

YOLOv3 Study Notes

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1 dataset.py

```
def parse_annotation(self, annotation):
    line = annotation.split()
    image_path = line[0]
    if not os.path.exists(image_path):
        raise KeyError("%s does not exist ... " % image_path)

    e_path)
    image = cv2.imread(image_path)
    bboxes = np.array([list(map(int, box.split(','))) for box in line[1:]])

    if self.data_aug:
        image, bboxes = self.random_horizontal_flip(np.copy(image), np.copy(bboxes))
        image, bboxes = self.random_crop(np.copy(image), np.copy(bboxes))
        image, bboxes = self.random_translate(np.copy(image), np.copy(bboxes))

    image = cv2.cvtColor(image, cv2.COLOR_BGR2RGB)
    image, bboxes = utils.image_preprocess(np.copy(image), [self.train_input_size, self.
    ↪ train_input_size], np.copy(bboxes))
    return image, bboxes
    line = annotation.split()
    image_path = line[0]
    if not os.path.exists(image_path):
        raise KeyError("%s does not exist ... " % image_path)
    image = cv2.imread(image_path)
    bboxes = np.array([list(map(int, box.split(','))) for box in line[1:]])

    if self.data_aug:
        image, bboxes = self.random_horizontal_flip(np.copy(image), np.copy(bboxes))
        image, bboxes = self.random_crop(np.copy(image), np.copy(bboxes))
        image, bboxes = self.random_translate(np.copy(image), np.copy(bboxes))

    image = cv2.cvtColor(image, cv2.COLOR_BGR2RGB)
    image, bboxes = utils.image_preprocess(np.copy(image), [self.train_input_size, self.
    ↪ train_input_size], np.copy(bboxes))
    return image, bboxes
```

This part is straightforward.

End of Function

To understand `preprocess_true_boxes`, we must first understand:

```
def bbox_iou(self, boxes1, boxes2):
    boxes1 = np.array(boxes1)
    boxes2 = np.array(boxes2)

    boxes1_area = boxes1[:, 2] * boxes1[:, 3]
    boxes2_area = boxes2[:, 2] * boxes2[:, 3]

    boxes1 = np.concatenate([boxes1[:, :2] - boxes1[:, 2:] * 0.5,
                              boxes1[:, :2] + boxes1[:, 2:] * 0.5], axis=-1)
    boxes2 = np.concatenate([boxes2[:, :2] - boxes2[:, 2:] * 0.5,
                              boxes2[:, :2] + boxes2[:, 2:] * 0.5], axis=-1)
```

From the function we can deduce that `box = (cx, cy, width, height)`, therefore

`boxes[:, :2] - boxes[:, 2:] * 0.5 = [all upper-left corners]`

and

```
boxes1[:, :2] + boxes1[:, 2:] * 0.5 = [all lower-right corners],
```

while concatenating (2,) `np`-array along the last axis simply means combining them into one (4,) `np`-array. Numerically in training `boxes1` and `boxes2` are like:

```
[[0.59375 3.78125 0.5      0.625  ]]
```

and

```
[[ 0.5      3.5      3.625    2.8125 ]
 [ 0.5      3.5      4.875    6.1875 ]
 [ 0.5      3.5     11.65625 10.1875 ]].
```

```
left_up = np.maximum(boxes1[..., :2], boxes2[..., :2])
right_down = np.minimum(boxes1[..., 2:], boxes2[..., 2:])
```

Think of the above as entrywise comparisons that give an array of maximum, which yields the coordinates of intersection rectangle for each fixed `boxes1` to boxes in `boxes2`.

```
inter_section = np.maximum(right_down - left_up, 0.0)
```

The entries in `inter_section` are the *width* and *height* of the intersection, the (broadcasted) `np.maximum` is just a tricky way to handle empty intersection.

```
inter_area = inter_section[..., 0] * inter_section[..., 1]
union_area = boxes1_area + boxes2_area - inter_area

return inter_area / union_area
```

