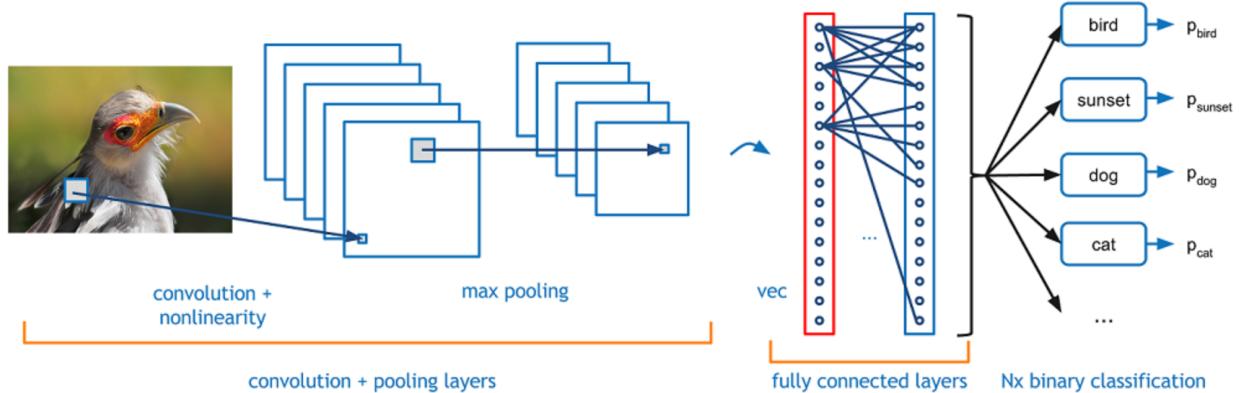


# Introduction to Image Classification

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## Overview

In this tutorial, we will build an image classifier model using convolutional neural network to distinguish dogs and cats in an image. Image classifier is a computer vision model that takes the pixels in the input image and performs a series of matrix multiplication and summation. The result from the series of matrix operation is a list of confidence values for the classes of interest. Image classification is helpful tool to categorize, index, and allow for search and retrieval in many different industry applications.

In this tutorial, we will go over the following:

- Components of CNN
- Build Simple CNN
- What is CNN learning ?

## Pre-requisites

Download the Dogs vs Cats dataset (<https://www.kaggle.com/c/dogs-vs-cats>). The tutorial uses Python 2.7 and requires the following Python libraries:

- Tensorflow
- Keras
- numpy
- cv2
- pylab
- skimage
- scipy
- tqdm
- imutils

If you are missing any of the packages and you are using Linux or Mac OS, use "**pip install [package\_name]**" in your terminal to perform the package installations. **pip** (<https://pip.pypa.io/en/stable/installing/>) is already installed if you are using Python 2 >=2.7.9 or Python 3 >=3.4 binaries.

## Imports

```
In [1]: from keras.models import Sequential
from keras.layers import Convolution2D, MaxPooling2D
from keras.layers import Activation, Dropout, Flatten, Dense

from imutils import paths
from shutil import copyfile
import os, cv2, random
import numpy as np
import pylab as pl
from tqdm import *
random.seed(13)

import matplotlib.cm as cm
import matplotlib.pyplot as plt
%matplotlib inline

/Users/donovanlo/anaconda2/lib/python2.7/site-packages/h5py/_init_.py:3
4: FutureWarning: Conversion of the second argument of issubdtype from `f
loat` to `np.floating` is deprecated. In future, it will be treated as `n
p.float64 == np.dtype(float).type`.
    from ._conv import register_converters as _register_converters
Using TensorFlow backend.
```

## Data

We will be using the Dogs vs Cats Dataset. This dataset stemmed from the Asirra challenge. Asirra (Animal Species Image Recognition for Restricting Access) is a HIP (Human Interactive Proof) that help protects web services from bot attempts. HIP are difficult for computers but easy for humans. For this tutorial, the dataset can be downloaded at Kaggle's [Dogs vs Cats dataset](https://www.kaggle.com/c/dogs-vs-cats) (<https://www.kaggle.com/c/dogs-vs-cats>).

**KEY:** After the dataset has been downloaded, define the absolute path to the **Dogs\_vs\_Cats**' train and test folder.

We will split the data into a train and validation folder. The validation set will not be used for training. The purpose of validation set is to verify the accuracy of the model on unseen data.

```
In [2]: # Path to the Dogs vs Cats train folder
path_to_data = "/Users/donovanlo/Documents/_Tools/data/Dogs_vs_Cats/train"
# Path to the Dogs vs Cats test folder
test_dir = '/Users/donovanlo/Documents/_Tools/data/Dogs_vs_Cats/test1'
```

```
In [3]: # Dimension of input images
img_width, img_height = 150, 150
nb_train_samples = 16000      #2000
nb_validation_samples = 6400 #800
# Path to the data
train_data_dir = 'data/train'
validation_data_dir = 'data/validation'

imagePaths = list(paths.list_images(path_to_data))

dogs_list = []
cats_list = []

for (i, imagePath) in tqdm(enumerate(imagePaths)):
    label = imagePath.split(os.path.sep)[-1].split(".")[0]
    file_name = imagePath.split(os.path.sep)[-1]
    if label == "dog":
        dogs_list.append( imagePath )
    else:
        cats_list.append( imagePath )

random.shuffle(dogs_list)
random.shuffle(cats_list)

def copy_nb_files(src_list,num,dst_folder):
    os.makedirs(dst_folder)
    for i in range(num):
        src = src_list[i]
        dst = os.path.join(dst_folder,src_list[i].split(os.path.sep)[-1])
        copyfile(src,dst)

nb_tr_samples = nb_train_samples/2
nb_va_samples = nb_validation_samples/2
# Create train/dogs and train/cats folder
if not os.path.exists(train_data_dir):
    copy_nb_files(dogs_list[:nb_tr_samples], nb_tr_samples, train_data_dir+
    copy_nb_files(cats_list[:nb_tr_samples], nb_tr_samples, train_data_dir+

# Create validation/dogs and validation/cats folder
if not os.path.exists(validation_data_dir):
    copy_nb_files(dogs_list[nb_tr_samples+1:nb_tr_samples+nb_va_samples+1],
    copy_nb_files(cats_list[nb_tr_samples+1:nb_tr_samples+nb_va_samples+1],
```

25000it [00:00, 359422.63it/s]

We will use the [ImageDataGenerator](https://keras.io/preprocessing/image/) (<https://keras.io/preprocessing/image/>) function to create data generators. The generator will load the feed batches of input images to the cnn model.

```
In [4]: from keras.preprocessing.image import ImageDataGenerator

batch_size = 32

# Rescale the pixel values from [0,255] to [0,1]
datagen = ImageDataGenerator(rescale=1./255)

train_generator = datagen.flow_from_directory(
    train_data_dir,
    target_size=(img_width,img_height),
    batch_size=batch_size,
    class_mode='binary')

validation_generator = datagen.flow_from_directory(
    validation_data_dir,
    target_size=(img_width,img_height),
    batch_size=batch_size,
    class_mode='binary')
```

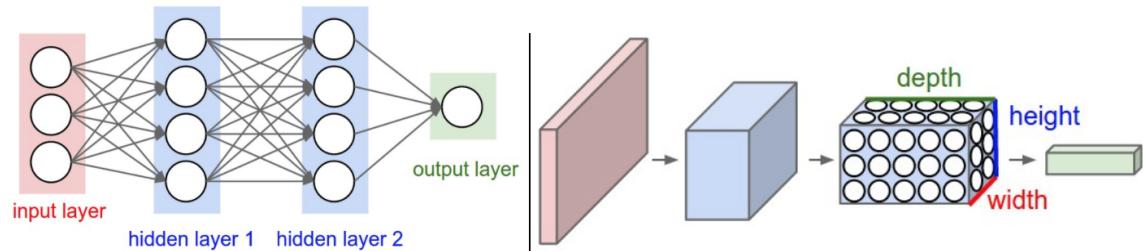
Found 16000 images belonging to 2 classes.

