# How to BubTFOD

Adapted from Nicholas Renotte

[GitHub - nicknochnack/TFODCourse](https://github.com/nicknochnack/TFODCourse)

* Uses Tensorflow (TF) Object Detection API
* Based on Transfer learning with TF Model zoo

[models/tf2\_detection\_zoo.md at master · tensorflow/models (github.com)](https://github.com/tensorflow/models/blob/master/research/object_detection/g3doc/tf2_detection_zoo.md)

* Comprises a folder structure that works with contained Code

**Codes**:

* Creation of artificial images (Based on code by Ivo Roghair)
  + maskGen.py
  + extract\_and\_save.py
  + Create\_training\_images.py
* Training and Testing
  + **1\_Train\_CNN\_from\_TFOD\_Zoo.ipynb**
  + **5\_Retrain\_custom\_CNN.ipynb**
* Analysis and further testing
  + **2\_Test\_CNN\_on\_new\_imgs.ipynb**
  + **3\_Detection\_and\_Analysis.py**
  + DetectAnalysis\_Functions.py
  + Metric\_Plots.py
  + CNNs\_Evaluations.py
  + EvalCoco\_PRCurve.py
* Bubble Tracker
  + **4\_BubbleTracker.py**
  + BubbleTracker\_plots.py
* Other files
  + TFODPaths.py
  + Create\_CocoJson.py
  + ODE\_bubble\_growth.py
  + Unify\_plots\_net8.py
  + Img\_postproc\_params.json

## Create Bubble instances: maskGen.py

Creates an image of the annotated bubbles where every bubble instance has a unique color

Creates a mask image with unique pixel values: background=0, each bubble instance has unique pixel value

* Anaconda prompt: cd to LabelMe folder; activate virtual environment tfod (conda activate tfod); call: labelme
* Annotate bubbles from images within labelme with Edit🡪Create circle🡪label: “Bubble”; save annotation file
* Images need to be Greyscale (no RGB format) *[img = cv2.cvtColor(img, cv2.COLOR\_BGR2GRAY)]*
* Mask image needs to be saved as .tif (for png and jpg inaccurate pixel values were included)

### What to Set up

* Json\_path: Name of annotation file
* MASK\_WIDTH: Width of annotated (original) image
* MASK\_HEIGHT: Height of annotated (original) image
* (opacity): In case of 4th color channel (alpha channel) usage

## Create mask pickle file: extract\_and\_save.py

Creates masks containing annotated bubbles that are needed for the creation of artificial training images

* Windows Terminal: cd to bubble\_extractor, activate virtual environment createimg
* Put original images into folder “org”; Masks (“labels” in file name) into folder “mask” (have to be tif format!)
* In file extract\_and\_save.py: give desired pickle name

## Create Artificial Images: create\_training\_images.py

Not part of the BubTFOD Set up, but essential for training a net

Creation of artificial bubble nucleation images

### What it does

* Random bubble instances are placed on a background showing a substrate
* Optional: perform random alterations (blur, rotate etc.)
* Storage of bounding box and mask of the image
* Optional: Save xml annotation file (containing info about placed bubbles) = necessary for training with BubTFOD

### What to set up

* Indicate mask name (including desired set of bubble instances) at program start
* n\_bubbles\_per\_image: Number of bubbles per image
* n\_training\_images: Number of images that should be generated
* iscale\_factor: Factor for scaling the output image (mask and background), when lower resolution of img is desired
* outdir: name of output directory (set to new name in order not to overwrite previously generated data)
* xml\_bdbox: Set to TRUE for saving bounding box annotations in xml file
* Sigma\_rotate\_degree
* Sigma\_scaling\_fraction
* Highlight\_bubbles
* Blur\_mask

## Training a CNN: 1\_Train\_CNN\_from\_TFOD\_Zoo.ipynb

Object Detection (here: Bubbles) with a Deep Learning Network

Executes transfer learning with pretrained model from Tensorflow model zoo

### What it does

1. Set up of paths for pretrained and custom model
2. Load pre-trained Model (from tf model zoo)
3. Create Label Map

- Contains all categories that should be detected

- Here: category name “Bubble”; label id 1

1. Create TF records

* .record = binary storage format
* Convert images and their annotations into format for training/testing
* Storing data as sequence of binary strings has impact on training time
* (less space on disk, copy faster, read efficiently)

1. Copy model config (pipeline.config) to training folder

* pipeline.config defines architecture of model
* contains e.g. prebuilt data augmentation, max. number of allowed detections etc.
* see preset configurations in pipeline file in pre-trained model folder

1. Update config for transfer learning

* Change preset configurations in pipeline.config
* E.g. batch size, label map etc.

