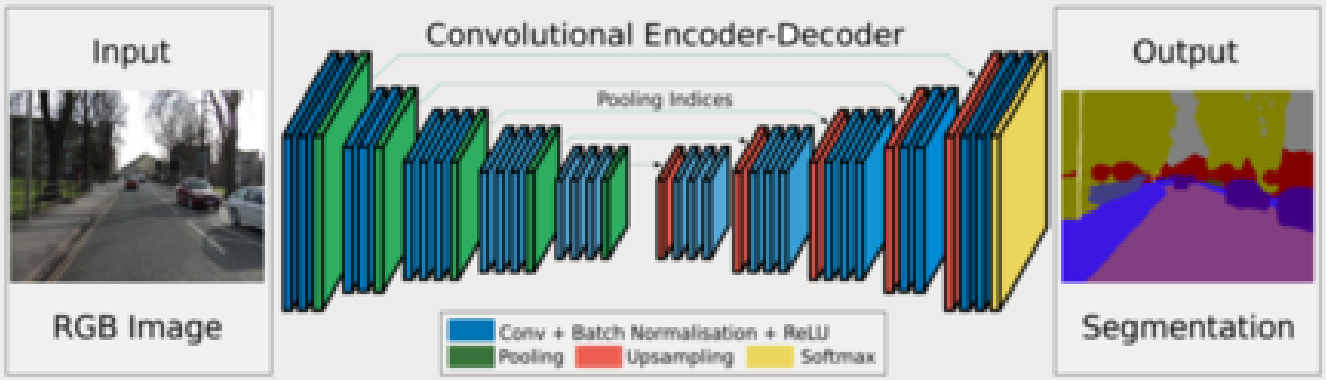
Regular neural networks vs. CNNs

- We can think of deep learning as algorithms for automatic feature engineering.
- CNNs help us to overcome the vanishing gradient challenge and facilitate the learning in neural networks with many layers.



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Deep Learning FrameWorks

- Caffe
- TensorFlow
- Microsoft CNTK
- Keras
- Theano
- Torch
- MXNet
- Deeplearning4j

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Caffe

- Interface: C++, Python
- One of the earliest GPU supported
- Initial focus on computer vision (and CNNs)

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TensorFlow

- Interface: Python, (C++)
- Automatic Differentiation
- Multi GPU, Cluster Support
- Currently most popular

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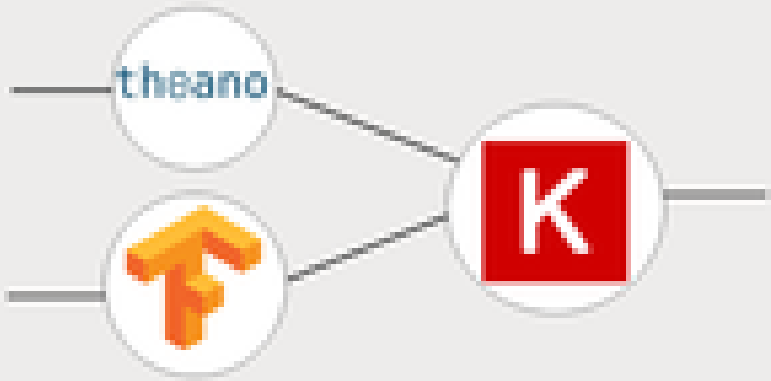
Keras

- On top of Tensorflow (and Theano)
- Interface: Python
- Goal: provide a simplified interface
- Also: TF Learn, TF Slim



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Theano

- Interface: Python (tight NumPy integration)
- One of the earlier frameworks with GPU support
- Encourages low-level tinkering

