

# Exploring Computer Vision in Deep Learning: Object Detection and Semantic Segmentation

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## ABSTRACT

This paper describes the new object detection and semantic segmentation features in SAS Deep Learning, which are targeted to solve a wider variety of problems that are related to computer vision. The paper focuses on algorithms that are supported on SAS® Viya®, specifically Faster R-CNN and YOLO (you only look once) for object detection, and U-Net for semantic segmentation. This paper shows how to use the functionality of the Deep Learning action set in SAS® Visual Data Mining and Machine Learning in addition to DLPy, an open-source, high-level Python package for deep learning. The paper demonstrates applications of object detection and semantic segmentation on different scenarios, and it shows how to prepare data, build networks, select parameters, load or train the weights, and display results. Future development and potential applications in different areas are discussed.

## INTRODUCTION

Computer vision is about understanding the visual world around us through digital images and videos. In applications such as self-driving cars, production line automation, face recognition, and medical image processing, computer software analyzes the image content and accomplishes one or several of the following basic tasks: image classification, keypoints detection, object detection, segmentation, and so on. Briefly, image classification represents the task of given an image, discovering the main content in the image. Object detection locates the positions and categories of objects in a given image. Semantic segmentation classifies the pixel-level category assignments, while instance segmentation, assigns different labels for pixels belong to different instances of the same object type.

Traditionally, computer vision tasks are accomplished by manually designed features, including Gabor filter, Gaussian filter, Scale Invariant Feature Transform (SIFT) filter, and so on. Recently, Deep Learning (that is, deep neural networks) has been proven to boost the field tremendously. Not only can computers complete the above tasks much faster, more accurately, but also with little human crafted features since these features are learned automatically using the input data.

SAS Viya® supports computer vision through SAS Deep Learning with features including image classification, keypoints detection, object detection, and semantic segmentation. For all these features, two interfaces are available:

- CAS (Cloud Analytic Services) actions: These give users more granular control over the various options.
- [DLPy \(https://github.com/sassoftware/python-dlpy\)](https://github.com/sassoftware/python-dlpy): It has a Keras-type Python interface with a higher abstraction.

From this paper, you will learn how to use the features of object detection and semantic segmentation by working through some real-world examples. The object detection examples use different CAS actions through our CAS action set python programming interface, while the semantic segmentation is illustrated through DLPy.

## OBJECT DETECTION

Object detection analyzes complex images that contain a mixed multitude of objects, at different distances and locations, amidst varying, often visually noisy backgrounds. Objects can appear anywhere within the visual frame, be near or far, and can overlap with each other. Object detection locates and classifies unknown objects, as well as determining their boundaries as shown in Figure 1.



**Figure 1. The Concept of Object Detection**

Object detection is a challenging and one of the most fundamental tasks in computer vision. Lately CNN (Convolutional Neural Networks) based deep learning algorithms like YOLO [1] (You only look once), SSD [2] (Singleshot multibox detector), R-CNN [3] (Region proposal networks), Faster R-CNN [3], RetinaNet [4], and so on, have been implemented to address this problem and have been very successful.

Object detection algorithms can be categorized as below:

1. The first algorithm category is to do region proposal first. This means regions highly likely to contain an object are selected either with traditional computer vision techniques (like selective search), or by using a deep learning based region proposal network (RPN). Once you have gathered the small set of candidate windows, you can formulate a set number of regression models and classification models to solve the object detection problem. This category includes algorithms like Faster R-CNN, R-FCN [5], and FPN-FRCN [6]. Algorithms in this category are usually called two-stage methods. They are generally more accurate, but slower than the single-stage method introduced below.
2. The second algorithm category only looks for objects at fixed locations with fixed sizes. These locations and sizes are strategically selected so that most scenarios are covered. These algorithms typically separate the original images into fixed size grid regions. For each region, these algorithms try to predict a fixed number of objects of certain, pre-determined shapes and sizes. Algorithms belonging to this category are called single-stage methods. Examples of such methods include YOLO, SSD, and RetinaNet. Algorithms in this category usually run faster but are less accurate. This type of algorithm is often used for applications requiring real-time detection.

SAS deep learning supports two representative algorithms, Faster R-CNN and YOLO, which belong to the two above algorithm categories respectively.

## **YOLO**

YOLO (You Only Look Once) is the representative algorithm in single-stage object detection method. The steps it follows to detect objects are represented in Figure 2 and in the list below:



**Figure 2 Steps illustrating the YOLO Algorithm**

1. Separate the original image into grids of equal size.
2. For each grid, predict a preset number of bounding boxes with predefined shapes centered around the grid center. Each prediction is associated with a class probability and an object confidence (whether it contains an object, or it is just the background).
3. Finally, select those bounding boxes associated with high object confidence and class probability. The object category is the object class with the highest class probability.

The preset number of bounding boxes with pre-defined shapes are called anchor boxes. They are obtained from the data by the K-means algorithm. The anchor box captures prior knowledge about object size and shape in the data set. Different anchors are designed to detect objects with different sizes and shapes.

For example, in Figure 3, there are three anchors at one location. The red anchor box turns out to detect the person in the middle. In other words, the algorithm detects the object with the approximate size of this anchor box. The final prediction is usually different from the anchor location or size itself; an optimized offset obtained from the feature map of the image is added to the anchor location or size.



**Figure 3 Anchor Boxes**

## FASTER R-CNN

Faster R-CNN is a two-stage object detection algorithm. Figure 4 illustrates the two stages in Faster R-CNN. Although “faster” is included in the algorithm name, that does not mean that it is faster than the one-stage method. The name is a historical artifact – it simply indicates that it is faster than its previous versions, the original R-CNN [7] algorithm, and the Fast R-CNN [8], by sharing the computation of feature extraction for each region of interest (RoI), and by introducing the deep learning-based region proposal network (RPN).

After using many CNN layers to extract feature maps, the region proposal network (RPN) generates many windows that are highly likely to contain an object. The algorithm then retrieves the feature maps inside each window, resizes (or pools) them into fixed sizes (RoI pooling), and predicts the class probability and a more accurate bounding box for the object.

One question to consider is how the RPN generates these windows. Like YOLO, RPN also uses anchor boxes. Unlike YOLO, the anchor boxes are not generated from data but instead are of fixed sizes and shapes selected strategically to cover main object shapes and sizes. The anchor boxes can also cover the image more densely. Note that instead of performing a classification on many object categories, the RPN only does a binary classification on whether the window contains an object or not.