Found 6400 images belonging to 2 classes.

## Model

### Convolutional Neural Network (CNN)

Convolutional Neural Network is a special case of linear Neural Network. Unlike the linear Neural Network, the neurons in the layer are 3 dimensional which captures width, height, and depth. In the case of linear Neural Network, the input is one hot vector of  $1 \times N$  array. The input images that we will be feeding to the CNN has the dimension of  $150 \times 150 \times 3$  (width,height,depth of rgb channel).



### Layers of CNN

CNN consists of five main components:

- **Input\_Image:** The input image is seen by the computer as a column (width,height,depth) of numbers.



What We See

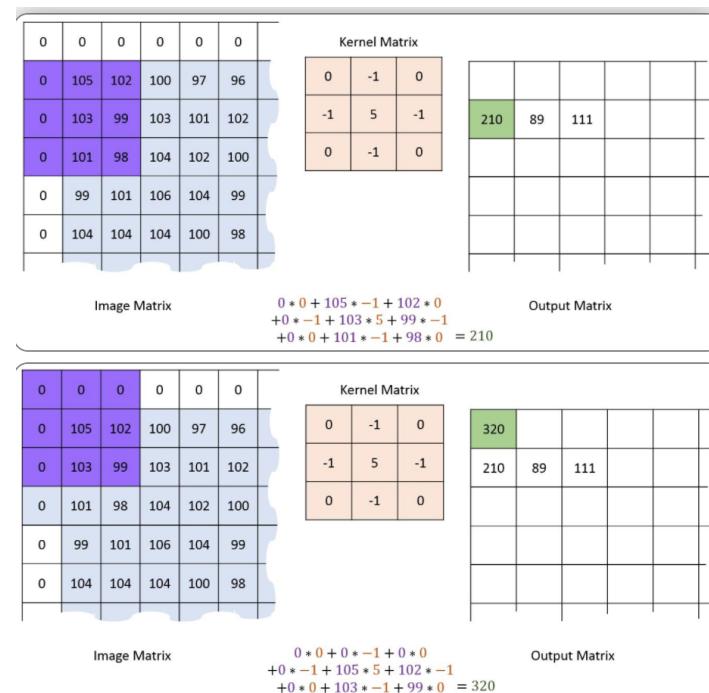
```

08 02 22 97 38 15 00 40 00 75 04 05 07 78 52 12 50 59 77 91 08
49 49 99 40 17 81 18 57 60 97 17 40 98 43 69 48 04 56 62 00
81 49 31 73 55 79 14 29 93 71 40 67 53 88 30 03 49 13 36 65
52 70 95 23 04 60 11 42 69 24 68 56 01 32 54 71 37 02 36 91
22 31 14 71 51 67 63 89 41 92 36 54 22 40 40 28 66 33 13 80
24 47 32 60 99 03 45 02 44 75 33 53 78 36 04 20 35 17 12 50
32 98 81 28 64 23 67 10 26 38 40 67 59 54 70 66 18 38 64 70
47 26 20 68 02 62 12 20 95 63 94 39 63 08 40 91 66 49 91 21
05 55 58 05 66 73 99 26 97 27 78 78 96 83 14 88 34 89 63 72
21 36 23 09 75 07 76 44 20 45 35 14 00 61 33 97 34 31 33 95
78 17 53 28 22 75 31 47 18 94 03 80 04 62 16 14 09 53 56 92
16 39 05 42 96 35 31 47 58 58 88 24 00 17 54 24 36 29 85 57
86 56 00 48 35 71 89 07 05 44 44 37 44 60 21 58 51 54 17 58
19 80 81 88 05 94 47 69 26 73 92 12 86 52 17 77 04 89 55 40
04 52 08 83 97 35 99 16 07 57 32 16 26 26 79 33 27 98 66
88 36 68 87 57 62 20 72 03 46 33 67 46 55 12 32 63 93 53 69
04 42 14 73 39 25 39 11 24 94 72 18 08 46 29 32 40 62 76 36
20 69 36 41 72 30 23 88 34 62 99 69 82 67 59 85 74 04 36 16
20 73 35 29 78 31 90 01 74 31 49 71 48 86 81 16 23 57 05 54
01 70 54 71 83 51 54 69 16 92 33 48 61 43 52 01 89 19 67 48

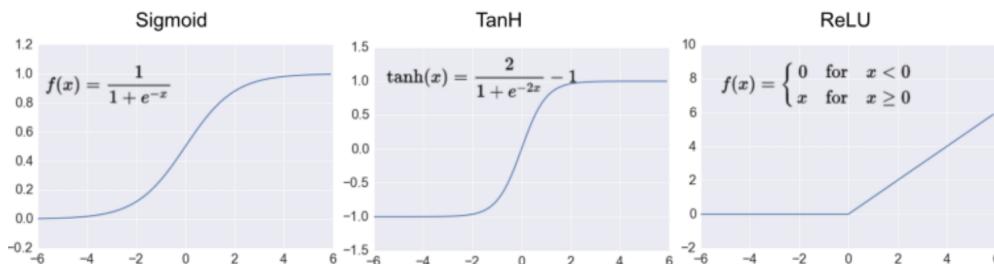
```

What Computers See

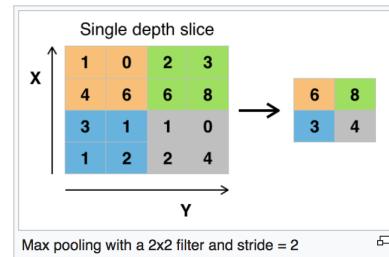
- **CONV layer :** Convolution layer consists of a set of learned filters. In inference, the input image is dot producted with each of the filter to produce the activation features. The learned filters dictate what features in the input image is extracted and fed to the next layer. The features are updated during Back-Propogation.



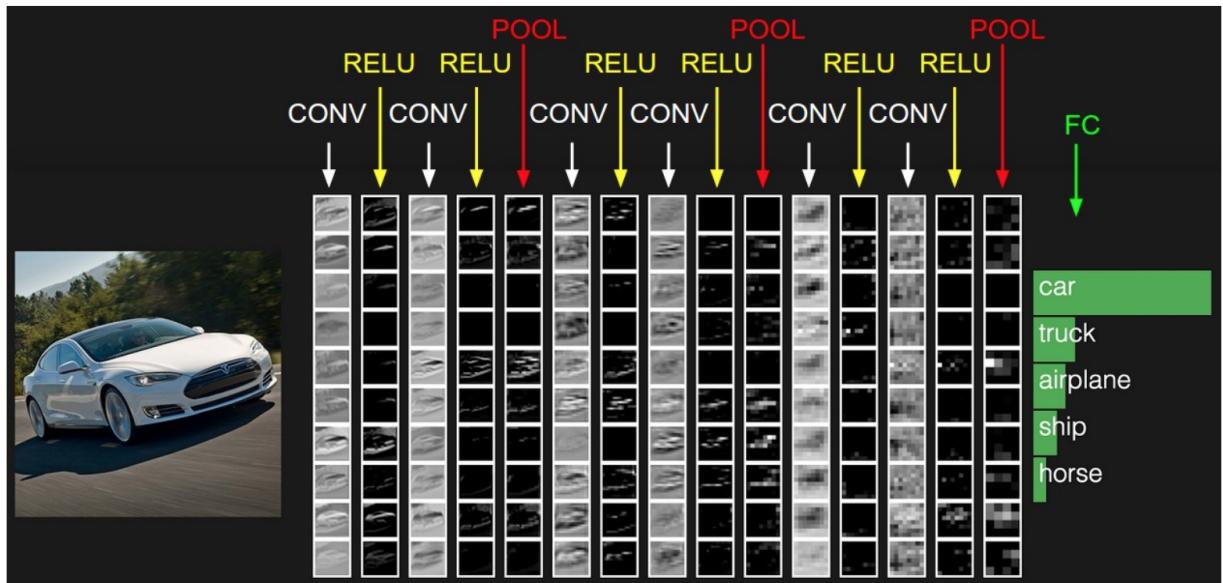
- **RELU layer :** RELU stands for Rectified Linear Units. This layer applies a nonlinear activation function of  $f(x)=\max(0,x)$ . Activation funtion is a decision function that drives a value towards a High (1) or a Low (0) value. There are other activation functions that can replace the RELU such as sigmoid, and tanh.