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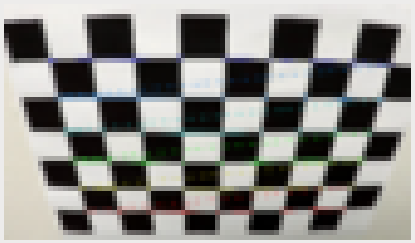
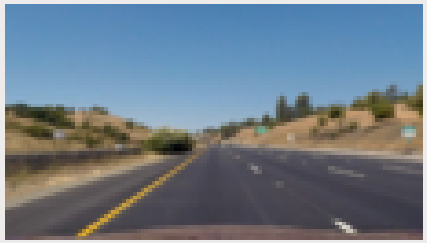
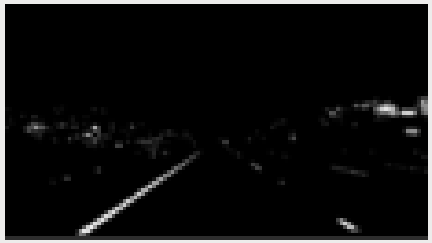
Finding Lane Lines

Algorithm overview

- Camera calibration
- Image thresholding
- Perspective transform
- Finding lines and drawing lane area

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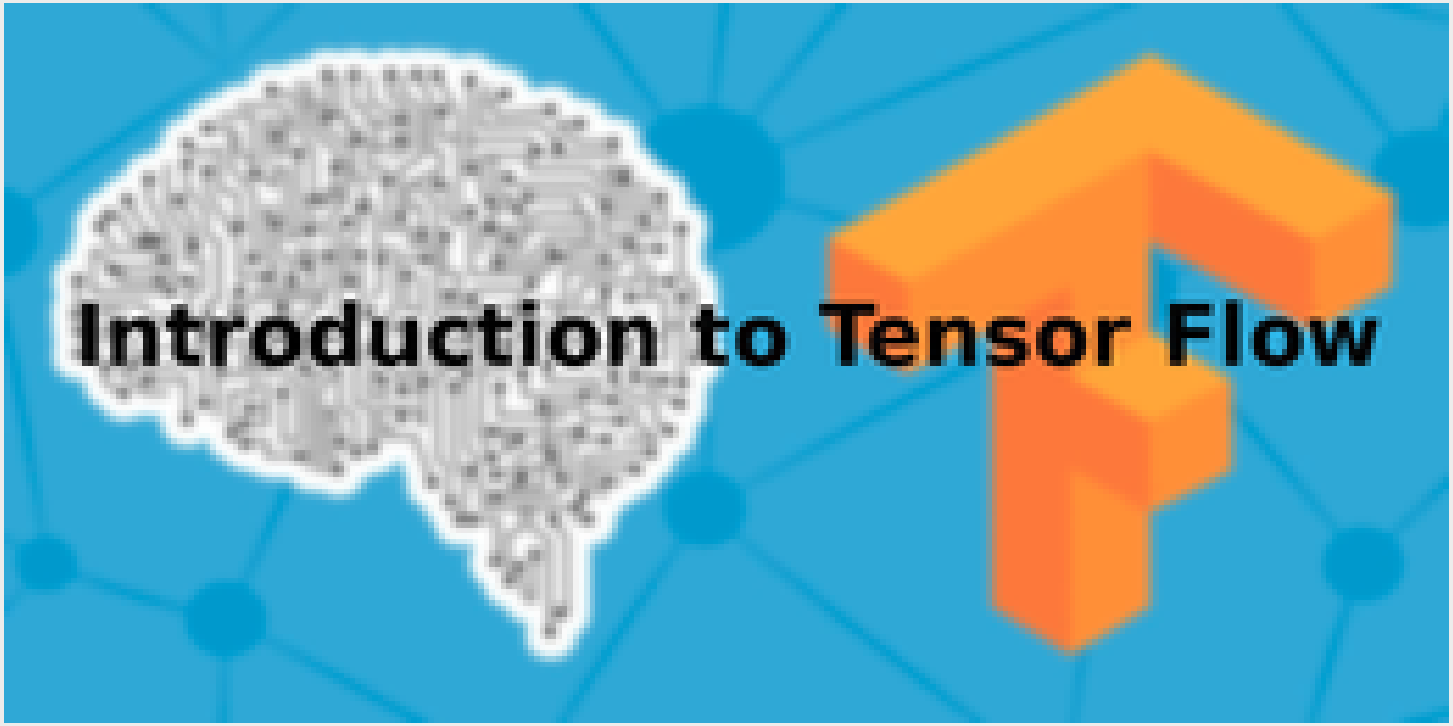