End of Function

```
def preprocess_true_boxes(self, bboxes):
```

Here `bboxes` are the boxes from annotation file in which each line takes the form:

```
some/directory/hash.jpg 79,537,107,574,0 297,547,318,575,0
```

```
label = [np.zeros((self.train_output_sizes[i],
                  self.train_output_sizes[i],
                  self.anchor_per_scale,
                  5 + self.num_classes)) for i in range(3)]
bboxes_xywh = [np.zeros((self.max_bbox_per_scale, 4)) for _ in range(3)]
bbox_count = np.zeros((3,))

for bbox in bboxes:
    bbox_coor = bbox[:4]
    bbox_class_ind = bbox[4]

    onehot = np.zeros(self.num_classes, dtype=np.float)
    onehot[bbox_class_ind] = 1.0
    uniform_distribution = np.full(self.num_classes, 1.0 / self.num_classes)
    deta = 0.01
    smooth_onehot = onehot * (1 - deta) + deta * uniform_distribution
    # bbox_xywh is ground truth
    bbox_xywh = np.concatenate([(bbox_coor[2:] + bbox_coor[:2]) * 0.5, bbox_coor[2:] - bbox_coor
    ↪[:2]], axis=-1)
    # bbox_xywh_scaled is scaled ground truth relative to stride (13, 26, 52, as a unit)
    bbox_xywh_scaled = 1.0 * bbox_xywh[np.newaxis, :] / self.strides[:, np.newaxis]
```

Note that `bbox_xywh[np.newaxis, :]` is of shape (1, 4) and `1/self.strides[:, np.newaxis]` is of shape (3, 1), their multiplication will be conducted by “broadcasting” in `numpy`, which yields a (3, 4) dimensional `numpy` array. The product `bbox_xywh_scaled` consists of (c_x, c_y, w, h) which use “stride” as a unit, so 1 means “1 grid” (recall there are 13×13 , 26×26 , 52×52 grids predictions from Darknet backbone).

```
iou = []
exist_positive = False
for i in range(3):
    anchors_xywh = np.zeros((self.anchor_per_scale, 4))
    anchors_xywh[:, 0:2] = np.floor(bbox_xywh_scaled[i, 0:2]).astype(np.int32) + 0.5
    anchors_xywh[:, 2:4] = self.anchors[i]
```

`anchors_xywh` essing boxes with objectiveneentially move centers of `bbox_xywh_scaled` to the middle of the grid that center lies in, then the anchor boxes' width and height are assigned, replacing the original width, height of `bbox_xywh_scaled`.

```
iou_scale = self.bbox_iou(bbox_xywh_scaled[i][np.newaxis, :], anchors_xywh)
```

The presence of `np.newaxis` is simply because multiplication between (4,) and (3,4) array does not make sense. The additional dimension expand (4,) array into (1,4) array, which is boardcasted and multiplied to (3,4) array to give anothoer (3,4) array, and theirfore, `iou_scale.shape = (3,)`.

```
iou.append(iou_scale)
iou_mask = iou_scale > 0.3 # a boolean list of length 3

if np.any(iou_mask): # if one of them is True
    xind, yind = np.floor(bbox_xywh_scaled[i, 0:2]).astype(np.int32)
    label[i][yind, xind, iou_mask, :] = 0
    label[i][yind, xind, iou_mask, 0:4] = bbox_xywh
    label[i][yind, xind, iou_mask, 4:5] = 1.0
    label[i][yind, xind, iou_mask, 5:] = smooth_onehot
```

`label[i]` is initialized at the beginning which is of size

$$\text{train_output_sizes} \times \text{train_output_sizes} \times 3 \times 85$$

for each `i`, where `train_output_sizes = 13, 26 or 52`.

```
bbox_ind = int(bbox_count[i] % self.max_bbox_per_scale)
bboxes_xywh[i][bbox_ind, :4] = bbox_xywh
```