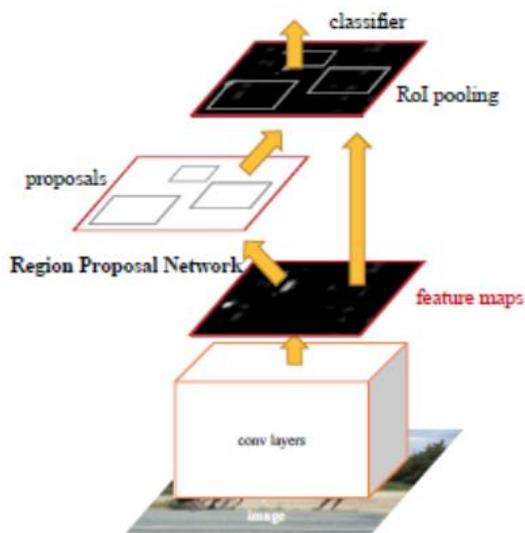


Figure 4 Stages in the Faster R-CNN Object Detection Algorithm

*Picture from the Original Faster R-CNN Paper [3]*

## BUILD DEEP LEARNING MODELS

Building and using any deep learning model involves four steps illustrated in Table 1. In the following sections, you can see how these steps are completed using SAS deep learning toolkit.

1. Preparing and Loading the Data
2. Building the model architecture, namely, the model DAG (Directed Acyclic Graph) consisting of many layers.
3. Loading or Training the weights
4. Inference and Visualization

**Table 1 Steps in Building and Using a Deep Learning Model**

## DATA EXPLORATION AND PREPARATION

An essential part of any data science project is to explore the data, complete any pre-processing if needed, and prepare it for training or inferences. CAS provides toolsets to help you through the process.

### *Images and Labels*

The images and label data need to be organized into a CAS table before training or scoring. Each image can contain more than one labeled object. Each label should contain the object category and the object bounding box.

In this paper, we assume images and associated labels are already joined and put in a CAS table. In the table there is a column for the image, and there are many columns for bounding box and category labels. Figure 5 shows some records for the table `trainset`.

#### § Fetch

Selected Rows from Table TRAINSET

	<code>_image_</code>	<code>_nObjects_</code>	<code>_Object0_</code>	<code>_Object0_x</code>	<code>_Object0_y</code>	<code>_Object0_width</code>	<code>_Object0_height</code>	<code>_Object1_</code>	<code>_Object1_x</code>	<code>_Object1_y</code>	<code>_Object1_width</code>	<code>_Object1</code>
598	<code>b'\xff\xd8\xff\xe0\x00\x10JFIF\x00\x01\x01\x00...</code>	2.0	Ball	0.563672	0.566667	0.046094	0.060417	SciSports	0.496484	0.276042	0.075781	
599	<code>b'\xff\xd8\xff\xe0\x00\x10JFIF\x00\x01\x01\x00...</code>	3.0	Ball	0.162109	0.660937	0.077344	0.076042	SciSports	0.784766	0.347917	0.082031	
600	<code>b'\xff\xd8\xff\xe0\x00\x10JFIF\x00\x01\x01\x00...</code>	1.0	SAS	0.460938	0.553646	0.403125	0.892708		NaN	NaN	NaN	

elapsed 0.00543s · user 0.00539s · sys 1.2e-05s · mem 1.39MB

**Figure 5 The Joined Table Containing Images and Labels**

### *Data Format*

In Figure 5, you can see that for record 598, there are two labeled objects, as shown in the `_nObjects_` column; the first object category, and bounding box location is stored in columns `_Object0_`, `_Object0_x`, `_Object0_y`, `_Object0_width`, `_Object0_height`. The values in location columns in the table are smaller than 1, because they are in YOLO format, which are normalized according to the input image size. YOLO is the recommended format since it is easier to do data augmentation with it.

### *Visualize the Images and Labels*

To check if your label is correct visually, you can use the `extractDetectedObjects` action to extract the object location/category and generate images with the bounding boxes, class names, and score values (when the table is the output of the `dlscore` action), annotated on the image.

```
s.image.extractdetectedobjects
(casout={'name':'trainSetAnnotated','replace':True},
 coordType='Yolo', maxobjects=30, table=s.CASTable('trainSet'))
```

Figure 6 shows the annotated images generated.

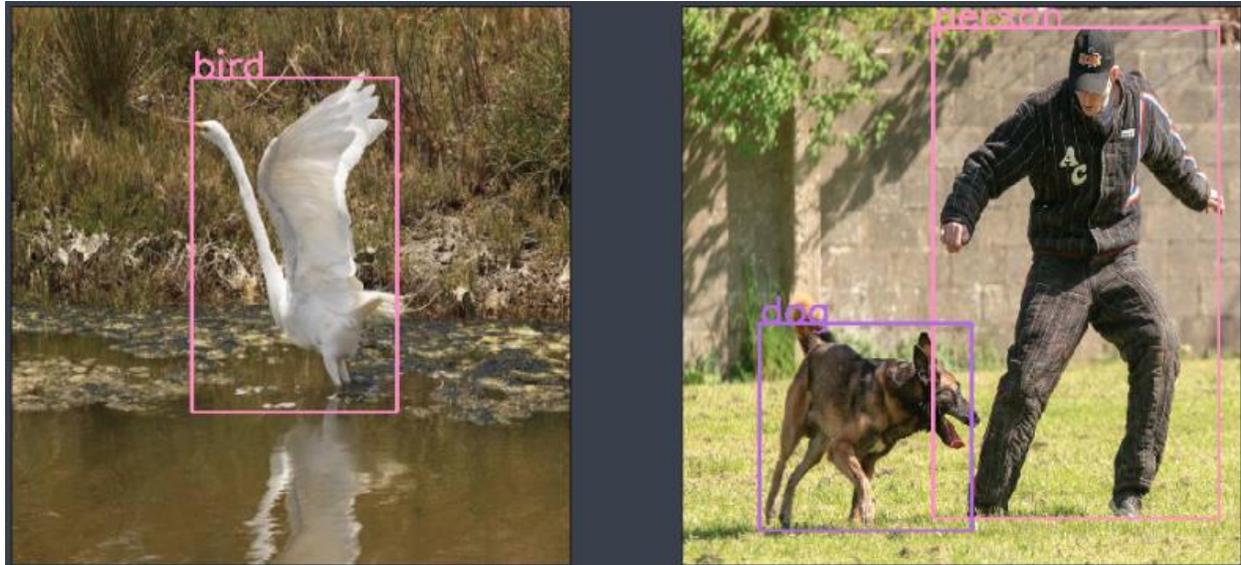


Figure 6 Images and Annotations: The Bounding Boxes and Categories

## BUILDING THE MODEL ARCHITECTURE

### *The Backbone Network*

Both YOLO and Faster R-CNN Object Detection model need a backbone network to extract features from the images. The backbone network typically is a well-known network used for image classification, for example, ResNet, VGG16, Darknet, and so on. The backbone network usually consists of the data layer, many convolutional layers, batch normalization and pooling layers.

Table 2 shows how you connect to a CAS server, load the action sets needed, create a CNN model with name `TinyYOLO` and add layers to build the backbone network for the model. Only the first few layers and the last layer for the backbone network is shown for simplicity.

```
import swat # The python interface to SAS Cloud Analytic Services (CAS).

s = CAS('cas04.unx.sas.com', 29990) # connect to the CAS server
s.loadactionset('image')           # load the image action set
s.loadactionset('deepLearn')       # load the deep learning action set

s.buildModel(model=dict(name='TinyYOLO',replace= True),type='CNN')
s.addLayer(model=modelName, name='data',
            layer=dict(type='input', nChannels=3,width=imgWidth,
                       height = imgHeight, scale = 1.0/255))
s.addLayer(model=modelName, name='conv1',
            layer=dict(type='convolution', nFilters=16, width=3, height=3,
                       stride=1, includeBias=False, std=1e-1, act='identity'),
            srcLayers = ['data'])
s.addLayer(model=modelName, name='bn1',
            layer=dict(type='batchnorm', act='leaky'),
            srcLayers = ['conv1'])
s.addLayer(model=modelName, name='pool1',
```

```

        layer=dict(type='pooling',width=2, height=2, stride=2, pool='max'),
        srcLayers = ['bn1']
.....
s.addLayer(model=modelName, name='conv9',
           layer=dict(type='convolution', nFilters=125,
                       width=1, height=1, # filter width and height
                       stride=1, includeBias=False, std=1e-1, act='identity'),
           srcLayers = ['bn8'])

```

**Table 2 Code Snippet to Build the Backbone Network for YOLO Object Detection Model**

### ***The YOLO Detection Layer***

Table 3 shows how to add the YOLO detection layer following the last layer of the backbone network, and some typical parameters used. In the last convolutional layer `conv9`, the width and height of the output feature map should both equal to `gridNumber` (13), and the depth (`nFilters`) should be equal to:

$$\text{predictionsPerGrid} * (\text{classNumber} + \text{coordNumber} + 1),$$

in which `gridNumber`, `predictionsPerGrid`, `classNumber` are parameters in the detection layer, and `coordNumber` is equal to 4, which is the number of values needed to represent a rectangle bounding box. Anchors are given directly here, which is pre-calculated using K-means algorithm. DLPy provides a function helping you to calculate proper anchors from a given data set.

```

s.addLayer(
    model = modelName,
    name = 'detection0',
    layer = dict(
        type = 'detection',
        detectionModelType = "YOLOV2",
        classNumber = 20,
        gridNumber = 13,
        predictionsPerGrid = 5,
        anchors=(1.08,1.19,3.42,4.41,6.63,11.38,9.42,5.11,16.62,10.52),
        coordType = "YOLO",
        detectionThreshold = 0.3,
        iouThreshold = 0.45,
    ),
    srcLayers = ['conv9']
)

```

**Table 3 YOLO Detection Layer**

### ***The Faster R-CNN Region Proposal and Object Detection***

The Faster R-CNN network architecture is a little bit more complicated. It consists of a CNN backbone network, followed by several parts:

1. A Region Proposal Layer and two special convolutional layers preceding it,
2. A Region Pooling Layer,
3. Several layers of fully connected layers to generate data for the final FastRCNN layer
4. the FastRCNN layer.

The major code components are shown in Table 4 and Table 5. In Table 4, You can see how the `rpn_score` layer's feature map depth (`nFilters`) is related with some parameters of

Region Proposal Layer. The variable `OrigAnchorNum` represents the number of anchors used in the Region Proposal Layer on each pixel on its input feature map. The actual anchors (in this example  $3*3=9$  anchors on each pixel) are generated according to these parameters: `baseAnchorSize`, `anchorScale`, `anchorRatio` in three steps:

1. Generate a base square anchor with width and height equal to `baseAnchorSize` (in number of pixels in the original input image scale) and centered around the first pixel.
2. Generate a number of anchors with different aspect ratios listed in `anchorRatio`, and with the same area as the base anchor.
3. From each anchor obtained from step 2, generate a number of anchors by multiplying the anchor width and height with the value in the array `anchorScale`.
4. Replicate the anchors generated from the steps 1-3 by shifting to each pixels in the feature map.

```
#Create a CNN model, and add layers for the VGG16 backbone network
#Assuming the last layer of the backbone network has the name 'conv5_3'
.....
modelName = 'FasterRCNNModel';
Add_VGG16_FELayers(s, modelName, width=1000, height=496)
.....
# Add two additional convolutional layers to extract features for the
Region Proposal Layer

nClasses = 2; # Region Proposal Layer only has 2 classes:
object/background
anchorScaleV=[8,16,32];      # Anchor size multiples
anchorRatioV=[0.5,1,2];      # Anchor aspect ratio
OrigAnchorNum = len(anchorScaleV) * len(anchorRatioV)

s.addLayer(
    model=modelName, name='rpn_conv_3x3',
    layer = dict(type='convolution',nFilters=512, width=3,
                 height=3, stride=1, act='relu'),
    srcLayers = ['conv5_3'])

s.addLayer(
    model=modelName, name='rpn_score',
    layer=dict(type='convolution',
               nFilters = (nClasses + 4) * OrigAnchorNum,
               width=1, height=1, stride=1, act = 'identity'),
    srcLayers = ['rpn_conv_3x3'])

# Add the region proposal Layer
s.addLayer(
    model = modelName,
    name = 'rois',
    layer = dict(
        type = 'REGIONPROPOSAL',
        act = 'identity',
        coordType='COCO',
        baseAnchorSize = 16,
        anchorNumToSample = 256,
        anchorScale=anchorScaleV,
        anchorRatio=anchorRatioV,
```

```

    ),
    srcLayers = ['rpn_score']
)

```

#### Table 4 The Region Proposal Layer and its Feature Extraction Layers

In Table 5, the `roipooling` layer is added with two source layers:

- the `conv5_3` layer, which is the last layer of the backbone network,
- the `rois` layer, which is the region proposal layer.

The order of two source layer defines their usage here.

After two additional fully connection (FC) layers, the output of `cls_score` layer is used to provide data to the final FastRCNN layer for classification of the object in the RoI, and the output of `bbox_pred` layer is used for object bounding box regression in the RoI. You can see how the output size `n` of the FC layers is related with the number of object categories.

The last layer for this model is the FastRCNN layer, which has three source layers; they are in order the FC layer with classification data, and FC layer with bounding box regression data, and the Region Proposal layer.

```

classNum = 20; # Number of Object Categories in the Model
s.addLayer(model=modelName, name='pool5',
            layer = dict(type='roipooling', poolWidth=7, poolHeight=7),
            srcLayers = ['conv5_3', 'rois']
)
s.addLayer(model=modelName, name='fc6',
            layer = dict(type='fullconnect', n=4096, act='relu'),
            srcLayers = ['pool5'])
s.addLayer(modelName, name='fc7',
            layer = dict(type='fullconnect', n=4096, act='relu'),
            srcLayers = ['fc6'])
s.addLayer(modelName, name='cls_score',
            layer = dict(type='fullconnect', n=(classNum+1), act='identity'),
            srcLayers = ['fc7'])
s.addLayer(modelName, name='bbox_pred',
            layer = dict(type='fullconnect',
                        n=4*(classNum+1), # The +1 is for the background category
                        act='identity'), srcLayers = ['fc7'])
s.addLayer(
    model = modelName,
    name = 'fastrcnn',
    layer = dict(
        type = 'fastrcnn',
        nmsIouThreshold = 0.3,
        detectionThreshold = 0.8
    ),
    srcLayers = ['cls_score', 'bbox_pred', 'rois'])

```

#### Table 5 The ROI (Region of Interest) Pooling Layers, and FastRCNN Layers

### TRAIN THE MODEL

After you prepared the images, the labeled data, and defined the model DAG as shown in the previous sections, you can now start to train the object detector. Here we use a tiny YOLO detector to show the process.

You can use the action `dlTrain` to train the detector. In the example listed in Table 6, the model DAG is `TinyYOLO`, which we built before using actions `buildModel` and `addLayer`. The training process uses data from the CAS table `trainSet`. The actual images and labels are read from different columns in the table, and the column names are specified in the `dataspecs` field.

This example uses pre-trained weights `yolov2InitdWeights_tiny` and continues to optimize on it. The final weights are saved in the CAS table `yolov2TrainedWeights_tiny`. The `optimizer` defines the algorithms used to search for the best solution while training the network. For details about the `optimizer`, you can refer to the [SAS® Visual Data Mining and Machine Learning DOC](#).

```
# Define the optimizer
optimizer=dict(miniBatchSize=10, logLevel=3, debugLevel=2, maxEpochs=10,
               algorithm=dict(method='momentum', # momentum=0.9,
                              clipGradMax=100, clipGradMin=-100,
                              learningRate=0.001, lrpolicy='step',
                              stepsize=20, gamma=0.9)
               )

# Train the network
r = s.dlTrain(table=dict(name='trainSet'),
              model = 'TinyYOLO',
              nThreads=1,
              gpu=1,
              initWeights=dict(name = 'yolov2InitWeights_tiny'),
              modelWeights=dict(name='yolov2TrainedWeights_tiny',
                                replace=True),

              dataspecs=[
                  dict(type='IMAGE', layer='data', data=inputVars),
                  dict(type='OBJECTDETECTION', layer='detection0',
                        data=targets)
              ],
              optimizer=optimizer,
              forceEqualPadding = True,
              seed=13308
              )
```

**Table 6 Invoking `dlTrain` to Train the Model**

### ***DataSpecs for the Detection Layer***

In the `dlTrain` action in Table 6, the `dataspecs` field specifies the names of the columns where the data needed for the layer is stored.

In the `dataspecs` statement, the variable `targets` and `inputVars` are two column name lists whose values are populated in Table 7. It is clearer if you look at the printed-out values of the variables in Table 8.

```
# Define the inputVars and targets that needed in dataspec in dlTrain
inputVars = [];
inputVars.insert(0, '_image_');
targets = ['_nObjects_'];
for i in range(0,10):
    targets.append('_Object%d_'%i);
    for sp in ["x", "y", "width", "height"]:
        targets.append ('_Object%d_%s'% (i, sp));
```

```

print ("targets")
print (targets);
print ("inputVars");
print (inputVars);

```

**Table 7 Code to Generate the Variables Used in Dataspec**

```

targets
['_nObjects_', '_Object0_', '_Object0_x', '_Object0_y', '_Object0_width',
'_Object0_height', '_Object1_', '_Object1_x', '_Object1_y',
'_Object1_width', '_Object1_height', '_Object2_', '_Object2_x',
'_Object2_y', '_Object2_width', '_Object2_height', '_Object3_',
'_Object3_x', '_Object3_y', '_Object3_width', '_Object3_height',
'_Object4_', '_Object4_x', '_Object4_y', '_Object4_width',
'_Object4_height', '_Object5_', '_Object5_x', '_Object5_y',
'_Object5_width', '_Object5_height', '_Object6_', '_Object6_x',
'_Object6_y', '_Object6_width', '_Object6_height', '_Object7_',
'_Object7_x', '_Object7_y', '_Object7_width', '_Object7_height',
'_Object8_', '_Object8_x', '_Object8_y', '_Object8_width',
'_Object8_height', '_Object9_', '_Object9_x', '_Object9_y',
'_Object9_width', '_Object9_height', '_Object10_', '_Object10_x',
'_Object10_y', '_Object10_width', '_Object10_height']
inputVars
['_image_']

```

**Table 8 Output of the Print Statement: Values of the Dataspec Variables**

Inside the dataSpecs statement in Table 6, the statement:

```
dict (type='IMAGE', layer='data', data=inputVars)
```

tells the training process that the input layer named `data` uses image data, and the name of the column containing the image is represented by the variable `inputVars`, which in this case means the image data needed is in the column `_image_` in the input CAS table `trainSet`.

The statement

```
dict (type='OBJECTDETECTION', layer='detection0', data=targets)
```

tells that the detection layer (with name `detection0`) uses data of type `OBJECTDETECTION`, which consists of a set of columns in the input table.

Data type `OBJECTDETECTION` defines the meaning of each field in the list `targets` as following:

- The number of labeled objects for each image is stored in a column whose name is given in the first string item in the list `targets`, in this example, in the column named `_nObjects_`;
- Each labeled object in the image uses five columns, whose names are in five consecutive items in the list, for example, in the column with names `_Object0_`, `_Object0_x`, `_Object0_y`, `_Object0_width`, `_Object0_height`
- The order, not the name, of the five consecutive items, determines the usage of the columns. Specifically, the first item points to the column for the object category, and the 2-5 items, if in YOLO format, points to the columns for the x, y position,

and width and height of the object bounding box in order respectively.

### **Monitoring the Training Process**

Table 9 shows some information you can see in the training process. The Fit Error currently is calculated as an average of the value 1-IOU (Intersection over Union) for all images; the IOU for each image is the average IOU for all the *labeled object v.s. best matching prediction pairs* in the image, regardless of whether the prediction is selected as one of the final detections or not.

```
WARNING: Only 1 out of 2 available GPU devices are used.
NOTE: The Synchronous mode is enabled.
NOTE: The total number of parameters is 15861648.
NOTE: The approximate memory cost is 357.00 MB.
NOTE: Loading weights cost          0.00 (s).
NOTE: Initializing each layer cost   1.47 (s).
NOTE: The total number of threads on each worker is 1.
NOTE: The total minibatch size per thread on each worker is 10.
NOTE: The maximum minibatch size across all workers for the synchronous mode is 10.
NOTE: Epoch          Learning Rate      Loss      Fit Error      Time (s)
NOTE:      0              0.001      44.367      0.7135      0.41
NOTE:      1              0.001      16.287      0.6829      0.40
NOTE:      2              0.001      10.311      0.6061      0.39
NOTE:      3              0.001      7.0372      0.542       0.40
NOTE:      4              0.001      6.2692      0.4923      0.39
NOTE:      5              0.001      5.3297      0.4786      0.39
NOTE:      6              0.001      5.1382      0.4639      0.40
NOTE:      7              0.001      4.9569      0.4291      0.41
NOTE:      8              0.001      4.5718      0.3865      0.40
NOTE:      9              0.001      4.3239      0.3875      0.40
NOTE: The optimization reached the maximum number of epochs.
NOTE: The total time is          3.99 (s).
```

**Table 9 Monitoring the Training Process**

It is an art to train a deep neural network. For object detection network like this, you can use pretrained weights that are trained on general publicly available classification data set like IMAGENET, since they have a huge amount of data. After that, you can transfer the weights into the detection network, and train it with your specific data set. When training a new model, always start with a small sample of the data and try to overfit it.

The L2 Norm of the pre-trained weights should be small, otherwise, it is an indication that the model lacks generalization capability. It is recommended to use L2 Norm and `randomMutation` to prevent overfitting. If L2 Norm is set, the value should decrease and be small during training.

During the detection network training, it is usually a good practice to start with a small learning rate, and after a few epochs, increase the rate by 10~50 times.

### **SCORE USING TRAINED WEIGHTS**

Scoring Using trained weights is similar with other deep learning tasks. In the following scripts, the scoring results are saved in the CAS table `detections`.

```
s.dlscore(model='TinyYOLO',
          initWeights='yolov2TrainedWeights_tiny',
          table = 'scoringSet',
          copyVars=['_path_', '_image_'],
```

```

nThreads=10,
miniBatchSize=1,
casout={'name':'detections', 'replace':True}
)

```

You can use the `extractDetectedObjects` action to extract and display the detection results; the bounding box, the object category, and the scored values are all added onto the image. Figure 7 shows some examples of such annotated images.

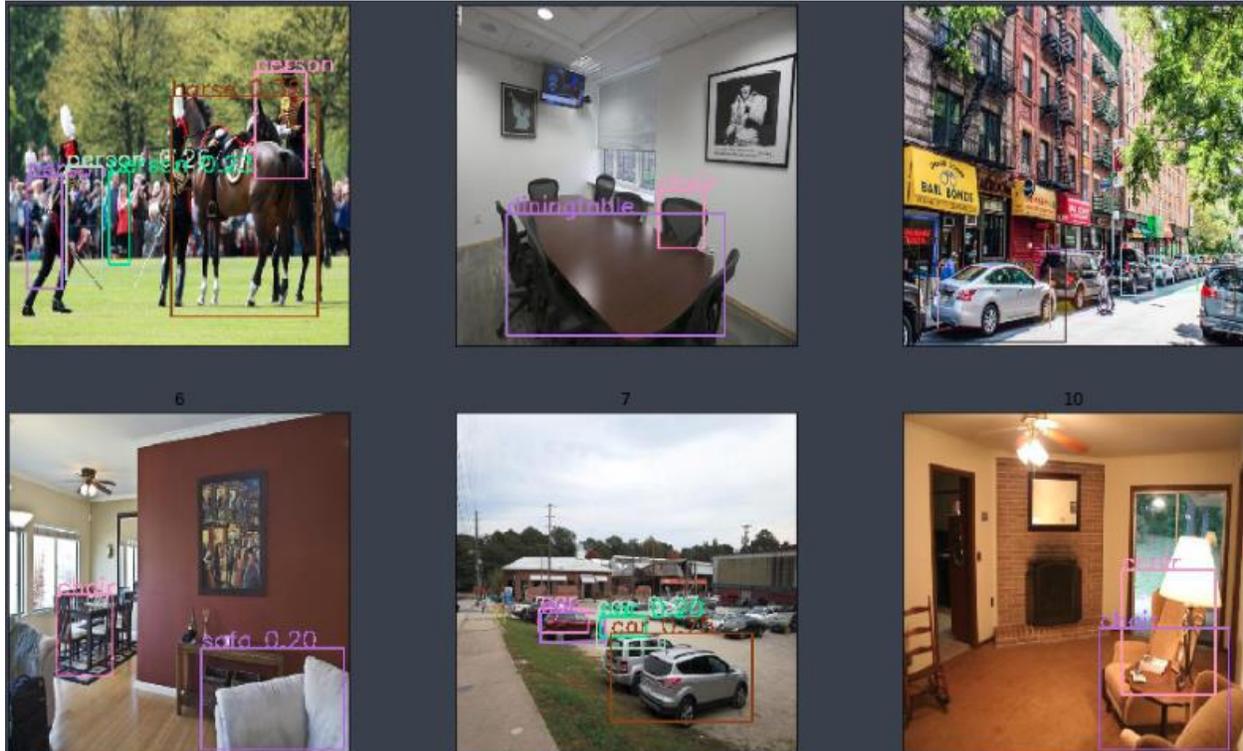


Figure 7 Score Results Displayed as Annotated Images

## SEMANTIC SEGMENTATION

Except locating objects in images, analysis of the images at pixel level is useful and widely used to solve many real-world problems, especially in areas such as self-driving, biomedical diagnosis, and so on, as illustrated in Figure 8.



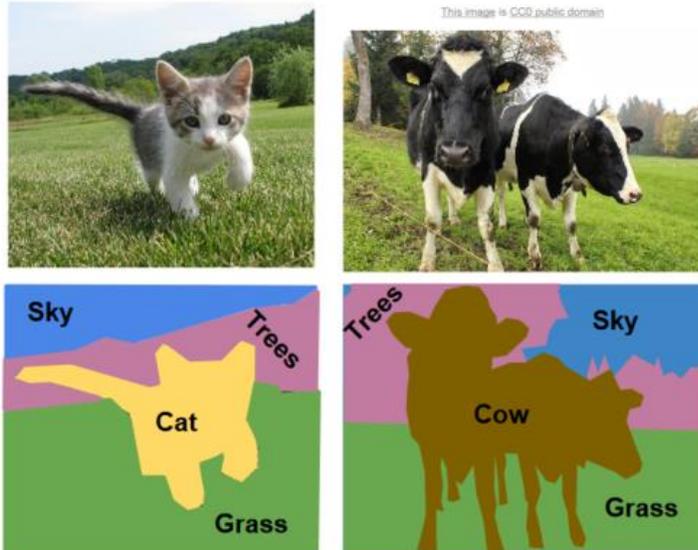
Figure 8 Application of semantic segmentation includes biomedical 3-D image segmentation, self-driving, super resolution, and so on. Images are from:

<https://arxiv.org/pdf/1803.08691.pdf>,

<https://www.kaggle.com/c/cvpr-2018-autonomous-driving/overview>

<https://paulvanderlaken.com/2017/11/23/super-resolution>.

Image semantic segmentation is one of the techniques to understand an image at pixel level. Specifically, it attempts to partition the image into semantically meaningful parts, and to classify each part into one of the pre-defined classes. That is, each pixel in the image is assigned to an object class as shown in Figure 9.



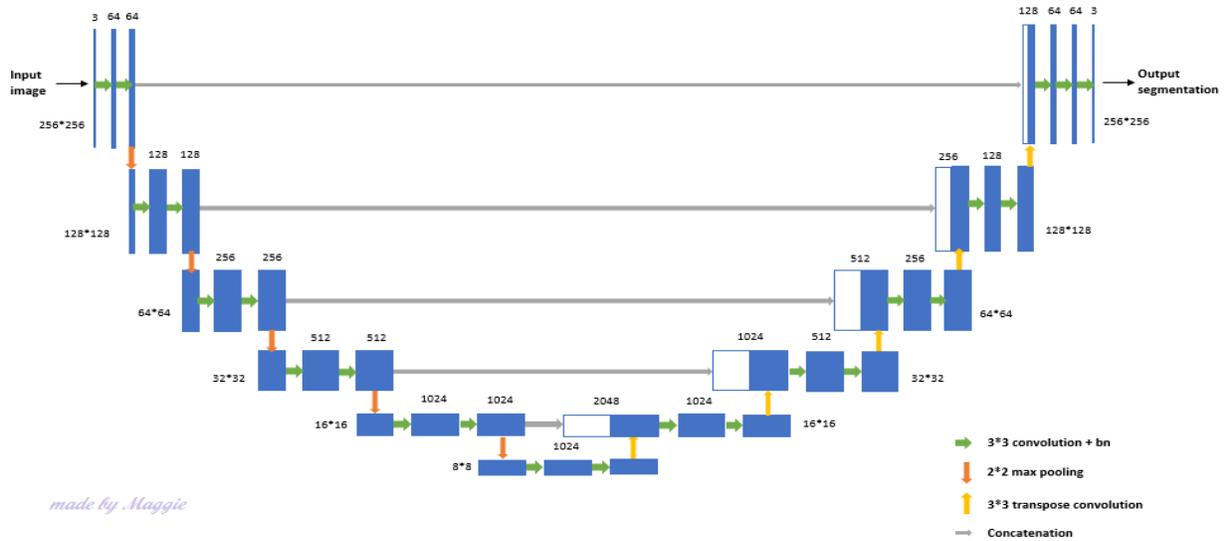
**Figure 9** An example of semantic segmentation. One of the four pre-defined labels is given to each pixel in the image to show the boundaries and shape of each object. Image is from <https://www.analyticsvidhya.com/blog/2017/11/heart-sound-segmentation-deep-learning>.

There are many promising semantic segmentation models, including FCN [9], U-Net [10], SegNet [11], and DeepLab [12]. This paper focuses on U-Net model, which consists of an encoding path to capture context, and a symmetric decoding path that enables pixelwise prediction. This paper also introduces the semantic segmentation feature in SAS Deep Learning through a practical example.

## MODEL SPECIFICATION

Fully connected (FC) layers connect every neuron in one layer to every neuron in another layer and are widely used in traditional neural networks to flatten the matrices and to classify the images. However, it fixes the dimension and throws away the spatial structure of the layers. Since for semantic segmentation the inference is at pixel level, it is crucial to maintain the dimensional structure, and naturally the FC layers are replaced by fully convolutional layers.

Based on this idea, the U-Net model contains two parts: the down-sampling encoding part, including convolution layers and pooling layers, that gradually reduces the spatial dimension of the input images, and the up-sampling decoding part, including convolution layers and transpose convolution layers, the recovers the object details. In order to inherit localization information from the encoding process, concatenation layers are also used in the model, as shown in Figure 10. This model is named after its U-shape, as the encoding part and decoding part are symmetric. Starting from the bottleneck layer, which in this case is the  $8*8*1024$  layer at the bottom of the U-shape, the up-sampling process is the reversed image of the down-sampling process, with pooling layers replaced by transpose convolution layers.



**Figure 10 U-Net architecture.** The input layer contains  $256 \times 256$  color images. The resolution of bottleneck layer is  $8 \times 8$ . Each blue box is a feature map of denoted size.

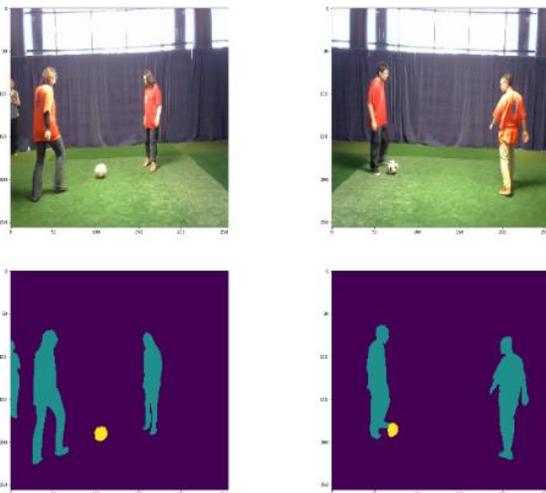
## GROUND TRUTH FORMAT

Both image and wide format data are supported in the segmentation model. If using the wide format, each column represents the value of one pixel of the input image. Specifically, the first column gives the class label of the top left pixel (0, 0), the second column represents the second pixel (0, 1). The column for the last pixel in the first row of the image is followed by that of the first pixel in the second row (1, 0) of the image. The last column gives the class of the bottom right pixel of the image. The values could be either numeric (0, 1, 2, ...) or categorical (people, car, background, ...).

If using image type ground truth for pixel-wise classification, then the pixel values should be an integer no more than the number of classes. For example, if there are four different classes in the image, then each pixel of the ground truth should be a number in [0, 1, 2, 3].

## SOCCER PLAYER DATA SET

The data set contains 170  $256 \times 256$  color images and annotations as shown in Figure 11. They are divided into three parts: training (70%), validation (20%) and testing (10%).



**Figure 11** The data set contains 170 color images and annotations. Three classes are pre-defined: soccer player, ball, and background.

Image type ground truth is used for this data set as in Figure 12. Specifically, the data would contain two columns of images, `_image_` and `_labels_`. The first is the input, which contains images of  $256 \times 256 \times 3$  taking values between  $[0, 255]$ . The second is the ground truth, which are  $256 \times 256 \times 1$  images taking values in  $[0, 1, 2]$ , representing their three classes: soccer player, ball, and background.

	Column	ID	Type	RawLength	FormattedLength	NFL	NFD
0	<code>_filename_0</code>	1	varchar	27	27	0	0
1	<code>_image_</code>	2	varbinary	118999	118999	0	0
2	<code>_label_</code>	3	varchar	0	1	0	0
3	<code>_id_</code>	4	int64	8	12	0	0
4	<code>labels</code>	5	varbinary	3173	3173	0	0
5	<code>idx</code>	6	double	8	12	0	0

Figure 12 Columns in the data set.

## BUILDING MODEL DAG

The model DAG is built using DLPy, an open-source, high-level Python package for deep learning. An example of the syntax is given below.

```
Inputs = InputLayer(3, 256, 256, scale = 1.0 / 255,
                    random_mutation='random', name='InputLayer_1')
conv1 = Conv2d(64, 3, act = 'identity', init=init)(inputs)
bn1 = BN(act = 'relu')(conv1)
conv1 = Conv2d(64, 3, act = 'identity', init=init)(bn1)
bn1 = BN(act = 'relu')(conv1)
pool1 = Pooling(2)(bn1)
.....
tconv7 = Transconvo(1024, 3, stride = 2, act='relu', padding = 1,
output_size = (16, 16, 1024), init=init)(bn6)
merge7 = Concat(src_layers = [bn5, tconv7])
conv7 = Conv2d(1024, 3, act = 'identity', init=init)(merge7)
bn7 = BN(act = 'relu')(conv7)
conv7 = Conv2d(1024, 3, act = 'identity', init=init)(bn7)
bn7 = BN(act = 'relu')(conv7)
.....
conv12 = Conv2d(3, 3, act = 'relu', init=init)(bn11)
seg1 = Segmentation(name='Segmentation_1', act='softmax',
                    error='entropy')
```

Since the tensor dimension of the segmentation layer is entirely inherited from its source layer, the feature map size of its source layer should be equal to that of the ground truth, while the number of channels should be equal to the number of classes. In this case, the output size of layer `conv12` is  $256 \times 256 \times 3$ . The default activation function is softmax and the default error type is cross-entropy.

## TRAINING AND SCORING

The model is trained using ADAM algorithm for 60 epochs, with mini-batch size = 10 and number of threads = 1. Sample code for training is as below. Part of the training process is shown in Figure 13.

```
Inputs = InputLayer(3, 256, 256, scale = 1.0 / 255,
                    random_mutation='random', name='InputLayer_1')
dataspecs=[dict(type='image', layer='InputLayer_1', data=['_image_']),
```

```

        dict(type='image', layer='Segmentation_1', data=['labels']))]
optimizer = dict(miniBatchSize=10, regL2=0.0005,
                  algorithm=dict(method="adam", lr=2e-4, lrPolicy='step',
                                 gamma=0.9, stepSize=10),
                  maxEpochs=60, logLevel=2)
s.dlTrain(model=model_name, table=train, validtable=valid, nthreads=1,
          modelWeights = dict(name = 'seg_weights', replace = True),
          dataspecs=dataspecs,
          optimizer = optimizer)

NOTE: The total number of parameters is 81716035.
NOTE: The approximate memory cost is 5320.00 MB.
NOTE: Loading weights cost      0.00 (s).
NOTE: Initializing each layer cost      6.65 (s).
NOTE: The total number of threads on each worker is 1.
NOTE: The total mini-batch size per thread on each worker is 10.
NOTE: The maximum mini-batch size across all workers for the synchronous mode is 10.
NOTE: Number of input variables:      1
NOTE: Number of numeric input variables:      1
NOTE: Epoch Learning Rate      Loss Fit Error Validation Loss Validation Error Time(s)
NOTE: 0      0.0002      6.568e+04      0.4404      7.389e+04      0.4229      13.05
NOTE: 1      0.0002      3.813e+04      0.05841      4.033e+04      0.1464      7.28
NOTE: 2      0.0002      2.581e+04      0.04767      2.97e+04      0.06102     7.27
NOTE: 3      0.0002      1.838e+04      0.03793      1.472e+04      0.02501     7.28
NOTE: 4      0.0002      1.287e+04      0.0249      1.332e+04      0.03527     7.27
NOTE: 5      0.0002      9257      0.02333      1.1e+04      0.03559     7.27
NOTE: 6      0.0002      6680      0.02156      8101      0.02656     7.27
NOTE: 7      0.0002      5073      0.02141      6852      0.03326     7.27
NOTE: 8      0.0002      3645      0.01691      3364      0.01582     7.28
NOTE: 9      0.0002      3088      0.01658      2748      0.01483     7.27
NOTE: 10     0.0002      2507      0.01392      2677      0.01499     7.27

```

**Figure 13 Part of the training process**

The loss error is the sum of cross-entropy of all pixels, while the fit error is the misclassification rate averaged on all pixels. Both errors are supposed to decrease during training process, as indicated in Figure 13.

For segmentation models, dataspecs must be specified for input layers and segmentation layers to define the data types and columns. In this example, images are used for both input and segmentation layers.

The following code is for scoring on the testing data. The testing output is also given below in Figure 14. For each image, the output table contains the pixel-wise prediction, along with the predicted probability. For example, the first pixel is assigned label 0 with probability higher than 0.99, as shown in columns `_DL_PredName0_` and `_DL_PredP0_`. Visualization of the scoring results can be easily achieved based on the output tables.

```

s.dlScore(modeltable=model_name, initweights='seg_weights', table=test,
          nthreads=1, casout=dict(name='output', replace=True))

```

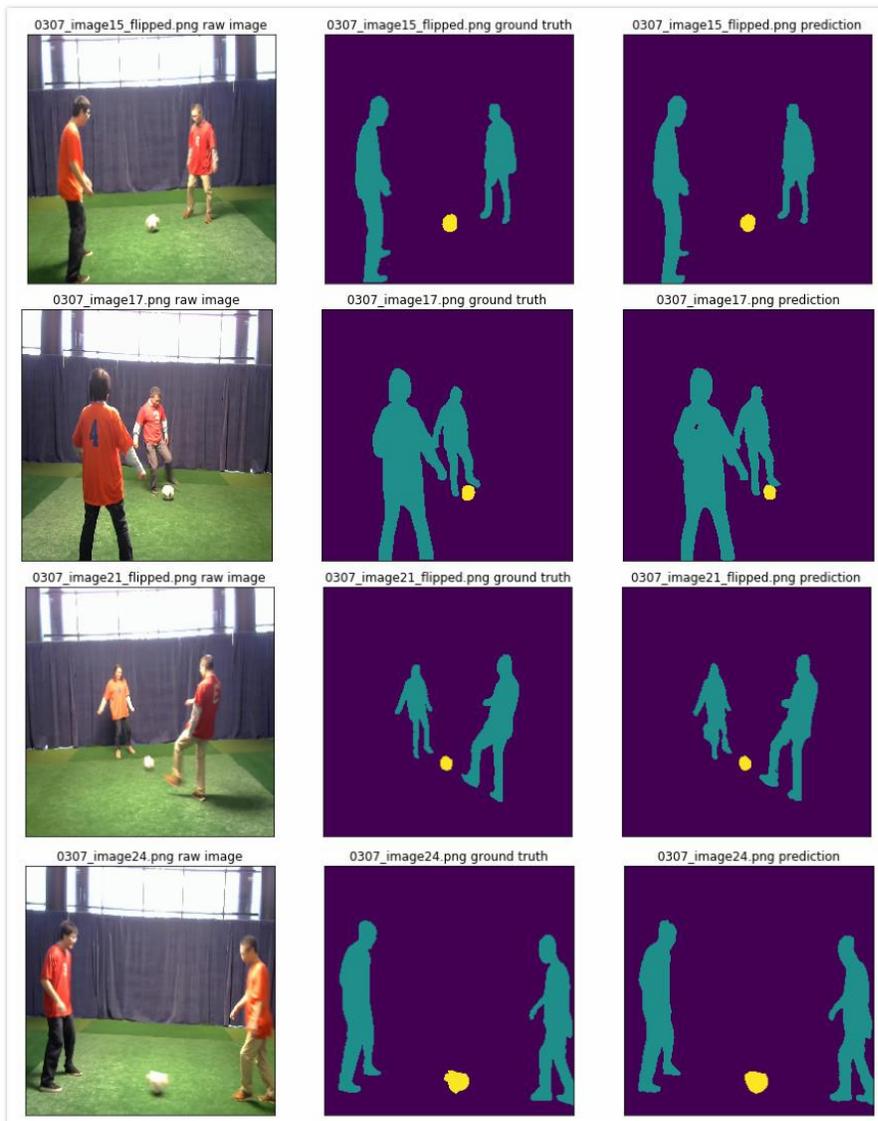
#### § ScoreInfo

	Descr	Value
0	Number of Observations Read	22
1	Number of Observations Used	22
2	Misclassification Error (%)	0.758362
3	Loss Error	1307.178

	_filename_0	_DL_PredName0_	_DL_PredP0_	_DL_PredName1_	_DL_PredP1_	_DL_PredName2_	_DL_PredP2_	_DL_PredName3_
0	0307_image78.png	0	0.990635	0	0.997753	0	0.999453	0
1	1358_image00163.png	0	0.990079	0	0.996777	0	0.998342	0
2	0307_image94.png	0	0.991555	0	0.997786	0	0.999458	0
3	0307_image23.png	0	0.994385	0	0.999123	0	0.999731	0
4	0307_image78_flipped.png	0	0.993368	0	0.998213	0	0.999360	0
5	0307_image24.png	0	0.991580	0	0.997847	0	0.999442	0
6	0307_image15_flipped.png	0	0.994278	0	0.998573	0	0.999483	0
7	0307_image17.png	0	0.990696	0	0.997499	0	0.999325	0
8	0307_image21_flipped.png	0	0.994408	0	0.998811	0	0.999602	0

**Figure 14 Scoring output on testing data.**

The scoring mis-classification rate on the testing data is 0.76%, which means out of 65,536 pixels in each image, only less than 500 pixels are miss-labeled. Some of the scoring visualization results are given in Figure 15.



**Figure 15 Scoring results visualization. The raw images are shown in the first column, followed by ground truth annotation in the second column. The third column contains predictions.**

## CONCLUSION

SAS has extended its deep learning toolkit to support object detection and semantic segmentation in its recent release. This new functionality is available through CAS action sets in SAS Visual Data Mining and Machine Learning, as well as in the DLPy open-source project.

With the new extension, SAS deep learning empowers customers to build an end to end solutions to computer vision problems involving tasks of image classification, keypoint detection, object detection, and semantic segmentation.

Specific examples demonstrate how some new layers, when combined with other deep learning, image processing action sets, enable customers to load, explore the data, build the model architecture, train the network, perform the inference, and visualize the results.

Development efforts involving instance segmentation is in progress and will be available to customers in the future.

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## RECOMMENDED READING

- SAS® *Visual Data Mining and Machine Learning DOC*, available at <http://support.sas.com/software/products/visual-data-mining-machine-learning/index.html#s1=2>
- *DLPy - SAS Viya Deep Learning API for Python*, available at <https://github.com/sassoftware/python-dlpy>

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