Introduction to Tensorflow

Tensorflow

- In TensorFlow, data is not stored as integers, floats, or strings.
- These values are encapsulated in an object called a tensor.
- There are some tensor types.
  - Variable
  - Constant
  - Placeholder
  - SparseTensor
- A TensorFlow session is an environment for running a graph on CPU/GPU.

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Hello world example

```
import tensorflow as tf

# Create TensorFlow object
hello_constant = tf.constant('Hello World!')

with tf.Session() as sess:
# Run the tf.constant operation
    output = sess.run(hello_constant)
    print(output)
```

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Tensor types

```
# This is a 0-dimensional string tensor
hello_constant = tf.constant('Hello World!')
# A is a 0-dimensional int32 tensor
A = tf.constant(1234)
# B is a 1-dimensional int32 tensor
B = tf.constant([123,456,789])
# C is a 2-dimensional int32 tensor
C = tf.constant([[123,456,789],[222,333,444]])
```

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Feeding Data into Tensorflow

```
x = tf.placeholder(tf.string)

with tf.Session() as sess:
    output = sess.run(x,
    feed_dict={x: 'Hello World'})
```

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Feeding Data into Tensorflow

```
x = tf.placeholder(tf.string)
y = tf.placeholder(tf.int32)
z = tf.placeholder(tf.float32)

with tf.Session() as sess:
    output = sess.run(x,
    feed_dict={x: 'Test String',
    y: 123, z: 45.67})
```

Introduction to Tensorflow

Tensorflow Math

- Addition
- Subtraction
- Multiplication

```
x = tf.add(5, 2) # 7
x = tf.subtract(10, 4) # 6
y = tf.multiply(2, 5) # 10
```

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Converting Types

```
# Converting float to int32
tf.cast(tf.constant(2.0), tf.int32)
```

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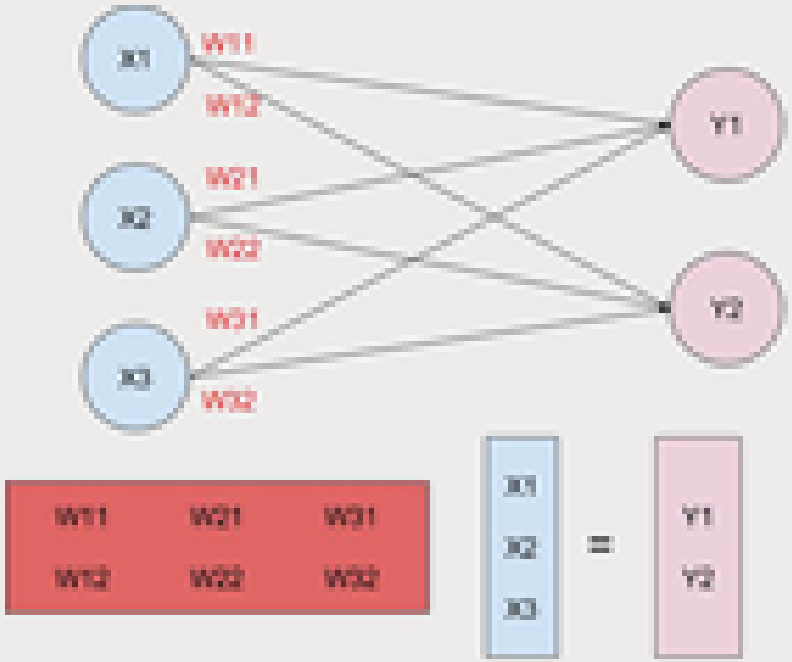
TensorFlow Linear Function

- Lets derive the function $y = Wx + b$.
- tf.placeholder() and tf.constant() can not be modified.
- The tf.Variable class creates a tensor with an initial value that can be modified.