`bboxes_xywh` is initialized (with zeros) at the beginning, `bboxes_xywh.shape = (3, 150, 4)`.

```
bbox_count[i] += 1

exist_positive = True

if not exist_positive:
    best_anchor_ind = np.argmax(np.array(iou).reshape(-1), axis=-1) # flatten and take max
    # best_detect belongs to which "i", namely, best "i"
    best_detect = int(best_anchor_ind / self.anchor_per_scale)
    # for this i, which index it is:
    best_anchor = int(best_anchor_ind % self.anchor_per_scale)
    # get the grid point in our 13x13, 26x26, 52x52 grid:
    xind, yind = np.floor(bbox_xywh_scaled[best_detect, 0:2]).astype(np.int32)

    label[best_detect][yind, xind, best_anchor, :] = 0
    label[best_detect][yind, xind, best_anchor, 0:4] = bbox_xywh
    label[best_detect][yind, xind, best_anchor, 4:5] = 1.0
    label[best_detect][yind, xind, best_anchor, 5:] = smooth_onehot

    bbox_ind = int(bbox_count[best_detect] % self.max_bbox_per_scale)
    bboxes_xywh[best_detect][bbox_ind, :4] = bbox_xywh
    # assign bbox_xywh into the list instead of append,
    # this is to make sure there are at most 150 boxes within all 3 scales.

    bbox_count[best_detect] += 1
label_sbbox, label_mbbox, label_lbbox = label
sbboxes, mbboxes, lbboxes = bboxes_xywh
return label_sbbox, label_mbbox, label_lbbox, sbboxes, mbboxes, lbboxes
```

In short,

$$\text{sbboxes, mbboxes, lbboxe}$$

are just ground truth bounding boxes (center, width and height), while

$$\text{label_sbbox, label_mbbox, label_lbbox}$$

are ground truth bounding boxes with objectiveness and probabilities of *each grid*.

End of Function

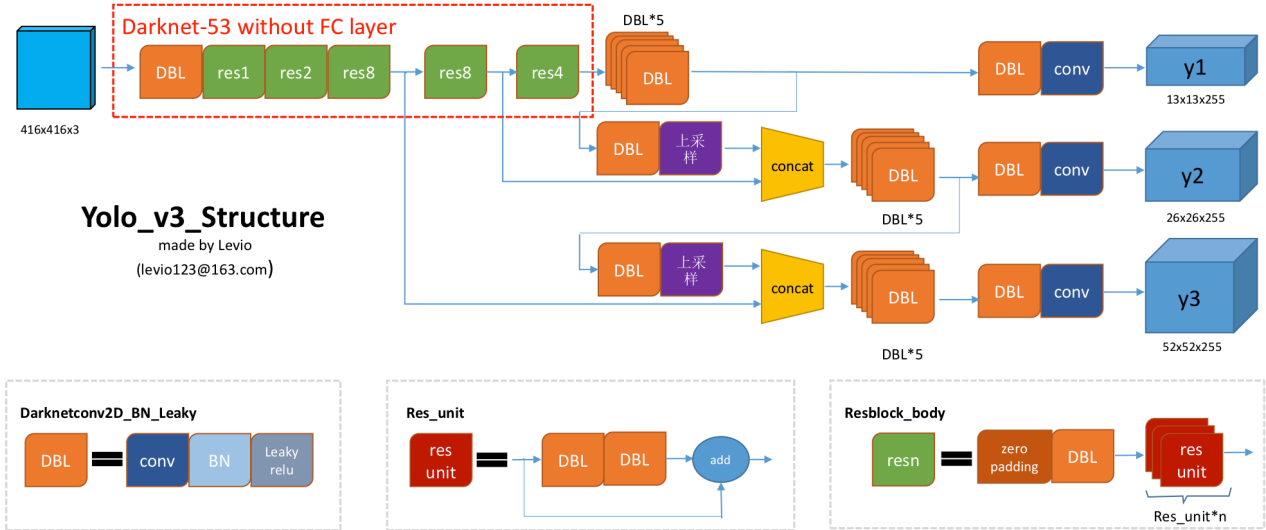


Figure 1: Structure of YOLOv3

2 yolov3.py

In darknet53 after a bunch of residue modules we get 3 branches `route_1`, `route_2` and `cov`, where

