test

October 30, 2022

Welcome to Object detection from scratch

[1]:
```
# necessary only if you are training your model on colab and want to save␣
↪checkpoints to your gdrive

from google.colab import drive
drive.mount('/content/drive')
```

```
Mounted at /content/drive
```

Necessary downloads

[2]:
```
# get the animals data
!gdown --id 1ZYwdQbYC_vfS255F1seJwWpfA8dfU-j5
```

```
/usr/local/lib/python3.7/dist-packages/gdown/cli.py:131: FutureWarning: Option
`--id` was deprecated in version 4.3.1 and will be removed in 5.0. You don't
need to pass it anymore to use a file ID.
  category=FutureWarning,
Downloading…
From: https://drive.google.com/uc?id=1ZYwdQbYC_vfS255F1seJwWpfA8dfU-j5
To: /content/animals.zip
100% 39.9k/39.9k [00:00<00:00, 39.4MB/s]
```

[3]:
```
# unzip and store in folder
!unzip animals.zip
```

```
Archive:  animals.zip
   creating: animals/
  inflating: animals/dog.png
  inflating: __MACOSX/animals/._dog.png
  inflating: animals/rabbit.png
  inflating: __MACOSX/animals/._rabbit.png
  inflating: animals/turtle.png
  inflating: __MACOSX/animals/._turtle.png
  inflating: animals/.DS_Store
  inflating: __MACOSX/animals/._.DS_Store
  inflating: animals/elephant.png
  inflating: __MACOSX/animals/._elephant.png
  inflating: animals/rat.png
```

```
  inflating: __MACOSX/animals/._rat.png
  inflating: animals/octopus.png
  inflating: __MACOSX/animals/._octopus.png
  inflating: animals/tiger.png
  inflating: __MACOSX/animals/._tiger.png
  inflating: animals/cow.png
  inflating: __MACOSX/animals/._cow.png
  inflating: animals/cheetah.png
  inflating: __MACOSX/animals/._cheetah.png
  inflating: animals/penguin.png
  inflating: __MACOSX/animals/._penguin.png
  inflating: animals/cat.png
  inflating: __MACOSX/animals/._cat.png
  inflating: animals/cock.png
  inflating: __MACOSX/animals/._cock.png
  inflating: animals/monkey.png
  inflating: __MACOSX/animals/._monkey.png
  inflating: animals/goat.png
  inflating: __MACOSX/animals/._goat.png
  inflating: animals/fish.png
  inflating: __MACOSX/animals/._fish.png
```

[4]:
```
# get the backgrounds data
!gdown --id 1_6cYCg9xLES0r65DcYeLV3V__wVy7JeV
```

```
/usr/local/lib/python3.7/dist-packages/gdown/cli.py:131: FutureWarning: Option
`--id` was deprecated in version 4.3.1 and will be removed in 5.0. You don't
need to pass it anymore to use a file ID.
  category=FutureWarning,
Downloading…
From: https://drive.google.com/uc?id=1_6cYCg9xLES0r65DcYeLV3V__wVy7JeV
To: /content/backgrounds_320x320.zip
100% 2.08M/2.08M [00:00<00:00, 145MB/s]
```

[5]:
```
# unzip and store
!unzip backgrounds_320x320.zip
```

```
Archive:  backgrounds_320x320.zip
   creating: backgrounds_320x320/
  inflating: backgrounds_320x320/image_1.jpg
  inflating: backgrounds_320x320/image_10.jpg
  inflating: backgrounds_320x320/image_11.jpg
  inflating: backgrounds_320x320/image_12.jpg
  inflating: backgrounds_320x320/image_13.jpg
  inflating: backgrounds_320x320/image_14.jpg
  inflating: backgrounds_320x320/image_15.jpg
  inflating: backgrounds_320x320/image_16.jpg
  inflating: backgrounds_320x320/image_17.jpg
  inflating: backgrounds_320x320/image_18.jpg
```

```
  inflating: backgrounds_320x320/image_19.jpg
  inflating: backgrounds_320x320/image_2.jpg
  inflating: backgrounds_320x320/image_20.jpg
  inflating: backgrounds_320x320/image_21.jpg
  inflating: backgrounds_320x320/image_22.jpg
  inflating: backgrounds_320x320/image_23.jpg
  inflating: backgrounds_320x320/image_24.jpg
  inflating: backgrounds_320x320/image_25.jpg
  inflating: backgrounds_320x320/image_3.jpg
  inflating: backgrounds_320x320/image_4.jpg
  inflating: backgrounds_320x320/image_5.jpg
  inflating: backgrounds_320x320/image_6.jpg
  inflating: backgrounds_320x320/image_7.jpg
  inflating: backgrounds_320x320/image_8.jpg
  inflating: backgrounds_320x320/image_9.jpg
  inflating: backgrounds_320x320/Type Machine.ttf
```

[6]:
```
# move the fonts file to main directory
"""
  Important STEP. must be done to avoid errors
"""
%mv '/content/backgrounds_320x320/Type Machine.ttf' '/content'
```

[7]:
```
# get trained weights

!gdown --id 1Eibp-Sedvc4xdAhs3n88R4o1kAwjP-M7
```

```
/usr/local/lib/python3.7/dist-packages/gdown/cli.py:131: FutureWarning: Option
`--id` was deprecated in version 4.3.1 and will be removed in 5.0. You don't
need to pass it anymore to use a file ID.
  category=FutureWarning,
Downloading…
From: https://drive.google.com/uc?id=1Eibp-Sedvc4xdAhs3n88R4o1kAwjP-M7
To: /content/final_weights_customOD.zip
100% 27.3M/27.3M [00:00<00:00, 173MB/s]
```

[8]:
```
# unzip and store
!unzip final_weights_customOD.zip
```

```
Archive:  final_weights_customOD.zip
  inflating: weights/checkpoint
  inflating: weights/epoch_latest.model.index
  inflating: weights/epoch_latest.model.data-00000-of-00001
```

Necessary imports

[9]:
```
# Import required libraries. TF version used is 2.9.2

%matplotlib inline
```

```
import tensorflow as tf
import numpy as np
import matplotlib.pyplot as plt
import os
import fnmatch
import cv2
import random


from PIL import Image, ImageDraw
from PIL import ImageFont
from IPython.display import Image as displayImage

font = ImageFont.truetype("Type Machine.ttf", 10)

from tensorflow.keras.layers import Input, Dense, Flatten, Conv2D, MaxPool2D,␣
↪BatchNormalization, Dropout, Concatenate, Reshape
import keras.losses

# from tensorflow.keras.layers.core import Reshape

from tensorflow.python.ops.numpy_ops import np_config
np_config.enable_numpy_behavior()

tf.config.run_functions_eagerly(True)

print('Using TensorFlow version', tf.__version__)
```

```
Using TensorFlow version 2.9.2
```

[10]:
```
np.set_printoptions(threshold=np.inf) # increase print threshold to infinity to␣
↪view full numpy outputs
```

Core functions for Object detection

Most of these functions (next 10 blocks) are sourced from here: https://d2l.ai/chapter_computer-vision/anchor.html you can read more about them there. originally written in torch, I converted them to tensorflow

[11]:
```
"""
Generates anchor boxes for a given image size, size of anchors
and ratios of anchors
"""


def multibox_prior(X, sizes, ratios):
    in_height, in_width = X.shape[-3:-1]
    num_sizes, num_ratios = len(sizes), len(ratios)
```

```
    boxes_per_pixel = (num_sizes + num_ratios - 1)
    size_tensor = tf.convert_to_tensor(sizes)
    ratio_tensor = tf.convert_to_tensor(ratios)
    # Offsets are required to move the anchor to the center of a pixel. Since
    # a pixel has height=1 and width=1, we choose to offset our centers by 0.5
    offset_h, offset_w = 0.5, 0.5
    steps_h = 1.0 / in_height  # Scaled steps in y axis
    steps_w = 1.0 / in_width  # Scaled steps in x axis
    # print("steps_h, steps_w", steps_h, steps_w)

    # Generate all center points for the anchor boxes
    center_h = (tf.range(in_height, dtype=tf.float32) + offset_h) * steps_h
    center_w = (tf.range(in_width, dtype=tf.float32) + offset_w) * steps_w
    shift_y, shift_x = tf.meshgrid(center_h, center_w, indexing='ij')
    shift_y, shift_x = shift_y.reshape(-1), shift_x.reshape(-1)
    # print("center_h, center_w", center_h, center_w)
    # print("shift_y, shift_x", shift_y, shift_x)

    # Generate `boxes_per_pixel` number of heights and widths that are later
    # used to create anchor box corner coordinates (xmin, xmax, ymin, ymax)
    w = tf.concat((size_tensor * tf.sqrt(ratio_tensor[0]), sizes[0] * tf.
↪sqrt(ratio_tensor[1:])), axis=0) * in_height / in_width  # Handle␣
↪rectangular inputs
    h = tf.concat((size_tensor / tf.sqrt(ratio_tensor[0]), sizes[0] / tf.
↪sqrt(ratio_tensor[1:])), axis=0)
    # print(w, h)
    # Divide by 2 to get half height and half width
    # print(type(tf.stack((-w, -h, w, h)).T.numpy()))
    # return
    anchor_manipulations = np.tile(tf.stack((-w, -h, w, h), axis=0).numpy(),␣
↪in_height * in_width) / 2
    anchor_manipulations = anchor_manipulations.T
    # print('anchor_manipulations: ', anchor_manipulations.shape)
    # print(anchor_manipulations)
    # Each center point will have `boxes_per_pixel` number of anchor boxes, so
    # generate a grid of all anchor box centers with `boxes_per_pixel` repeats
    # print('outgrid: ', tf.stack([shift_x, shift_y, shift_x, shift_y], axis=1).
↪numpy().repeat(boxes_per_pixel, 0))
    out_grid = tf.stack([shift_x, shift_y, shift_x, shift_y], axis=1).numpy().
↪repeat(boxes_per_pixel, 0)
    output = out_grid + anchor_manipulations
    print('output: ', output.shape)
    # print(output)
    return tf.expand_dims(output, 0)
```

[12]:
```
"""
Computes IoU of one list of boxes over other
box format: np.array([[xmin, ymin, xmax, ymax], ...])
returns ious of size [len(boxes1), len(boxes2)]
"""
def box_iou(boxes1, boxes2):
    """Compute pairwise IoU across two lists of anchor or bounding boxes."""
    box_area = lambda boxes: ((boxes[:, 2] - boxes[:, 0]) *
                              (boxes[:, 3] - boxes[:, 1]))
    # Shape of `boxes1`, `boxes2`, `areas1`, `areas2`: (no. of boxes1, 4),
    # (no. of boxes2, 4), (no. of boxes1,), (no. of boxes2,)
    areas1 = box_area(boxes1)
    areas2 = box_area(boxes2)
    # print('curr area: ', areas1, '\n')
    # Shape of `inter_upperlefts`, `inter_lowerrights`, `inters`: (no. of
    # boxes1, no. of boxes2, 2)
    inter_upperlefts = tf.math.maximum(boxes1[:, None, :2], boxes2[:, :2])
    inter_lowerrights = tf.math.minimum(boxes1[:, None, 2:], boxes2[:, 2:])
    inters = (inter_lowerrights - inter_upperlefts).numpy().clip(min=0)
    # print(inters)
    # Shape of `inter_areas` and `union_areas`: (no. of boxes1, no. of boxes2)
    inter_areas = inters[:, :, 0] * inters[:, :, 1]
    union_areas = areas1[:, None] + areas2 - inter_areas
    return inter_areas / union_areas
```

[13]:
```
"""
Compute if a new object in an Image is overlapping with alraedy existing␣
 ↪object's boxes.
"""

def overlap(boxes1, boxes2):
    box_area = lambda boxes: ((boxes[:, 2] - boxes[:, 0]) * (boxes[:, 3] -␣
 ↪boxes[:, 1]))

    areas1 = box_area(boxes1)
    areas2 = box_area(boxes2)

    inter_upperlefts = tf.math.maximum(boxes1[:, None, :2], boxes2[:, :2])
    inter_lowerrights = tf.math.minimum(boxes1[:, None, 2:], boxes2[:, 2:])
    inters = (inter_lowerrights - inter_upperlefts).numpy().clip(min=0)

    inter_areas = inters[:, :, 0] * inters[:, :, 1]
    union_areas = areas1[:, None] + areas2 - inter_areas

    if np.where(((inter_areas / union_areas) * areas1)[0] > 0.01)[0].shape[0] >␣
 ↪0:
        return True
```

```
    return False
```

[14]:
```
"""
Assign closest ground-truth bounding boxes to anchor boxes.
One or more than one overlapping anchor boxes are assigned to each bounding␣
 ↪boxes depending
upon the given iou_threshhold
"""

def assign_anchor_to_bbox(ground_truth, anchors, iou_threshold=0.4):

    num_anchors, num_gt_boxes = anchors.shape[0], ground_truth.shape[0]
    # Element x_ij in the i-th row and j-th column is the IoU of the anchor
    # box i and the ground-truth bounding box j
    jaccard = box_iou(anchors, ground_truth)
    # print('jaccard: ', jaccard)
    # Initialize the tensor to hold the assigned ground-truth bounding box for
    # each anchor
    anchors_bbox_map = tf.fill((num_anchors,), -1)
    # print('anchors_bbox_map: ', anchors_bbox_map)
    # Assign ground-truth bounding boxes according to the threshold
    # print(tf.math.reduce_max(jaccard, axis=1))

    max_ious = tf.math.reduce_max(jaccard, axis=1)
    indices = tf.math.argmax(jaccard, axis=1)
    # print('max_ious, indices: ', max_ious, indices)
    anc_i = tf.where(max_ious >= iou_threshold).reshape(-1)
    # print('anc_i: ', anc_i)
    box_j = indices[max_ious >= iou_threshold]
    # print('box_j: ', box_j)
    anchors_bbox_map_np = np.array(anchors_bbox_map)
    anchors_bbox_map_np[np.array(anc_i[:])] = box_j
    # print('anchors_bbox_map: ', anchors_bbox_map_np)
    col_discard = tf.fill((num_anchors,), -1)
    row_discard = tf.fill((num_gt_boxes,), -1)
    # print('row_discard, col_discard: ', row_discard, col_discard)
    jaccard = np.array(jaccard)
    for i in range(num_gt_boxes):
        max_idx = tf.math.argmax(jaccard[:, i])  # Find the largest IoU
        # print('max_idx: ', max_idx)
        box_idx = i
        anc_idx = max_idx
        # print('box_idx, anc_idx: ', box_idx, anc_idx)
        anchors_bbox_map_np[anc_idx] = box_idx
        jaccard[:, box_idx] = col_discard
```

```
        jaccard[anc_idx, :] = row_discard
    # print('jaccard: ', jaccard)
    return tf.convert_to_tensor(anchors_bbox_map_np)
```

[15]:
```
"""
Converts bounding box from (xmin, ymin, xmax, ymax) format
to (cx, cy, width, height) format
"""

def box_corner_to_center(cords):
    try:
        ret = cords.numpy()
    except:
        ret = np.copy(cords)
    ret[:, 0] = cords[:, 0] + (cords[:, 2] - cords[:, 0]) / 2
    ret[:, 1] = cords[:, 1] + (cords[:, 3] - cords[:, 1]) / 2
    ret[:, 2] = cords[:, 2] - cords[:, 0]
    ret[:, 3] = cords[:, 3] - cords[:, 1]
    return tf.convert_to_tensor(ret)
```

[16]:
```
"""
Converts bounding box from (cx, cy, width, height) format
to (xmin, ymin, xmax, ymax) format
"""

def box_center_to_corner(cords):
    try:
        ret = cords.numpy()
    except:
        ret = np.copy(cords)
    ret[:, 0] = cords[:, 0] - cords[:, 2] / 2
    ret[:, 1] = cords[:, 1] - cords[:, 3] / 2
    ret[:, 2] = cords[:, 2] + ret[:, 0]
    ret[:, 3] = cords[:, 3] + ret[:, 1]
    return tf.convert_to_tensor(ret)
```

[17]:
```
"""
Calculates offsets of actual bounding boxes from predefined anchors
"""

def offset_boxes(anchors, assigned_bb, eps=1e-6):
    # print("offset_boxes", anchors.shape, assigned_bb.shape)
    # print(assigned_bb, assigned_bb)
    """Transform for anchor box offsets."""
    # change anchors to yolo form (cx, cy, width, height)
    c_anc = box_corner_to_center(anchors)
    # print('c_anc: ', c_anc)
```

```
    # change bbox to yolo form (cx, cy, width, height)
    c_assigned_bb = box_corner_to_center(assigned_bb)
    # print('c_assigned_bb: ', c_assigned_bb)
    offset_xy = 10 * (c_assigned_bb[:, :2] - c_anc[:, :2]) / c_anc[:, 2:]
    offset_wh = 5 * tf.math.log(eps + c_assigned_bb[:, 2:] / c_anc[:, 2:])
    offset = tf.concat([offset_xy, offset_wh], axis=1)
    return offset
```

