In [1]:

```
# Load CIFAR-10 data set
from keras.datasets import cifar10
(X_train, y_train), (X_test, y_test) = cifar10.load_data()
```

```
Downloading data from https://www.cs.toronto.edu/~kriz/cifar-10-python.tar.gz
170500096/170498071 [==============================] - 4s 0us/step
```

In [2]:

```
# Show examples from each class
import numpy as np
import matplotlib.pyplot as plt

num_classes = len(np.unique(y_train))
class_names = ['airplane','automobile','bird','cat','deer','dog','frog','horse','shi
fig = plt.figure(figsize=(8,3))
for i in range(num_classes):
    ax = fig.add_subplot(2, 5, 1 + i, xticks=[], yticks=[])
    ax.set_title(class_names[i])
    idx = np.where(y_train[:]==i)[0]
    features_idx = X_train[idx,::]
    rnd_img = np.random.randint(features_idx.shape[0])
    im = np.transpose(features_idx[rnd_img,::], (0, 1, 2))
    plt.imshow(im)
plt.show()
```

In [3]:

```
# Data pre-processing
X_train = X_train.astype('float32')
X_test = X_test.astype('float32')
X_train /= 255.0
X_test /= 255.0

from keras.utils import np_utils
Y_train = np_utils.to_categorical(y_train, num_classes)
Y_test = np_utils.to_categorical(y_test, num_classes)
```

In [4]:

```
def plot_model_history(model_history):
    fig, axs = plt.subplots(1,2,figsize=(15,5))
    # Summarize history for accuracy
    axs[0].plot(range(1,len(model_history.history['accuracy'])+1),model_history.hist
    axs[0].plot(range(1,len(model_history.history['val_accuracy'])+1),model_history.
    axs[0].set_ylim(0, 1)
    axs[0].set_title('Model Accuracy')
    axs[0].set_ylabel('Accuracy')
    axs[0].set_xlabel('Epoch')
```

```
    axs[0].set_xticks(np.arange(1,len(model_history.history['accuracy'])+1,step=len(
    axs[0].legend(['train', 'val'], loc='best')
    # summarize history for loss
    axs[1].plot(range(1,len(model_history.history['loss'])+1),model_history.history[
    axs[1].plot(range(1,len(model_history.history['val_loss'])+1),model_history.hist
    axs[1].set_title('Model Loss')
    axs[1].set_ylabel('Loss')
    axs[1].set_xlabel('Epoch')
    axs[1].set_xticks(np.arange(1,len(model_history.history['loss'])+1,step=len(mode
    axs[1].legend(['train', 'val'], loc='best')
    plt.show()
```

In [5]:

```
# Tensorboard
from time import time
from keras.callbacks import TensorBoard
tensorboard = TensorBoard(log_dir='logs/{}'.format(time()))
```

In [6]:

```
# Data augmentation
from keras.preprocessing.image import ImageDataGenerator
datagen = ImageDataGenerator(
                             #  featurewise_center=True,
                             #  featurewise_std_normalization=True,
                              rotation_range=10.,
                              width_shift_range=0.1,
                              height_shift_range=0.1,
                              horizontal_flip=True,
                              zoom_range=0.1,
                              shear_range=0.1,
                              fill_mode='nearest')
datagen.fit(X_train)
```