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Weights and Bias in TensorFlow

- tf.global_variables_initializer() function is used to initialize the state of all the variable tensors.
- tf.truncated_normal() function is used to generate random numbers from a normal distribution.
- The tf.zeros() function returns a tensor with all zeros which is used for biases.

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Weights

```
n_features = 120
n_labels = 5
weights = tf.Variable(tf.truncated_normal(
(n_features, n_labels)))
```

Introduction to Tensorflow

Biases

```
n_labels = 5
bias = tf.Variable(tf.zeros(n_labels))
```

Introduction to Tensorflow

Mnist Example

- get_weights function returns a tf.variable of weights.
- get_biases function returns a tf.variable of biases.
- The linear function $XW + b$ is implemented.
- All weights are initialized.

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Softmax

- The Softmax function is used to convert logits to probabilities.

```
def run():
    output = None
    logit_data = [20.0, 10.0, 1.0]
    logits = tf.placeholder(tf.float32)
    softmax = tf.nn.softmax(logits)

    with tf.Session() as sess:
        output = sess.run(softmax,
        feed_dict={logits: logit_data})
    return output
```

Introduction to Tensorflow

Cross Entropy - One hot encoding

```
softmax_data = [0.7, 0.2, 0.1]
one_hot_data = [1.0, 0.0, 0.0]
softmax = tf.placeholder(tf.float32)
one_hot = tf.placeholder(tf.float32)
cross_entropy = -tf.reduce_sum(tf.multiply
(one_hot, tf.log(softmax)))

with tf.Session() as sess:
    print(sess.run(cross_entropy, feed_dict=
    {softmax: softmax_data, one_hot:
    one_hot_data}))
```

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Tensorflow Mini-batching

- Mini-batching is a technique for training on subsets of the dataset instead of all the data at one time.
- This-provides the ability to train a model, even if a computer lacks the memory to store the entire dataset.
- Mini-batching is computationally inefficient, since you can't calculate the loss simultaneously across all samples.

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Epochs

- An epoch is a single forward and backward pass of the whole dataset.
- This is used to increase the accuracy of the model without requiring more data.

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Training

- The dataset is divided into training, validation and test sets.
- Learning rate shall be selected appropriately.

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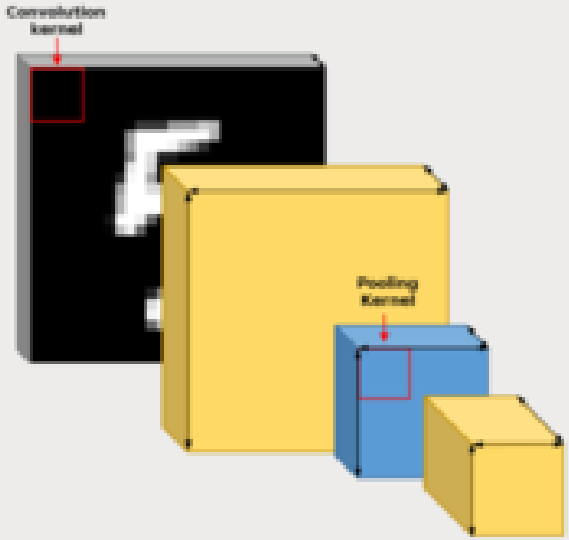
Traffic sign classification