[18]:
```
"""
One of the most important function/step for Object detection

Input:
1. pre generated anchors boxes
2. the class labels from training input
3. the bounding box labels from training input

The following things takes place in this function:
------------------------------------------------

for each batch of input,
1.  a anchors_bbox_map is created of size 2140 which tells that out of 2140␣
 ↪anchor boxes
    which are those anchor boxes active or overlaps with input labels

2.  bbox_mask of shape 8560 is created which copies over the active␣
 ↪anchors_box_map
    4 times to match with output bounding boxes of shape (batch_size, 8560)
    It has values 0 or 1 which signifies active or inactive

3.  new class_labels and assigned_bb (bounding box) are created initialized as
    empty arrays of shape(2140, 16) and (2140, 4) respectively

4.  these new labels and bb are fed with values from input labels with respect␣
 ↪to
    anchors indexes (print and see yourself for in depth clarification)

5.  offsets are created for the new bb with respect to prdefined anchors.␣
 ↪During training, inference
    those are offsets what are predicted by the model, they go through␣
 ↪offset_inverse
    for plotting and iou calculations


At the end after completeng all steps for every batch the new bbox_offset,␣
 ↪bbox_masks,
class_labels ( initialised as one hot encoded class for active anchors and one␣
 ↪hot encoded background
```

```
for background anchors ), all these values are returned to caller function␣
 ↪(loss function for
loss calculation)

"""

def multibox_target(anchors, cls_labels, box_labels):
    """Label anchor boxes using ground-truth bounding boxes."""
    batch_size, anchors, n_classes = len(cls_labels), anchors[0], cls_labels.
 ↪shape[-1]
    batch_offset, batch_mask, batch_class_labels = [], [], []
    num_anchors = anchors.shape[0]
    for i in range(batch_size):
        label = box_labels[i]
        c_label = cls_labels[i]
        # print('c_label: ', c_label)
        anchors_bbox_map = assign_anchor_to_bbox(label, anchors)
        # print('anchors_bbox_map: ', anchors_bbox_map)
        bbox_mask = (anchors_bbox_map >= 0).numpy().repeat(4, 0).reshape(-1, 4).
 ↪astype('float16')
        # print('bbox_mask: ', bbox_mask)

        # Initialize class labels and assigned bounding box coordinates with
        # zeros
        class_labels = np.zeros((num_anchors, 16))

        # make sure to mark the last column as 1 by default so that it␣
 ↪signifies
        #background class
        class_labels[:, 15] = np.ones(num_anchors)
        # print(class_labels[:, 15])

        assigned_bb = np.zeros((num_anchors, 4))
        # print('class_labels, assigned_bb: ', class_labels, assigned_bb)

        # Label classes of anchor boxes using their assigned ground-truth
        # bounding boxes. If an anchor box is not assigned any, we label its
        # class as background (the value remains one)
        indices_true = tf.where(anchors_bbox_map >= 0).numpy()
        # print('indices_true: ', indices_true)
        bb_idx = np.array(anchors_bbox_map[indices_true])
        # print('bb_idx: ', bb_idx)

        # print(bb_idx.shape, indices_true.shape)
        # print(class_labels.shape, cls_labels[bb_idx[:, 0]].shape)
```

```
        class_labels[indices_true] = c_label[bb_idx] #np.
↪argmax(class_labels[i][bb_idx]) + 1 #label[bb_idx, 0] + 1
        class_labels[indices_true, 15] = 0
        # assigned_bb = assigned_bb.numpy()

        assigned_bb[indices_true] = label[bb_idx]

        # print('class_labels, assigned_bb after: ', class_labels, assigned_bb)
        # Offset transformation
        offset = offset_boxes(anchors, assigned_bb) * bbox_mask
        # print('offset: ', offset)
        batch_offset.append(offset.reshape(-1))
        batch_mask.append(bbox_mask.reshape(-1))
        batch_class_labels.append(class_labels)
    bbox_offset = tf.stack(batch_offset)
    bbox_mask = tf.stack(batch_mask)
    class_labels = tf.stack(batch_class_labels)
    return (bbox_offset, bbox_mask, class_labels)
```

[19]:
```
"""
Converts offsets back to actual bounding boxes of form (xmin, ymin, xmax, ymax)
with respect to predefined anchors
"""

def offset_inverse(anchors, offset_preds):
    anc = box_corner_to_center(anchors)
    pred_bbox_xy = (offset_preds[:, :2] * anc[:, 2:] / 10) + anc[:, :2]
    pred_bbox_wh = tf.math.exp(offset_preds[:, 2:] / 5) * anc[:, 2:]
    pred_bbox = tf.concat((pred_bbox_xy, pred_bbox_wh), axis=1)
    predicted_bbox = box_center_to_corner(pred_bbox)
    return predicted_bbox
```

[20]:
```
"""
Major function

Creates anchors boxes for our model.
For our model we need anchors boxes of size
"""

def create_anchors():

    sizes = [[0.2, 0.272], [0.37, 0.447], [0.54, 0.619], [0.71, 0.79], [0.88, 0.
↪961]]
    input_shapes = [[20, 20, 3], [10, 10, 3], [5, 5, 3], [3, 3, 3], [1, 1, 3]]
    ratios = [0.5, 1, 2]
    output_anchors = multibox_prior(np.zeros(input_shapes[0]), sizes=sizes[0],␣
↪ratios=ratios)
```

```
    for i in range(1,5):
        anchors_t = multibox_prior(np.zeros(input_shapes[i]), sizes=[0.75, 0.
↪5], ratios=[1, 2, 0.5])
        output_anchors = tf.concat([output_anchors, anchors_t], axis=1)

    return output_anchors
```

[22]:
```
"""
Anchors are architecture dependent and they wont change over time.
So the anchors created here will be used for entire training and inferencing
process.
"""

anchors = create_anchors()
anchors.shape
```

```
output:  (1600, 4)
output:  (400, 4)
output:  (100, 4)
output:  (36, 4)
output:  (4, 4)
```

[22]:
```
TensorShape([1, 2140, 4])
```

Understanding anchors

simple and precise explanation: https://www.youtube.com/watch?v=5sYK0z–lqU more here: https://machinethink.net/blog/object-detection/#anchors

[23]:
```
# creating 2x2 anchors for demonstrartion (choose different values for better␣
↪understanding)
# play with sizes and ratios for better understanding

anchors_test = multibox_prior(np.zeros([2,2,3]), sizes=[0.2, 0.272], ratios=[0.
↪5, 1, 2])
anchors_test
```

```
output:  (16, 4)
```

[23]:
```
<tf.Tensor: shape=(1, 16, 4), dtype=float32, numpy=
array([[[0.17928931, 0.10857864, 0.3207107 , 0.39142138],
        [0.15383348, 0.05766694, 0.34616652, 0.44233304],
        [0.15      , 0.15      , 0.35      , 0.35      ],
        [0.10857864, 0.17928931, 0.39142138, 0.3207107 ],
        [0.67928934, 0.10857864, 0.82071066, 0.39142138],
        [0.65383345, 0.05766694, 0.84616655, 0.44233304],
        [0.65      , 0.15      , 0.85      , 0.35      ],
        [0.6085786 , 0.17928931, 0.8914214 , 0.3207107 ],
```

```
        [0.17928931, 0.6085786 , 0.3207107 , 0.8914214 ],
        [0.15383348, 0.55766696, 0.34616652, 0.94233304],
        [0.15      , 0.65      , 0.35      , 0.85      ],
        [0.10857864, 0.67928934, 0.39142138, 0.82071066],
        [0.67928934, 0.6085786 , 0.82071066, 0.8914214 ],
        [0.65383345, 0.55766696, 0.84616655, 0.94233304],
        [0.65      , 0.65      , 0.85      , 0.85      ],
        [0.6085786 , 0.67928934, 0.8914214 , 0.82071066]]], dtype=float32)>
```

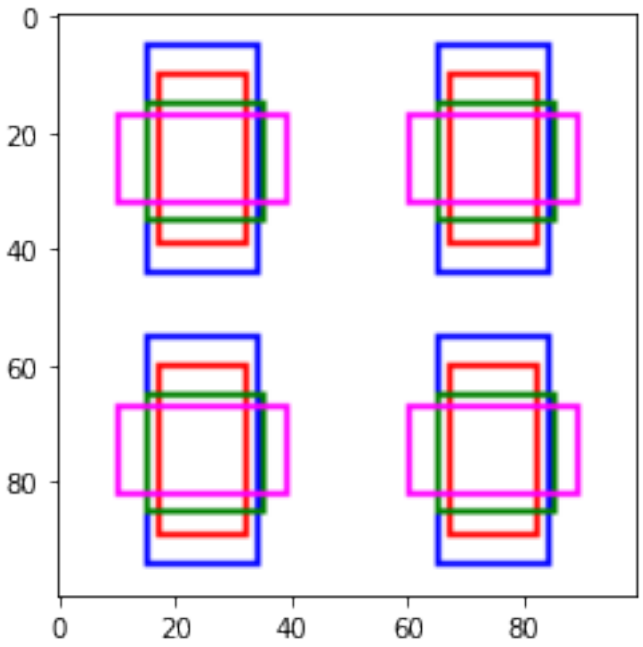
[24]:
```
image = Image.new("RGB", (100, 100), (255, 255, 255))
draw = ImageDraw.Draw(image)
```

[25]:
```
anchors_test = anchors_test * 100
anchors_test
```

[25]:
```
<tf.Tensor: shape=(1, 16, 4), dtype=float32, numpy=
array([[[17.92893  , 10.857863 , 32.071068 , 39.14214  ],
        [15.3833475,  5.766694 , 34.616653 , 44.233303 ],
        [15.000001 , 15.000001 , 35.       , 35.       ],
        [10.857863 , 17.92893  , 39.14214  , 32.071068 ],
        [67.92893  , 10.857863 , 82.07107  , 39.14214  ],
        [65.38335  ,  5.766694 , 84.61665  , 44.233303 ],
        [65.       , 15.000001 , 85.       , 35.       ],
        [60.85786  , 17.92893  , 89.142136 , 32.071068 ],
        [17.92893  , 60.85786  , 32.071068 , 89.142136 ],
        [15.3833475, 55.766697 , 34.616653 , 94.23331  ],
        [15.000001 , 65.       , 35.       , 85.       ],
        [10.857863 , 67.92893  , 39.14214  , 82.07107  ],
        [67.92893  , 60.85786  , 82.07107  , 89.142136 ],
        [65.38335  , 55.766697 , 84.61665  , 94.23331  ],
        [65.       , 65.       , 85.       , 85.       ],
        [60.85786  , 67.92893  , 89.142136 , 82.07107  ]]], dtype=float32)>
```

[26]:
```
colors = ['red', 'blue', 'green', 'magenta']
```

[27]:
```
for i in range(anchors_test.numpy().shape[1]):
  draw.rectangle(anchors_test.numpy()[0][i], outline=colors[i%4], width=1)
  plt.imshow(image)
```



[27]:

Data Generator implementation

[28]:
```
"""
default size of the png images is 72x72
and below are the bounding boxes of animals inside image at this scale
"""

# animals_boxes = {
#     'cat': [3, 68, 14, 57],
#     'cheetah': [0, 70, 20, 57],
#     'cock': [10, 61, 10, 62],
#     'cow': [4, 66, 19, 58],
#     'dog': [4, 64, 11, 63],
#     'elephant': [3, 67, 15, 59],
#     'fish': [11, 65, 15, 61],
#     'goat': [4, 65, 11, 64],
#     'monkey': [6, 66, 8, 63],
#     'octopus': [7, 65, 9, 59],
#     'penguin': [12, 60, 4, 64],
#     'rabbit': [7, 64, 9, 58],
#     'rat': [4, 68, 20, 63],
#     'tiger': [3, 68, 22, 57],
#     'turtle': [4, 67, 14, 57]
# }
```

[28]:
```
'\ndefault size of the png images is 72x72\nand below are the bounding boxes of animals inside image at this scale\n'
```

[29]:
```
# for key in animals_boxes.keys():
#     animals_boxes[key] = np.array(animals_boxes[key])/72
```

[30]:
```
# animals_boxes
```

[31]:
```
# animals = {}
# filenames = fnmatch.filter(os.listdir('animals'), '*.png')

# for idx, filename in enumerate(filenames):
#     temp = {}
#     temp['name'] = filename.split('.')[0]
#     temp['file'] = filename
#     temp['boxes'] = animals_boxes[filename.split('.')[0]]
#     animals[idx] = temp
```

[32]:
```
# dictionary of animals with scaled bounding boxes 0 to 1

animals = {
    0: {'name': 'octopus',
      'file': 'octopus.png',
      'boxes': [0.09722222, 0.90277778, 0.125     , 0.81944444]},
     1: {'name': 'cat',
      'file': 'cat.png',
      'boxes': [0.04166667, 0.94444444, 0.19444444, 0.79166667]},
     2: {'name': 'cow',
      'file': 'cow.png',
      'boxes': [0.05555556, 0.91666667, 0.26388889, 0.80555556]},
     3: {'name': 'tiger',
      'file': 'tiger.png',
      'boxes': [0.04166667, 0.94444444, 0.30555556, 0.79166667]},
     4: {'name': 'cock',
      'file': 'cock.png',
      'boxes': [0.13888889, 0.84722222, 0.13888889, 0.86111111]},
     5: {'name': 'turtle',
      'file': 'turtle.png',
      'boxes': [0.05555556, 0.93055556, 0.19444444, 0.79166667]},
     6: {'name': 'monkey',
      'file': 'monkey.png',
      'boxes': [0.08333333, 0.91666667, 0.11111111, 0.875     ]},
     7: {'name': 'rat',
      'file': 'rat.png',
      'boxes': [0.05555556, 0.94444444, 0.27777778, 0.875     ]},
     8: {'name': 'elephant',
      'file': 'elephant.png',
```

```
      'boxes': [0.04166667, 0.93055556, 0.20833333, 0.81944444]},
     9: {'name': 'goat',
      'file': 'goat.png',
      'boxes': [0.05555556, 0.90277778, 0.15277778, 0.88888889]},
     10: {'name': 'dog',
      'file': 'dog.png',
      'boxes': [0.05555556, 0.88888889, 0.15277778, 0.875     ]},
     11: {'name': 'rabbit',
      'file': 'rabbit.png',
      'boxes': [0.09722222, 0.88888889, 0.125     , 0.80555556]},
     12: {'name': 'cheetah',
      'file': 'cheetah.png',
      'boxes': [0.        , 0.97222222, 0.27777778, 0.79166667]},
     13: {'name': 'fish',
      'file': 'fish.png',
      'boxes': [0.15277778, 0.90277778, 0.20833333, 0.84722222]},
     14: {'name': 'penguin',
      'file': 'penguin.png',
      'boxes': [0.16666667, 0.83333333, 0.05555556, 0.88888889]}
}
```

[33]:
```
backgrounds = {}
filenames = fnmatch.filter(os.listdir('backgrounds_320x320'), '*.jpg')

for idx, filename in enumerate(filenames):
    temp = {}
    temp['name'] = filename.split('.')[0]
    temp['file'] = filename
    backgrounds[idx] = temp
```

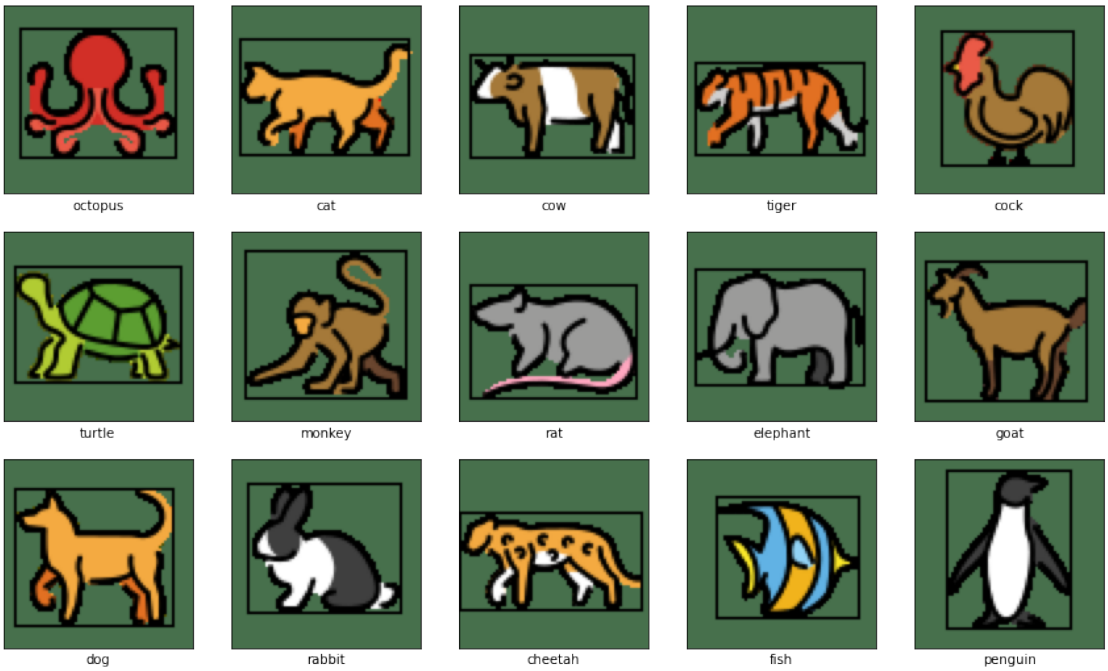
[34]:
```
# 25 background images for synthetic random backgrounds
backgrounds
```

[34]:
```
{0: {'name': 'image_22', 'file': 'image_22.jpg'},
 1: {'name': 'image_1', 'file': 'image_1.jpg'},
 2: {'name': 'image_18', 'file': 'image_18.jpg'},
 3: {'name': 'image_2', 'file': 'image_2.jpg'},
 4: {'name': 'image_17', 'file': 'image_17.jpg'},
 5: {'name': 'image_4', 'file': 'image_4.jpg'},
 6: {'name': 'image_24', 'file': 'image_24.jpg'},
 7: {'name': 'image_7', 'file': 'image_7.jpg'},
 8: {'name': 'image_15', 'file': 'image_15.jpg'},
 9: {'name': 'image_5', 'file': 'image_5.jpg'},
 10: {'name': 'image_21', 'file': 'image_21.jpg'},
 11: {'name': 'image_9', 'file': 'image_9.jpg'},
 12: {'name': 'image_12', 'file': 'image_12.jpg'},
 13: {'name': 'image_11', 'file': 'image_11.jpg'},
```

```
 14: {'name': 'image_10', 'file': 'image_10.jpg'},
 15: {'name': 'image_3', 'file': 'image_3.jpg'},
 16: {'name': 'image_19', 'file': 'image_19.jpg'},
 17: {'name': 'image_25', 'file': 'image_25.jpg'},
 18: {'name': 'image_8', 'file': 'image_8.jpg'},
 19: {'name': 'image_23', 'file': 'image_23.jpg'},
 20: {'name': 'image_14', 'file': 'image_14.jpg'},
 21: {'name': 'image_13', 'file': 'image_13.jpg'},
 22: {'name': 'image_16', 'file': 'image_16.jpg'},
 23: {'name': 'image_20', 'file': 'image_20.jpg'},
 24: {'name': 'image_6', 'file': 'image_6.jpg'}}
```

[35]:
```
# The total number of classes we have
N_CLASSES = len(animals) + 1 # one extra for background
```