- **POOL layer :** This layer is a non-linear downsampling. The pooling function partitions the input image into sub-region. Each sub-region is computes to a single value either by the max, average, or min function.



- **FC layer :** The Fully Connected layer allows the model to output the decision in a linear vector. It connects all the previous neuron activations to each neuron in this layer. Each of the elements in the vector is a class score.



## Build a Simple CNN

### Model architecture definition

```
In [5]: model = Sequential()
model.add(Convolution2D(32, 3, 3, input_shape=(img_width, img_height,3)))
model.add(Activation('relu'))

model.add(Convolution2D(32, 3, 3))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))

model.add(Convolution2D(64, 3, 3))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))

model.add(Flatten())
model.add(Dense(64))
model.add(Activation('relu'))
model.add(Dropout(0.5))
model.add(Dense(1))
model.add(Activation('sigmoid'))

# Uncomment this if you would like to see the graph visualization of model
# from IPython.display import SVG
# from keras.utils.vis_utils import model_to_dot
# SVG(model_to_dot(model).create(prog='dot', format='svg'))
```

```
model.summary()
```

```
/Users/donovanlo/anaconda2/lib/python2.7/site-packages/ipykernel_launcher.py:2: UserWarning: Update your `Conv2D` call to the Keras 2 API: `Conv2D(32, (3, 3), input_shape=(150, 150,...)`
```

```
/Users/donovanlo/anaconda2/lib/python2.7/site-packages/ipykernel_launcher.py:5: UserWarning: Update your `Conv2D` call to the Keras 2 API: `Conv2D(32, (3, 3))`  
"""
```

```
/Users/donovanlo/anaconda2/lib/python2.7/site-packages/ipykernel_launcher.py:9: UserWarning: Update your `Conv2D` call to the Keras 2 API: `Conv2D(64, (3, 3))`  
if __name__ == '__main__':
```

WARNING:tensorflow:From /Users/donovanlo/anaconda2/lib/python2.7/site-packages/keras/backend/tensorflow\_backend.py:1264: calling reduce\_prod (from tensorflow.python.ops.math\_ops) with keep\_dims is deprecated and will be removed in a future version.

Instructions for updating:

keep\_dims is deprecated, use keepdims instead

Layer (type)	Output Shape	Param #
conv2d_1 (Conv2D)	(None, 148, 148, 32)	896
activation_1 (Activation)	(None, 148, 148, 32)	0
conv2d_2 (Conv2D)	(None, 146, 146, 32)	9248
activation_2 (Activation)	(None, 146, 146, 32)	0
max_pooling2d_1 (MaxPooling2D)	(None, 73, 73, 32)	0

<code>conv2d_3</code> (Conv2D)	(None, 71, 71, 64)	18496
<code>activation_3</code> (Activation)	(None, 71, 71, 64)	0
<code>max_pooling2d_2</code> (MaxPooling2D)	(None, 35, 35, 64)	0
<code>flatten_1</code> (Flatten)	(None, 78400)	0
<code>dense_1</code> (Dense)	(None, 64)	5017664
<code>activation_4</code> (Activation)	(None, 64)	0
<code>dropout_1</code> (Dropout)	(None, 64)	0
<code>dense_2</code> (Dense)	(None, 1)	65
<code>activation_5</code> (Activation)	(None, 1)	0
<hr/>		
Total params: 5,046,369		
Trainable params: 5,046,369		
Non-trainable params: 0		

```
In [6]: model.compile(loss='binary_crossentropy',
                      optimizer='rmsprop',
                      metrics=['accuracy'])
```

WARNING:tensorflow:From /Users/donovanlo/anaconda2/lib/python2.7/site-packages/keras/backend/tensorflow\_backend.py:1349: calling reduce\_mean (from tensorflow.python.ops.math\_ops) with keep\_dims is deprecated and will be removed in a future version.

Instructions for updating:  
 keep\_dims is deprecated, use keepdims instead

## Training

We will perform our training below on 16000 training samples on 1 epoch. Epoch is the number of iterations that the model has trained on the entire set of training data. I am using my MacBook Pro's CPU to do the training, which took **~1 hour** to run.

```
In [9]: nb_epoch = 1
```

```
model.fit_generator(
    train_generator,
    samples_per_epoch=nb_train_samples,
    nb_epoch=nb_epoch,
    validation_data=validation_generator,
    nb_val_samples=nb_validation_samples)
```

/Users/donovanlo/anaconda2/lib/python2.7/site-packages/ipykernel\_launcher.py:8: UserWarning: The semantics of the Keras 2 argument `steps\_per\_epoch` is not the same as the Keras 1 argument `samples\_per\_epoch`. `steps\_per\_epoch` is the number of batches to draw from the generator at each epoch. Basically `steps_per_epoch = samples_per_epoch/batch_size`. Similarly `nb\_val\_samples`->`validation\_steps` and `val\_samples`->`steps` arguments have changed. Update your method calls accordingly.

/Users/donovanlo/anaconda2/lib/python2.7/site-packages/ipykernel\_launcher.py:8: UserWarning: Update your `fit\_generator` call to the Keras 2 API: `fit\_generator(<keras.pre..., validation\_data=<keras.pre..., steps\_per\_epoch=500, epochs=1, validation\_steps=6400)`

```
Epoch 1/1
500/500 [=====] - 4384s 9s/step - loss: 0.6741 - acc: 0.6122 - val_loss: 0.5511 - val_acc: 0.7283
```

```
Out[9]: <keras.callbacks.History at 0x12faaae50>
```

Let's go over what is going behind the scene for the training above. The weights in the convolutional layers are initialized to random values. These weights are updated in a training process called **backpropagation**. **Backpropagation** is broken in to 4 process:

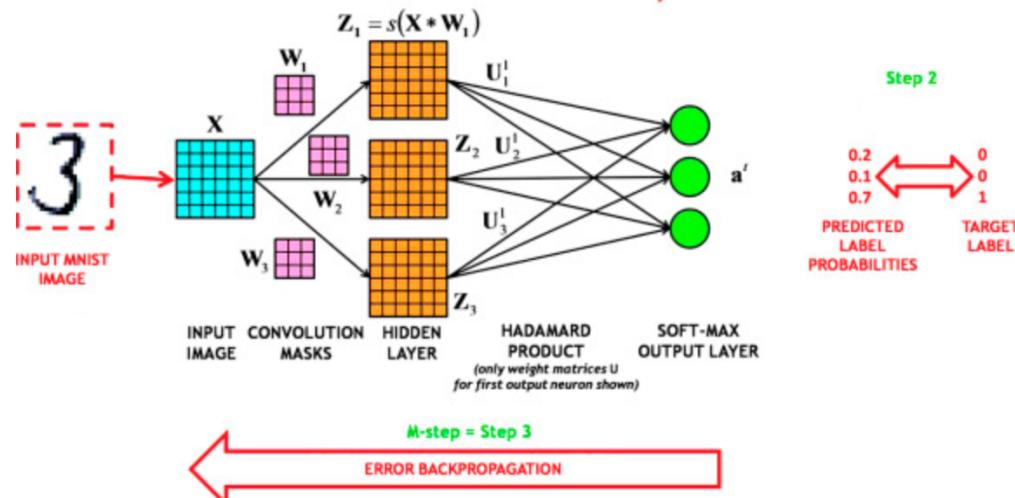
- **Forward Pass:** Each training image of dimension 150x150x3 is passed through the CNN. Since the weights are randomly initialized, the prediction of the network would not be reasonable. The poor prediction will be fed to the loss function.
- **Loss Function:** Each training image is associated with a label. For example, an image of a dog will have the label as [1] and image of a cat have the label [0]. There different definition for the loss function. The most common loss function used is the MSE (mean squared error). If the predicted label and the trained label are different the loss will be high, and conversely. To get the model to predict correctly, we would like to minimize this loss by changing the weights that most contribute to the loss. This minimization of the error or the optimization of the network is expressed as  $dL/dW$  where  $L$  is the loss and  $W$  are the weights at a layer.

$$L = E_{total} = \sum \frac{1}{2} (actual - predicted)^2$$

- **Backward Pass:** In this process, we compute the derivative to determine which weights contributed the most to the loss, so they can be adjusted.
- **Weight Update:** The adjustment of weights value are changed opposite direction of the gradient.

E-step = Step 1

FORWARD PASS



(Ref: K. Audhkhasi, Backpropagation - "Noise-enhanced convolutional neural networks")

The **backpropagation** is performed for one training iteration. The backpropagation is performed numerous of times for each set of training images, called **epoch**, until the network is updated with high enough validation accuracy.

You can save the model's weights here so you do not have to re-train your model everytime you would like to do inference. You can simply load the weights and restore the model from where you left it.

```
In [17]: model.save_weights('model-16000-samples--1-epochs.h5')
```

## Testing

Let's first load our trained weights in to the model and the first 1000 test images from the test directory to a List.

```
In [ ]: model.load_weights('model-16000-samples--1-epochs.h5')
```

```
In [7]: test_images = [test_dir+'/'+i for i in os.listdir(test_dir)]
random.shuffle(test_images)
test_images = test_images[:1000]
count = len(test_images)
test_data = np.ndarray((count,3,img_width,img_height), dtype=np.uint8)
for i, image_file in enumerate(test_images):
    img = cv2.imread(image_file, cv2.IMREAD_COLOR)
    b, g, r = cv2.split(img)
    img2 = cv2.merge([r,g,b])
    image = cv2.resize(img2, (img_width, img_height), interpolation=cv2.INTER_T
    test_data[i] = image.T
```

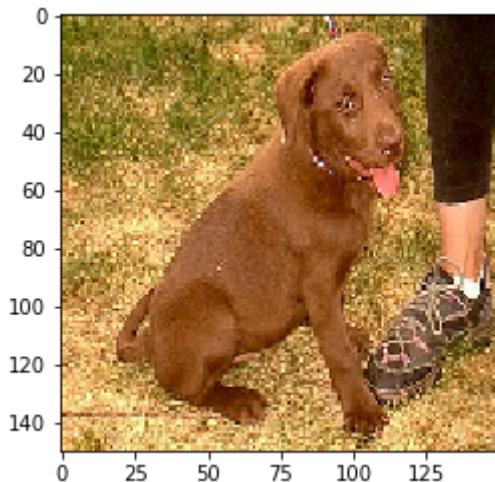
After the test images has been loaded to a List, we will pick the first test image as our test sample. By feeding the image to the model, it performs a forward propogation through the series of CONV, RELU, POOL, and FC layer. The output of the CNN is a single value of either 0 or 1. Value of 1

translates to a Dog and 0 to a Cat.

```
In [8]: test_image = test_data[25].T
plt.imshow(test_image,cmap='binary')
prediction = model.predict( np.expand_dims(test_image, axis=0) )

if prediction[0][0] == 1:
    print('The model thinks the image is a Dog.')
else:
    print('The model thinks the image is a Cat.')
```

The model thinks the image is a Dog.



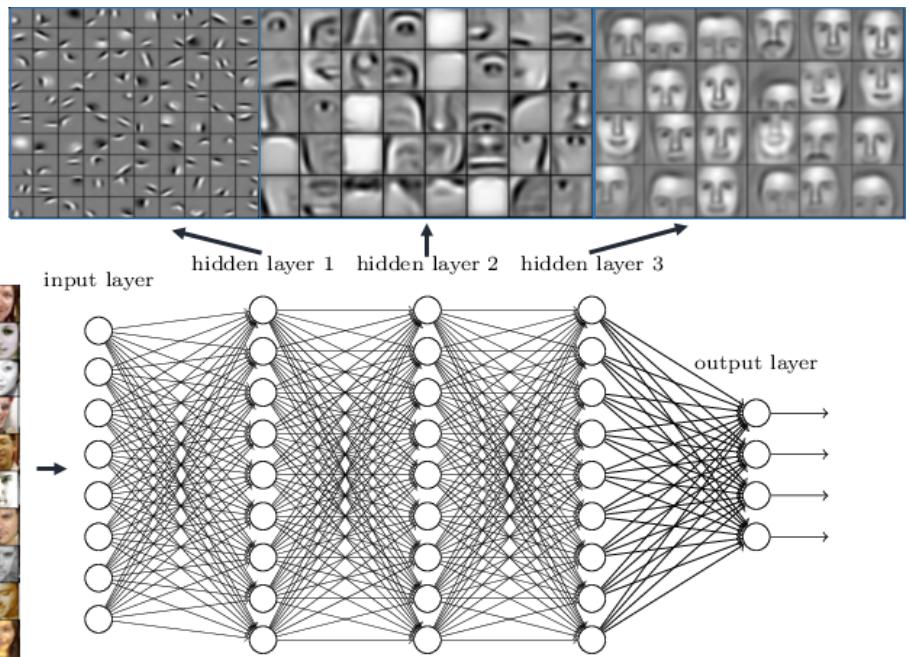
Nicely Done! Since our accuracy is 61% over 1 epoch, our model either got really lucky or guessed wrong. To improve the validation accuracy, try changing the **epoch** from 1 to 30 in the training section. This will take some time on CPU, but it will be worth it.

## Explore convnet filters

Here we will take a dive and see what the deep convolutional neural network (convnets) has learned. When we say "learned", we are saying what the weights (or values) in the filter have been updated to. Each filter are features the model would like to learn such as edges, texture, part of the body, and body of interest.

As seen below the filter in the lower layers has features such as horizontal and vertical lines. For each feature found in the image from the previous layer will be responsible in generating a larger activation for the next layer. For example, the activation found with different angle lines from the nose, eye, or mouth. Those features of nose, eye, and mouth from the larger activation of different faces in the next layer.