Convolution & Pooling

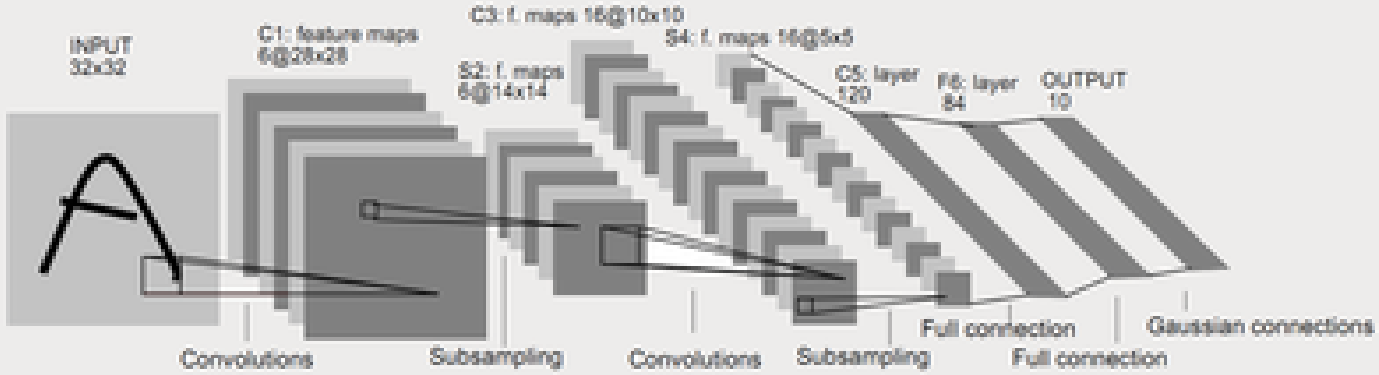
- The first layer in a CNN is always a Convolutional Layer.
- A kernel is convolved with the input layer, producing results for the next layer.
- Subsampling is applied in the form of Max Pool in the LeNet architecture.



Traffic sign classification

LeNet Architecture

- A 32×32 image.
- Convolutional layer.
- Subsampling layer.
- Sequence of convolution layers
- Sequence of pooling layers.
- 3 fully connected layers.



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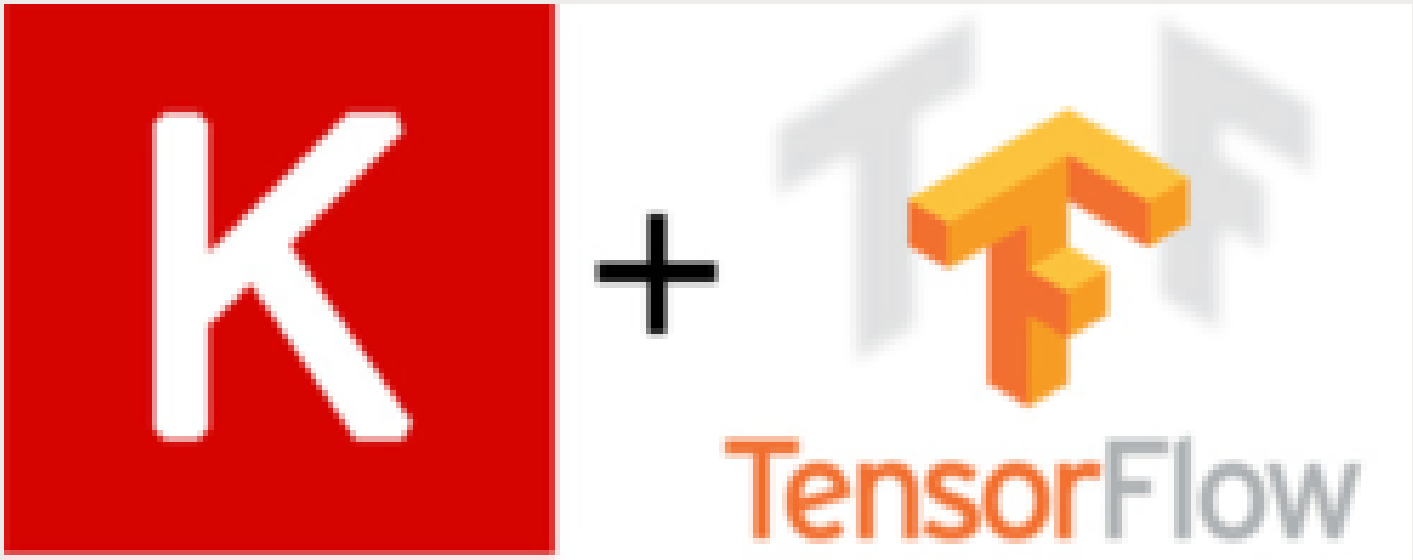

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Keras Models

- There are two types of models in Keras:
  - Sequential: The Sequential model is a linear stack of layers.
  - Model (functional API): In the functional API, given some input tensor(s) and output tensor(s), you can instantiate a Model.