[36]:
```
plt.figure(figsize=(N_CLASSES - 1, 9))

for i, (j, e) in enumerate(animals.items()):
    plt.subplot(3, 5, i + 1)
    image = cv2.imread(os.path.join('animals', e['file']))
    image = Image.fromarray(image[:,:,::-1])
    draw = ImageDraw.Draw(image)
    anml = animals[i]
    draw.rectangle((anml['boxes'][0] * 72, anml['boxes'][2]*72,␣
 ↪anml['boxes'][1]*72, anml['boxes'][3]*72), outline='black', width=1)
    plt.imshow(image)
    plt.xlabel(e['name'])
    plt.xticks([])
    plt.yticks([])
plt.show() # all objects with their bounding boxes visualized
```



[37]:
```
# storing image with the animals dictionary for easy image access
for class_id, values in animals.items():
    png_file = Image.open(os.path.join('animals', values['file'])).
 ↪convert('RGBA')
    animals[class_id]['image'] = png_file
```

[38]:
```
animals
```

[38]:
```
{0: {'name': 'octopus',
  'file': 'octopus.png',
  'boxes': [0.09722222, 0.90277778, 0.125, 0.81944444],
  'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF3F0115450>},
 1: {'name': 'cat',
  'file': 'cat.png',
  'boxes': [0.04166667, 0.94444444, 0.19444444, 0.79166667],
  'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF3F016AD50>},
 2: {'name': 'cow',
  'file': 'cow.png',
  'boxes': [0.05555556, 0.91666667, 0.26388889, 0.80555556],
  'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF3F0115410>},
 3: {'name': 'tiger',
  'file': 'tiger.png',
  'boxes': [0.04166667, 0.94444444, 0.30555556, 0.79166667],
  'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF384B2B2D0>},
 4: {'name': 'cock',
```

```
 'file': 'cock.png',
 'boxes': [0.13888889, 0.84722222, 0.13888889, 0.86111111],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF383279810>},
5: {'name': 'turtle',
 'file': 'turtle.png',
 'boxes': [0.05555556, 0.93055556, 0.19444444, 0.79166667],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF38327EDD0>},
6: {'name': 'monkey',
 'file': 'monkey.png',
 'boxes': [0.08333333, 0.91666667, 0.11111111, 0.875],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF383285D90>},
7: {'name': 'rat',
 'file': 'rat.png',
 'boxes': [0.05555556, 0.94444444, 0.27777778, 0.875],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF383285D50>},
8: {'name': 'elephant',
 'file': 'elephant.png',
 'boxes': [0.04166667, 0.93055556, 0.20833333, 0.81944444],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF383285C90>},
9: {'name': 'goat',
 'file': 'goat.png',
 'boxes': [0.05555556, 0.90277778, 0.15277778, 0.88888889],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF383285F50>},
10: {'name': 'dog',
 'file': 'dog.png',
 'boxes': [0.05555556, 0.88888889, 0.15277778, 0.875],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF383285ED0>},
11: {'name': 'rabbit',
 'file': 'rabbit.png',
 'boxes': [0.09722222, 0.88888889, 0.125, 0.80555556],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF3F0115510>},
12: {'name': 'cheetah',
 'file': 'cheetah.png',
 'boxes': [0.0, 0.97222222, 0.27777778, 0.79166667],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF383285DD0>},
13: {'name': 'fish',
 'file': 'fish.png',
 'boxes': [0.15277778, 0.90277778, 0.20833333, 0.84722222],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF383285E50>},
14: {'name': 'penguin',
 'file': 'penguin.png',
 'boxes': [0.16666667, 0.83333333, 0.05555556, 0.88888889],
 'image': <PIL.Image.Image image mode=RGBA size=72x72 at 0x7FF3832797D0>}}
```

[39]:
```
# same goes for backgrounds
for img_id, values in backgrounds.items():
```

```
    image = Image.open(os.path.join('backgrounds_320x320', values['file'])).
↪convert('RGB')
    backgrounds[img_id]['image'] = image
```

[40]:
```
backgrounds
```

[40]:
```
{0: {'name': 'image_22',
  'file': 'image_22.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF3832966D0>},
 1: {'name': 'image_1',
  'file': 'image_1.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383290E50>},
 2: {'name': 'image_18',
  'file': 'image_18.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF3832906D0>},
 3: {'name': 'image_2',
  'file': 'image_2.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF3832909D0>},
 4: {'name': 'image_17',
  'file': 'image_17.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296790>},
 5: {'name': 'image_4',
  'file': 'image_4.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296810>},
 6: {'name': 'image_24',
  'file': 'image_24.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296890>},
 7: {'name': 'image_7',
  'file': 'image_7.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF384B61510>},
 8: {'name': 'image_15',
  'file': 'image_15.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296990>},
 9: {'name': 'image_5',
  'file': 'image_5.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296A10>},
 10: {'name': 'image_21',
  'file': 'image_21.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296A90>},
 11: {'name': 'image_9',
  'file': 'image_9.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296A50>},
 12: {'name': 'image_12',
  'file': 'image_12.jpg',
  'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296B50>},
 13: {'name': 'image_11',
  'file': 'image_11.jpg',
```

```
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296BD0>},
14: {'name': 'image_10',
 'file': 'image_10.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296C50>},
15: {'name': 'image_3',
 'file': 'image_3.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296CD0>},
16: {'name': 'image_19',
 'file': 'image_19.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296D50>},
17: {'name': 'image_25',
 'file': 'image_25.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296DD0>},
18: {'name': 'image_8',
 'file': 'image_8.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296E50>},
19: {'name': 'image_23',
 'file': 'image_23.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296690>},
20: {'name': 'image_14',
 'file': 'image_14.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296FD0>},
21: {'name': 'image_13',
 'file': 'image_13.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383290A90>},
22: {'name': 'image_16',
 'file': 'image_16.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF383296F50>},
23: {'name': 'image_20',
 'file': 'image_20.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF38329C110>},
24: {'name': 'image_6',
 'file': 'image_6.jpg',
 'image': <PIL.Image.Image image mode=RGB size=320x320 at 0x7FF38329C190>}}
```

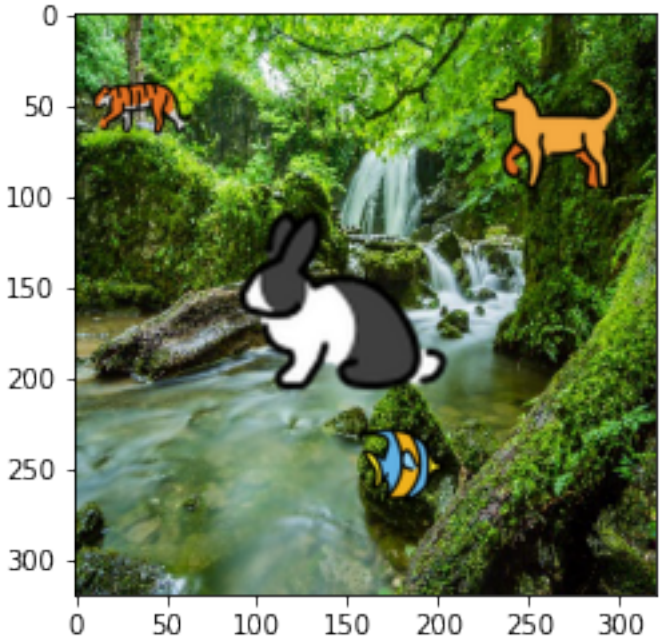
[41]:
```python
# generate random cordinates with random size given a class id
def get_random_cords(class_id):
    size = np.random.randint(50, 160)
    animal_image = animals[class_id]['image'].resize((size, size), Image.
 ↪LANCZOS)
    row = np.random.randint(0, 320-size)
    col = np.random.randint(0, 320-size)

    xmin = col+(animals[class_id]['boxes'][0]*size)
    xmax = col+(animals[class_id]['boxes'][1]*size)
    ymin = row+(animals[class_id]['boxes'][2]*size)
    ymax = row+(animals[class_id]['boxes'][3]*size)
```

```
    return [xmin/320, ymin/320, xmax/320, ymax/320], row, col, animal_image
```

[42]:
```
"""
Creates an image with n number of objects in the image
and returns the generated image along with one hot encoded class array and bbox␣
 ↪array
"""
def create_example(n=4):
    # image = Image.new("RGB", (320, 320), (255, 255, 255))
    image = backgrounds[np.random.randint(0, 25)]['image'].copy()
    # n_objects = np.random.randint(1, 5)
    n_objects = n
    class_ids = []
    xmins = []
    xmaxs = []
    ymins = []
    ymaxs = []
    cords = []

    for _ in range(n_objects):

        class_id = np.random.randint(0, N_CLASSES-1)
        new_cord, row, col, animal_image = get_random_cords(class_id)

        # print(animals[class_id]['name'])
        if(len(cords) > 0):
            pasted = False
            while not pasted:
                if not overlap(np.array(new_cord).reshape(1, 4), np.
 ↪array(cords)):
                    pasted = True
                else:
                    new_cord, row, col, animal_image =␣
 ↪get_random_cords(class_id)

        image.paste(animal_image, (col, row), mask=animal_image.split()[3])

        one_hot_class = [0 for x in range(N_CLASSES)]
        one_hot_class[class_id] = 1
        class_ids.append(one_hot_class)

        cords.append(new_cord)
    return image, class_ids, cords
```

[43]:
```
image, class_ids, bboxes = create_example()
# plt.xlabel(size)
plt.imshow(image)
```

[43]: <matplotlib.image.AxesImage at 0x7ff383256f50>



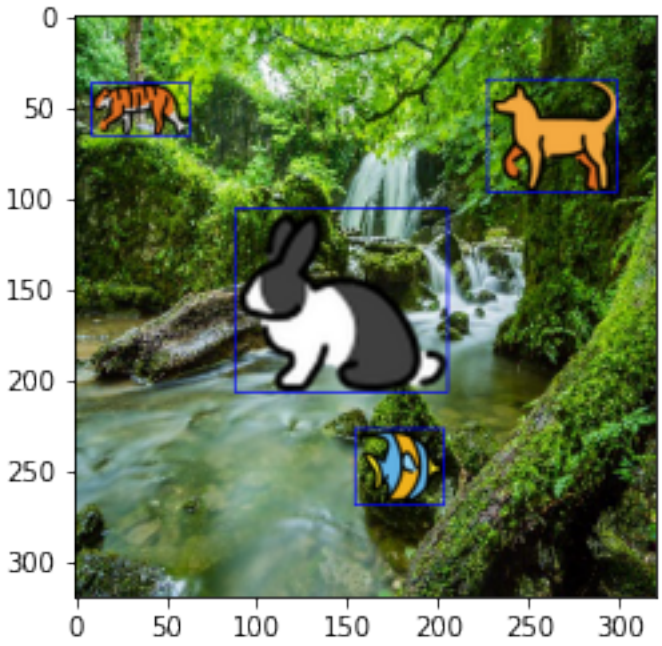
[44]:
```
class_ids, bboxes
```

[44]:
```
([[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0],
  [0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0]],
 [[0.711631945625, 0.11245659781250002, 0.9329861114062499, 0.304296875],
  [0.029687500625000002, 0.11666666750000002, 0.1989583325, 0.207812500625],
  [0.27621527675, 0.3328125, 0.642361111625, 0.6475694465],
  [0.48415798656250003,
   0.71106770765625,
   0.6365017365625001,
   0.8408420134375]])
```

[45]:
```
# plot bboxes around object for confirmation of proper synthetic image is␣
 ↪generated

def plot_bounding_box(image, gt_bbox, norm=False):
    # print(gt_bbox)
    if norm:
        image *= 255
        image = image.astype('uint8')
```

```
    try:
        draw = ImageDraw.Draw(image)
    except:
        image = Image.fromarray(image)
        draw = ImageDraw.Draw(image)

    for i in range(len(gt_bbox)):
        xmin, ymin, xmax, ymax = gt_bbox[i]
        xmin *= 320
        xmax *= 320
        ymin *= 320
        ymax *= 320

        draw.rectangle((xmin, ymin, xmax, ymax), outline='blue', width=1)
    return image
```

[46]:
```
image = plot_bounding_box(image, gt_bbox=bboxes)
plt.imshow(image)
plt.show()
```



[47]:
```
"""
Generates data of given batch size and number of objects
This is the generator function used for training the model with
synthetic data
"""
```

```
def data_generator(batch_size=16, nObjects=4):
    while True:
        x_batch = np.zeros((batch_size, 320, 320, 3))

        bbox_batch = np.zeros((batch_size, nObjects, 4))
        y_batch = np.zeros((batch_size, nObjects, 16))

        for i in range(0, batch_size):
            image, class_ids, bboxes = create_example(nObjects)

            x_batch[i] = np.array(image)/255.
            y_batch[i, :len(class_ids)] = np.array(class_ids)
            # print(np.array(bboxes).shape)
            bbox_batch[i, :len(class_ids)] = np.array(bboxes)
            labels = np.concatenate((bbox_batch, y_batch), axis=2)
        yield {'image': x_batch}, labels
```

[48]:
```
example, label = next(data_generator(6))
x = example['image']
print('image_shape: ', x.shape) # image of shape 320 X 320 X 3
print('label_shape: ', label.shape) # 16 classes and 4 bounding boxes
```

```
image_shape:  (6, 320, 320, 3)
label_shape:  (6, 4, 20)
```

[49]:
```
print('bbox_shape: ', label[:, :, :4].shape) # batch_size * nObjects * 4
label[:, :, :4]
```

```
bbox_shape:  (6, 4, 4)
```

[49]:
```
array([[[0.37604167, 0.43802083, 0.71979167, 0.7359375 ],
        [0.31636285, 0.63710937, 0.55138889, 0.83914931],
        [0.5625    , 0.15555556, 0.75694444, 0.25833333],
        [0.36875   , 0.23315972, 0.68168403, 0.39856771]],

       [[0.26488715, 0.17825521, 0.4453559 , 0.33198785],
        [0.28194445, 0.67048611, 0.58333333, 0.86006945],
        [0.60121528, 0.56271701, 0.80694444, 0.74101562],
        [0.31835938, 0.37630208, 0.71614583, 0.63945313]],

       [[0.52725695, 0.3188368 , 0.71046007, 0.44388021],
        [0.56180556, 0.65277778, 0.83715278, 0.89201389],
        [0.19930556, 0.33194444, 0.58211806, 0.59322917],
        [0.565625  , 0.47118056, 0.92413194, 0.66067708]],

       [[0.71302083, 0.53385417, 0.92135417, 0.67382812],
        [0.43046875, 0.18958333, 0.79765625, 0.52617187],
        [0.30026042, 0.62421875, 0.45494792, 0.75598958],
```

```
        [0.3828125 , 0.20742188, 0.59726563, 0.39375   ]],

       [[0.30234375, 0.10859375, 0.55234375, 0.28046875],
        [0.03949653, 0.11328125, 0.18550347, 0.2391493 ],
        [0.1609809 , 0.54804688, 0.50486111, 0.8436632 ],
        [0.40585938, 0.25963542, 0.66822917, 0.43320313]],

       [[0.115625  , 0.35520833, 0.46197917, 0.53828125],
        [0.6125    , 0.55729167, 0.8875    , 0.90104167],
        [0.59348958, 0.24236111, 0.93463542, 0.55507812],
        [0.67630208, 0.35277778, 0.81432292, 0.47929688]]])
```