`route_1.shape = (-1, 52, 52, 256)`

`route_2.shape = (-1, 26, 26, 512)`

`conv.shape = (-1, 13, 13, 1024)`

Each branch then jumps into several stages of feature extractions, the whole process finally gives another 3 branches of undecoded/raw data of features, and they are endowed with the meaning of “grid-based detection” after reshaping into $(-1, \text{output_size}, \text{output_size}, 3, 85)$ dimensional array.

```
def YOLOv3(input_layer):
    route_1, route_2, conv = backbone.darknet53(input_layer)

    conv = common.convolutional(conv, (1, 1, 1024, 512))
    conv = common.convolutional(conv, (3, 3, 512, 1024))
    conv = common.convolutional(conv, (1, 1, 1024, 512))
    conv = common.convolutional(conv, (3, 3, 512, 1024))
    conv = common.convolutional(conv, (1, 1, 1024, 512))
```

As padding="same" is being used along the chain of conv nets, there is no spatial dimension change.

```
conv_lobj_branch = common.convolutional(conv, (3, 3, 512, 1024))
conv_lbbox = common.convolutional(conv_lobj_branch, (1, 1, 1024, 3*(NUM_CLASS + 5)), activate=
    ↪ False, bn=False)

conv = common.convolutional(conv, (1, 1, 512, 256))
conv = common.upsample(conv)

conv = tf.concat([conv, route_2], axis=-1)

conv = common.convolutional(conv, (1, 1, 768, 256))
conv = common.convolutional(conv, (3, 3, 256, 512))
conv = common.convolutional(conv, (1, 1, 512, 256))
conv = common.convolutional(conv, (3, 3, 256, 512))
conv = common.convolutional(conv, (1, 1, 512, 256))

conv_mobj_branch = common.convolutional(conv, (3, 3, 256, 512))
conv_mbbox = common.convolutional(conv_mobj_branch, (1, 1, 512, 3*(NUM_CLASS + 5)), activate=
    ↪ False, bn=False)

conv = common.convolutional(conv, (1, 1, 256, 128))
```

```

conv = common.upsample(conv)

conv = tf.concat([conv, route_1], axis=-1)

conv = common.convolutional(conv, (1, 1, 384, 128))
conv = common.convolutional(conv, (3, 3, 128, 256))
conv = common.convolutional(conv, (1, 1, 256, 128))
conv = common.convolutional(conv, (3, 3, 128, 256))
conv = common.convolutional(conv, (1, 1, 256, 128))

conv_sobj_branch = common.convolutional(conv, (3, 3, 128, 256))
conv_sbbox = common.convolutional(conv_sobj_branch, (1, 1, 256, 3*(NUM_CLASS + 5)), activate=
↪ False, bn=False)

return [conv_sbbox, conv_mbbox, conv_lbbox]

```

End of Function

```

def decode(conv_output, i=0):
    """
    return tensor of shape [batch_size, output_size, output_size, anchor_per_scale, 5 + num_classes]
        contains (x, y, w, h, score, probability)
    """

```

conv_output is the output of YOLOv3 (conv_sbbox, conv_mbbox or conv_lbbox).

```

conv_shape      = tf.shape(conv_output)
batch_size      = conv_shape[0]
output_size     = conv_shape[1]

conv_output = tf.reshape(conv_output, (batch_size, output_size, output_size, 3, 5 + NUM_CLASS))

conv_raw_dxdy = conv_output[:, :, :, :, 0:2]
conv_raw_dwdh = conv_output[:, :, :, :, 2:4]
conv_raw_conf = conv_output[:, :, :, :, 4:5]
conv_raw_prob = conv_output[:, :, :, :, 5: ]

y = tf.tile(tf.range(output_size, dtype=tf.int32)[:, tf.newaxis], [1, output_size])
x = tf.tile(tf.range(output_size, dtype=tf.int32)[tf.newaxis, :], [output_size, 1])