1. Train the model

* Set the number of training steps
* Print a command
* Run command in command prompt (in VS Code in included prompt possible)
* Event file (info/outcome of training) stored in model path – “Train”

1. Evaluate the model

* Calculate performance metrics
* Precision @ different IoUs and for different object sizes
* Recall @ different numbers of detection and for different object sizes
* Event file (info/outcome of test) stored in model path – “Eval”

### What to Set up

* **Prerequisite: Installed Tensorflow and dependent packages**
* CUSTOM\_MODEL\_NAME: Name custom model (own name)
* PRETRAINED\_MODEL\_URL: Indicate url of pretrained model from tf model zoo (right click on desired model, copy link)
* PRETRAINED\_MODEL\_NAME: Indicate proper name of pretrained model (part of copied url string)
* Modify pipeline.config
  + Pipeline\_config.model: indicate right model name
  + Set batch size
* Train the model:
  + command: Set number of training steps
  + Copy command into command prompt and run from there for being able so track the training
* Evaluate the model:
  + Print command, run from command prompt
  + Possible to see results with tensorboard (instructions in code)
* Custom model under: **Tensorflow/workspace/models**

## Get evaluation metrics of custom network on new images: 2\_Test\_CNN\_on\_new\_imgs.ipynb

### What it does

Evaluates performance of custom bubble detection model on new test images that were not tested yet during the training process

* Calculates various precision, recall values
* Creates event file that can be further analyzed with Models\_Evaluations.py

### What to set up

* CUSTOM\_MODEL: Name of custom trained model
* CUSTOM\_CHECKPOINT: Indicate (training) checkpoint of custom model (check model folder for latest checkpoint to use fully trained model)
* NEW\_TEST\_IMGS: Name of folder of new test images
* NEW\_RECORD\_FILE\_NAME: Unique name for tf record file
* Run evaluation command in terminal
* Possible to call tensorboard in order to view evaluation values there

## Plotting Training and Evaluation metrics: Metric\_Plots.py

Contains functions for plotting training and evaluation metrics

* Precision\_plot()
  + 6 Subplots that show:
    - mAP (mean average precision)
    - mAP @ 0.5 IOU
    - mAP @ 0.75 IOU
    - mAP for small/medium/large objects
  + input: dictionary with model names as keys; contains evaluation metrics
* Recall\_plot()
  + 6 Subplots that show:
    - AR (average recall) @ 1/10/100
    - AR @ 100 for small/large/medium objects
  + input: dictionary with model names as keys; contains evaluation metrics
* Plot\_total\_loss()
  + Plot loss curve from training
  + Input: df containing loss over time from (from training event file)
* Plot\_learningrate()
  + Plot learning rate from training
  + Input: df containing learningrate over time (from training event file)

## Compare performance (evaluation/test metrics) of several models: CNNs\_Evaluations.py

### What it does

* Gets properties from Train and Eval Event files of custom models (created during training and evaluation procedure; contains important properties/characteristics regarding the respective procedure)
* Properties that can be seen with tensorboard (interactive interface)
* Train properties: Total loss, Detection loss, learning rate etc.
* Eval properties: Precisions, Recalls
* Uses Functions precision\_plot(), recall\_plot(), plot\_total\_loss(), and plot\_learningrate() from MetricPlots.py

1. Set\_paths()
2. Get\_event\_file()
3. Launch\_tensorboard()
4. Get\_evaluation\_metrics()
5. Save\_dict\_to\_excel()

### What to set up

* custom\_models: Indicate custom model names that you want to evaluate
* Optional: calling *save\_dict\_to\_excel():* Set name of excel file containing Train\_Metrics and Eval\_Metrics
* *plt.savefig():* Set name of precision plot
* *plt.savefig():* Set name of recall plot
* Optional: launch tensorboard