Model Architecture

[50]:
```
"""
Model Architecture
-------------------

5 class heads of shapes:

20 x 20 x 64,
10 x 10 x 64,
5 x 5 x 64,
3 x 3 x 64,
1 x 1 x 64
-----------
Total : 535 X 64

This 64 output channel of each head will be rehaped to 4 X 16
 [4 for each anchor box and 16 for classes]
and then stacked to get final class output shape of (2140 X 16)


5 box heads of shapes:

20 x 20 x 16,
10 x 10 x 16,
5 x 5 x 16,
3 x 3 x 16,
1 x 1 x 16
-----------
Total : 535 X 16

This 16 channels will be rehaped to a 4 channel i.e 4 anchors X 4 boxes anchors␣
 ↪being stacked atop
```

```
each other, so the total output shape will be (2140 X 4).



  2140 X 20 where first 4 colums are bboxes and last 16 colums are class␣
 ↪probabilities (not in probabilistic form)

"""
input_ = Input(shape=(320, 320, 3), name='image')


conv2d_1 = Conv2D(16, 3, activation='relu', name='conv2d_1',␣
 ↪padding='same')(input_)
maxpool2d_1 = MaxPool2D(2, name='maxpool2d_1')(conv2d_1)
batchnorm_1 = BatchNormalization(name='batchnorm_1')(maxpool2d_1)


conv2d_2 = Conv2D(32, 3, activation='relu', name='conv2d_2',␣
 ↪padding='same')(batchnorm_1)
maxpool2d_2 = MaxPool2D(2, name='maxpool2d_2')(conv2d_2)
batchnorm_2 = BatchNormalization(name='batchnorm_2')(maxpool2d_2)


conv2d_3 = Conv2D(64, 3, activation='relu', name='conv2d_3',␣
 ↪padding='same')(batchnorm_2)
maxpool2d_3 = MaxPool2D(2, name='maxpool2d_3')(conv2d_3)
batchnorm_3 = BatchNormalization(name='batchnorm_3')(maxpool2d_3)


conv2d_4 = Conv2D(128, 3, activation='relu', name='conv2d_4',␣
 ↪padding='same')(batchnorm_3)
maxpool2d_4 = MaxPool2D(2, name='maxpool2d_4')(conv2d_4) # 20x20x128
batchnorm_4 = BatchNormalization(name='batchnorm_4')(maxpool2d_4)


conv2d_5 = Conv2D(256, 3, activation='relu', name='conv2d_5',␣
 ↪padding='same')(batchnorm_4)
maxpool2d_5 = MaxPool2D(2, name='maxpool2d_5')(conv2d_5) # 10x10x128
batchnorm_5 = BatchNormalization(name='batchnorm_5')(maxpool2d_5)


conv2d_6 = Conv2D(256, 3, activation='relu', name='conv2d_6',␣
 ↪padding='same')(batchnorm_5)
maxpool2d_6 = MaxPool2D(2, name='maxpool2d_6')(conv2d_6) # 5x5x128 output
batchnorm_6 = BatchNormalization(name='batchnorm_6')(maxpool2d_6)
```

```
conv2d_7 = Conv2D(256, 3, activation='relu', name='conv2d_7')(batchnorm_6) #␣
 ↪3x3x128 output
conv2d_8 = Conv2D(512, 3, activation='relu', name='conv2d_8')(conv2d_7) #␣
 ↪1x1x256 output


class_20x20 = Conv2D(64, 3, name='class_20x20', activation='linear',␣
 ↪padding='same')(maxpool2d_4)
class_20x20_reshape = Reshape((-1, 16), name='class_20x20_reshape')(class_20x20)
# class_20x20_reshape_sm = tf.keras.layers.
 ↪Softmax(name='class_20x20_reshape_softmax')(class_20x20_reshape)
box_20x20 = Conv2D(16, 3, name='box_20x20', padding='same')(maxpool2d_4)
box_20x20_reshape = Reshape((-1, 4), name='box_20x20_reshape')(box_20x20)


class_10x10 = Conv2D(64, 3, name='class_10x10', activation='linear',␣
 ↪padding='same')(maxpool2d_5)
class_10x10_reshape = Reshape((-1, 16), name='class_10x10_reshape')(class_10x10)
# class_10x10_reshape_sm = tf.keras.layers.
 ↪Softmax(name='class_10x10_reshape_softmax')(class_10x10_reshape)
box_10x10 = Conv2D(16, 3, name='box_10x10', padding='same')(maxpool2d_5)
box_10x10_reshape = Reshape((-1, 4), name='box_10x10_reshape')(box_10x10)


class_5x5 = Conv2D(64, 3, name='class_5x5', activation='linear',␣
 ↪padding='same')(maxpool2d_6)
class_5x5_reshape = Reshape((-1, 16), name='class_5x5_reshape')(class_5x5)
# class_5x5_reshape_sm = tf.keras.layers.
 ↪Softmax(name='class_5x5_reshape_softmax')(class_5x5_reshape)
box_5x5 = Conv2D(16, 3, name='box_5x5', padding='same')(maxpool2d_6)
box_5x5_reshape = Reshape((-1, 4), name='box_5x5_reshape')(box_5x5)


class_3x3 = Conv2D(64, 3, name='class_3x3', activation='linear',␣
 ↪padding='same')(conv2d_7)
class_3x3_reshape = Reshape((-1, 16), name='class_3x3_reshape')(class_3x3)
# class_3x3_reshape_sm = tf.keras.layers.
 ↪Softmax(name='class_3x3_reshape_softmax')(class_3x3_reshape)
box_3x3 = Conv2D(16, 3, name='box_3x3', padding='same')(conv2d_7)
box_3x3_reshape = Reshape((-1, 4), name='box_3x3_reshape')(box_3x3)


class_1x1 = Conv2D(64, 3, name='class_1x1', activation='linear',␣
 ↪padding='same')(conv2d_8)
class_1x1_reshape = Reshape((-1, 16), name='class_1x1_reshape')(class_1x1)
```

```
# class_1x1_reshape_sm = tf.keras.layers.
 ↪Softmax(name='class_1x1_reshape_softmax')(class_1x1_reshape)
box_1x1 = Conv2D(16, 3, name='box_1x1', padding='same')(conv2d_8)
box_1x1_reshape = Reshape((-1, 4), name='box_1x1_reshape')(box_1x1)




# class_out = Concatenate(axis=1, name='class_out')([class_20x20_reshape_sm,␣
 ↪class_10x10_reshape_sm, class_5x5_reshape_sm, class_3x3_reshape_sm,␣
 ↪class_1x1_reshape_sm])

class_out = Concatenate(axis=1, name='class_out')([class_20x20_reshape,␣
 ↪class_10x10_reshape, class_5x5_reshape, class_3x3_reshape,␣
 ↪class_1x1_reshape])
box_out = Concatenate(axis=1, name='box_out')([box_20x20_reshape,␣
 ↪box_10x10_reshape, box_5x5_reshape, box_3x3_reshape, box_1x1_reshape])

# box_out_reshape = Reshape((-1, 4), name='box_out_reshape')(box_out)
final_output = Concatenate(axis=2, name='final_output')([box_out, class_out])


# model = tf.keras.models.Model(input_, [class_out, box_out])
model = tf.keras.models.Model(input_, final_output)
model.summary()
```

```
Model: "model"
__________________________________________________________________________________
__________________
 Layer (type)                   Output Shape         Param #     Connected to
==================================================================================
==================
 image (InputLayer)             [(None, 320, 320, 3  0           []
                                )]

 conv2d_1 (Conv2D)              (None, 320, 320, 16  448         ['image[0][0]']
                                )

 maxpool2d_1 (MaxPooling2D)     (None, 160, 160, 16  0
['conv2d_1[0][0]']
                                )

 batchnorm_1 (BatchNormalizatio  (None, 160, 160, 16  64
['maxpool2d_1[0][0]']
 n)                             )

 conv2d_2 (Conv2D)              (None, 160, 160, 32  4640
```

```
['batchnorm_1[0][0]']
                                )

 maxpool2d_2 (MaxPooling2D)     (None, 80, 80, 32)   0
['conv2d_2[0][0]']

 batchnorm_2 (BatchNormalizatio  (None, 80, 80, 32)  128
['maxpool2d_2[0][0]']
 n)

 conv2d_3 (Conv2D)              (None, 80, 80, 64)   18496
['batchnorm_2[0][0]']

 maxpool2d_3 (MaxPooling2D)     (None, 40, 40, 64)   0
['conv2d_3[0][0]']

 batchnorm_3 (BatchNormalizatio  (None, 40, 40, 64)  256
['maxpool2d_3[0][0]']
 n)

 conv2d_4 (Conv2D)              (None, 40, 40, 128)  73856
['batchnorm_3[0][0]']

 maxpool2d_4 (MaxPooling2D)     (None, 20, 20, 128)  0
['conv2d_4[0][0]']

 batchnorm_4 (BatchNormalizatio  (None, 20, 20, 128)  512
['maxpool2d_4[0][0]']
 n)

 conv2d_5 (Conv2D)              (None, 20, 20, 256)  295168
['batchnorm_4[0][0]']

 maxpool2d_5 (MaxPooling2D)     (None, 10, 10, 256)  0
['conv2d_5[0][0]']

 batchnorm_5 (BatchNormalizatio  (None, 10, 10, 256)  1024
['maxpool2d_5[0][0]']
 n)

 conv2d_6 (Conv2D)              (None, 10, 10, 256)  590080
['batchnorm_5[0][0]']

 maxpool2d_6 (MaxPooling2D)     (None, 5, 5, 256)    0
['conv2d_6[0][0]']

 batchnorm_6 (BatchNormalizatio  (None, 5, 5, 256)   1024
['maxpool2d_6[0][0]']
```

```
 n)

 conv2d_7 (Conv2D)              (None, 3, 3, 256)    590080
['batchnorm_6[0][0]']

 conv2d_8 (Conv2D)              (None, 1, 1, 512)    1180160
['conv2d_7[0][0]']

 box_20x20 (Conv2D)             (None, 20, 20, 16)   18448
['maxpool2d_4[0][0]']

 box_10x10 (Conv2D)             (None, 10, 10, 16)   36880
['maxpool2d_5[0][0]']

 box_5x5 (Conv2D)               (None, 5, 5, 16)     36880
['maxpool2d_6[0][0]']

 box_3x3 (Conv2D)               (None, 3, 3, 16)     36880
['conv2d_7[0][0]']

 box_1x1 (Conv2D)               (None, 1, 1, 16)     73744
['conv2d_8[0][0]']

 class_20x20 (Conv2D)           (None, 20, 20, 64)   73792
['maxpool2d_4[0][0]']

 class_10x10 (Conv2D)           (None, 10, 10, 64)   147520
['maxpool2d_5[0][0]']

 class_5x5 (Conv2D)             (None, 5, 5, 64)     147520
['maxpool2d_6[0][0]']

 class_3x3 (Conv2D)             (None, 3, 3, 64)     147520
['conv2d_7[0][0]']

 class_1x1 (Conv2D)             (None, 1, 1, 64)     294976
['conv2d_8[0][0]']

 box_20x20_reshape (Reshape)    (None, 1600, 4)      0
['box_20x20[0][0]']

 box_10x10_reshape (Reshape)    (None, 400, 4)       0
['box_10x10[0][0]']

 box_5x5_reshape (Reshape)      (None, 100, 4)       0
['box_5x5[0][0]']

 box_3x3_reshape (Reshape)      (None, 36, 4)        0
```

```
['box_3x3[0][0]']

 box_1x1_reshape (Reshape)      (None, 4, 4)         0
['box_1x1[0][0]']

 class_20x20_reshape (Reshape)  (None, 1600, 16)     0
['class_20x20[0][0]']

 class_10x10_reshape (Reshape)  (None, 400, 16)      0
['class_10x10[0][0]']

 class_5x5_reshape (Reshape)    (None, 100, 16)      0
['class_5x5[0][0]']

 class_3x3_reshape (Reshape)    (None, 36, 16)       0
['class_3x3[0][0]']

 class_1x1_reshape (Reshape)    (None, 4, 16)        0
['class_1x1[0][0]']

 box_out (Concatenate)          (None, 2140, 4)      0
['box_20x20_reshape[0][0]',
'box_10x10_reshape[0][0]',
'box_5x5_reshape[0][0]',
'box_3x3_reshape[0][0]',
'box_1x1_reshape[0][0]']

 class_out (Concatenate)        (None, 2140, 16)     0
['class_20x20_reshape[0][0]',
'class_10x10_reshape[0][0]',
'class_5x5_reshape[0][0]',
'class_3x3_reshape[0][0]',
'class_1x1_reshape[0][0]']

 final_output (Concatenate)     (None, 2140, 20)     0
['box_out[0][0]',
'class_out[0][0]']

==================================================================================
==================
Total params: 3,770,096
Trainable params: 3,768,592
Non-trainable params: 1,504
----------------------------------------------------------------------------------
------------------
```

[51]:
```
tf.keras.utils.plot_model(model, "architecture.png", show_shapes=True,␣
↪show_layer_names=True,
                          show_layer_activations=True, show_dtype=True, dpi=200)
```

[51]:

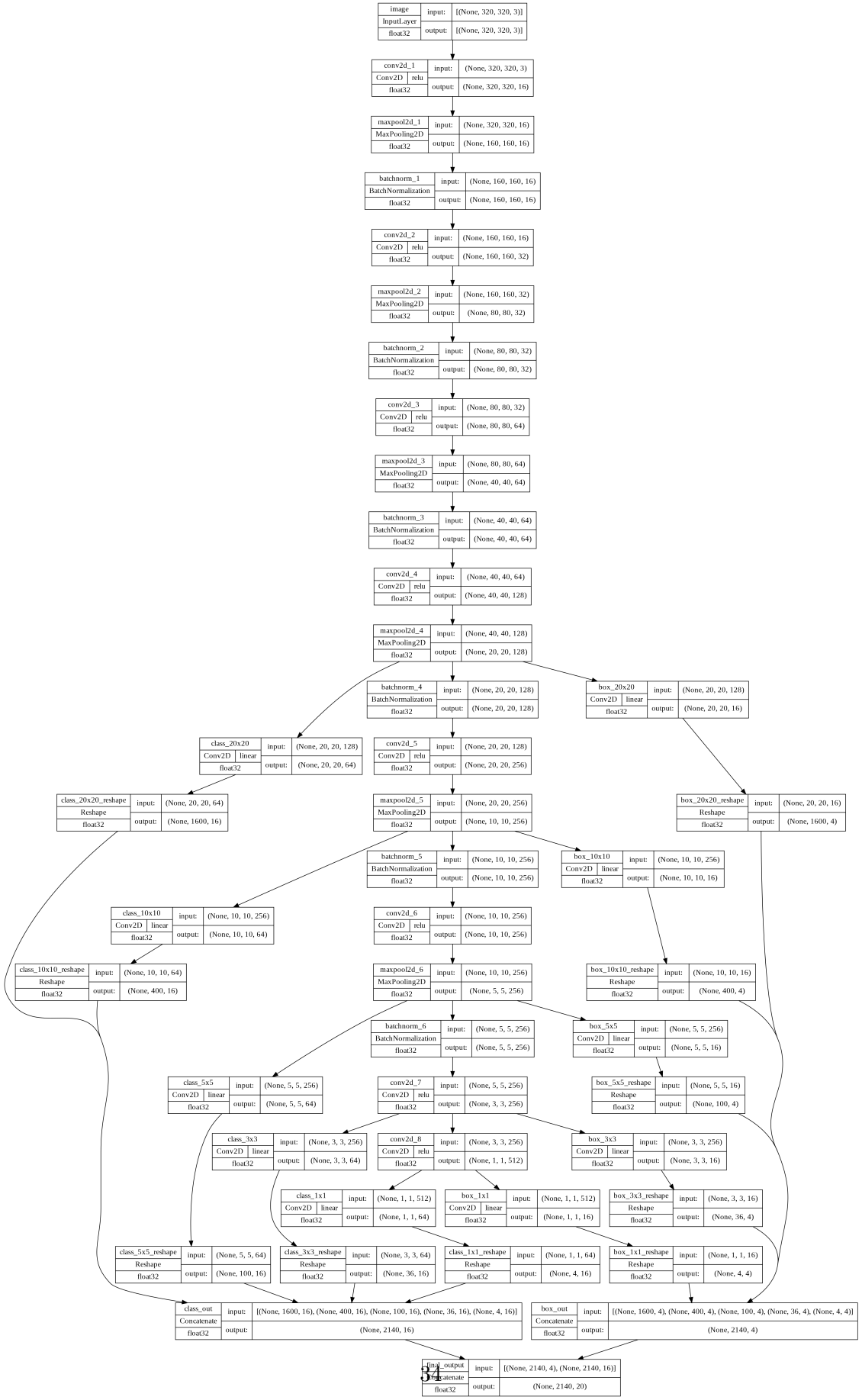


image | InputLayer | float32 | input: [(None, 320, 320, 3)] | output: [(None, 320, 320, 3)]
conv2d_1 | Conv2D | relu | float32 | input: (None, 320, 320, 3) | output: (None, 320, 320, 16)
maxpool2d_1 | MaxPooling2D | float32 | input: (None, 320, 320, 16) | output: (None, 160, 160, 16)
batchnorm_1 | BatchNormalization | float32 | input: (None, 160, 160, 16) | output: (None, 160, 160, 16)
conv2d_2 | Conv2D | relu | float32 | input: (None, 160, 160, 16) | output: (None, 160, 160, 32)
maxpool2d_2 | MaxPooling2D | float32 | input: (None, 160, 160, 32) | output: (None, 80, 80, 32)
batchnorm_2 | BatchNormalization | float32 | input: (None, 80, 80, 32) | output: (None, 80, 80, 32)
conv2d_3 | Conv2D | relu | float32 | input: (None, 80, 80, 32) | output: (None, 80, 80, 64)
maxpool2d_3 | MaxPooling2D | float32 | input: (None, 80, 80, 64) | output: (None, 40, 40, 64)
batchnorm_3 | BatchNormalization | float32 | input: (None, 40, 40, 64) | output: (None, 40, 40, 64)
conv2d_4 | Conv2D | relu | float32 | input: (None, 40, 40, 64) | output: (None, 40, 40, 128)
maxpool2d_4 | MaxPooling2D | float32 | input: (None, 40, 40, 128) | output: (None, 20, 20, 128)
batchnorm_4 | BatchNormalization | float32 | input: (None, 20, 20, 128) | output: (None, 20, 20, 128)
box_20x20 | Conv2D | linear | float32 | input: (None, 20, 20, 128) | output: (None, 20, 20, 16)
class_20x20 | Conv2D | linear | float32 | input: (None, 20, 20, 128) | output: (None, 20, 20, 64)
conv2d_5 | Conv2D | relu | float32 | input: (None, 20, 20, 128) | output: (None, 20, 20, 256)
class_20x20_reshape | Reshape | float32 | input: (None, 20, 20, 64) | output: (None, 1600, 16)
maxpool2d_5 | MaxPooling2D | float32 | input: (None, 20, 20, 256) | output: (None, 10, 10, 256)
box_20x20_reshape | Reshape | float32 | input: (None, 20, 20, 16) | output: (None, 1600, 4)
batchnorm_5 | BatchNormalization | float32 | input: (None, 10, 10, 256) | output: (None, 10, 10, 256)
box_10x10 | Conv2D | linear | float32 | input: (None, 10, 10, 256) | output: (None, 10, 10, 16)
class_10x10 | Conv2D | linear | float32 | input: (None, 10, 10, 256) | output: (None, 10, 10, 64)
conv2d_6 | Conv2D | relu | float32 | input: (None, 10, 10, 256) | output: (None, 10, 10, 256)
class_10x10_reshape | Reshape | float32 | input: (None, 10, 10, 64) | output: (None, 400, 16)
maxpool2d_6 | MaxPooling2D | float32 | input: (None, 10, 10, 256) | output: (None, 5, 5, 256)
box_10x10_reshape | Reshape | float32 | input: (None, 10, 10, 16) | output: (None, 400, 4)
batchnorm_6 | BatchNormalization | float32 | input: (None, 5, 5, 256) | output: (None, 5, 5, 256)
box_5x5 | Conv2D | linear | float32 | input: (None, 5, 5, 256) | output: (None, 5, 5, 16)
class_5x5 | Conv2D | linear | float32 | input: (None, 5, 5, 256) | output: (None, 5, 5, 64)
conv2d_7 | Conv2D | relu | float32 | input: (None, 5, 5, 256) | output: (None, 3, 3, 256)
box_5x5_reshape | Reshape | float32 | input: (None, 5, 5, 16) | output: (None, 100, 4)
class_3x3 | Conv2D | linear | float32 | input: (None, 3, 3, 256) | output: (None, 3, 3, 64)
conv2d_8 | Conv2D | relu | float32 | input: (None, 3, 3, 256) | output: (None, 1, 1, 512)
box_3x3 | Conv2D | linear | float32 | input: (None, 3, 3, 256) | output: (None, 3, 3, 16)
class_1x1 | Conv2D | linear | float32 | input: (None, 1, 1, 512) | output: (None, 1, 1, 64)
box_1x1 | Conv2D | linear | float32 | input: (None, 1, 1, 512) | output: (None, 1, 1, 16)
box_3x3_reshape | Reshape | float32 | input: (None, 3, 3, 16) | output: (None, 36, 4)
class_5x5_reshape | Reshape | float32 | input: (None, 5, 5, 64) | output: (None, 100, 16)
class_3x3_reshape | Reshape | float32 | input: (None, 3, 3, 64) | output: (None, 36, 16)
class_1x1_reshape | Reshape | float32 | input: (None, 1, 1, 64) | output: (None, 4, 16)
box_1x1_reshape | Reshape | float32 | input: (None, 1, 1, 16) | output: (None, 4, 4)
class_out | Concatenate | float32 | input: [(None, 1600, 16), (None, 400, 16), (None, 100, 16), (None, 36, 16), (None, 4, 16)] | output: (None, 2140, 16)
box_out | Concatenate | float32 | input: [(None, 1600, 4), (None, 400, 4), (None, 100, 4), (None, 36, 4), (None, 4, 4)] | output: (None, 2140, 4)
final_output | Concatenate | float32 | input: [(None, 2140, 4), (None, 2140, 16)] | output: (None, 2140, 20)