```

For example, let's take output_size = 13, then

```
y = np.tile(np.arange(13)[:, np.newaxis], [1, 13])
```

and

```
x = np.tile(np.arange(13)[np.newaxis, :], [13, 1])
```

are respectively:

```

[[ 0  0  0  0  0  0  0  0  0  0  0  0  0]  [[ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[ 1  1  1  1  1  1  1  1  1  1  1  1  1]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[ 2  2  2  2  2  2  2  2  2  2  2  2  2]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[ 3  3  3  3  3  3  3  3  3  3  3  3  3]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[ 4  4  4  4  4  4  4  4  4  4  4  4  4]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[ 5  5  5  5  5  5  5  5  5  5  5  5  5]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[ 6  6  6  6  6  6  6  6  6  6  6  6  6]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[ 7  7  7  7  7  7  7  7  7  7  7  7  7]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[ 8  8  8  8  8  8  8  8  8  8  8  8  8]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[ 9  9  9  9  9  9  9  9  9  9  9  9  9]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[10 10 10 10 10 10 10 10 10 10 10 10 10]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[11 11 11 11 11 11 11 11 11 11 11 11 11]  [ 0  1  2  3  4  5  6  7  8  9 10 11 12]
[12 12 12 12 12 12 12 12 12 12 12 12 12]] [ 0  1  2  3  4  5  6  7  8  9 10 11 12]]

```

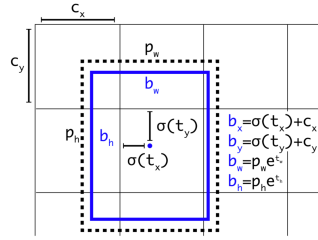
For x and y we expand dimension again along the last axis (break every single element into a bracketed element) before concatenation:

```
xy_grid = tf.concat([x[:, :, tf.newaxis], y[:, :, tf.newaxis]], axis=-1)
```

At this point, xy_grid is (13,13,2) dimensional.

```
xy_grid = tf.tile(xy_grid[tf.newaxis, :, :, tf.newaxis, :], [batch_size, 1, 1, 3, 1])
xy_grid = tf.cast(xy_grid, tf.float32)
```

Now `xy_grid` is (batch_size, 13, 13, 3, 2) dimensional. Recall that



```
pred_xy = (tf.sigmoid(conv_raw_dxdy) + xy_grid) * STRIDES[i]
pred_wh = (tf.exp(conv_raw_dwdh) * ANCHORS[i]) * STRIDES[i]
pred_xywh = tf.concat([pred_xy, pred_wh], axis=-1)

pred_conf = tf.sigmoid(conv_raw_conf)
pred_prob = tf.sigmoid(conv_raw_prob)

return tf.concat([pred_xywh, pred_conf, pred_prob], axis=-1)
```

Bear in mind that decoded x, y in `pred_xywh` denote the center of prediction rectangle, as is the output of the function `preprocess_true_boxes`.

End of Function

3 yolov3.compute_loss

```
def bbox_giou(boxes1, boxes2):

    boxes1 = tf.concat([boxes1[..., :2] - boxes1[..., 2:] * 0.5,
                        boxes1[..., :2] + boxes1[..., 2:] * 0.5], axis=-1)
    boxes2 = tf.concat([boxes2[..., :2] - boxes2[..., 2:] * 0.5,
                        boxes2[..., :2] + boxes2[..., 2:] * 0.5], axis=-1)

    boxes1 = tf.concat([tf.minimum(boxes1[..., :2], boxes1[..., 2:]),
                        tf.maximum(boxes1[..., :2], boxes1[..., 2:])], axis=-1)
    boxes2 = tf.concat([tf.minimum(boxes2[..., :2], boxes2[..., 2:]),
                        tf.maximum(boxes2[..., :2], boxes2[..., 2:])], axis=-1)

    boxes1_area = (boxes1[..., 2] - boxes1[..., 0]) * (boxes1[..., 3] - boxes1[..., 1])
    boxes2_area = (boxes2[..., 2] - boxes2[..., 0]) * (boxes2[..., 3] - boxes2[..., 1])

    left_up = tf.maximum(boxes1[..., :2], boxes2[..., :2])
    right_down = tf.minimum(boxes1[..., 2:], boxes2[..., 2:])

    inter_section = tf.maximum(right_down - left_up, 0.0)
    inter_area = inter_section[..., 0] * inter_section[..., 1]
    union_area = boxes1_area + boxes2_area - inter_area
    iou = inter_area / union_area

    enclose_left_up = tf.minimum(boxes1[..., :2], boxes2[..., :2])
    enclose_right_down = tf.maximum(boxes1[..., 2:], boxes2[..., 2:])
    enclose = tf.maximum(enclose_right_down - enclose_left_up, 0.0)
    enclose_area = enclose[..., 0] * enclose[..., 1]
    giou = iou - 1.0 * (enclose_area - union_area) / enclose_area

    return giou
```

```
def compute_loss(pred, conv, label, bboxes, i=0):

    conv_shape = tf.shape(conv)
    batch_size = conv_shape[0]
    output_size = conv_shape[1]
    input_size = STRIDES[i] * output_size
    conv = tf.reshape(conv, (batch_size, output_size, output_size, 3, 5 + NUM_CLASS))
```

```

conv_raw_conf = conv[:, :, :, :, 4:5]
conv_raw_prob = conv[:, :, :, :, 5:]

pred_xywh      = pred[:, :, :, :, 0:4]
pred_conf      = pred[:, :, :, :, 4:5]

label_xywh     = label[:, :, :, :, 0:4]
respond_bbox   = label[:, :, :, :, 4:5] # objectiveness
label_prob     = label[:, :, :, :, 5:]

giou = tf.expand_dims(bbox_giou(pred_xywh, label_xywh), axis=-1)
input_size = tf.cast(input_size, tf.float32)

bbox_loss_scale = 2.0 - 1.0 * label_xywh[:, :, :, :, 2:3] * label_xywh[:, :, :, :, 3:4] / (
    ↪ input_size ** 2)
giou_loss = respond_bbox * bbox_loss_scale * (1- giou)

```

Note that for two sets $U, V \in \mathcal{C}$, where $\mathcal{C} \in 2^{\mathbb{R}^2}$, the function $d(U, V) := 1 - \text{giou}(U, V)$ defines a metric, so `giou_loss` makes sense.

```

iou = bbox_iou(pred_xywh[:, :, :, :, np.newaxis, :], bboxes[:, np.newaxis, np.newaxis, np.
    ↪ newaxis, :, :])

```

`bboxes` are batched inside `Dataset("train").__next__` before passing into `compute_loss` (in a while loop until image count reaches batch size). Therefore `bboxes.shape = (16, 150, 4)`, where 150 is the maximal number of anchors (most of them are zeros due to initialization), so we see 3 ':'s in `bboxes`.

Finally

`pred_xywh.shape = (16, 13, 13, 3, 150, 4) = bboxes.shape`

and

`iou.shape = (16, 13, 13, 3, 150)`

where computation gets rid of the last dimension. `bboxes` is copied to every grid for computation because from original paper:

“the confidence prediction represents the IOU between the predicted box and any ground truth box”

```

max_iou = tf.expand_dims(tf.reduce_max(iou, axis=-1), axis=-1)
respond_bgd = (1.0 - respond_bbox) * tf.cast( max_iou < IOU_LOSS_THRESH, tf.float32 )

```

In the internet some people call `IOU_LOSS_THRESH` as `ignore_thresh`. `respond_bgd` determines whether to penalize a prediction

- that overlaps too few with ground truth anchors (i.e., detected wrong location) *and*
- that makes false positive error.

```

conf_focal = tf.pow(respond_bbox - pred_conf, 2)