Deep neural networks learn hierarchical feature representations



Let's look at what features and activation output our model generates. First we need to extract each of the model's layer as objects.

```
In [9]: # get the symbolic outputs of each 'key' layer
layer_dict = dict([(layer.name, layer) for layer in model.layers])
layer_dict
```

```
Out[9]: {'activation_1': <keras.layers.core.Activation at 0x12dded690>,
'activation_2': <keras.layers.core.Activation at 0x12e2ae950>,
'activation_3': <keras.layers.core.Activation at 0x12ddd4810>,
'activation_4': <keras.layers.core.Activation at 0x12e322250>,
'activation_5': <keras.layers.core.Activation at 0x12e3c9350>,
'conv2d_1': <keras.layers.convolutional.Conv2D at 0x12dd97210>,
'conv2d_2': <keras.layers.convolutional.Conv2D at 0x12dded790>,
'conv2d_3': <keras.layers.convolutional.Conv2D at 0x10bc454d0>,
'dense_1': <keras.layers.core.Dense at 0x12e332790>,
'dense_2': <keras.layers.core.Dense at 0x12e332890>,
'dropout_1': <keras.layers.core.Dropout at 0x10ac26e90>,
'flatten_1': <keras.layers.core.Flatten at 0x10bc22450>,
'max_pooling2d_1': <keras.layers.pooling.MaxPooling2D at 0x12dd97790>,
'max_pooling2d_2': <keras.layers.pooling.MaxPooling2D at 0x12e2c3d10>}
```

Next we will convert each of the convolution layers of interest into a function. The functions will be called later with an input of the image.

```
In [10]: from keras import backend as K
inputs = [K.learning_phase()] + model.inputs

_convout1_f = K.function(inputs, [layer_dict['activation_1'].output])
_convout2_f = K.function(inputs, [layer_dict['activation_2'].output])
_convout3_f = K.function(inputs, [layer_dict['activation_3'].output])
def convout1_f(X):
    return _convout1_f([0]+[X])
def convout2_f(X):
    return _convout2_f([0]+[X])
def convout3_f(X):
    return _convout3_f([0]+[X])
```

We will define some helper functions to visualize all the filters at a particular layer or the activation output from a layer.

```
In [11]: # utility functions
from mpl_toolkits.axes_grid1 import make_axes_locatable

def nice_imshow(ax, data, vmin=None, vmax=None, cmap=None):
    """Wrapper around pl.imshow"""
    if cmap is None:
        cmap = cm.jet
    if vmin is None:
        vmin = data.min()
    if vmax is None:
        vmax = data.max()
    divider = make_axes_locatable(ax)
    cax = divider.append_axes("right", size="5%", pad=0.05)
    im = ax.imshow(data, vmin=vmin, vmax=vmax, interpolation='nearest', cmap=cmap)
    pl.colorbar(im, cax=cax)

import numpy.ma as ma
def make_mosaic(imgs, nrows, ncols, border=1):
    """
    Given a set of images with all the same shape, makes a
    mosaic with nrows and ncols
    """
    nimgs = imgs.shape[0]
    imshape = imgs.shape[1:]

    mosaic = ma.masked_all((nrows * imshape[0] + (nrows - 1) * border,
                           ncols * imshape[1] + (ncols - 1) * border),
                           dtype=np.float32)

    paddedh = imshape[0] + border
    paddedw = imshape[1] + border
    for i in xrange(nimags):
        row = int(np.floor(i / ncols))
        col = i % ncols

        mosaic[row * paddedh:row * paddedh + imshape[0],
               col * paddedw:col * paddedw + imshape[1]] = imgs[i].T
    return mosaic
```

Let's look at our model again to remind ourselves what it looks.

The first line shows us that the model takes an input image (width,height) of 148 x 148. At the **conv2d\_4 (Conv2D)** layer, there are 32 filters ready for learning features. Each filter in this layer is 3x3. Each of the filters will learn values to capture features to assist the final decision in the classification layer.

<b>conv2d_X</b>	<b>[AxAxB]</b>	<b>weights: (filter_w x filter_h x previous_neurons)x(current_neurons) + bias</b>
Input:	[150x150x3]	weights: 0
conv2d_4	[148x148x32]	weights: (3x3x3)x32 + 32 = 896
conv2d_5	[146x146x32]	weights: (3x3x32)x32 + 32 = 9248
conv2d_6	[71x71x64]	weights: (3x3x32)x64 + 64 = 18496
dense_3	[None, 64]	weights: (1x1x78400)x64 + 64 = 5017664
dense_4	[None, 1]	weights: (1x1x64)x1 + 1 = 65

```
In [12]: model.summary()
```

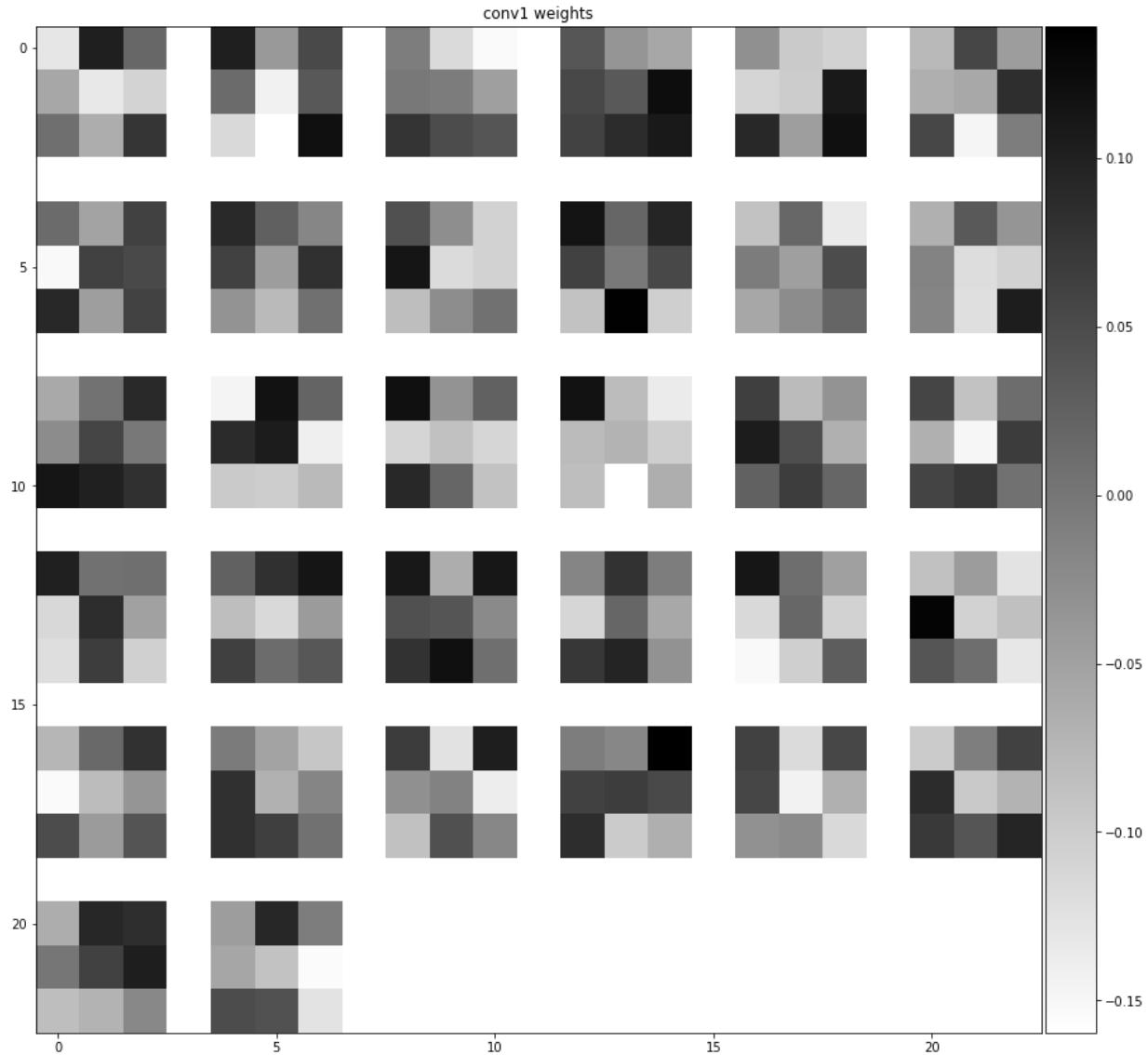
Layer (type)	Output Shape	Param #
<hr/>		
conv2d_1 (Conv2D)	(None, 148, 148, 32)	896
activation_1 (Activation)	(None, 148, 148, 32)	0
conv2d_2 (Conv2D)	(None, 146, 146, 32)	9248
activation_2 (Activation)	(None, 146, 146, 32)	0
max_pooling2d_1 (MaxPooling2D)	(None, 73, 73, 32)	0
conv2d_3 (Conv2D)	(None, 71, 71, 64)	18496
activation_3 (Activation)	(None, 71, 71, 64)	0
max_pooling2d_2 (MaxPooling2D)	(None, 35, 35, 64)	0
flatten_1 (Flatten)	(None, 78400)	0
dense_1 (Dense)	(None, 64)	5017664
activation_4 (Activation)	(None, 64)	0
dropout_1 (Dropout)	(None, 64)	0
dense_2 (Dense)	(None, 1)	65
activation_5 (Activation)	(None, 1)	0
<hr/>		
Total params:	5,046,369	
Trainable params:	5,046,369	
Non-trainable params:	0	

Let's examine what the 32 3x3 filters look like in the first convolutional layer (conv2d\_4).

```
In [14]: # Visualize weights in the first Convolutional Layer
W = layer_dict['conv2d_1'].get_weights()[0][:,:,0,:]
W = np.squeeze(W)
print("W shape : ", W.T.shape)

pl.figure(figsize=(15, 15))
pl.title('conv1 weights')
nice_imshow(pl.gca(), make_mosaic(W.T, 6, 6), cmap=cm.binary)

('W shape : ', (32, 3, 3))
```

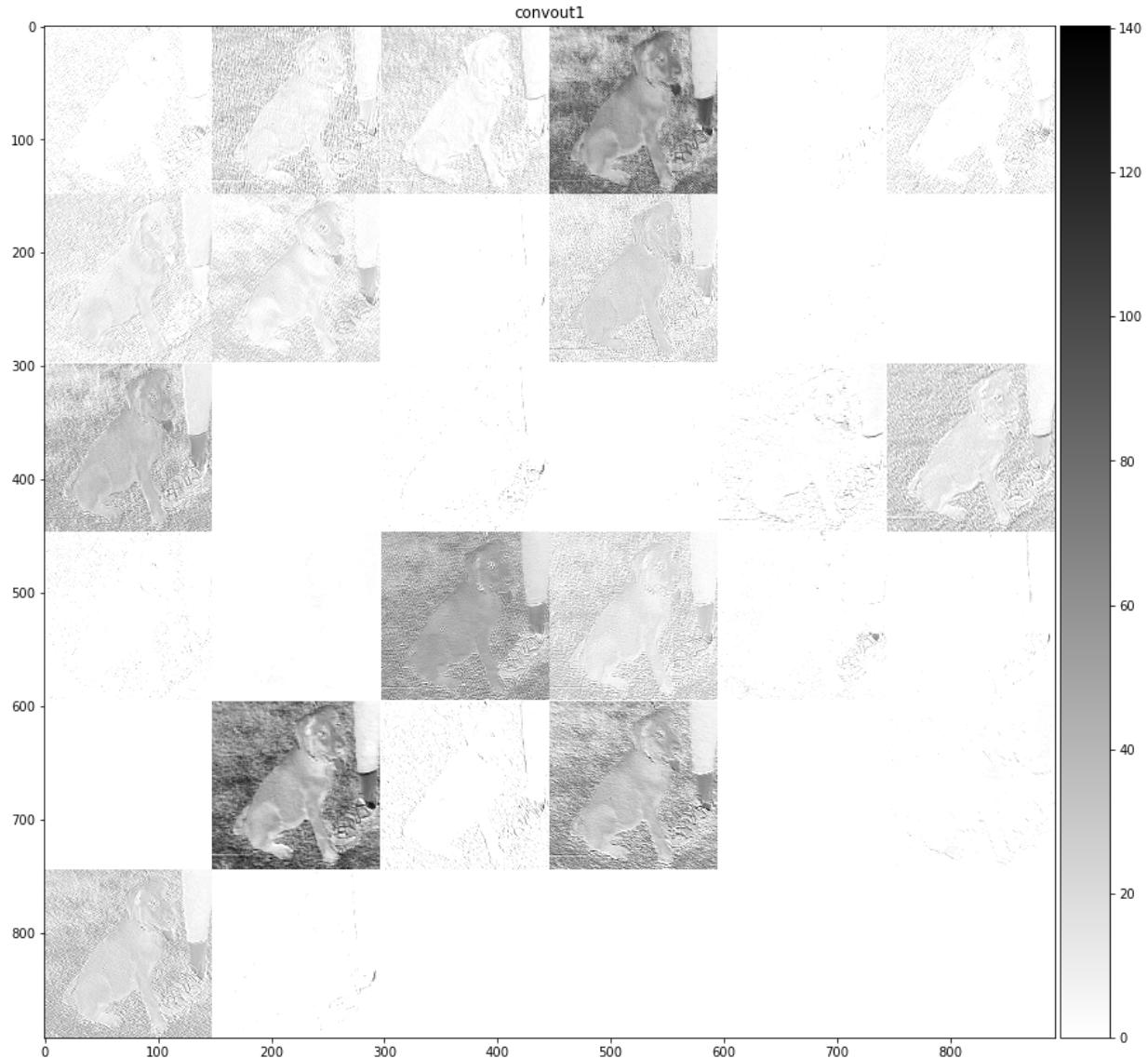


Let's examine what the output looks like after the input is convolved with each of the 32 filters followed by the RELU activation function.

```
In [15]: # Visualize first convolutional result (after activation)
import pylab as pl
import matplotlib.cm as cm
C1 = convout1_f([test_image])
C1 = np.squeeze(C1)
print("C1 shape : ", C1.T.shape)

pl.figure(figsize=(15, 15))
pl.title('convout1')
nice_imshow(pl.gca(), make_mosaic(C1.T, 6, 6), cmap=cm.binary)

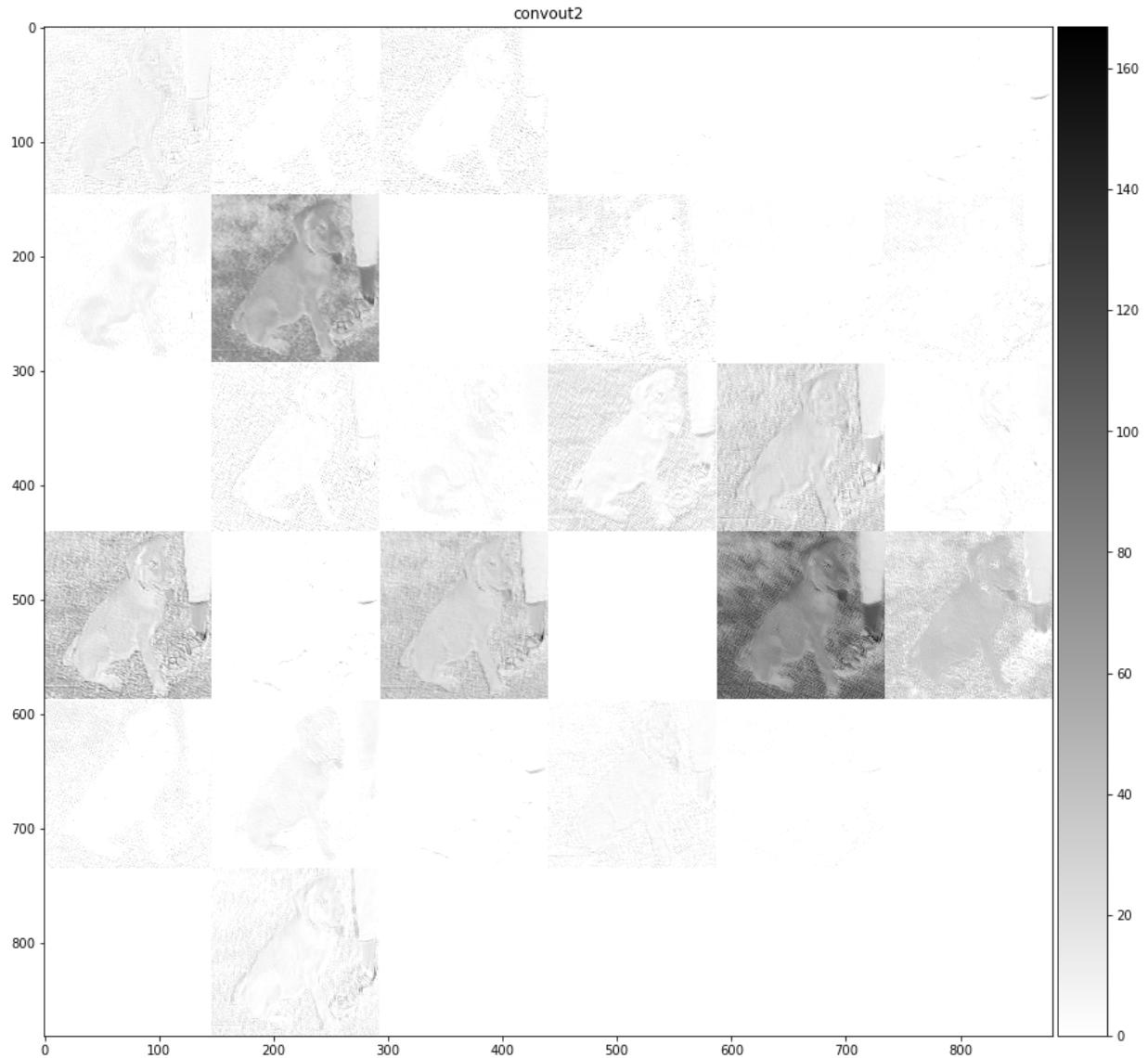
('C1 shape : ', (32, 148, 148))
```



```
In [16]: # Visualize second convolution result (after activation)
C2 = convout2_f([test_image])
C2 = np.squeeze(C2)
print("C2 shape : ", C2.T.shape)

pl.figure(figsize=(15, 15))
pl.title('convout2')
nice_imshow(pl.gca(), make_mosaic(C2.T, 6, 6), cmap=cm.binary)

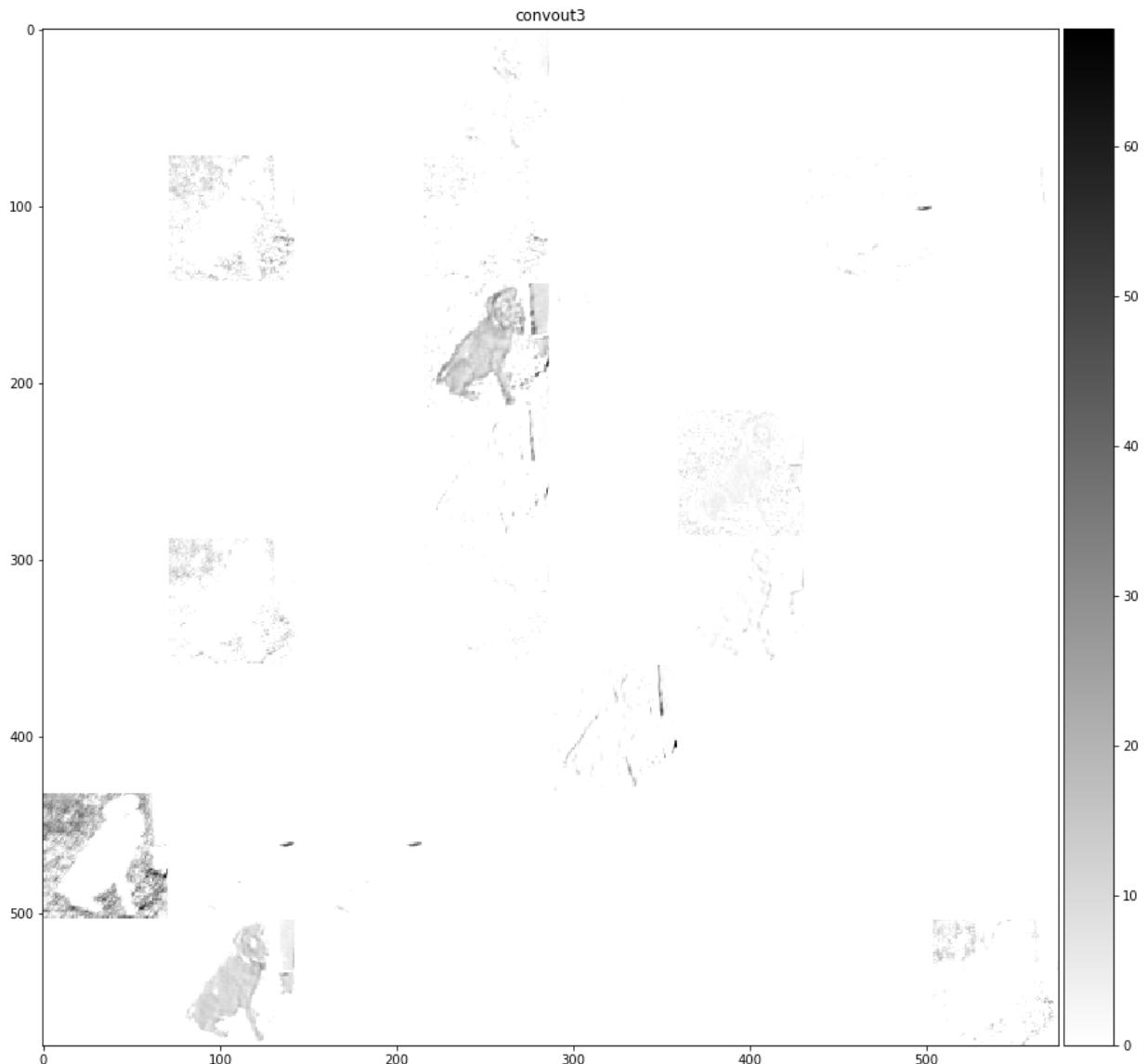
('C2 shape : ', (32, 146, 146))
```



```
In [17]: # Visualize third convolution result (after activation)
C3 = convout3_f([test_image])
C3 = np.squeeze(C3)
print("C3 shape : ", C3.T.shape)

pl.figure(figsize=(15, 15))
pl.title('convout3')
nice_imshow(pl.gca(), make_mosaic(C3.T, 8, 8), cmap=cm.binary)

('C3 shape : ', (64, 71, 71))
```



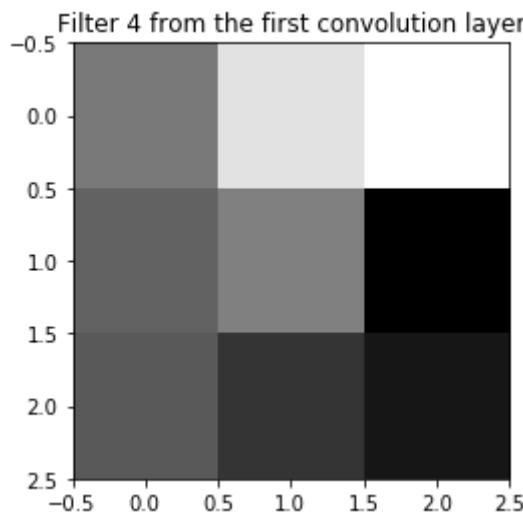
## Confirm if the CNN is convolving

```
In [18]: from skimage import color
import scipy.signal

filter_num = 3

test_image_gray = color.rgb2gray(test_image) # Load the image
kernel = W.T[ filter_num ].T # Load the kernel
plt.title('Filter {} from the first convolution layer'.format(filter_num+1))
plt.imshow(kernel, cmap=cm.binary)
print( kernel )

[[ 0.03859435 -0.03527762 -0.05623741]
 [ 0.05411343  0.03318811  0.12380508]
 [ 0.06013179  0.08664402  0.10797784]]
```

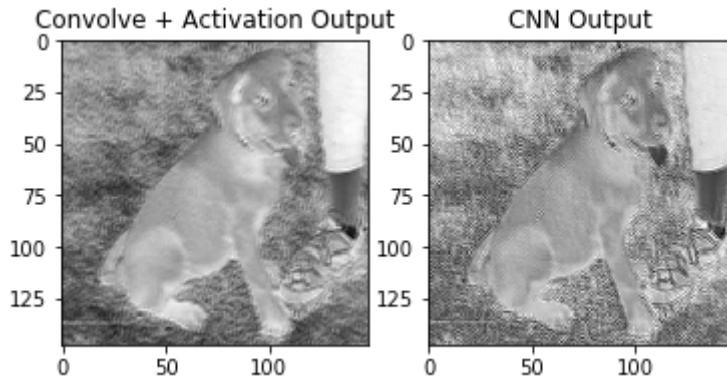


```
In [19]: # we use 'valid' which means we do not add zero padding to our image
filtered_image = scipy.signal.convolve2d(test_image_gray, kernel, 'valid')
filtered_image = np.maximum(filtered_image, 0)

# Output using the convolve2d() and maximum() method
plt.subplot(1,2,1)
plt.title('Convolve + Activation Output')
plt.imshow(filtered_image, cmap=cm.binary)

# Output from the CNN's first activation layer, second filter
plt.subplot(1,2,2)
plt.title('CNN Output')
plt.imshow(C1.T[ filter_num ].T, cmap=cm.binary)
```

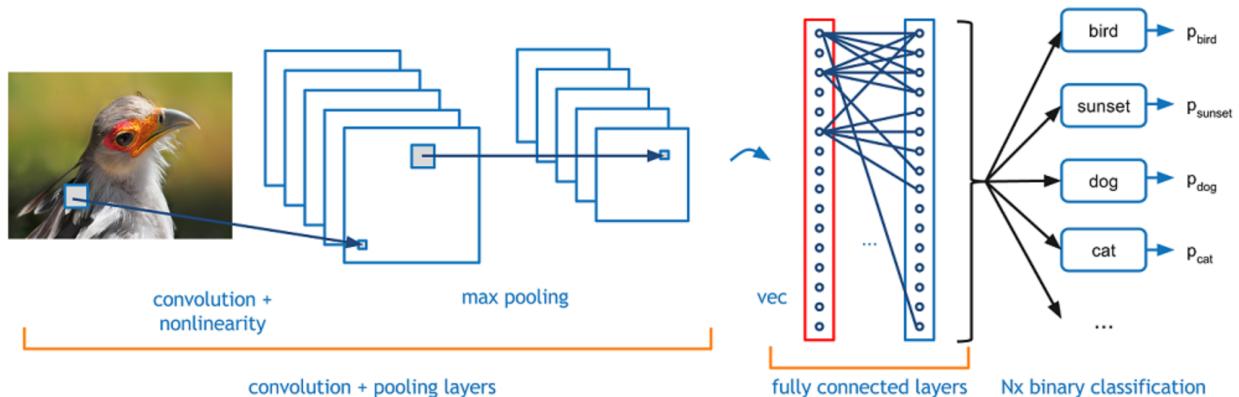
Out[19]: <matplotlib.image.AxesImage at 0x12e8c4c90>



## Review

In this tutorial, we explored the following items:

1. Components of CNN
  - Input, CONV, RELU, POOL, FC layers
2. Built a CNN
  - Trained CNN with 1 epoch
  - Tested CNN with loaded weights
3. Examined what CNN learned
  - Filters in a CONV layer



## Further Reading

The reader is encouraged to implement the additional tasks below to become more familiar with the code and further advance their understanding of convolutional neural network concepts:

1. Convolution  
([http://machinelearningguru.com/computer\\_vision/basics/convolution/image\\_convolution\\_1.html](http://machinelearningguru.com/computer_vision/basics/convolution/image_convolution_1.html)  
([http://machinelearningguru.com/computer\\_vision/basics/convolution/image\\_convolution\\_1.html](http://machinelearningguru.com/computer_vision/basics/convolution/image_convolution_1.html)))
2. Commonly used activation function (<http://cs231n.github.io/neural-networks-1/#actfun>  
(<http://cs231n.github.io/neural-networks-1/#actfun>))
3. Backpropagation (<http://cs231n.github.io/optimization-2/> (<http://cs231n.github.io/optimization-2/>) (<http://colah.github.io/posts/2015-08-Backprop/> (<http://colah.github.io/posts/2015-08-Backprop/>) ([http://deeplearning.stanford.edu/wiki/index.php/Backpropagation\\_Algorithm](http://deeplearning.stanford.edu/wiki/index.php/Backpropagation_Algorithm)  
([http://deeplearning.stanford.edu/wiki/index.php/Backpropagation\\_Algorithm](http://deeplearning.stanford.edu/wiki/index.php/Backpropagation_Algorithm))))
4. Setting up data and model (<http://cs231n.github.io/neural-networks-2/>  
(<http://cs231n.github.io/neural-networks-2/>))
5. Go the extra step and do Transfer Learning (<http://cs231n.github.io/transfer-learning/>  
(<http://cs231n.github.io/transfer-learning/>) (<https://blog.keras.io/building-powerful-image-classification-models-using-very-little-data.html> (<https://blog.keras.io/building-powerful-image-classification-models-using-very-little-data.html>)))

## References

### CNN architecture

- <https://www.kdnuggets.com/2017/09/neural-network-foundations-explained-activation-function.html> (<https://www.kdnuggets.com/2017/09/neural-network-foundations-explained-activation-function.html>)
- <https://adeshpande3.github.io/AdeshPande3.github.io/A-Beginner%27s-Guide-To-Understanding-Convolutional-Neural-Networks/>  
(<https://adeshpande3.github.io/AdeshPande3.github.io/A-Beginner%27s-Guide-To-Understanding-Convolutional-Neural-Networks/>)
- <http://cs231n.github.io/convolutional-networks/> (<http://cs231n.github.io/convolutional-networks/>)
- <https://gggdomi.github.io/keras-workshop/notebook.html> (<https://gggdomi.github.io/keras-workshop/notebook.html>)
- <https://www.learnopencv.com/image-classification-using-convolutional-neural-networks-in-keras/> (<https://www.learnopencv.com/image-classification-using-convolutional-neural-networks-in-keras/>)
- <https://www.strong.io/blog/deep-neural-networks-go-to-the-movies>  
(<https://www.strong.io/blog/deep-neural-networks-go-to-the-movies>)

### CNN parameter calculation

- <https://stackoverflow.com/questions/28232235/how-to-calculate-the-number-of-parameters-of-convolutional-neural-networks> (<https://stackoverflow.com/questions/28232235/how-to-calculate-the-number-of-parameters-of-convolutional-neural-networks>)

## External Code

- [https://github.com/julienr/ipynb\\_playground/blob/master/keras/convmnist/keras\\_cnn\\_mnist\\_v1.ipynb](https://github.com/julienr/ipynb_playground/blob/master/keras/convmnist/keras_cnn_mnist_v1.ipynb)