Load pre trained weights if you want directly to go for inferencing

[64]:
```
# load pre trained weights if you want to directly go for inferencing
model.load_weights('/content/weights/epoch_latest.model')
```

[64]:
```
<tensorflow.python.training.tracking.util.CheckpointLoadStatus at
0x7ff3828957d0>
```

[53]:
```
batch_size = 1
example, label = next(data_generator(batch_size))
x = example['image']

pred = model.predict(x)
print('predicted: ', pred.shape)


bbox_labels, bbox_masks, cls_labels = multibox_target(anchors, label[:, :, 4:],␣
 ↪label[:, :, :4])
print('generated_labels_wrt_anchors: ', bbox_labels.shape, bbox_masks.shape,␣
 ↪cls_labels.shape)
```

```
/usr/local/lib/python3.7/dist-
packages/tensorflow/python/data/ops/structured_function.py:265: UserWarning:
Even though the `tf.config.experimental_run_functions_eagerly` option is set,
this option does not apply to tf.data functions. To force eager execution of
tf.data functions, please use `tf.data.experimental.enable_debug_mode()`.
  "Even though the `tf.config.experimental_run_functions_eagerly` "

1/1 [==============================] - 7s 7s/step
predicted:  (1, 2140, 20)
generated_labels_wrt_anchors:  (1, 8560) (1, 8560) (1, 2140, 16)
```

Inferencing functions

[54]:
```
"""
One of the most important function for post processing the multiple same class
overlapping output boxes. Check comments inside function for details
"""
def non_max_supression(sortedArr):
    final_list = np.array([sortedArr[0]])
    sortedArr = sortedArr[1:]
    for element in sortedArr:

        # if same class is already present in target list
        if element[0] in final_list[:, 0]:

            # get the indexes of all present same elements
```

```
            indexes_present = np.where(final_list[:, 0]==element[0])[0]

            # calclulate iou for all present same class element
            # print('indexes_present: ', indexes_present)
            # print('shapes: ', element[2:].reshape(1, 4).shape,␣
 ↪final_list[indexes_present, 2:].shape)
            ious = box_iou(element[2:].reshape(1, 4),␣
 ↪final_list[indexes_present, 2:])

            # get indexes of all ious above 0.5
            # print('ious: ', ious)
            ious_indexes = np.where(ious[0, :] > 0.5)[0]

            # if there is no element present which alraedy has an iou of
            # over 0.5 with current element then push it
            # print('ious_indexes: ', ious_indexes)
            if ious_indexes.size == 0:
                final_list = np.vstack([final_list, element])
        else:
            final_list = np.vstack([final_list, element])

    return final_list
```

[55]:
```
# generate random image and perform inference on it with visual outputs

def test_predictions():

    n_objects = 4
    image, labels = next(data_generator(1, n_objects))
    predicted = model.predict(image)

    predicted_cls, predicted_box = predicted[:, :, 4:], predicted[:, :, :4]
    bbox_labels, bbox_masks, cls_labels = multibox_target(anchors, labels[:, :,␣
 ↪4:], labels[:, :, :4])

    inversed_pred_boxes = offset_inverse(anchors[0], predicted_box[0])

    predicted_cls = tf.nn.softmax(predicted_cls[0])
    class_ids = np.argmax(predicted_cls, axis=1)
    class_prob = []

    for idx, cls_id in enumerate(class_ids):
        class_prob.append([cls_id, predicted_cls[idx][cls_id]])

    class_prob = np.array(class_prob)

    combined = np.concatenate([class_prob, inversed_pred_boxes], axis=1)
```

```
    # print('shape: ', combined.shape)
    indexes = np.where((combined[:, 0] < 15) & (combined[:, 1] > 0.1))
    combined = combined[indexes].astype(np.float16)
    sortedArr = combined[combined[:,1].argsort()][::-1]
    if sortedArr.shape[0] == 0:
        return  draw_boxes(sortedArr, image['image'][0], display_label=True)
    detetctions = non_max_supression(sortedArr)
    # for x in detetctions[:, 0]:
    #     print(animals[x]['name'])
    painted_img = draw_boxes(detetctions, image['image'][0], display_label=True)

    return painted_img
```

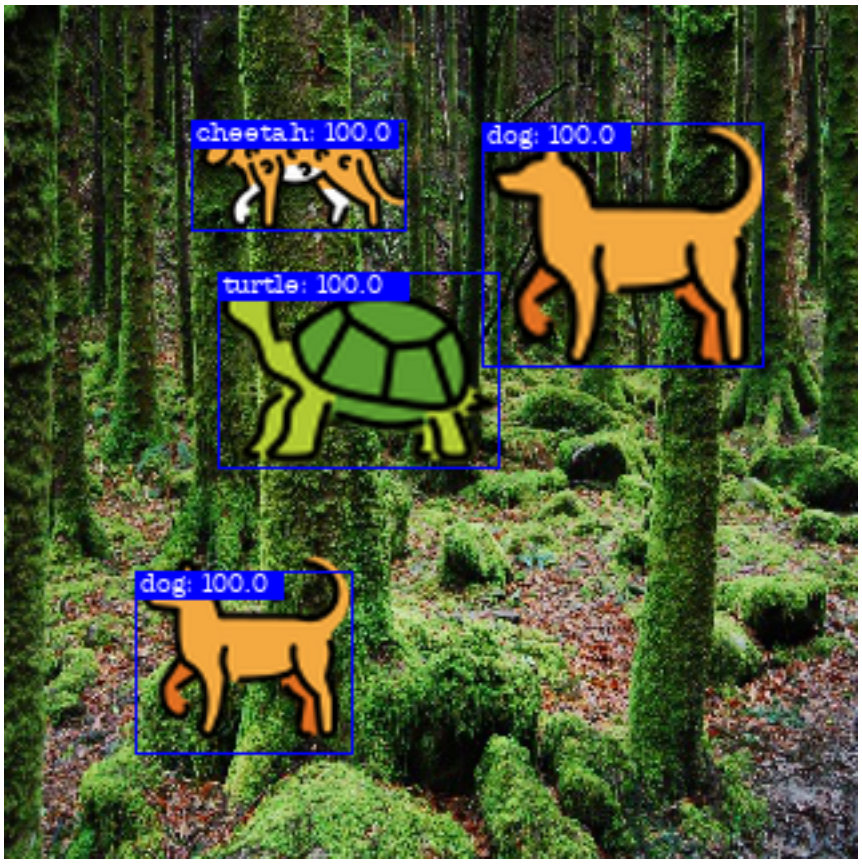
[56]:
```
def draw_boxes(boxes, image, display_label=True):

    cv2.imwrite('test.png', image * 255)
    image = cv2.imread('test.png')

    size = image.shape[0]
    boxes = boxes * size
    image = Image.fromarray(image)
    draw = ImageDraw.Draw(image)

    # if the values are ground truth
    if(boxes.shape[1] == 5):
        for box in boxes:
            draw.rectangle((box[1], box[2], box[3], box[4]), outline='red',␣
↪width=1)
            if display_label:
                text = animals[box[0]/size]['name']
                draw.rectangle((box[1], box[2], box[1] + len(text)*6.5,␣
↪box[2]+10), fill='red', width=1)
                draw.text((box[1]+2, box[2]-2), text, 'white', font=font)

    # if the values are predicted
    else:
        for box in boxes:
            draw.rectangle((box[2], box[3], box[4], box[5]), outline='blue',␣
↪width=1)
            if display_label:
                text = animals[box[0]/size]['name'] + ': ' + str(box[1]/size *␣
↪1000 // 1 / 10)
                draw.rectangle((box[2], box[3], box[2] + len(text)*5.5,␣
↪box[3]+10), fill='blue', width=1)
                draw.text((box[2]+2, box[3]-2), text, 'white', font=font)
```

```
    return image
```

[57]:
```
test_predictions()
```

```
1/1 [==============================] - 0s 36ms/step
```

[57]:



[57]:
```
```

[58]:
```
def test(model):
    plt.figure(figsize=(32, 8))
    for i in range(0, 4):
        plt.subplot(1, 4, i+1)
        plt.imshow(test_predictions())
    plt.show()
```

helper functions for training and TRAINING..

[59]:
```
# callback function for Image inferencing during training
class testImages(tf.keras.callbacks.Callback):
    def on_epoch_end(self, epoch, logs=None):
        test(self.model)
```

[60]:
```
# callback function for saving checkpoints during training
class saveCheckpoint(tf.keras.callbacks.Callback):
    def on_epoch_end(self, epoch, logs=None):
        model.save_weights('/content/drive/MyDrive/customOD/weights291022/
 ↪epoch_latest.model')
```

[63]:
```
test(model)
```

```
1/1 [==============================] - 0s 49ms/step
1/1 [==============================] - 0s 37ms/step
1/1 [==============================] - 0s 40ms/step
1/1 [==============================] - 0s 34ms/step
```

[244]:
```
"""
while calculating box accuracy if we consider all 2140 outputs then most of␣
 ↪them has zero values in both predicted
and ground truth boxes so it will lead to very high box accuracy even when␣
 ↪thats not the case
"""

def calc_box_accuracy(pred_class, pred_box, bbox_labels):
    batchwise_loss = []
    batch_size = pred_class.shape[0]
    for i in range(batch_size):
        indexes = tf.where(tf.argmax(pred_class[i, :, :], axis=1) != 15)
        if(indexes.shape[0] == 0):
            continue
        box_indexes = tf.convert_to_tensor([indexes*4, indexes*4+1,␣
 ↪indexes*4+2, indexes*4+3]).reshape(-1)
        batchwise_loss.append(tf.abs(bbox_labels[i, box_indexes] - pred_box[i,␣
 ↪box_indexes]).numpy().sum() / box_indexes.shape[0])

    if len(batchwise_loss) == 0:
        return 1.9
    return np.array(batchwise_loss).astype(np.float16).mean()
```

[245]:
```
"""
Custom loss function for:
Calculating and Logging class, box losses and accuracy metrics

Both are being done at same place to save resources calculating same thing in
multiple places
"""

accuracy = tf.keras.metrics.CategoricalAccuracy()

box_loss_log = []
class_loss_log = []
box_accuracy_log = []
class_accuracy_log = []

def custom_loss(label, pred):

    # extract the predicted and ground truth boxes and classes
    label_box = label[:, :, :4]
    label_class = label[:, :, 4:]

    batch_size = pred.shape[0]

    pred_box = pred[:, :, :4].reshape(-1, 8560)
    pred_class = pred[:, :, 4:]


    # get the ground truth lables dimensions changed to prediction dimensions␣
↪by using anchors
    bbox_labels, bbox_masks, cls_labels = multibox_target(anchors, label_class,␣
↪label_box)

    # calculate losses
    bbox_loss = tf.keras.metrics.mean_squared_error(bbox_labels * bbox_masks,␣
↪pred_box * bbox_masks).mean()

    """
    For class loss the classes are not already softmaxed from model so they are␣
↪passed
    through "softmax_cross_entropy_with_logits" which calculates the softmax␣
↪inplace and calculates
    loss using it in accurate manner

    For class loss all the 2140 predictions are used for loss calculation␣
↪because any class which is background
    and not classified as background needs to be punished and vice-versa
```

```
    while in the case of box loss only the masked boxes (masked boxes are those␣
 ↪anchor boxes which has a probability that
    it contains an object) are considered for loss calculation
    because whatever value the unwanted predicted boxes have doesnt matters␣
 ↪here and considering them will
    incur unwanted loss addition in training
    """
    class_loss = tf.nn.softmax_cross_entropy_with_logits(cls_labels,␣
 ↪pred_class).mean()

    # calculate accuracies
    accuracy.update_state(cls_labels, pred_class)
    box_accuracy = 1 - calc_box_accuracy(pred_class, pred_box, bbox_labels)

    # log the metrices
    box_loss_log.append(bbox_loss.numpy())
    class_loss_log.append(class_loss.numpy())
    box_accuracy_log.append(box_accuracy)
    class_accuracy_log.append(accuracy.result().numpy())


    # print metrices
    print('\n\nbox_loss: ', bbox_loss.numpy())
    print('class_loss: ', class_loss.numpy())

    print('class_accuracy: ', accuracy.result().numpy())
    print('bbox_accuracy: ', box_accuracy)

    # return total loss for proper model convergence
    return class_loss + bbox_loss
```

[246]:
```
""" For Experimnets """
lab_cls = np.zeros((4, 2140, 16))
for k in range(4):
    for i in range(2140):
        # if(i%4==0):
        #     continue
        lab_cls[k, i, np.random.randint(0, 16)] = 1

# lab_cls
prd_cls = np.random.randint(-10, 15, [4, 2140, 16])/10
prd_cls = tf.nn.softmax(prd_cls, axis=2)

# for i in range(4):
#     # print(tf.argmax(lab_cls[i, :, :], axis=1) == 15)
```

```
#     indexes = tf.where(tf.argmax(lab_cls[i, :, :], axis=1) == 15)
#     print(indexes)
    # print(tf.convert_to_tensor([indexes*4, indexes*4+1, indexes*4+2,␣
 ↪indexes*4+3]).reshape(-1))
# tf.stack([indexes, indexes[:, 1] * 4], axis=0)

# print(prd_cls[0, :5, :])
# print(lab_cls[0, :5, :])
# print(tf.nn.softmax(prd_cls[0, :1, :]).numpy().sum())

# # m = tf.keras.metrics.Accuracy()
# # m.update_state([1.00, 0.00, 0.00, 0.00], [0.99, 0.05, 0.004, 0.001])
# # m.result().numpy()

# # tf.keras.metrics.mean_absolute_error([1, 0, 0, 0], [0.99, 0.005, 0.004, 0.
 ↪001])
# m = tf.keras.metrics.CategoricalAccuracy()
# m.update_state(lab_cls, prd_cls)
# m.result().numpy()

# 1 - tf.keras.metrics.mean_absolute_error(lab_cls[0, :5, :], prd_cls[0, :5, :
 ↪]).mean().numpy()
```

[247]:
```
"""
Only one custom loss is used to calculate loss, metrics
displaying them and storing them in list. ALL these tasks are handled by a␣
 ↪single
function "custom_loss"
"""
keras.losses.custom_loss = custom_loss
model.compile(
    loss = 'custom_loss',
    optimizer = tf.keras.optimizers.Adam(learning_rate=0.0001),
)
```

[248]:
```
def lr_schedule(epoch, lr):
    if (epoch+1) % 5 == 0:
        lr = lr*0.8
    return max(lr, 0.0000003)
```

[ ]:
```
"""
Train the model with callbacks for periodically saving checkpoints,
showing outputs at the end of each epoch
"""

history = model.fit(
    data_generator(32),
```

```
    epochs = 50,
    steps_per_epoch = 100,
    callbacks = [
        tf.keras.callbacks.LearningRateScheduler(lr_schedule),
        saveCheckpoint(),
        testImages()

    ]
)
```

[ ]:
```
# all the losses and metrics below can be accessed and plotted as desired
np.array(class_loss_log)
np.array(box_loss_log)
np.array(box_accuracy_log)
np.array(class_accuracy_log)
```

[ ]:
```
"""
Save the model if you wish to...
"""
# %mkdir saved_model_back
# model.save_weights('saved_model_back/epoch20.model')
# !zip -r 'saved_model_back.zip' 'saved_model_back'
```

```
  adding: saved_model_back/ (stored 0%)
  adding: saved_model_back/epoch20.model.data-00000-of-00001 (deflated 40%)
  adding: saved_model_back/checkpoint (deflated 41%)
  adding: saved_model_back/epoch20.model.index (deflated 77%)
```

Inside inference logic

How each line of inferencing works will be explained below.