```

The concept of focal loss with $\gamma = 2$ was introduced in [3], which down-weights the loss contributed by well-classified (high confidence) examples.

```

conf_loss = conf_focal *
(
    respond_bbox * tf.nn.sigmoid_cross_entropy_with_logits(labels=respond_bbox, logits=
    ↪ conv_raw_conf)
    +
    respond_bgd * tf.nn.sigmoid_cross_entropy_with_logits(labels=respond_bbox, logits=
    ↪ conv_raw_conf)
)

```

Where `tf.nn.sigmoid_cross_entropy_with_logits(labels=z, logits=x)` is

$$z * -\log(\text{sigmoid}(x)) + (1 - z) * -\log(1 - \text{sigmoid}(x)),$$

therefore `x` has to be a raw prediction data.

```

prob_loss = respond_bbox * tf.nn.sigmoid_cross_entropy_with_logits(labels=label_prob, logits=
↪ conv_raw_prob)

giou_loss = tf.reduce_mean(tf.reduce_sum(giou_loss, axis=[1,2,3,4]))
conf_loss = tf.reduce_mean(tf.reduce_sum(conf_loss, axis=[1,2,3,4]))
prob_loss = tf.reduce_mean(tf.reduce_sum(prob_loss, axis=[1,2,3,4]))

return giou_loss, conf_loss, prob_loss

```

End of Function

4 train.py

```

def train_step(image_data, target, epoch):

    # image_data = batch of images

    with tf.GradientTape() as tape:
        pred_result = model(image_data, training=True)
        giou_loss = conf_loss = prob_loss = 0

        # optimizing process
        for i in range(3):
            conv, pred = pred_result[i*2], pred_result[i*2+1]

            loss_items = compute_loss(pred, conv, *target[i], i)
            giou_loss += loss_items[0]
            conf_loss += loss_items[1]
            prob_loss += loss_items[2]

        total_loss = giou_loss + conf_loss + prob_loss

        gradients = tape.gradient(total_loss, model.trainable_variables)
        optimizer.apply_gradients(zip(gradients, model.trainable_variables))

        # update learning rate
        global_steps.assign_add(1)
        if global_steps < warmup_steps:
            lr = global_steps / warmup_steps * cfg.TRAIN.LR_INIT
        else:
            lr = cfg.TRAIN.LR_END + 0.5 * (cfg.TRAIN.LR_INIT - cfg.TRAIN.LR_END) * (
                (1 + tf.cos((global_steps - warmup_steps) / (total_steps - warmup_steps) * np.pi))
            )
        optimizer.lr.assign(lr.numpy())

        # writing summary data
        with writer.as_default():
            tf.summary.scalar("lr", optimizer.lr, step=global_steps)
            tf.summary.scalar("loss/total_loss", total_loss, step=global_steps)
            tf.summary.scalar("loss/giou_loss", giou_loss, step=global_steps)
            tf.summary.scalar("loss/conf_loss", conf_loss, step=global_steps)
            tf.summary.scalar("loss/prob_loss", prob_loss, step=global_steps)
        writer.flush()

for epoch in range(cfg.TRAIN.EPOCHS):
    for index, (image_data, target) in enumerate(trainset):
        train_step(image_data, target, epoch)

    model.save_weights("./checkpoints/yolov3-{}-{}.h5".format(cfg.WEIGHT_NAME_TO_SAVE, epoch))

```

References

- [1] YOLOv3 源码解析 1-5, <https://blog.csdn.net/sxlsxl119/article/details/103028021>.
- [2] YOLOv3 算法的一点理解, <https://yunyang1994.gitee.io/2018/12/28/YOLOv3/>.

- [3] Tsung-Yi Lin, Priya Goyal, Ross Girshick, Kaiming He and Piotr Dollar, *Focal Loss for Dense Object Detection*, https://arxiv.org/pdf/1708.02002.pdf?fbclid=IwAR38T65chV0UNPhBDbAExH021_afC0L6o9PEztpBPBAzqY3dBR8v0Gy2qwg.
- [4] Joseph Redmon, Ali Farhadi, *YOLOv3: An Incremental Improvement*, <https://arxiv.org/abs/1804.02767>.