Definición de una red convolucional multicapa

In [7]:

```
# Convolutional Neural Network (CNN)
# Here you are allowed to use convolutional layers
# You may use also any regularizacion (see class slides)

from keras.models import Sequential
from keras.layers import Dense, Activation, Flatten, Dropout, BatchNormalization
from keras import optimizers
from keras.callbacks import EarlyStopping
from keras.regularizers import l2
from keras.layers.convolutional import Conv2D, MaxPooling2D
import keras.backend as K
from keras.callbacks import ModelCheckpoint

checkpoint_path = "/gdrive/My Drive/Colab Notebooks/MUIA-ComputerVision/P4/Alberto_C
checkpoint_callback = ModelCheckpoint(
   checkpoint_path, monitor='val_accuracy', verbose=1, save_weights_only=True,
   # Save weights, every epoch.
   save_freq='epoch',mode='auto',save_best_only=True)

learning_rate=0.001
epochs=500
batch_size=256
es = EarlyStopping(monitor='val_loss', mode='auto', verbose=1, patience=int(epochs*0
p_dropou_layert=[0,0.2,0.3,0.5]
```

```
i=0
d_augm=1

model = Sequential()
model.add(Conv2D(filters=32, kernel_size=(3, 3),activation='relu', padding='same', i
model.add(BatchNormalization())
model.add(Conv2D(filters=32, kernel_size=(3, 3),activation='relu', padding='same'))
model.add(BatchNormalization())
model.add(MaxPooling2D( pool_size=(2, 2)))
model.add(Dropout(p_dropou_layert[i]))
i+=1
model.add(Conv2D(filters=64, kernel_size=(3, 3), activation='relu', padding='same'))
model.add(BatchNormalization())
model.add(Conv2D(filters=64, kernel_size=(3, 3), activation='relu', padding='same'))
model.add(BatchNormalization())
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(p_dropou_layert[i]))
i+=1
model.add(Conv2D(filters=128, kernel_size=(3, 3), activation='relu', padding='same')
model.add(BatchNormalization())
model.add(Conv2D(filters=128, kernel_size=(3, 3), activation='relu', padding='same')
model.add(BatchNormalization())
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(p_dropou_layert[i]))
i+=1
model.add(Conv2D(filters=256, kernel_size=(3, 3), activation='relu', padding='same')
model.add(BatchNormalization())
model.add(Conv2D(filters=256, kernel_size=(3, 3), activation='relu', padding='same')
model.add(BatchNormalization())
model.add(MaxPooling2D(pool_size=(2, 2)))
# model.add(BatchNormalization())
model.add(Dropout(p_dropou_layert[i]))
i+=1
model.add(Conv2D(filters=512, kernel_size=(3, 3), activation='relu', padding='same')
model.add(BatchNormalization())
model.add(Conv2D(filters=512, kernel_size=(3, 3), activation='relu', padding='same')
model.add(BatchNormalization())
model.add(Conv2D(filters=num_classes, kernel_size=(2, 2), padding='valid'))
model.add(Flatten())
model.add(Activation('softmax'))

# opt = optimizers.SGD(lr=learning_rate, momentum=0.9, nesterov=True)
opt = optimizers.Adam(lr=learning_rate, beta_1=0.9, beta_2=0.999)

model.compile(optimizer=opt, loss='categorical_crossentropy', metrics=['accuracy'])
model.summary()
```

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d (Conv2D)              (None, 32, 32, 32)        896       
_________________________________________________________________
batch_normalization (BatchNo (None, 32, 32, 32)        128       
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 32, 32, 32)        9248      
_________________________________________________________________
batch_normalization_1 (Batch (None, 32, 32, 32)        128       
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 16, 16, 32)        0         
_________________________________________________________________
dropout (Dropout)            (None, 16, 16, 32)        0         
```

```
conv2d_2 (Conv2D)            (None, 16, 16, 64)        18496
_________________________________________________________________
batch_normalization_2 (Batch (None, 16, 16, 64)        256
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 16, 16, 64)        36928
_________________________________________________________________
batch_normalization_3 (Batch (None, 16, 16, 64)        256
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 8, 8, 64)          0
_________________________________________________________________
dropout_1 (Dropout)          (None, 8, 8, 64)          0
_________________________________________________________________
conv2d_4 (Conv2D)            (None, 8, 8, 128)         73856
_________________________________________________________________
batch_normalization_4 (Batch (None, 8, 8, 128)         512
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 8, 8, 128)         147584
_________________________________________________________________
batch_normalization_5 (Batch (None, 8, 8, 128)         512
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 4, 4, 128)         0
_________________________________________________________________
dropout_2 (Dropout)          (None, 4, 4, 128)         0
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 4, 4, 256)         295168
_________________________________________________________________
batch_normalization_6 (Batch (None, 4, 4, 256)         1024
_________________________________________________________________
conv2d_7 (Conv2D)            (None, 4, 4, 256)         590080
_________________________________________________________________
batch_normalization_7 (Batch (None, 4, 4, 256)         1024
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 2, 2, 256)         0
_________________________________________________________________
dropout_3 (Dropout)          (None, 2, 2, 256)         0
_________________________________________________________________
conv2d_8 (Conv2D)            (None, 2, 2, 512)         1180160
_________________________________________________________________
batch_normalization_8 (Batch (None, 2, 2, 512)         2048
_________________________________________________________________
conv2d_9 (Conv2D)            (None, 2, 2, 512)         2359808
_________________________________________________________________
batch_normalization_9 (Batch (None, 2, 2, 512)         2048
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 1, 1, 10)          20490
_________________________________________________________________
flatten (Flatten)            (None, 10)                0
_________________________________________________________________
activation (Activation)      (None, 10)                0
=================================================================
Total params: 4,740,650
Trainable params: 4,736,682
Non-trainable params: 3,968
_________________________________________________________________
```

In [8]:

```
# Training
if d_augm==1:
  # Fit the model with real time data augmentation
  print("Fitting model with data augmentation")
  start = time()
  history = model.fit(datagen.flow(X_train, Y_train, batch_size=batch_size),
                              epochs=epochs, verbose=2, validation_data=(X_test, Y_test
  end = time()
```

```
else:
  # Fit the model with plain dataset
  print("Fitting model")
  start = time()
  history = model.fit(X_train, Y_train, batch_size=batch_size, epochs=epochs, verbos
  end = time()
```

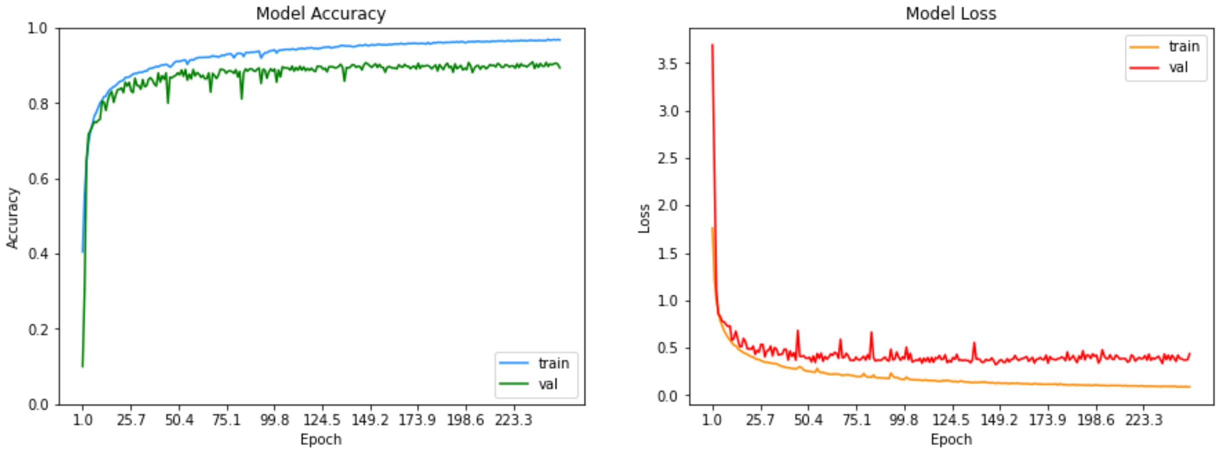
```
Fitting model with data augmentation
Epoch 1/500
196/196 - 33s - loss: 1.7607 - accuracy: 0.4047 - val_loss: 3.6903 - val_accuracy:
0.1000

Epoch 00001: val_accuracy improved from -inf to 0.10000, saving model to /gdrive/My
Drive/Colab Notebooks/MUIA-ComputerVision/P4/Alberto_CIFAR10CNN1/best_epoch_val_acc.
ckpt
Epoch 2/500
196/196 - 24s - loss: 1.2237 - accuracy: 0.5575 - val_loss: 2.3818 - val_accuracy:
0.3017

Epoch 00002: val_accuracy improved from 0.10000 to 0.30170, saving model to /gdrive/
My Drive/Colab Notebooks/MUIA-ComputerVision/P4/Alberto_CIFAR10CNN1/best_epoch_val_a
cc.ckpt
Epoch 3/500
196/196 - 24s - loss: 1.0069 - accuracy: 0.6440 - val_loss: 1.1037 - val_accuracy:
0.6463

Epoch 00003: val_accuracy improved from 0.30170 to 0.64630, saving model to /gdrive/
My Drive/Colab Notebooks/MUIA-ComputerVision/P4/Alberto_CIFAR10CNN1/best_epoch_val_a
cc.ckpt
Epoch 4/500
196/196 - 23s - loss: 0.8802 - accuracy: 0.6919 - val_loss: 0.8553 - val_accuracy:
0.7177

Epoch 00004: val_accuracy improved from 0.64630 to 0.71770, saving model to /gdrive/
My Drive/Colab Notebooks/MUIA-ComputerVision/P4/Alberto_CIFAR10CNN1/best_epoch_val_a
cc.ckpt
Epoch 5/500
196/196 - 24s - loss: 0.7881 - accuracy: 0.7246 - val_loss: 0.8301 - val_accuracy:
0.7260

Epoch 00005: val_accuracy improved from 0.71770 to 0.72600, saving model to /gdrive/
My Drive/Colab Notebooks/MUIA-ComputerVision/P4/Alberto_CIFAR10CNN1/best_epoch_val_a
cc.ckpt
Epoch 6/500
196/196 - 24s - loss: 0.7349 - accuracy: 0.7439 - val_loss: 0.7803 - val_accuracy:
0.7382

Epoch 00006: val_accuracy improved from 0.72600 to 0.73820, saving model to /gdrive/
My Drive/Colab Notebooks/MUIA-ComputerVision/P4/Alberto_CIFAR10CNN1/best_epoch_val_a
cc.ckpt
Epoch 7/500
196/196 - 24s - loss: 0.6785 - accuracy: 0.7651 - val_loss: 0.7724 - val_accuracy:
0.7504

Epoch 00007: val_accuracy improved from 0.73820 to 0.75040, saving model to /gdrive/
My Drive/Colab Notebooks/MUIA-ComputerVision/P4/Alberto_CIFAR10CNN1/best_epoch_val_a
cc.ckpt
Epoch 8/500
196/196 - 24s - loss: 0.6431 - accuracy: 0.7752 - val_loss: 0.7465 - val_accuracy:
0.7480

Epoch 00008: val_accuracy did not improve from 0.75040
Epoch 9/500
```

```
196/196 - 24s - loss: 0.0871 - accuracy: 0.9689 - val_loss: 0.3765 - val_accuracy:
0.9033

Epoch 00246: val_accuracy did not improve from 0.90940
Epoch 247/500
196/196 - 24s - loss: 0.0903 - accuracy: 0.9681 - val_loss: 0.4375 - val_accuracy:
0.8938

Epoch 00247: val_accuracy did not improve from 0.90940
Epoch 00247: early stopping
```

In [9]:

```python
print("Training CNN took " + str(end - start) + " seconds")
plot_model_history(history)
```

```
Training CNN took 5831.713987112045 seconds
```



In [10]:

```python
start = time()
loss, acc = model.evaluate(X_test, Y_test, verbose=0)
end = time()
print('CNN took ' + str(end - start) + ' seconds')
print('For final weights configuration:\n\tTest loss: ' + str(loss) + ' - Accuracy:
```

```
CNN took 1.297666072845459 seconds
For final weights configuration:
	Test loss: 0.4375062882900238 - Accuracy: 0.8938000202178955
```

In [11]:

```python
model.load_weights(checkpoint_path)
start = time()
loss, acc = model.evaluate(X_test, Y_test, verbose=0)
end = time()
print('CNN took ' + str(end - start) + ' seconds')
print('For best validation accuracy weights configuration found in training:\n\tTest
```

```
CNN took 1.2773823738098145 seconds
For best validation accuracy weights configuration found in training:
	Test loss: 0.3355124890804291 - Accuracy: 0.9093999862670898
```