[278]:
```
# generate an image with n no. of objects and batch_size of 1 ( don't change␣
↪the
# batch size as the logic is written only for single batch)

n_objects = 6
image, labels = next(data_generator(1, n_objects))
predicted = model.predict(image) # perform prediction on the generated image
```

```
1/1 [==============================] - 0s 41ms/step

/usr/local/lib/python3.7/dist-
packages/tensorflow/python/data/ops/structured_function.py:265: UserWarning:
Even though the `tf.config.experimental_run_functions_eagerly` option is set,
this option does not apply to tf.data functions. To force eager execution of
tf.data functions, please use `tf.data.experimental.enable_debug_mode()`.
  "Even though the `tf.config.experimental_run_functions_eagerly` "
```

[279]:
```
"""The predicted object has a shape of 2140 rows and 20 columns.
first 4 columns are bounding boxes in format (xmin, ymin, xmax, ymax)
and the remaining 16 are class predictions
"""

print('predicted_shape: ', predicted.shape)
predicted_cls, predicted_box = predicted[:, :, 4:], predicted[:, :, :4] #␣
 ↪spereate bbox and classes from prediction
bbox_labels, bbox_masks, cls_labels = multibox_target(anchors, labels[:, :, 4:
 ↪], labels[:, :, :4]) # seperate bbox and classes from ground truth
```

```
predicted_shape:  (1, 2140, 20)
```

[280]:
```
# respective class ids with its bounding boxes

label_box = np.hstack([np.argmax(labels[:, :, 4:], axis=2).reshape(n_objects,␣
 ↪1), labels[0, :, :4]])
label_box
```

[280]:
```
array([[ 4.        ,  0.17595486,  0.45720486,  0.48363715,  0.77092014],
       [12.        ,  0.1625    ,  0.77829861,  0.41467014,  0.91158854],
       [ 1.        ,  0.34856771,  0.6672743 ,  0.58836805,  0.82591146],
       [11.        ,  0.08190104,  0.25351563,  0.34166667,  0.47682292],
       [11.        ,  0.73802083,  0.6921875 ,  0.94583333,  0.87083333],
       [11.        ,  0.51419271,  0.10664063,  0.65520833,  0.22786458]])
```

[281]:
```
# as we know the predictions are actually offsets of default anchors so
# it needs to pass through offset_inverse to get back the required bbox values

inversed_pred_boxes = offset_inverse(anchors[0], predicted_box[0])
inversed_pred_boxes.shape
```

[281]:
```
TensorShape([2140, 4])
```

[282]:
```
# our model is not doing a softmax operation on predicted classes so a softmax␣
 ↪is needed before
# proceeding
predicted_cls = tf.nn.softmax(predicted_cls[0])

# get the predicted class of row i.e. the highest value index of each row
class_ids = np.argmax(predicted_cls, axis=1)

# create a pair of classes and respective probability score
class_prob = []
for idx, cls_id in enumerate(class_ids):
    class_prob.append([cls_id, predicted_cls[idx][cls_id]])

class_prob = np.array(class_prob)
```

```
print(class_prob.shape)
```

```
(2140, 2)
```

[283]:
```
# join bboxes and class, score arrays together to get required 6 columned array
combined = np.concatenate([class_prob, inversed_pred_boxes], axis=1)
print('shape: ', combined.shape) # shape of combined class probabilities and␣
 ↪predicted bounding boxes

# get indexes of rows where the predicted class is not background and the␣
 ↪confidence
# is greater than 50% (can be any value of our choice)
indexes = np.where((combined[:, 0] < 15) & (combined[:, 1] > 0.5))
combined = combined[indexes].astype(np.float16)
combined # this is the array which contains all our required objects but␣
 ↪overlapped with
# multiple instances of same object
```

```
shape:  (2140, 6)
```

[283]:
```
array([[11.    ,  0.848 ,  0.5044 ,  0.0973 ,  0.654 ,  0.2288 ],
       [11.    ,  0.992 ,  0.5093 ,  0.1101 ,  0.651 ,  0.2302 ],
       [11.    ,  0.995 ,  0.5195 ,  0.1183 ,  0.652 ,  0.2294 ],
       [11.    ,  0.792 ,  0.514  ,  0.1186 ,  0.653 ,  0.2279 ],
       [11.    ,  0.963 ,  0.5166 ,  0.1102 ,  0.6567 ,  0.2246 ],
       [11.    ,  0.5005 ,  0.5156 ,  0.1048 ,  0.645 ,  0.223  ],
       [11.    ,  0.927 ,  0.0721 ,  0.2502 ,  0.3384 ,  0.4768 ],
       [11.    ,  0.951 ,  0.08105,  0.2632 ,  0.3347 ,  0.4824 ],
       [11.    ,  0.9644 ,  0.0836 ,  0.2551 ,  0.3472 ,  0.4746 ],
       [11.    ,  1.    ,  0.0847 ,  0.2546 ,  0.355 ,  0.4785 ],
       [11.    ,  1.    ,  0.0901 ,  0.2534 ,  0.3533 ,  0.4763 ],
       [11.    ,  1.    ,  0.0951 ,  0.256  ,  0.3489 ,  0.4768 ],
       [11.    ,  0.996 ,  0.07776,  0.2522 ,  0.3474 ,  0.4775 ],
       [11.    ,  1.    ,  0.0787 ,  0.2496 ,  0.3442 ,  0.4739 ],
       [11.    ,  1.    ,  0.0757 ,  0.253  ,  0.346 ,  0.4785 ],
       [11.    ,  1.    ,  0.0749 ,  0.2554 ,  0.345 ,  0.4788 ],
       [11.    ,  0.852 ,  0.07855,  0.245  ,  0.344 ,  0.4712 ],
       [11.    ,  0.7046 ,  0.07025,  0.238  ,  0.3552 ,  0.4802 ],
       [11.    ,  0.991 ,  0.07245,  0.2429 ,  0.34 ,  0.469  ],
       [11.    ,  0.945 ,  0.07996,  0.2466 ,  0.3398 ,  0.463  ],
       [11.    ,  1.    ,  0.0783 ,  0.2474 ,  0.3582 ,  0.4783 ],
       [11.    ,  1.    ,  0.0842 ,  0.2512 ,  0.3542 ,  0.476  ],
       [11.    ,  1.    ,  0.0856 ,  0.2498 ,  0.357 ,  0.4763 ],
       [11.    ,  1.    ,  0.0856 ,  0.2473 ,  0.354 ,  0.4758 ],
       [11.    ,  1.    ,  0.0768 ,  0.2493 ,  0.347 ,  0.474  ],
       [11.    ,  1.    ,  0.0812 ,  0.2544 ,  0.3413 ,  0.4724 ],
       [11.    ,  1.    ,  0.0806 ,  0.2478 ,  0.3438 ,  0.4739 ],
       [11.    ,  1.    ,  0.0821 ,  0.2483 ,  0.3433 ,  0.473  ],
```

```
[11.     ,  0.9985 ,  0.06396,  0.2466 ,  0.3364 ,  0.4758 ],
[11.     ,  1.     ,  0.0678 ,  0.2457 ,  0.3337 ,  0.4717 ],
[11.     ,  0.994  ,  0.0722 ,  0.2452 ,  0.3352 ,  0.4702 ],
[11.     ,  0.9995 ,  0.088  ,  0.2454 ,  0.364  ,  0.4727 ],
[11.     ,  0.8657 ,  0.0665 ,  0.252  ,  0.351  ,  0.481  ],
[11.     ,  0.5635 ,  0.06107,  0.2544 ,  0.343  ,  0.4854 ],
[11.     ,  1.     ,  0.06976,  0.2563 ,  0.322  ,  0.4824 ],
[11.     ,  0.9956 ,  0.0832 ,  0.2434 ,  0.3525 ,  0.4834 ],
[11.     ,  0.998  ,  0.08307,  0.2468 ,  0.3552 ,  0.4863 ],
[ 4.     ,  0.918  ,  0.167  ,  0.4656 ,  0.4663 ,  0.7617 ],
[ 4.     ,  0.992  ,  0.1765 ,  0.4531 ,  0.4802 ,  0.752  ],
[ 4.     ,  0.8794 ,  0.1941 ,  0.4656 ,  0.484  ,  0.7495 ],
[ 4.     ,  1.     ,  0.1825 ,  0.452  ,  0.4868 ,  0.781  ],
[ 4.     ,  0.866  ,  0.1644 ,  0.458  ,  0.479  ,  0.7695 ],
[ 4.     ,  1.     ,  0.1772 ,  0.4631 ,  0.479  ,  0.7773 ],
[ 4.     ,  0.9434 ,  0.1727 ,  0.4575 ,  0.4717 ,  0.7695 ],
[ 4.     ,  0.971  ,  0.1699 ,  0.4553 ,  0.4795 ,  0.776  ],
[ 4.     ,  1.     ,  0.179  ,  0.4617 ,  0.4785 ,  0.776  ],
[ 4.     ,  0.9414 ,  0.1884 ,  0.4634 ,  0.4841 ,  0.7656 ],
[ 4.     ,  0.997  ,  0.1715 ,  0.4624 ,  0.478  ,  0.7715 ],
[ 4.     ,  1.     ,  0.1831 ,  0.459  ,  0.4802 ,  0.7744 ],
[ 4.     ,  0.956  ,  0.175  ,  0.4658 ,  0.4817 ,  0.768  ],
[ 4.     ,  0.9854 ,  0.1781 ,  0.4717 ,  0.4773 ,  0.7725 ],
[ 4.     ,  1.     ,  0.1798 ,  0.4639 ,  0.4802 ,  0.777  ],
[ 4.     ,  0.9937 ,  0.1753 ,  0.4705 ,  0.4666 ,  0.7695 ],
[ 4.     ,  0.973  ,  0.1714 ,  0.4688 ,  0.473  ,  0.778  ],
[ 4.     ,  0.988  ,  0.1932 ,  0.4749 ,  0.4792 ,  0.7695 ],
[ 4.     ,  1.     ,  0.1825 ,  0.474  ,  0.4778 ,  0.777  ],
[ 4.     ,  0.8154 ,  0.1936 ,  0.4731 ,  0.4778 ,  0.765  ],
[ 4.     ,  0.6475 ,  0.2072 ,  0.4824 ,  0.503  ,  0.777  ],
[ 4.     ,  1.     ,  0.1794 ,  0.4507 ,  0.4785 ,  0.7607 ],
[ 4.     ,  0.9995 ,  0.1741 ,  0.4614 ,  0.4912 ,  0.773  ],
[ 4.     ,  0.8037 ,  0.1859 ,  0.4922 ,  0.4885 ,  0.782  ],
[ 4.     ,  0.9517 ,  0.1877 ,  0.4893 ,  0.4954 ,  0.7837 ],
[ 4.     ,  0.9854 ,  0.1832 ,  0.4736 ,  0.515  ,  0.788  ],
[ 1.     ,  0.732  ,  0.3398 ,  0.663  ,  0.5825 ,  0.835  ],
[ 1.     ,  0.999  ,  0.3389 ,  0.6597 ,  0.584  ,  0.8325 ],
[ 1.     ,  0.9995 ,  0.3447 ,  0.6553 ,  0.588  ,  0.827  ],
[ 1.     ,  0.9756 ,  0.3455 ,  0.6675 ,  0.5894 ,  0.824  ],
[ 1.     ,  1.     ,  0.3542 ,  0.6694 ,  0.5967 ,  0.8247 ],
[ 1.     ,  1.     ,  0.3538 ,  0.663  ,  0.598  ,  0.824  ],
[ 1.     ,  1.     ,  0.347  ,  0.6655 ,  0.5786 ,  0.8257 ],
[ 1.     ,  1.     ,  0.338  ,  0.6626 ,  0.5757 ,  0.825  ],
[11.     ,  0.9995 ,  0.7466 ,  0.695  ,  0.9453 ,  0.8716 ],
[11.     ,  0.8223 ,  0.744  ,  0.699  ,  0.942  ,  0.8696 ],
[11.     ,  0.9995 ,  0.7354 ,  0.69   ,  0.936  ,  0.872  ],
[11.     ,  0.9814 ,  0.74   ,  0.702  ,  0.9365 ,  0.871  ],
```

```
       [11.     ,  0.848  ,  0.743  ,  0.687  ,  0.942  ,  0.865  ],
       [ 1.     ,  0.9033 ,  0.356  ,  0.6636 ,  0.585  ,  0.82   ],
       [ 1.     ,  0.999  ,  0.348  ,  0.6587 ,  0.589  ,  0.816  ],
       [ 1.     ,  0.9995 ,  0.352  ,  0.659  ,  0.598  ,  0.814  ],
       [ 1.     ,  0.9927 ,  0.3438 ,  0.6675 ,  0.6016 ,  0.8228 ],
       [ 1.     ,  1.     ,  0.3506 ,  0.6675 ,  0.598  ,  0.8247 ],
       [ 1.     ,  1.     ,  0.354  ,  0.666  ,  0.6016 ,  0.824  ],
       [ 1.     ,  0.9985 ,  0.345  ,  0.6675 ,  0.5757 ,  0.826  ],
       [ 1.     ,  0.999  ,  0.3442 ,  0.665  ,  0.5806 ,  0.825  ],
       [11.     ,  0.992  ,  0.7363 ,  0.6855 ,  0.9404 ,  0.8687 ],
       [11.     ,  0.999  ,  0.736  ,  0.6865 ,  0.945  ,  0.8677 ],
       [11.     ,  1.     ,  0.74   ,  0.6953 ,  0.943  ,  0.868  ],
       [11.     ,  1.     ,  0.7383 ,  0.696  ,  0.9424 ,  0.873  ],
       [11.     ,  1.     ,  0.7427 ,  0.694  ,  0.9434 ,  0.8735 ],
       [11.     ,  1.     ,  0.7437 ,  0.6934 ,  0.9453 ,  0.8687 ],
       [11.     ,  1.     ,  0.7446 ,  0.691  ,  0.944  ,  0.8706 ],
       [11.     ,  1.     ,  0.7456 ,  0.6895 ,  0.942  ,  0.869  ],
       [11.     ,  0.8423 ,  0.749  ,  0.6997 ,  0.9546 ,  0.8755 ],
       [12.     ,  0.8    ,  0.1614 ,  0.7744 ,  0.3962 ,  0.9106 ],
       [12.     ,  0.9995 ,  0.159  ,  0.7793 ,  0.398  ,  0.9077 ],
       [12.     ,  1.     ,  0.1704 ,  0.7803 ,  0.4055 ,  0.9062 ],
       [12.     ,  1.     ,  0.1729 ,  0.782  ,  0.411  ,  0.9106 ],
       [12.     ,  1.     ,  0.1606 ,  0.787  ,  0.418  ,  0.921  ],
       [12.     ,  1.     ,  0.1647 ,  0.787  ,  0.4138 ,  0.9185 ],
       [12.     ,  0.6426 ,  0.1754 ,  0.77   ,  0.446  ,  0.9067 ],
       [11.     ,  1.     ,  0.742  ,  0.696  ,  0.9478 ,  0.877  ],
       [11.     ,  1.     ,  0.74   ,  0.689  ,  0.9414 ,  0.8687 ],
       [11.     ,  1.     ,  0.74   ,  0.6885 ,  0.9424 ,  0.868  ],
       [11.     ,  0.999  ,  0.737  ,  0.6934 ,  0.942  ,  0.878  ],
       [11.     ,  1.     ,  0.737  ,  0.6934 ,  0.9453 ,  0.879  ],
       [11.     ,  0.999  ,  0.738  ,  0.694  ,  0.9478 ,  0.875  ],
       [12.     ,  0.6094 ,  0.1676 ,  0.7764 ,  0.398  ,  0.9175 ],
       [12.     ,  0.929  ,  0.165  ,  0.7793 ,  0.4048 ,  0.916  ],
       [12.     ,  1.     ,  0.1675 ,  0.783  ,  0.406  ,  0.907  ],
       [12.     ,  1.     ,  0.1694 ,  0.7827 ,  0.4102 ,  0.909  ],
       [12.     ,  1.     ,  0.1615 ,  0.779  ,  0.4194 ,  0.9062 ],
       [12.     ,  1.     ,  0.1714 ,  0.779  ,  0.4211 ,  0.9062 ],
       [11.     ,  0.627  ,  0.7446 ,  0.6807 ,  0.9443 ,  0.86   ]],
      dtype=float16)
```

[284]:
```
# same array sorted in descending order of score
sortedArr = combined[combined[:,1].argsort()][::-1]
sortedArr
```