Introduction to Keras

Keras Layers

- Keras will automatically infer the shape of all layers after the rst layer. This means you only have to set the input dimensions for the rst layer.
- A Keras layer is just like a neural network layer.
- There are many types of layers in Keras:
  - Core layers.
  - Convolutional layers.
  - Pooling layers
  - Locally connected layers
  - Activation layers.
  - ...

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Car Driving Simulator

- A car draving simulator is used for beharioral cloning.
- 3 cameras are installed on the car, grabbing left, right and center images.
- In the training mode, drive the car like in a video game.
- Collect the training data using the record button.
- Collected images are stored in a local directory.
- The autonomous mode is used after the training of the network.
- The trained network can drive the car inside the road.

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Strategies for Collecting Data

- The car should stay in the center of the road as much as possible.
- If the car veers o to the side, it should recover back to center.
- Driving counter-clockwise can help the model generalize.
- flipping the images is a quick way to augment the data.
- Collecting data from the second track can also help generalize the model.
- We want to avoid over tting or under tting when training the model.
- Knowing when to stop collecting more data.

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Training a Network

- Run the simulator and select a driving track.
- Press the record button and start driving.
- left, right and center images are stored in a local directory.
- The steering angle for each image is stored in a CSV file.
- Build in a network in Keras.
- Use grabbed images for training of the network.
- Use 80% of the images for training and 20% for validation.
- The training and validation can be 70% and 30%.

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Training a Network ...

- In case of poor predictions on both training and validation sets (high mean square on both):
  - Increase the number of epochs.
  - Add more convolutions to the network.
- In case of good predictions of the training set but poor predictions on the validations set (overfitting):
  - Use drop out or pooling layers.
  - Use fewer convolution or fewer connected layers.
  - Collect more data or furthere augment the data set.

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Training a Network ...

- Training using un-normalized data results in poor car driving.
- In order to normalize the images, the pixel values are divided by 255.
- In order to mean center the data, each element is subtracted by 0.5.
- Flipping images improves the quality of training.

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Training a Network ...

some general guidelines for data collection:

- Two or three laps of center lane driving.
- One lap of recovery driving from the sides.
- One lap focusing on driving smoothly around curves.

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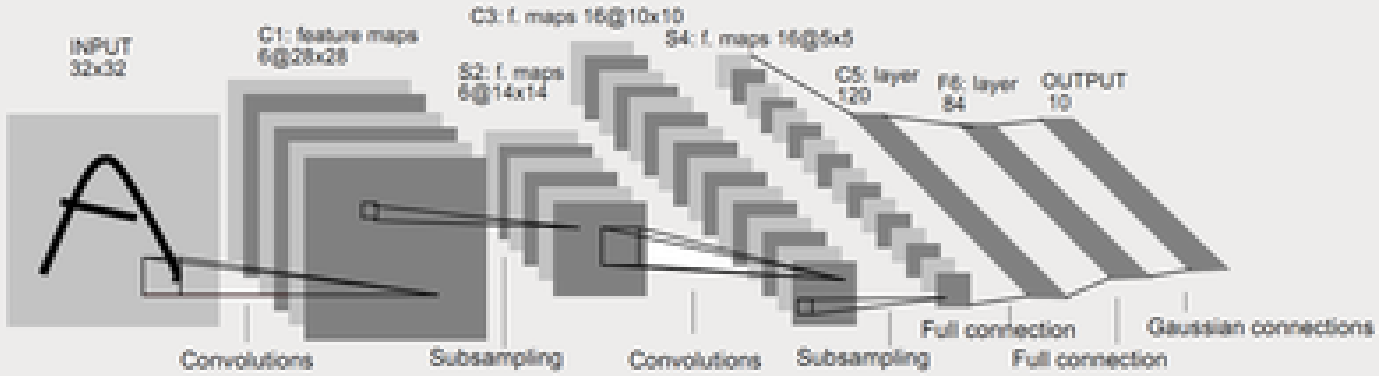
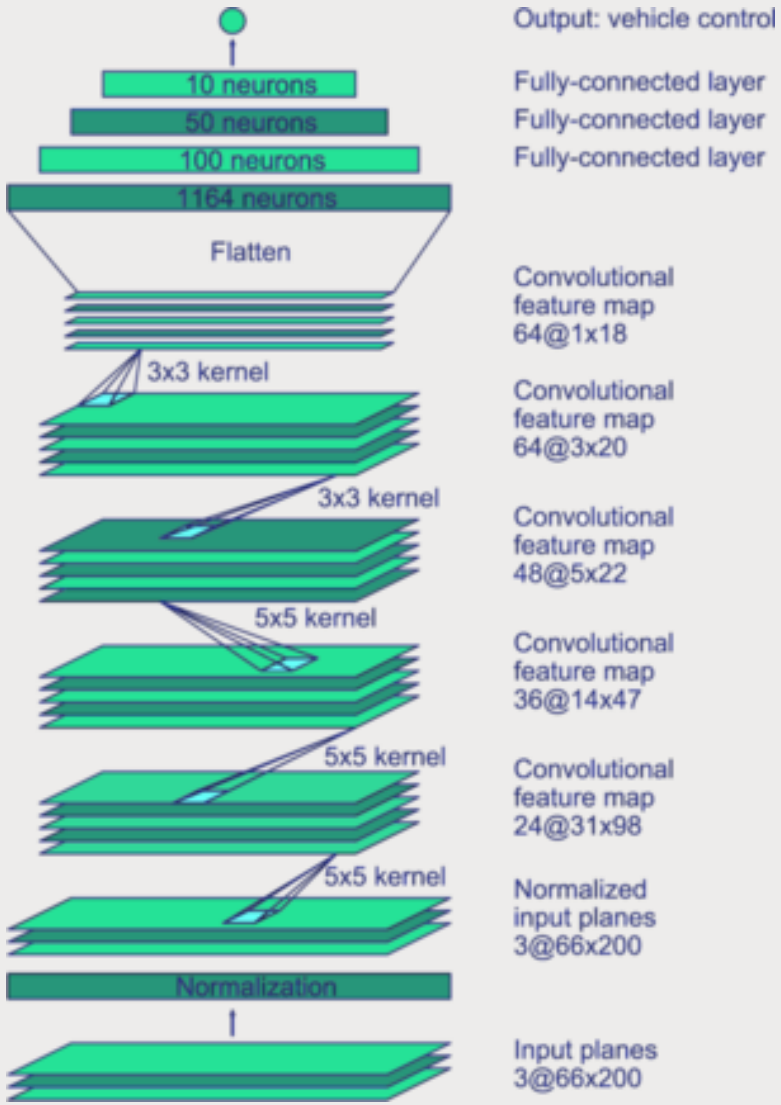
Training by LeNet architecture



Training by Nvidia architecture



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Defining Nvidia network in Keras

```
from keras.models import Sequential
from keras.layers import Flatten, Dense,
Lambda, Convolution2D, Cropping2D, Dropout
from keras.layers.pooling import MaxPooling2D

model = Sequential()
model.add(Cropping2D(cropping=((50,20),
(0,0)), input_shape=(160,320,3)))
model.add(Lambda(lambda x: x/255. - 0.5))
model.add(Convolution2D(24,5,5,subsample=
(2,2),activation='relu'))
...
model.add(Flatten())
```

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Defining Nvidia network in Keras

```
model.compile(loss='mse',optimizer='adam')

model.fit_generator( train_generator,
    steps_per_epoch = train_steps,
    epochs=5 )
```

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