## Make detections and analyze them: 3\_Detection\_and\_Analysis.py

### What it does

* Tests custom model on set of test images
  + Code works with images with and without annotations
  + Works with png and tif files (needs extension in case of other file formats)
* Visualize Detections / Ground Truth bounding boxes
* Calculate and plot several bubble characteristics

Can produce the following plots/images:

1. Visualize the bounding boxes of predicted/detected bubbles in the original image
2. Visualize the bounding boxes of annotated bubbles in the original image
3. Visualize the bounding boxes of both predicted and annotated bubbles
4. Bubble size distribution: Histogram of the diameter; probability density (kernel density estimation – Gaussian) [for Prediction, Annotation, and the comparison of Prediction & Annotation]
5. Boxplot: Compare statistical properties of predicted and annotated bubble diameters
6. Plot: total number of bubbles over time

### What to set up

* CUSTOM\_MODEL: Indicate name of custom model that should be tested
* CUSTOM\_CHECKPOINT: Indicate (training) checkpoint of custom model (check model folder for latest checkpoint to use fully trained model)
* max\_detect: Indicate max. allowed detections in one image
* test\_path: contains set of images that model should be tested with (put images into custom img folder under **Tensorflow/workspace/images**)
* MIN\_SCORE\_THRESH: Set Threshold; only bounding boxes of bubbles with a detection score > threshold will be visualized in the plot
* Scaling\_factor: factor for changing resolution of image; do not change resolution if annotation is present for image because the bounding box coordinates are based on original image size
* img\_width\_mm: Indicate the width of the image in millimeters
* img\_height\_mm: Indicate the height of the image in millimeters
* Visualized detections and json files (containing bounding box coordinates) under: **Tensorflow/workspace/images/tested/CUSTOM\_MODEL**

## TFODPaths.py

Contains function for getting the folder/path structure for a custom DL model

* Input: my\_model\_name (Name of custom model)
* Output
  + paths: All paths for custom model that fit to folder structure of BubTFOD
  + files: Paths to files such as pipeline.config, labelmap, tf\_record\_script

## 4\_BubbleTracker.py

Kalman Filter based Centroid Tracker

### What it does

Helps characterizing detachment and coalescence throughout the nucleation process (time series)

Assigns detected bounding boxes (img n+1) to tracked bounding boxes (img n) using IoU as a distance metric

That way bubble sequences can be traced 🡪 creates a data set of matched and unmatched bounding boxes

### What to set up

* CUSTOM\_MODEL: Model that provided detections
* TESTED\_IMG\_FOLDER: Folder containing the detections (COCO json files containing bounding boxes) on (experimental) images, provided by the custom model
* IMG\_FOLDER: Folder containing the original images that the detections were made on
* img\_format: format of the images
* tracker\_threshold: centroid distance threshold
* img\_width\_mm: original width of the region of interest within the image (in mm)
* Names of the textfiles for saving the number of unmatched bubbles and the average diameter of unmatched bubbles

## EvalCoco\_PRCurve.py

### Plots the Precision Recall Curve for a tested image set

### Needs coco json files containing the annotation and detection bounding boxes

### What to set up

* CUSTOM\_MODEL: Model that provided detections
* TESTED\_IMG\_FOLDER: Folder containing the annotations and detections (COCO json files containing bounding boxes) on images, provided by the custom model

## 

## Create\_CocoJson.py

Creates json file in COCO format containing the bounding box characteristics (e.g. coordinates) of annotations or detections

used for calculation of evaluation metrics

## 

## ODE\_bubble\_growth.py

### What it does

Solves the model of Epstein and Plesset for the growth of a single bubble in a bulk liquid via diffusion

### What to set up

* Indicate pressure values before and after the pressure drop (that initializes supersaturation conditions in the experiments) and the time span

1. File for specifying the region of interest within images: Img\_postproc\_params.json

### What it does

Contains parameters for specifying the region of interest within an (experimental) image where detections should be made on

Corresponds to the region on the metal substrate that is colored with the marker