[284]:
```
array([[11.     ,  1.     ,  0.0847 ,  0.2546 ,  0.355  ,  0.4785 ],
       [11.     ,  1.     ,  0.0783 ,  0.2474 ,  0.3582 ,  0.4783 ],
       [ 4.     ,  1.     ,  0.1794 ,  0.4507 ,  0.4785 ,  0.7607 ],
```

```
[ 4.     ,  1.     ,  0.1825 ,  0.452  ,  0.4868 ,  0.781  ],
[11.     ,  1.     ,  0.0821 ,  0.2483 ,  0.3433 ,  0.473  ],
[11.     ,  1.     ,  0.06976,  0.2563 ,  0.322  ,  0.4824 ],
[ 1.     ,  1.     ,  0.354  ,  0.666  ,  0.6016 ,  0.824  ],
[ 1.     ,  1.     ,  0.3506 ,  0.6675 ,  0.598  ,  0.8247 ],
[ 4.     ,  1.     ,  0.1825 ,  0.474  ,  0.4778 ,  0.777  ],
[ 4.     ,  1.     ,  0.1772 ,  0.4631 ,  0.479  ,  0.7773 ],
[11.     ,  1.     ,  0.0901 ,  0.2534 ,  0.3533 ,  0.4763 ],
[12.     ,  1.     ,  0.1714 ,  0.779  ,  0.4211 ,  0.9062 ],
[11.     ,  1.     ,  0.0842 ,  0.2512 ,  0.3542 ,  0.476  ],
[11.     ,  1.     ,  0.7383 ,  0.696  ,  0.9424 ,  0.873  ],
[ 1.     ,  1.     ,  0.338  ,  0.6626 ,  0.5757 ,  0.825  ],
[ 1.     ,  1.     ,  0.347  ,  0.6655 ,  0.5786 ,  0.8257 ],
[ 1.     ,  1.     ,  0.3538 ,  0.663  ,  0.598  ,  0.824  ],
[ 1.     ,  1.     ,  0.3542 ,  0.6694 ,  0.5967 ,  0.8247 ],
[11.     ,  1.     ,  0.0856 ,  0.2498 ,  0.357  ,  0.4763 ],
[11.     ,  1.     ,  0.0806 ,  0.2478 ,  0.3438 ,  0.4739 ],
[11.     ,  1.     ,  0.0856 ,  0.2473 ,  0.354  ,  0.4758 ],
[11.     ,  1.     ,  0.0951 ,  0.256  ,  0.3489 ,  0.4768 ],
[11.     ,  1.     ,  0.0768 ,  0.2493 ,  0.347  ,  0.474  ],
[11.     ,  1.     ,  0.0812 ,  0.2544 ,  0.3413 ,  0.4724 ],
[11.     ,  1.     ,  0.74   ,  0.6953 ,  0.943  ,  0.868  ],
[ 4.     ,  1.     ,  0.1798 ,  0.4639 ,  0.4802 ,  0.777  ],
[11.     ,  1.     ,  0.7427 ,  0.694  ,  0.9434 ,  0.8735 ],
[11.     ,  1.     ,  0.0678 ,  0.2457 ,  0.3337 ,  0.4717 ],
[12.     ,  1.     ,  0.1615 ,  0.779  ,  0.4194 ,  0.9062 ],
[12.     ,  1.     ,  0.1694 ,  0.7827 ,  0.4102 ,  0.909  ],
[12.     ,  1.     ,  0.1675 ,  0.783  ,  0.406  ,  0.907  ],
[11.     ,  1.     ,  0.0787 ,  0.2496 ,  0.3442 ,  0.4739 ],
[ 4.     ,  1.     ,  0.179  ,  0.4617 ,  0.4785 ,  0.776  ],
[11.     ,  1.     ,  0.737  ,  0.6934 ,  0.9453 ,  0.879  ],
[ 4.     ,  1.     ,  0.1831 ,  0.459  ,  0.4802 ,  0.7744 ],
[11.     ,  1.     ,  0.74   ,  0.6885 ,  0.9424 ,  0.868  ],
[11.     ,  1.     ,  0.74   ,  0.689  ,  0.9414 ,  0.8687 ],
[11.     ,  1.     ,  0.7437 ,  0.6934 ,  0.9453 ,  0.8687 ],
[11.     ,  1.     ,  0.742  ,  0.696  ,  0.9478 ,  0.877  ],
[12.     ,  1.     ,  0.1647 ,  0.787  ,  0.4138 ,  0.9185 ],
[12.     ,  1.     ,  0.1606 ,  0.787  ,  0.418  ,  0.921  ],
[12.     ,  1.     ,  0.1729 ,  0.782  ,  0.411  ,  0.9106 ],
[12.     ,  1.     ,  0.1704 ,  0.7803 ,  0.4055 ,  0.9062 ],
[11.     ,  1.     ,  0.0757 ,  0.253  ,  0.346  ,  0.4785 ],
[11.     ,  1.     ,  0.0749 ,  0.2554 ,  0.345  ,  0.4788 ],
[11.     ,  1.     ,  0.7456 ,  0.6895 ,  0.942  ,  0.869  ],
[11.     ,  1.     ,  0.7446 ,  0.691  ,  0.944  ,  0.8706 ],
[11.     ,  0.9995 ,  0.7354 ,  0.69   ,  0.936  ,  0.872  ],
[11.     ,  0.9995 ,  0.7466 ,  0.695  ,  0.9453 ,  0.8716 ],
[ 1.     ,  0.9995 ,  0.352  ,  0.659  ,  0.598  ,  0.814  ],
```

```
[12.     ,  0.9995 ,  0.159  ,  0.7793 ,  0.398  ,  0.9077 ],
[ 1.     ,  0.9995 ,  0.3447 ,  0.6553 ,  0.588  ,  0.827  ],
[11.     ,  0.9995 ,  0.088  ,  0.2454 ,  0.364  ,  0.4727 ],
[ 4.     ,  0.9995 ,  0.1741 ,  0.4614 ,  0.4912 ,  0.773  ],
[ 1.     ,  0.999  ,  0.348  ,  0.6587 ,  0.589  ,  0.816  ],
[ 1.     ,  0.999  ,  0.3389 ,  0.6597 ,  0.584  ,  0.8325 ],
[ 1.     ,  0.999  ,  0.3442 ,  0.665  ,  0.5806 ,  0.825  ],
[11.     ,  0.999  ,  0.736  ,  0.6865 ,  0.945  ,  0.8677 ],
[11.     ,  0.999  ,  0.737  ,  0.6934 ,  0.942  ,  0.878  ],
[11.     ,  0.999  ,  0.738  ,  0.694  ,  0.9478 ,  0.875  ],
[ 1.     ,  0.9985 ,  0.345  ,  0.6675 ,  0.5757 ,  0.826  ],
[11.     ,  0.9985 ,  0.06396,  0.2466 ,  0.3364 ,  0.4758 ],
[11.     ,  0.998  ,  0.08307,  0.2468 ,  0.3552 ,  0.4863 ],
[ 4.     ,  0.997  ,  0.1715 ,  0.4624 ,  0.478  ,  0.7715 ],
[11.     ,  0.996  ,  0.07776,  0.2522 ,  0.3474 ,  0.4775 ],
[11.     ,  0.9956 ,  0.0832 ,  0.2434 ,  0.3525 ,  0.4834 ],
[11.     ,  0.995  ,  0.5195 ,  0.1183 ,  0.652  ,  0.2294 ],
[11.     ,  0.994  ,  0.0722 ,  0.2452 ,  0.3352 ,  0.4702 ],
[ 4.     ,  0.9937 ,  0.1753 ,  0.4705 ,  0.4666 ,  0.7695 ],
[ 1.     ,  0.9927 ,  0.3438 ,  0.6675 ,  0.6016 ,  0.8228 ],
[ 4.     ,  0.992  ,  0.1765 ,  0.4531 ,  0.4802 ,  0.752  ],
[11.     ,  0.992  ,  0.7363 ,  0.6855 ,  0.9404 ,  0.8687 ],
[11.     ,  0.992  ,  0.5093 ,  0.1101 ,  0.651  ,  0.2302 ],
[11.     ,  0.991  ,  0.07245,  0.2429 ,  0.34   ,  0.469  ],
[ 4.     ,  0.988  ,  0.1932 ,  0.4749 ,  0.4792 ,  0.7695 ],
[ 4.     ,  0.9854 ,  0.1832 ,  0.4736 ,  0.515  ,  0.788  ],
[ 4.     ,  0.9854 ,  0.1781 ,  0.4717 ,  0.4773 ,  0.7725 ],
[11.     ,  0.9814 ,  0.74   ,  0.702  ,  0.9365 ,  0.871  ],
[ 1.     ,  0.9756 ,  0.3455 ,  0.6675 ,  0.5894 ,  0.824  ],
[ 4.     ,  0.973  ,  0.1714 ,  0.4688 ,  0.473  ,  0.778  ],
[ 4.     ,  0.971  ,  0.1699 ,  0.4553 ,  0.4795 ,  0.776  ],
[11.     ,  0.9644 ,  0.0836 ,  0.2551 ,  0.3472 ,  0.4746 ],
[11.     ,  0.963  ,  0.5166 ,  0.1102 ,  0.6567 ,  0.2246 ],
[ 4.     ,  0.956  ,  0.175  ,  0.4658 ,  0.4817 ,  0.768  ],
[ 4.     ,  0.9517 ,  0.1877 ,  0.4893 ,  0.4954 ,  0.7837 ],
[11.     ,  0.951  ,  0.08105,  0.2632 ,  0.3347 ,  0.4824 ],
[11.     ,  0.945  ,  0.07996,  0.2466 ,  0.3398 ,  0.463  ],
[ 4.     ,  0.9434 ,  0.1727 ,  0.4575 ,  0.4717 ,  0.7695 ],
[ 4.     ,  0.9414 ,  0.1884 ,  0.4634 ,  0.4841 ,  0.7656 ],
[12.     ,  0.929  ,  0.165  ,  0.7793 ,  0.4048 ,  0.916  ],
[11.     ,  0.927  ,  0.0721 ,  0.2502 ,  0.3384 ,  0.4768 ],
[ 4.     ,  0.918  ,  0.167  ,  0.4656 ,  0.4663 ,  0.7617 ],
[ 1.     ,  0.9033 ,  0.356  ,  0.6636 ,  0.585  ,  0.82   ],
[ 4.     ,  0.8794 ,  0.1941 ,  0.4656 ,  0.484  ,  0.7495 ],
[ 4.     ,  0.866  ,  0.1644 ,  0.458  ,  0.479  ,  0.7695 ],
[11.     ,  0.8657 ,  0.0665 ,  0.252  ,  0.351  ,  0.481  ],
[11.     ,  0.852  ,  0.07855,  0.245  ,  0.344  ,  0.4712 ],
```

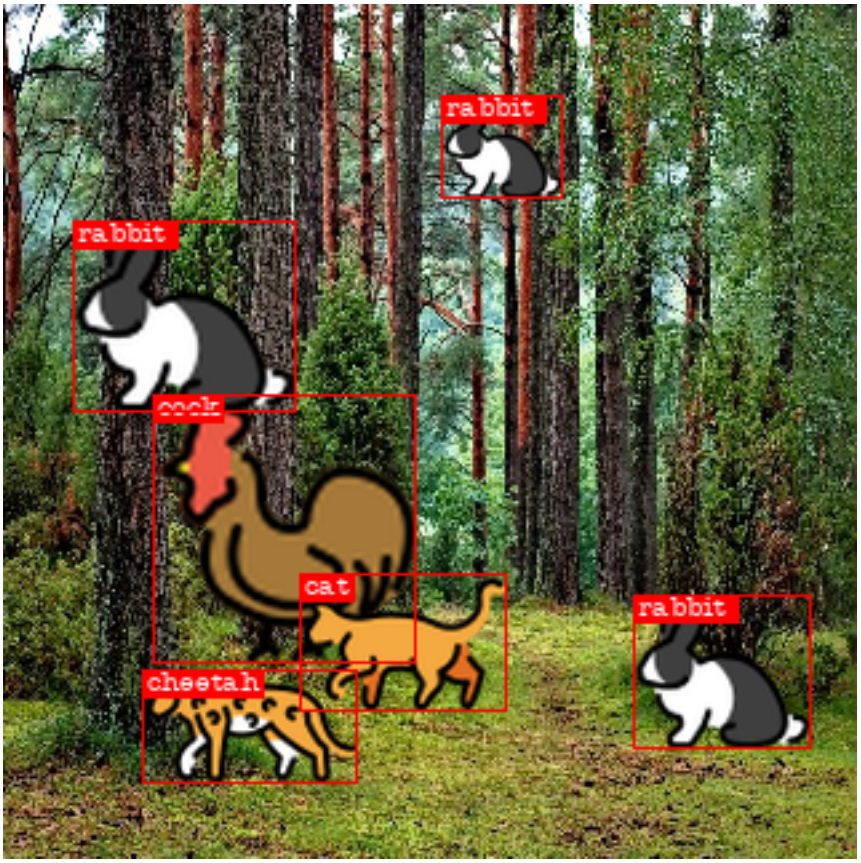
```
       [11.     ,  0.848  ,  0.743  ,  0.687  ,  0.942  ,  0.865  ],
       [11.     ,  0.848  ,  0.5044 ,  0.0973 ,  0.654  ,  0.2288 ],
       [11.     ,  0.8423 ,  0.749  ,  0.6997 ,  0.9546 ,  0.8755 ],
       [11.     ,  0.8223 ,  0.744  ,  0.699  ,  0.942  ,  0.8696 ],
       [ 4.     ,  0.8154 ,  0.1936 ,  0.4731 ,  0.4778 ,  0.765  ],
       [ 4.     ,  0.8037 ,  0.1859 ,  0.4922 ,  0.4885 ,  0.782  ],
       [12.     ,  0.8    ,  0.1614 ,  0.7744 ,  0.3962 ,  0.9106 ],
       [11.     ,  0.792  ,  0.514  ,  0.1186 ,  0.653  ,  0.2279 ],
       [ 1.     ,  0.732  ,  0.3398 ,  0.663  ,  0.5825 ,  0.835  ],
       [11.     ,  0.7046 ,  0.07025,  0.238  ,  0.3552 ,  0.4802 ],
       [ 4.     ,  0.6475 ,  0.2072 ,  0.4824 ,  0.503  ,  0.777  ],
       [12.     ,  0.6426 ,  0.1754 ,  0.77   ,  0.446  ,  0.9067 ],
       [11.     ,  0.627  ,  0.7446 ,  0.6807 ,  0.9443 ,  0.86   ],
       [12.     ,  0.6094 ,  0.1676 ,  0.7764 ,  0.398  ,  0.9175 ],
       [11.     ,  0.5635 ,  0.06107,  0.2544 ,  0.343  ,  0.4854 ],
       [11.     ,  0.5005 ,  0.5156 ,  0.1048 ,  0.645  ,  0.223  ]],
      dtype=float16)
```

[285]:
```
label_box.shape
```

[285]:
```
(6, 5)
```

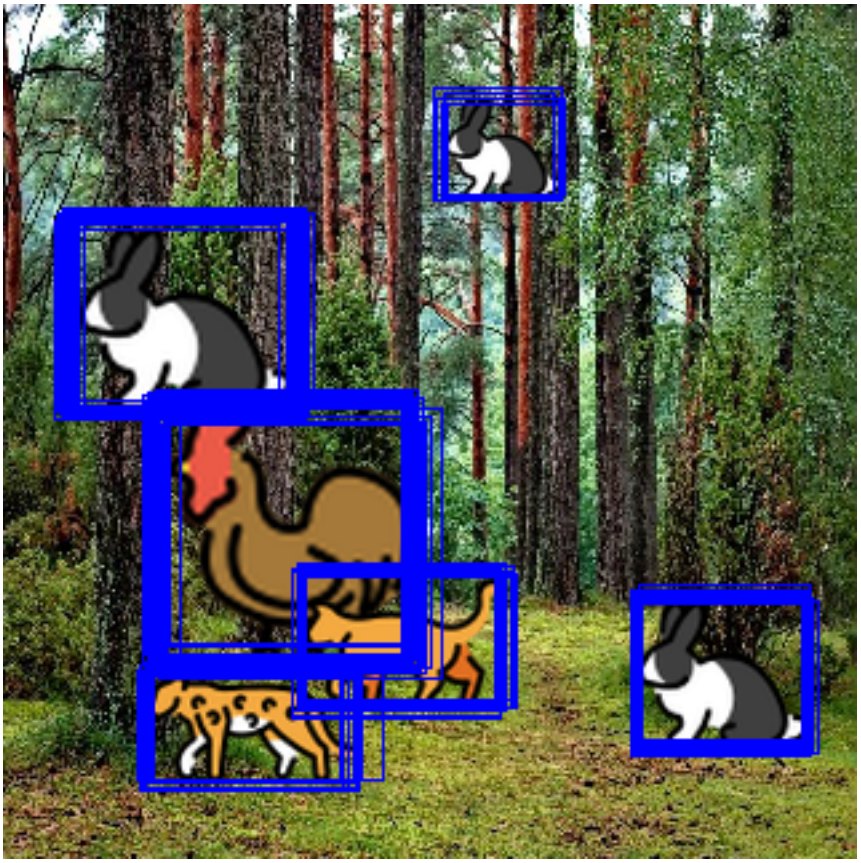
[293]:
```
# drawing boxes on ground truth values
painted_img = draw_boxes(label_box, image['image'][0])
painted_img
```

[293]:



[287]:
```
# drawing boxes over filtered predicted values, but the final output is still␣
  ↪to come
painted_img = draw_boxes(sortedArr, image['image'][0], display_label=False)
painted_img
```

[287]:

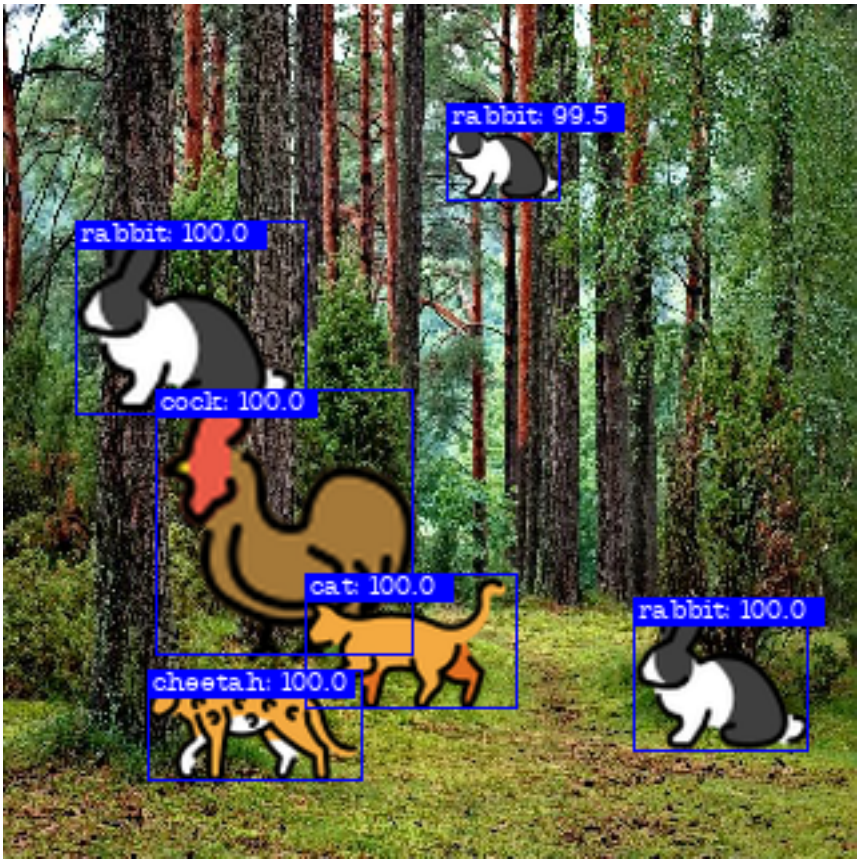


[288]:
```
# now the previous overlapping boxes goes for NMS for the final filtering and␣
 ↪below
#  are the final results for this example image
detetctions = non_max_supression(sortedArr) # details of this functions is␣
 ↪given as comments in it's definition please follow that
detetctions
```

[288]:
```
array([[11.    ,  1.    ,  0.0847,  0.2546,  0.355 ,  0.4785],
       [ 4.    ,  1.    ,  0.1794,  0.4507,  0.4785,  0.7607],
       [ 1.    ,  1.    ,  0.354 ,  0.666 ,  0.6016,  0.824 ],
       [12.    ,  1.    ,  0.1714,  0.779 ,  0.4211,  0.9062],
       [11.    ,  1.    ,  0.7383,  0.696 ,  0.9424,  0.873 ],
       [11.    ,  0.995 ,  0.5195,  0.1183,  0.652 ,  0.2294]],
      dtype=float16)
```

[289]:
```
# THE FINAL OUTPUT

painted_img = draw_boxes(detetctions, image['image'][0], display_label=True)
painted_img
```

[289]:



[67]:

[ ]:

[ ]:

0.1 Evaluating Model using mAP (mean Average Precision)

[256]:
```
"""
Using library to calculate different mAP outputs using this wonderful repo.
Dont want to invest extra time for mAP calculation from scratch
"""
!git clone https://github.com/Cartucho/mAP.git
```

```
Cloning into 'mAP'…
remote: Enumerating objects: 908, done.
remote: Total 908 (delta 0), reused 0 (delta 0), pack-reused 908
Receiving objects: 100% (908/908), 14.71 MiB | 16.68 MiB/s, done.
Resolving deltas: 100% (321/321), done.
```

[257]:
```
# remove dummy files provided in folder

%rm -rf /content/mAP/input/detection-results/*
%rm -rf /content/mAP/input/ground-truth/*
%rm -rf /content/mAP/input/images-optional/*
```

[258]:
```
"""
Same logic as for inferencing with added blocks to save labels and predictions
as text files as required by the library to calculate mAP
"""

for i in range(100):
    print(i)

    n_objects = np.random.randint(1,6)
    image, labels = next(data_generator(1, n_objects))
    predicted = model.predict(image)
    predicted_cls, predicted_box = predicted[:, :, 4:], predicted[:, :, :4]
    bbox_labels, bbox_masks, cls_labels = multibox_target(anchors, labels[:, :,␣
 ↪4:], labels[:, :, :4])

    label_box = np.hstack([np.argmax(labels[:, :, 4:], axis=2).
 ↪reshape(n_objects, 1), labels[0, :, :4]])

    # write ground truth labels to txt file
    f = open('mAP/input/ground-truth/label_' + str(i+1) + '.txt','w+')
    for j in range(label_box.shape[0]):
        f.write(animals[label_box[j, 0]]['name'] + ' '
                + str(int(label_box[j, 1] * 320)) + ' '
                + str(int(label_box[j, 2] * 320)) + ' '
                + str(int(label_box[j, 3] * 320)) + ' '
                + str(int(label_box[j, 4] * 320)) + '\n')
    f.close()

    inversed_pred_boxes = offset_inverse(anchors[0], predicted_box[0])
    predicted_cls = tf.nn.softmax(predicted_cls[0])
    class_ids = np.argmax(predicted_cls, axis=1)
    class_prob = []

    for idx, cls_id in enumerate(class_ids):
        class_prob.append([cls_id, predicted_cls[idx][cls_id]])

    class_prob = np.array(class_prob)

    combined = np.concatenate([class_prob, inversed_pred_boxes], axis=1)
    indexes = np.where((combined[:, 0] < 15) & (combined[:, 1] > 0.5))
    combined = combined[indexes].astype(np.float16)
```

```
    # write predicted labels to txt file
    f = open('mAP/input/detection-results/label_' + str(i+1) + '.txt','w+')
    for j in range(combined.shape[0]):
        f.write(animals[combined[j, 0]]['name'] + ' '
                + str(combined[j, 1]) + ' '
                + str(int(combined[j, 2] * 320)) + ' '
                + str(int(combined[j, 3] * 320)) + ' '
                + str(int(combined[j, 4] * 320)) + ' '
                + str(int(combined[j, 5] * 320)) + '\n')
```

```
0
1/1 [==============================] - 0s 37ms/step
1
1/1 [==============================] - 0s 34ms/step
2
1/1 [==============================] - 0s 33ms/step
3
1/1 [==============================] - 0s 37ms/step
4
1/1 [==============================] - 0s 34ms/step
5
1/1 [==============================] - 0s 34ms/step
6
1/1 [==============================] - 0s 37ms/step
7
1/1 [==============================] - 0s 34ms/step
8
1/1 [==============================] - 0s 36ms/step
9
1/1 [==============================] - 0s 34ms/step
10
1/1 [==============================] - 0s 35ms/step
11
1/1 [==============================] - 0s 33ms/step
12
1/1 [==============================] - 0s 37ms/step
13
1/1 [==============================] - 0s 39ms/step
14
1/1 [==============================] - 0s 34ms/step
15
1/1 [==============================] - 0s 35ms/step
16
1/1 [==============================] - 0s 35ms/step
17
1/1 [==============================] - 0s 34ms/step
```

```
18
1/1 [==============================] - 0s 34ms/step
19
1/1 [==============================] - 0s 37ms/step
20
1/1 [==============================] - 0s 40ms/step
21
1/1 [==============================] - 0s 35ms/step
22
1/1 [==============================] - 0s 34ms/step
23
1/1 [==============================] - 0s 34ms/step
24
1/1 [==============================] - 0s 59ms/step
25
1/1 [==============================] - 0s 58ms/step
26
1/1 [==============================] - 0s 36ms/step
27
1/1 [==============================] - 0s 35ms/step
28
1/1 [==============================] - 0s 54ms/step
29
1/1 [==============================] - 0s 38ms/step
30
1/1 [==============================] - 0s 35ms/step
31
1/1 [==============================] - 0s 37ms/step
32
1/1 [==============================] - 0s 39ms/step
33
1/1 [==============================] - 0s 79ms/step
34
1/1 [==============================] - 0s 60ms/step
35
1/1 [==============================] - 0s 35ms/step
36
1/1 [==============================] - 0s 147ms/step
37
1/1 [==============================] - 0s 55ms/step
38
1/1 [==============================] - 0s 34ms/step
39
1/1 [==============================] - 0s 61ms/step
40
1/1 [==============================] - 0s 83ms/step
41
1/1 [==============================] - 0s 34ms/step
```

```
42
1/1 [==============================] - 0s 64ms/step
43
1/1 [==============================] - 0s 69ms/step
44
1/1 [==============================] - 0s 53ms/step
45
1/1 [==============================] - 0s 37ms/step
46
1/1 [==============================] - 0s 35ms/step
47
1/1 [==============================] - 0s 43ms/step
48
1/1 [==============================] - 0s 38ms/step
49
1/1 [==============================] - 0s 56ms/step
50
1/1 [==============================] - 0s 35ms/step
51
1/1 [==============================] - 0s 61ms/step
52
1/1 [==============================] - 0s 88ms/step
53
1/1 [==============================] - 0s 60ms/step
54
1/1 [==============================] - 0s 55ms/step
55
1/1 [==============================] - 0s 41ms/step
56
1/1 [==============================] - 0s 35ms/step
57
1/1 [==============================] - 0s 73ms/step
58
1/1 [==============================] - 0s 53ms/step
59
1/1 [==============================] - 0s 34ms/step
60
1/1 [==============================] - 0s 61ms/step
61
1/1 [==============================] - 0s 39ms/step
62
1/1 [==============================] - 0s 80ms/step
63
1/1 [==============================] - 0s 35ms/step
64
1/1 [==============================] - 0s 43ms/step
65
1/1 [==============================] - 0s 35ms/step
```

```
66
1/1 [==============================] - 0s 34ms/step
67
1/1 [==============================] - 0s 34ms/step
68
1/1 [==============================] - 0s 34ms/step
69
1/1 [==============================] - 0s 53ms/step
70
1/1 [==============================] - 0s 43ms/step
71
1/1 [==============================] - 0s 98ms/step
72
1/1 [==============================] - 0s 73ms/step
73
1/1 [==============================] - 0s 34ms/step
74
1/1 [==============================] - 0s 35ms/step
75
1/1 [==============================] - 0s 35ms/step
76
1/1 [==============================] - 0s 34ms/step
77
1/1 [==============================] - 0s 38ms/step
78
1/1 [==============================] - 0s 35ms/step
79
1/1 [==============================] - 0s 34ms/step
80
1/1 [==============================] - 0s 37ms/step
81
1/1 [==============================] - 0s 42ms/step
82
1/1 [==============================] - 0s 34ms/step
83
1/1 [==============================] - 0s 34ms/step
84
1/1 [==============================] - 0s 41ms/step
85
1/1 [==============================] - 0s 38ms/step
86
1/1 [==============================] - 0s 44ms/step
87
1/1 [==============================] - 0s 35ms/step
88
1/1 [==============================] - 0s 36ms/step
89
1/1 [==============================] - 0s 35ms/step
```

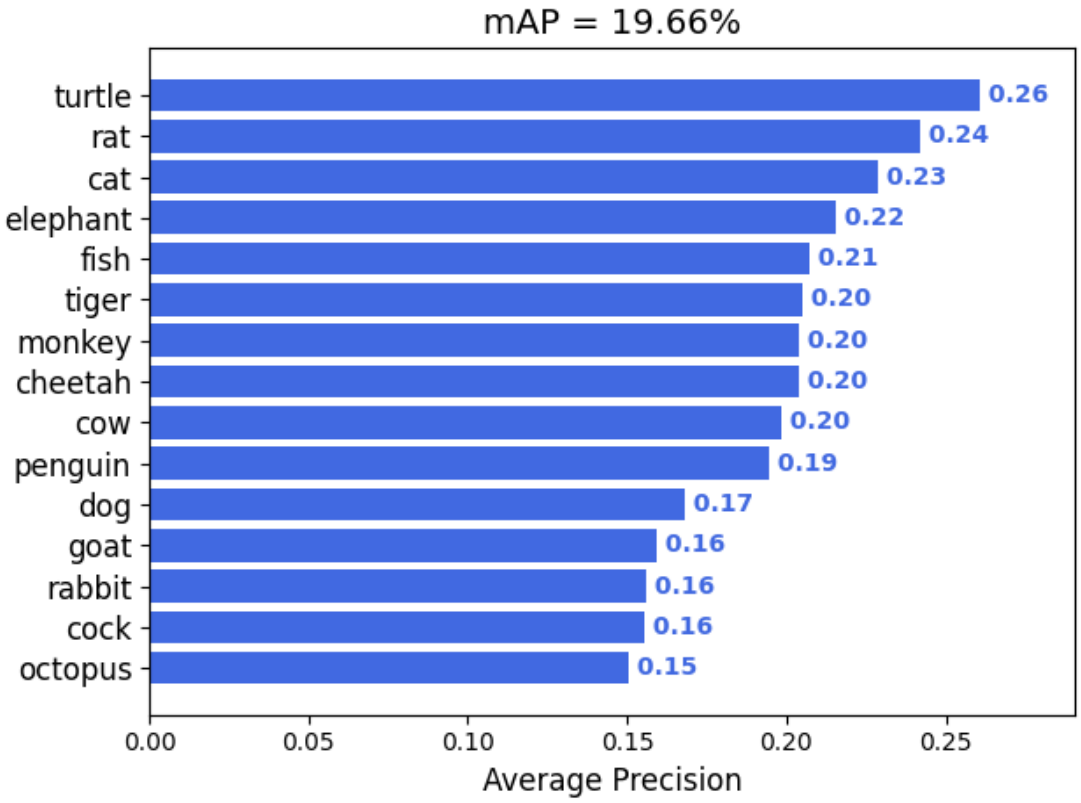
```
90
1/1 [==============================] - 0s 34ms/step
91
1/1 [==============================] - 0s 38ms/step
92
1/1 [==============================] - 0s 36ms/step
93
1/1 [==============================] - 0s 34ms/step
94
1/1 [==============================] - 0s 59ms/step
95
1/1 [==============================] - 0s 35ms/step
96
1/1 [==============================] - 0s 73ms/step
97
1/1 [==============================] - 0s 35ms/step
98
1/1 [==============================] - 0s 34ms/step
99
1/1 [==============================] - 0s 63ms/step
```

[259]:
```
!python mAP/main.py --no-animation
```

```
22.86% = cat AP
20.39% = cheetah AP
15.52% = cock AP
19.84% = cow AP
16.79% = dog AP
21.57% = elephant AP
20.71% = fish AP
15.92% = goat AP
20.42% = monkey AP
15.08% = octopus AP
19.48% = penguin AP
15.57% = rabbit AP
24.22% = rat AP
20.50% = tiger AP
26.07% = turtle AP
mAP = 19.66%
Figure(640x480)
```

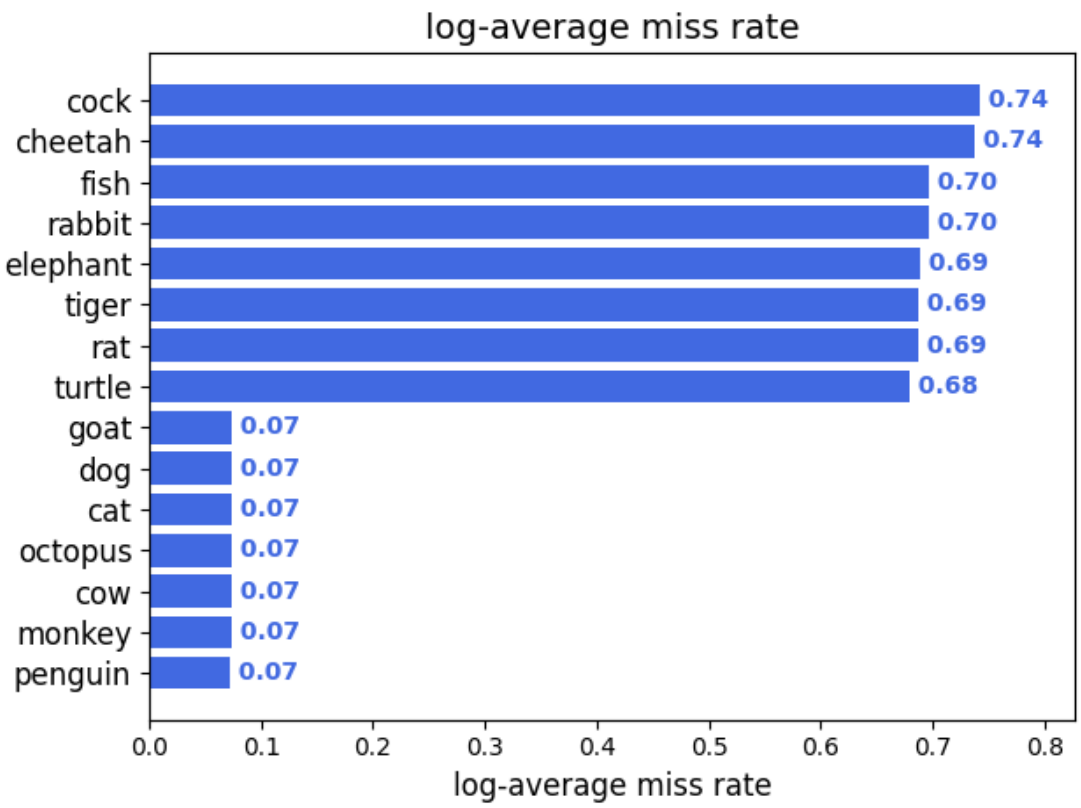
[260]:
```
displayImage(filename='/content/mAP/output/mAP.png',width=700,height=500)
```

[260]:



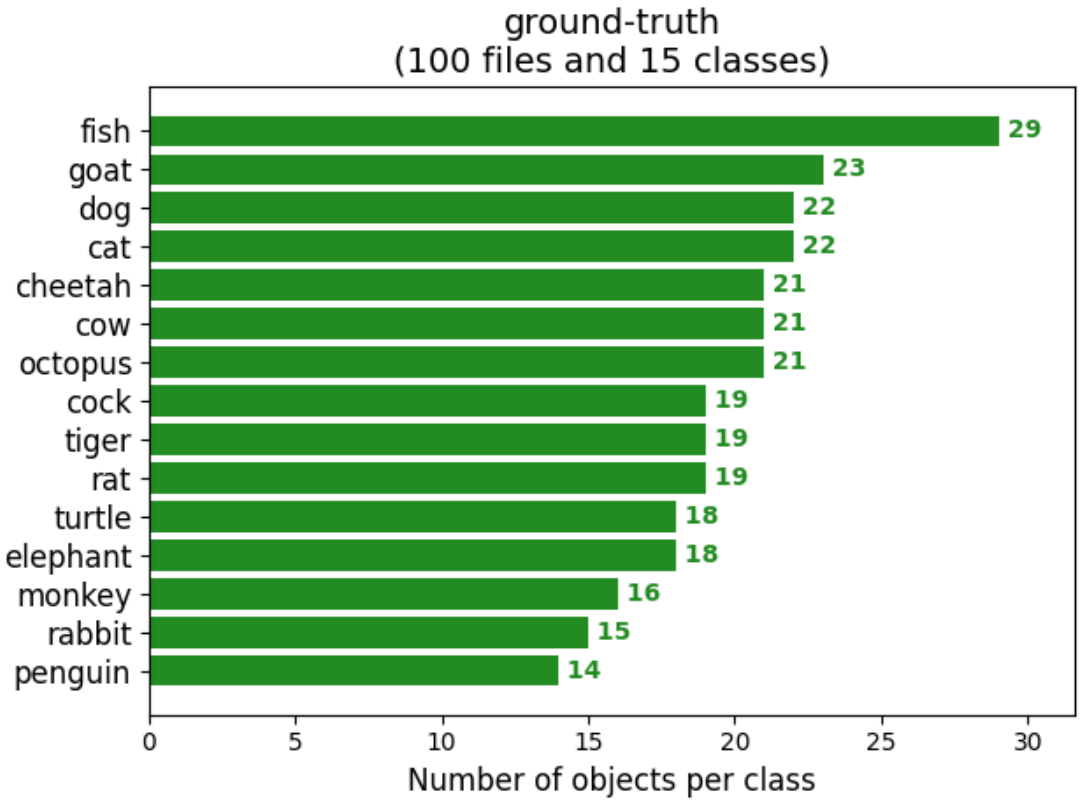
[261]:
```
displayImage(filename='/content/mAP/output/lamr.png',width=700,height=500)
```

[261]:



[262]:
```
displayImage(filename='/content/mAP/output/ground-truth-info.
↪png',width=700,height=500)
```

[262]:



[263]:
```
displayImage(filename='/content/mAP/output/detection-results-info.
↪png',width=700,height=500)
```

[263]:


detection-results
(100 files and 15 detected classes)
fish
dog
goat
octopus
monkey
cock
turtle
elephant
rat
rabbit
cat
penguin
cow
cheetah
tiger
528 27
470 22
462 23
419 21
340 16
336 17
298 17
293 17
283 18
259 14
245 22
250 14
177 21
176 19
158 18
False Positive
True Positive
0
100
200
300
400
500
600
Number of objects per class

[ ]:

[ ]:

[ ]:

[ ]: