Pollution Image Classification

Artificial Vision - Project

Professor: Lanzarotti Raffaella
Student: Francesco Ruggeri - 871798

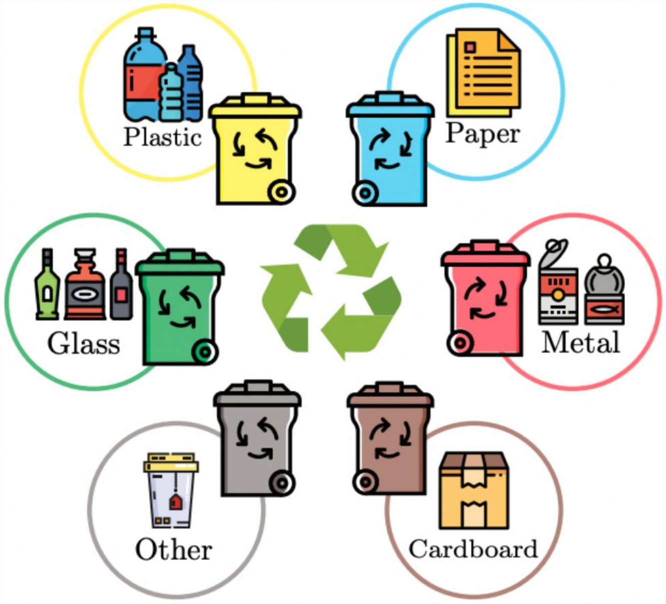
A.A. 2023/2024

UNIVERSITÀ
DEGLI STUDI
DI MILANO

Introduction

Objective

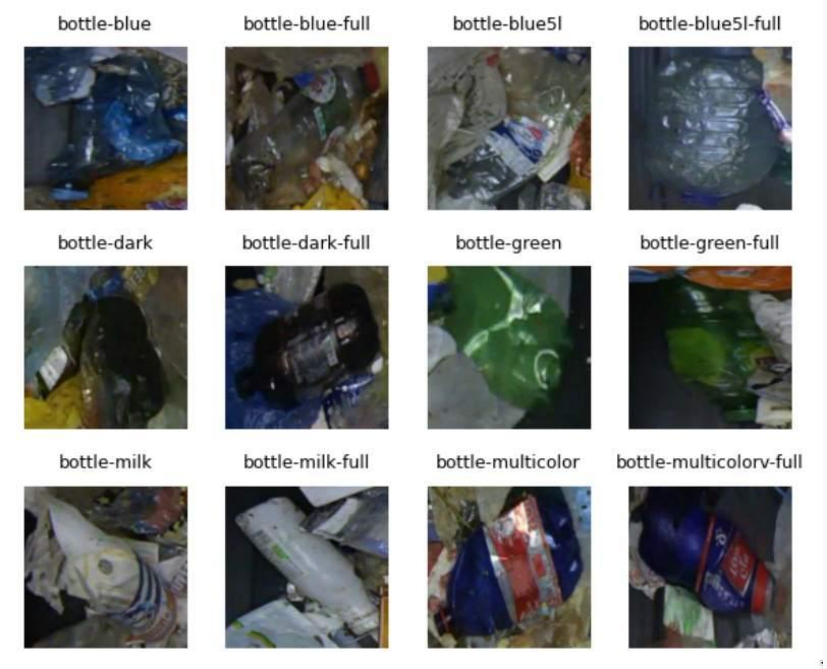
Develop a waste image classification model using artificial vision techniques



Dataset

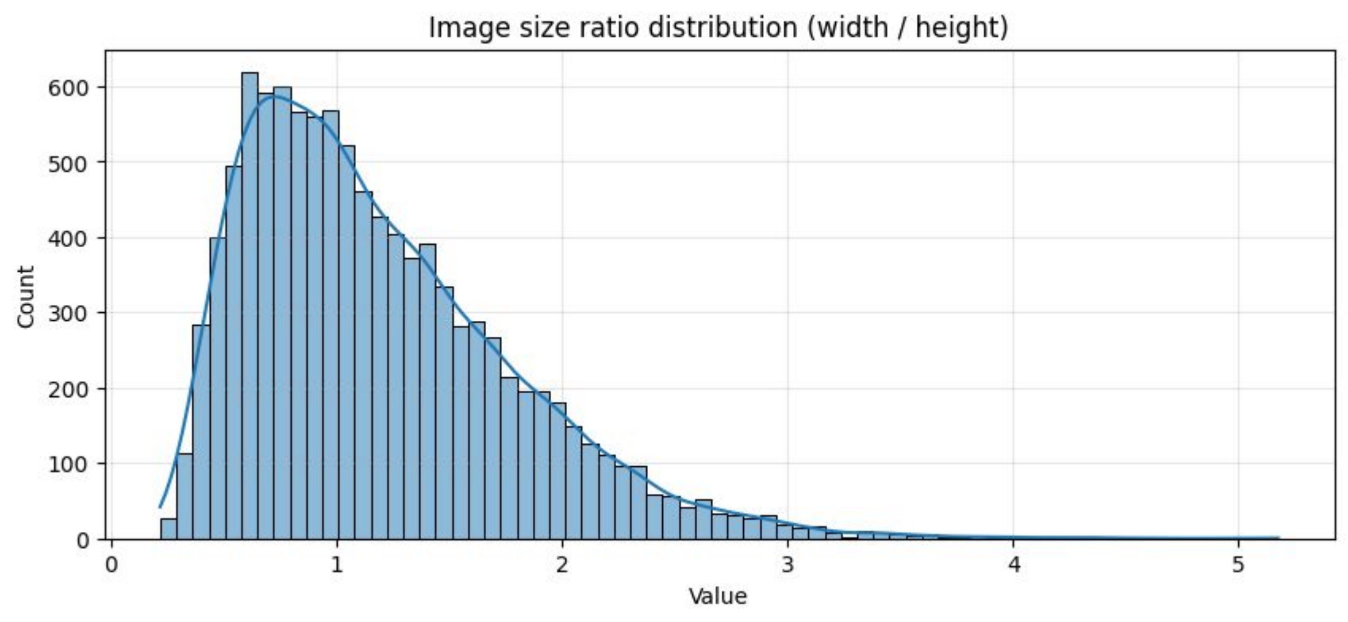
WaRP
Waste Recycling Plant Dataset

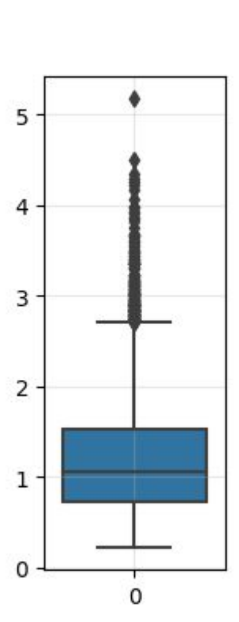
- Sourced in Kaggle
- 28 distinct classes
- 10000 images



Dataset Exploration

Aspect-Ratio Distribution

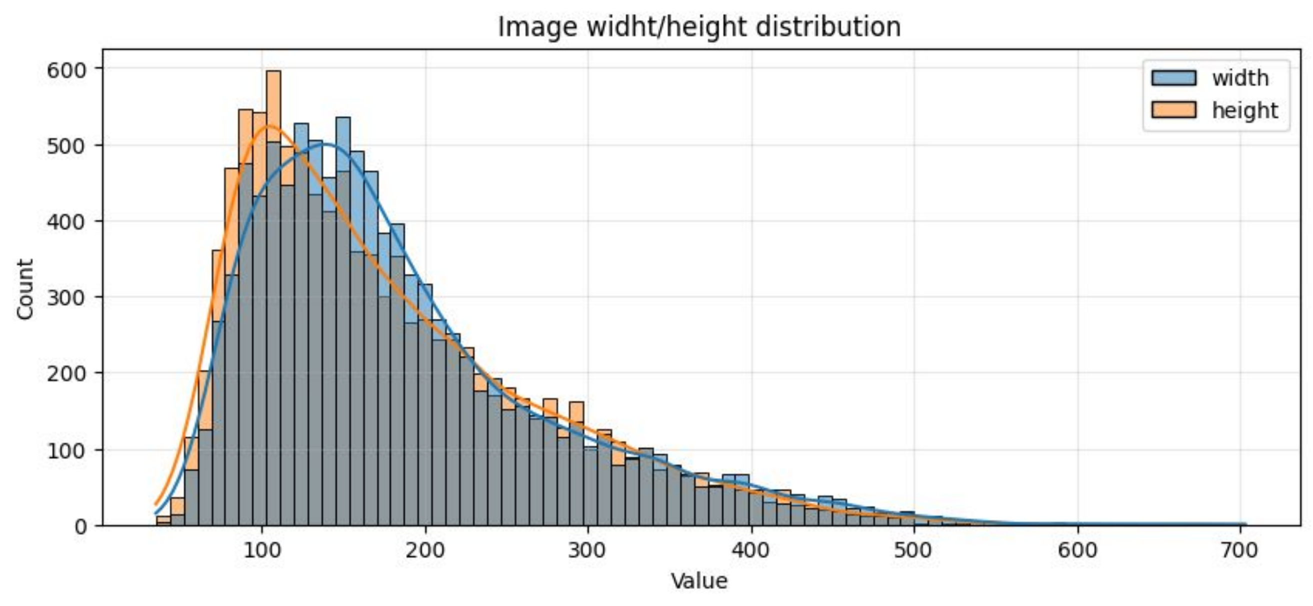


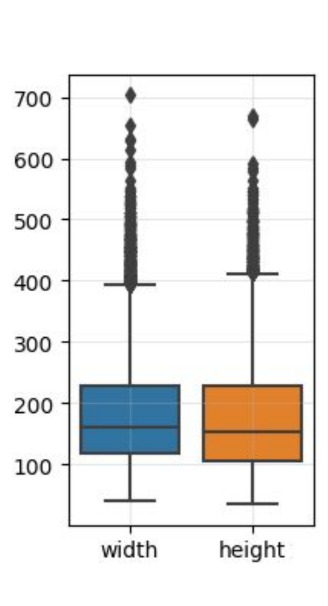


Dataset Exploration

Images Width and Height Distribution

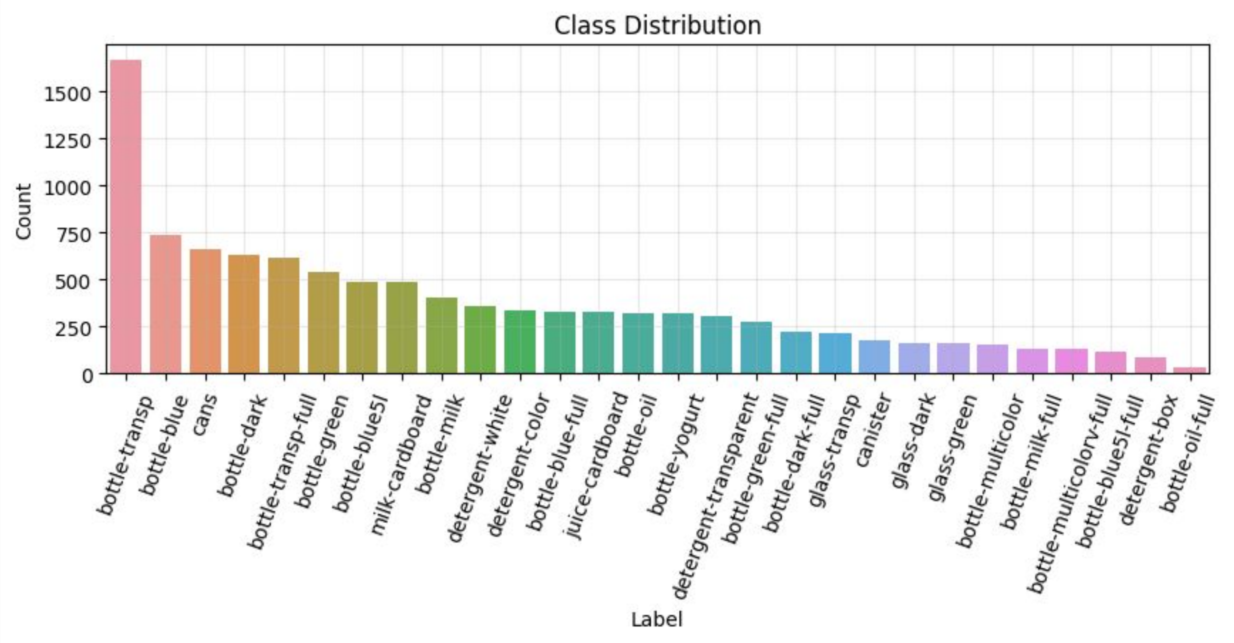
Optimal width, height: 128, 128





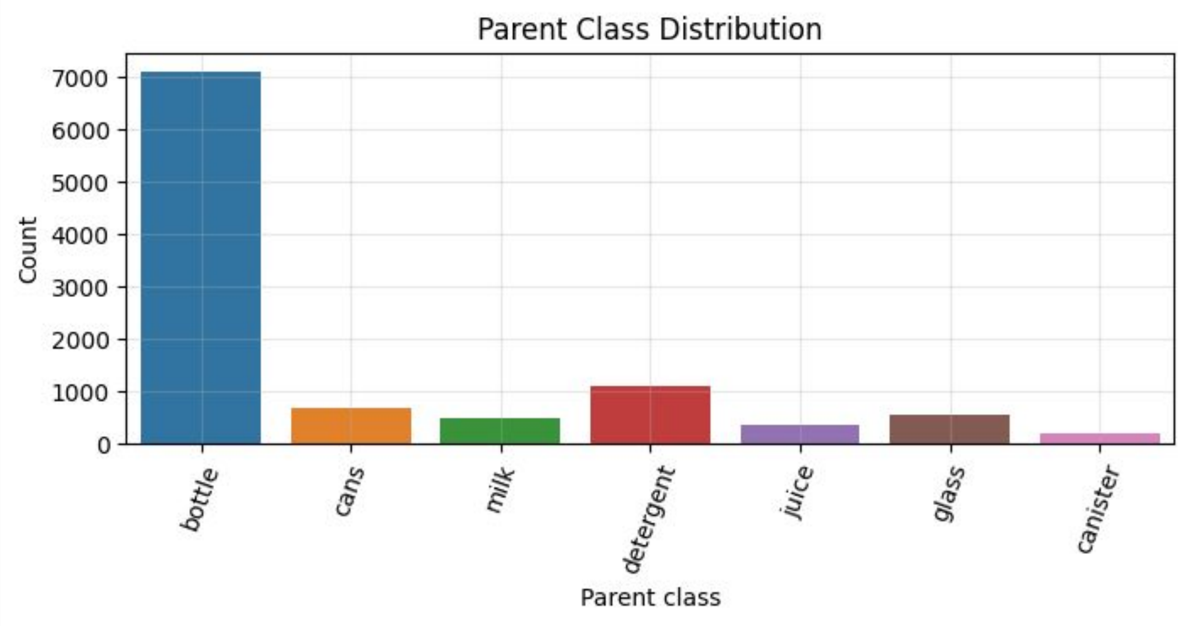
Dataset Exploration

Class Distribution



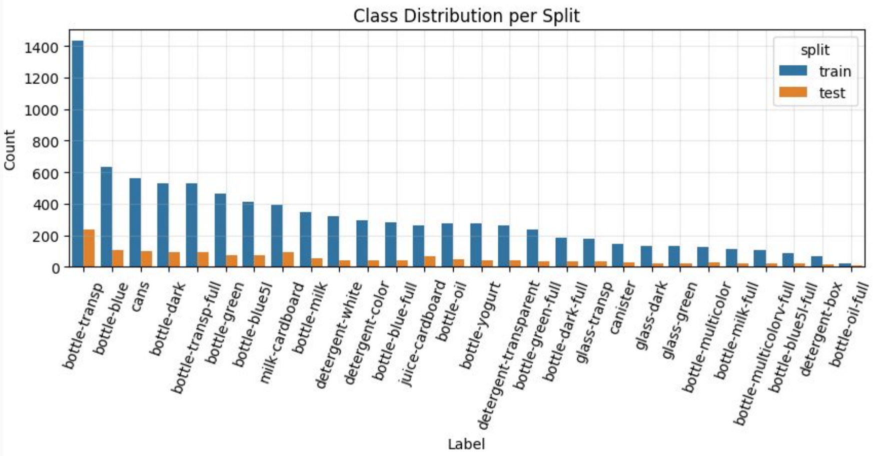
Dataset Exploration

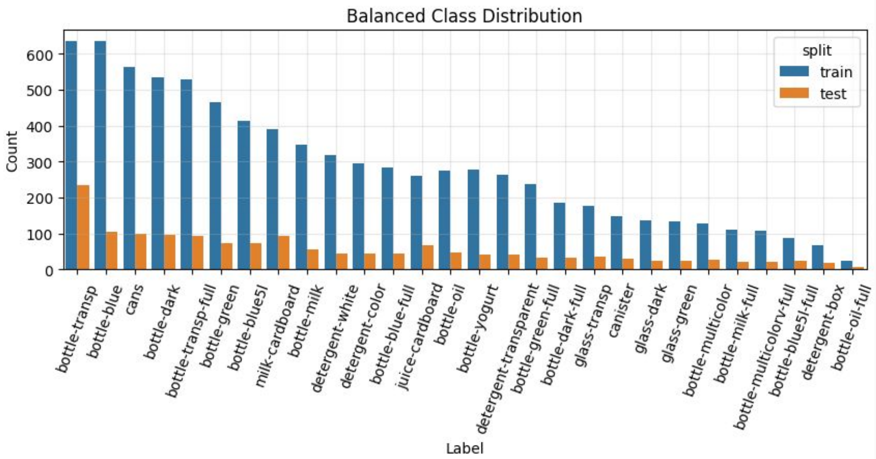
Parent Class Distribution



Dataset Preprocessing

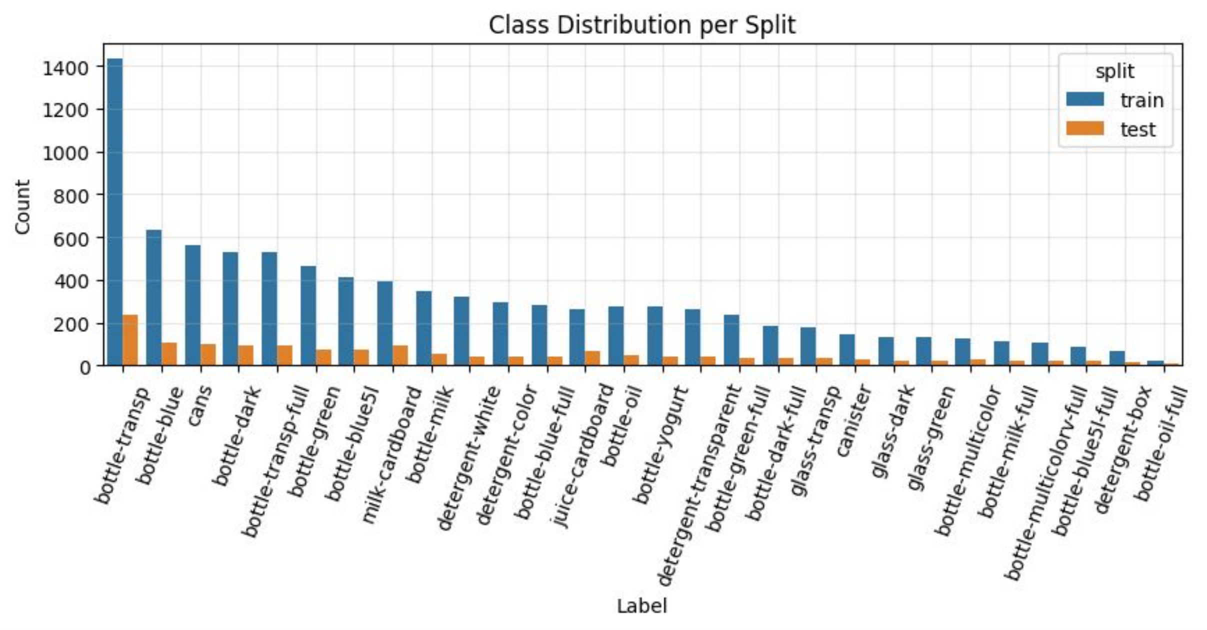
Balancing over populated class (bottle-transp)





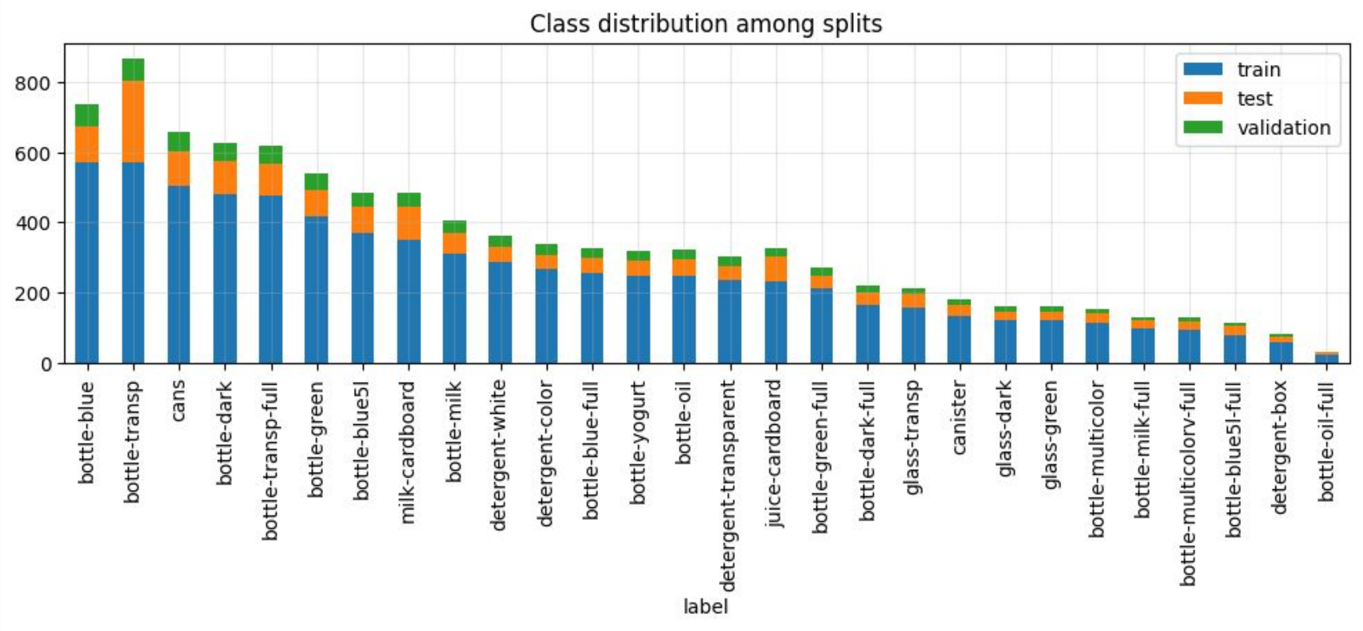
Dataset Exploration

Class Distribution Training, Test



Dataset Preprocessing

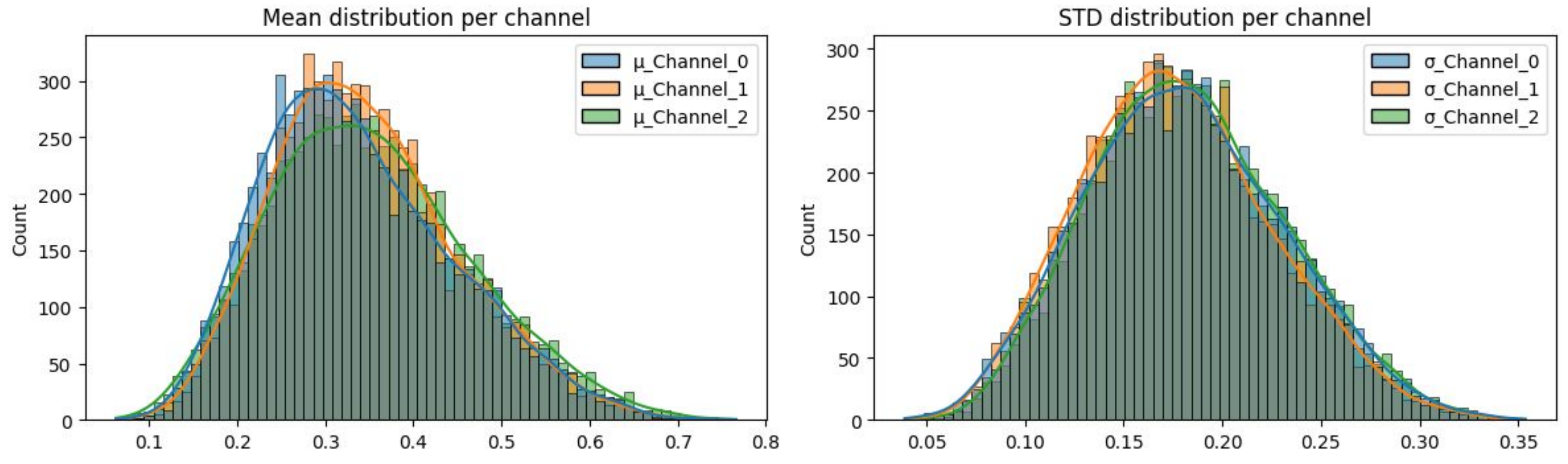
Training, test, validation split (75/15/10)



Dataset Preprocessing

Color normalization

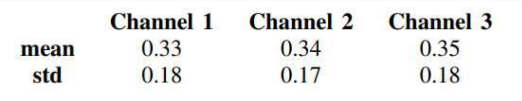
Computed mean and standard deviation for each channel



Mean distribution per channel

STD distribution per channel

Averaged values for normalization

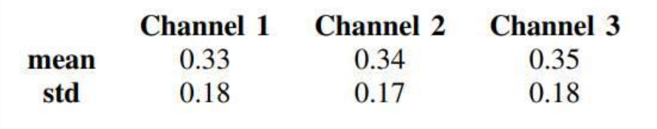


	Channel 1	Channel 2	Channel 3
mean	0.33	0.34	0.35
std	0.18	0.17	0.18

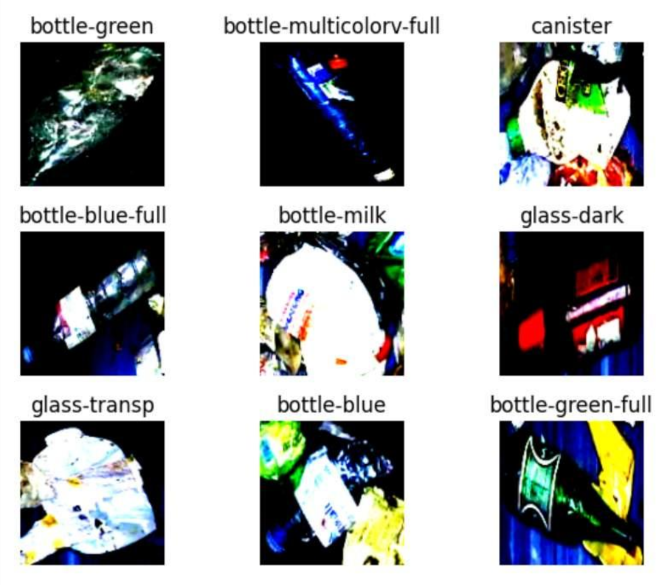
Dataset Preprocessing

Color normalization

Averaged values for normalization:

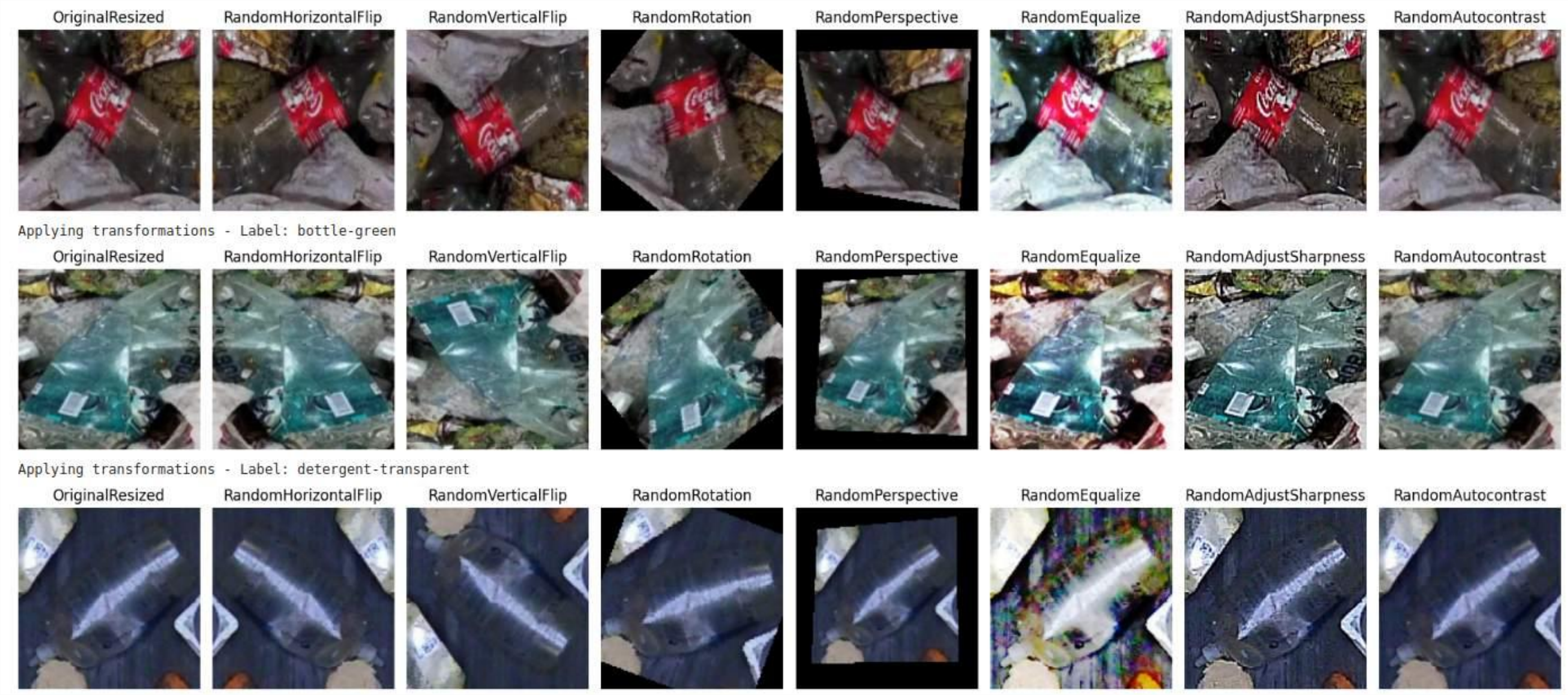


	Channel 1	Channel 2	Channel 3
mean	0.33	0.34	0.35
std	0.18	0.17	0.18



Dataset Preprocessing

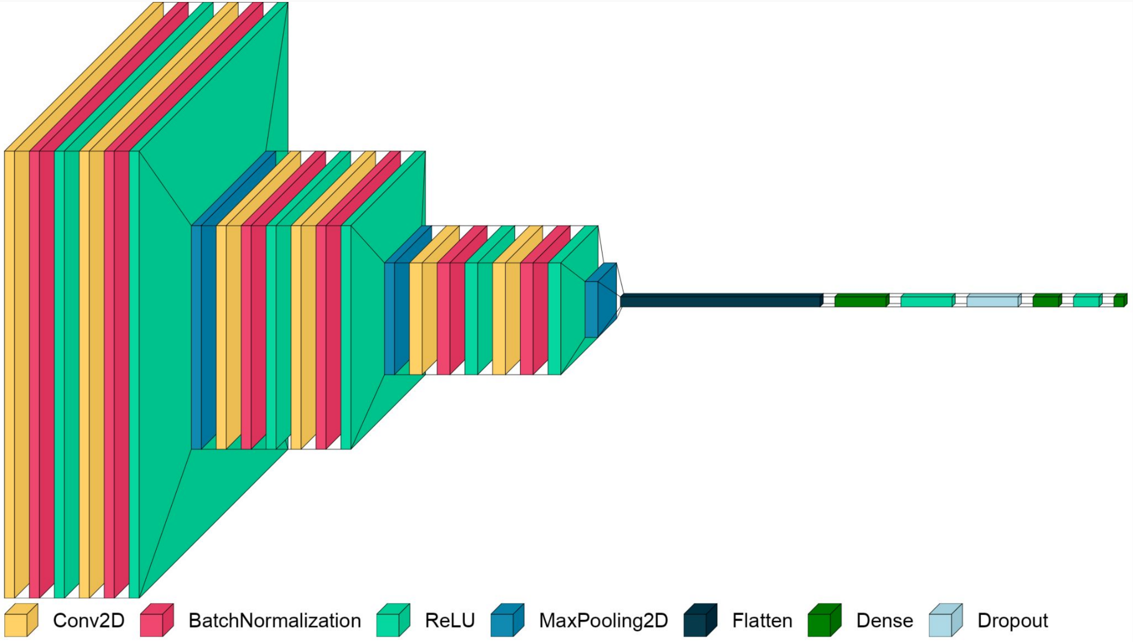
Dataset augmentation



```
Applying transformations - Label: bottle-green
Applying transformations - Label: detergent-transparent
```

Model

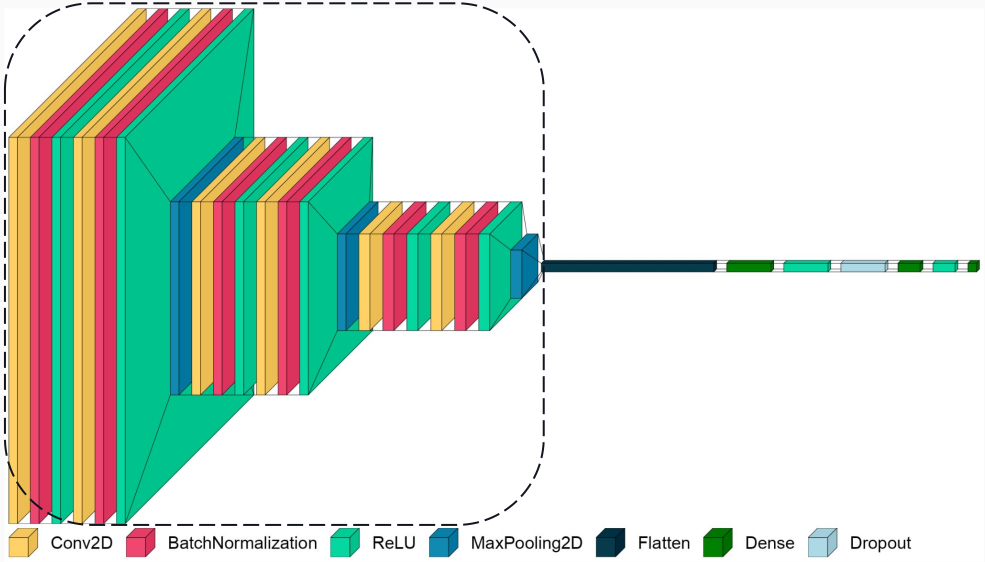
CNN Architecture



Model

Feature extraction layers

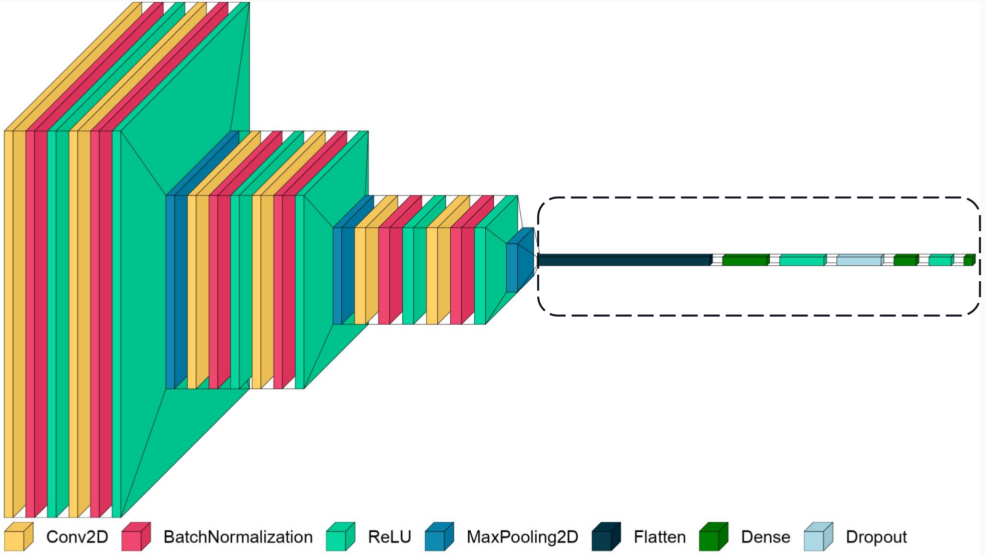
- Convolutional layers
- Batch normalization
- ReLU activation functions
- Max-pooling layers
- Dense layers



Model

Classification layers

- Flatten
- Dropout
- Dense layers
- Final Dense layers



Training

Hyperparameter tuning & Early Stopping

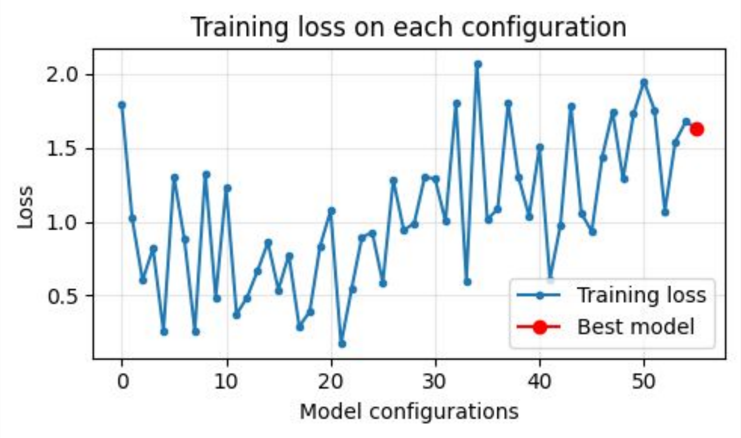
Learning rate	0.0005, 0.0001
Convolutional unit	16, 32, 64
Batch size	16, 64, 128
Dropout rate	0, 0.2
Weight decay	0.01, 0.001
Early stopping patience	15

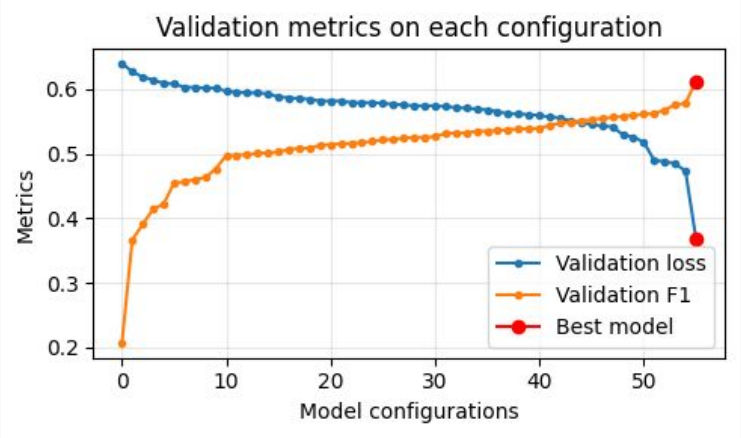
- Memory constraints: combinations with convolutional units 64 and batch size 128 were excluded from the grid search
- Total hyperparameter combinations is 56

Training

Hyperparameter tuning & Early Stopping

Loss and metrics on validation set for every parameter combination





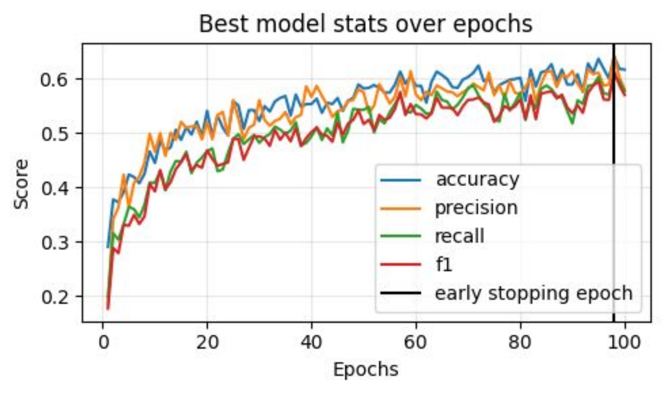
Training

Best model elected

Optimal model chosen on the highest F1-score achieved

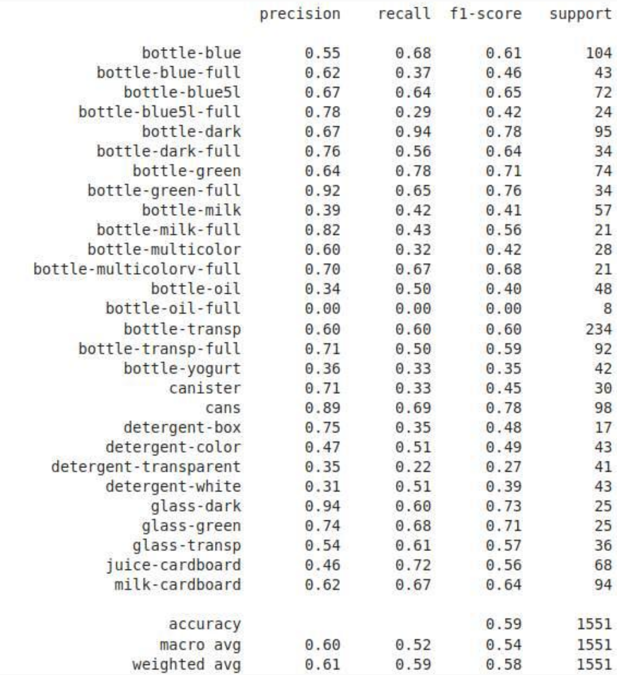
Parameters	
Learning rate	0.0001
Convolutional unit	32
Batch size	16
Dropout rate	0
Weight decay	0.01

Metrics	
Training loss	1.798
Validation loss	0.640
Validation precision	0.641
Validation recall	0.602
Validation f1-score	0.612

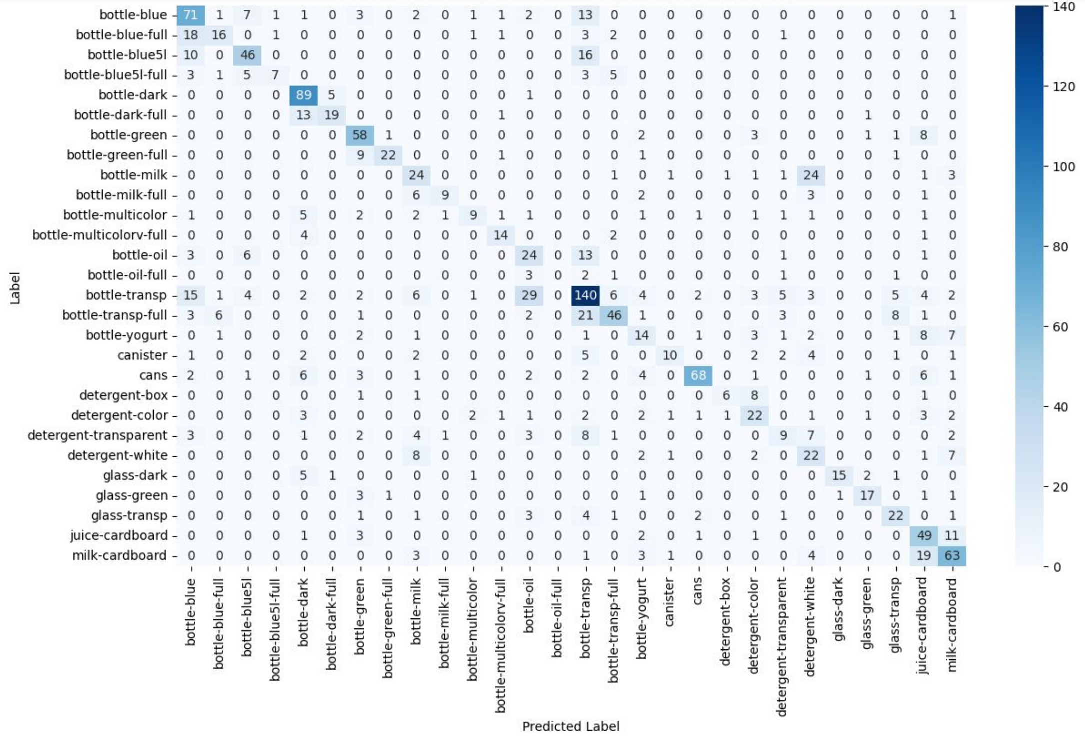


Performances

Test set classification report



```
                        precision    recall  f1-score   support

           bottle-blue       0.55      0.68      0.61       104
      bottle-blue-full       0.62      0.37      0.46        43
          bottle-blue5l      0.67      0.64      0.65        72
     bottle-blue5l-full      0.78      0.29      0.42        24
           bottle-dark       0.67      0.94      0.78        95
      bottle-dark-full       0.76      0.56      0.64        34
          bottle-green       0.64      0.78      0.71        74
     bottle-green-full       0.92      0.65      0.76        34
           bottle-milk       0.39      0.42      0.41        57
      bottle-milk-full       0.82      0.43      0.56        21
      bottle-multicolor       0.60      0.32      0.42        28
bottle-multicolorv-full       0.70      0.67      0.68        21
            bottle-oil       0.34      0.50      0.40        48
       bottle-oil-full       0.00      0.00      0.00         8
         bottle-transp       0.60      0.60      0.60       234
    bottle-transp-full       0.71      0.50      0.59        92
         bottle-yogurt       0.36      0.33      0.35        42
              canister       0.71      0.33      0.45        30
                  cans       0.89      0.69      0.78        98
         detergent-box       0.75      0.35      0.48        17
       detergent-color       0.47      0.51      0.49        43
 detergent-transparent       0.35      0.22      0.27        41
       detergent-white       0.31      0.51      0.39        43
            glass-dark       0.94      0.60      0.73        25
           glass-green       0.74      0.68      0.71        25
          glass-transp       0.54      0.61      0.57        36
        juice-cardboard       0.46      0.72      0.56        68
         milk-cardboard       0.62      0.67      0.64        94

              accuracy                           0.59      1551
             macro avg       0.60      0.52      0.54      1551
          weighted avg       0.61      0.59      0.58      1551
```

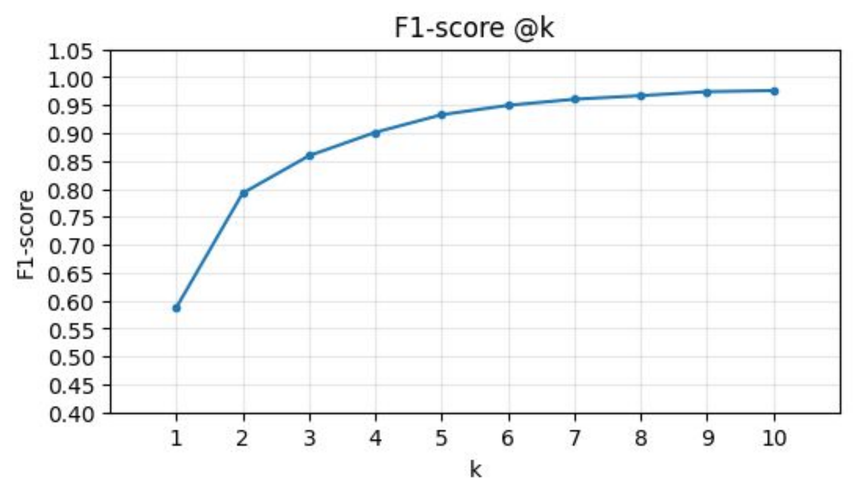


Label	bottle-blue	bottle-blue-full	bottle-blue5l	bottle-blue5l-full	bottle-dark	bottle-dark-full	bottle-green	bottle-green-full	bottle-milk	bottle-milk-full	bottle-multicolor	bottle-multicolorv-full	bottle-oil	bottle-oil-full	bottle-transp	bottle-transp-full	bottle-yogurt	canister	cans	detergent-box	detergent-color	detergent-transparent	detergent-white	glass-dark	glass-green	glass-transp	juice-cardboard	milk-cardboard
bottle-blue	71	1	7	1	1	0	3	0	2	0	1	1	2	0	13	0	0	0	0	0	0	0	0	0	0	0	0	1
bottle-blue-full	18	16	0	1	0	0	0	0	0	0	1	1	0	0	3	2	0	0	0	0	0	1	0	0	0	0	0	0
bottle-blue5l	10	0	46	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-blue5l-full	3	1	5	7	0	0	0	0	0	0	0	0	0	0	3	5	0	0	0	0	0	0	0	0	0	0	0	0
bottle-dark	0	0	0	0	89	5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-dark-full	0	0	0	0	13	19	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
bottle-green	0	0	0	0	0	0	58	1	0	0	0	0	0	0	0	0	2	0	0	0	3	0	0	0	1	1	8	0
bottle-green-full	0	0	0	0	0	0	9	22	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
bottle-milk	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	1	0	1	0	1	1	1	24	0	0	0	1	3
bottle-milk-full	0	0	0	0	0	0	0	0	6	9	0	0	0	0	0	0	2	0	0	0	0	0	3	0	0	0	1	0
bottle-multicolor	1	0	0	0	5	0	2	0	2	1	9	1	1	0	0	0	1	0	1	0	1	1	1	0	0	0	1	0
bottle-multicolorv-full	0	0	0	0	4	0	0	0	0	0	0	14	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0
bottle-oil	3	0	6	0	0	0	0	0	0	0	0	0	24	0	13	0	0	0	0	0	0	1	0	0	0	0	1	0
bottle-oil-full	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2	1	0	0	0	0	0	1	0	0	0	1	0	0
bottle-transp	15	1	4	0	2	0	2	0	6	0	1	0	29	0	140	6	4	0	2	0	3	5	3	0	0	5	4	2
bottle-transp-full	3	6	0	0	0	0	1	0	0	0	0	0	2	0	21	46	1	0	0	0	0	3	0	0	0	8	1	0
bottle-yogurt	0	1	0	0	0	0	2	0	1	0	0	0	0	0	1	0	14	0	1	0	3	1	2	0	0	1	8	7
canister	1	0	0	0	2	0	0	0	2	0	0	0	0	0	5	0	0	10	0	0	2	2	4	0	0	1	0	1
cans	2	0	1	0	6	0	3	0	1	0	0	0	2	0	2	0	4	0	68	0	1	0	0	0	1	0	6	1
detergent-box	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	6	8	0	0	0	0	0	1	0
detergent-color	0	0	0	0	3	0	0	0	0	0	2	1	1	0	2	0	2	1	1	1	22	0	1	0	1	0	3	2
detergent-transparent	3	0	0	0	1	0	2	0	4	1	0	0	3	0	8	1	0	0	0	0	0	9	7	0	0	0	0	2
detergent-white	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	2	1	0	0	2	0	22	0	0	0	1	7
glass-dark	0	0	0	0	5	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	15	2	1	0	0
glass-green	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	17	0	1	1
glass-transp	0	0	0	0	0	0	1	0	1	0	0	0	3	0	4	1	0	0	2	0	0	1	0	0	0	22	0	1
juice-cardboard	0	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	2	0	1	0	1	0	0	0	0	0	49	11
milk-cardboard	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	3	1	0	0	0	0	4	0	0	0	19	63

Performances

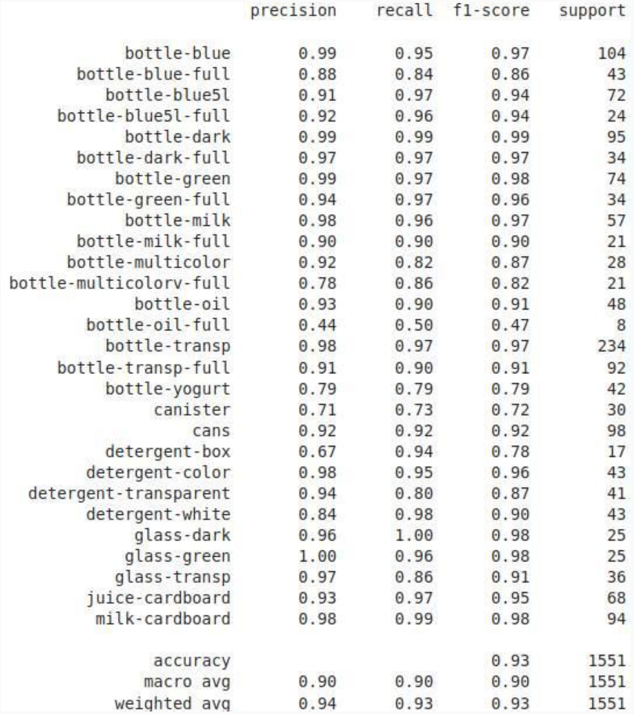
Model performance @ top-k

For this study *k=5* was chosen

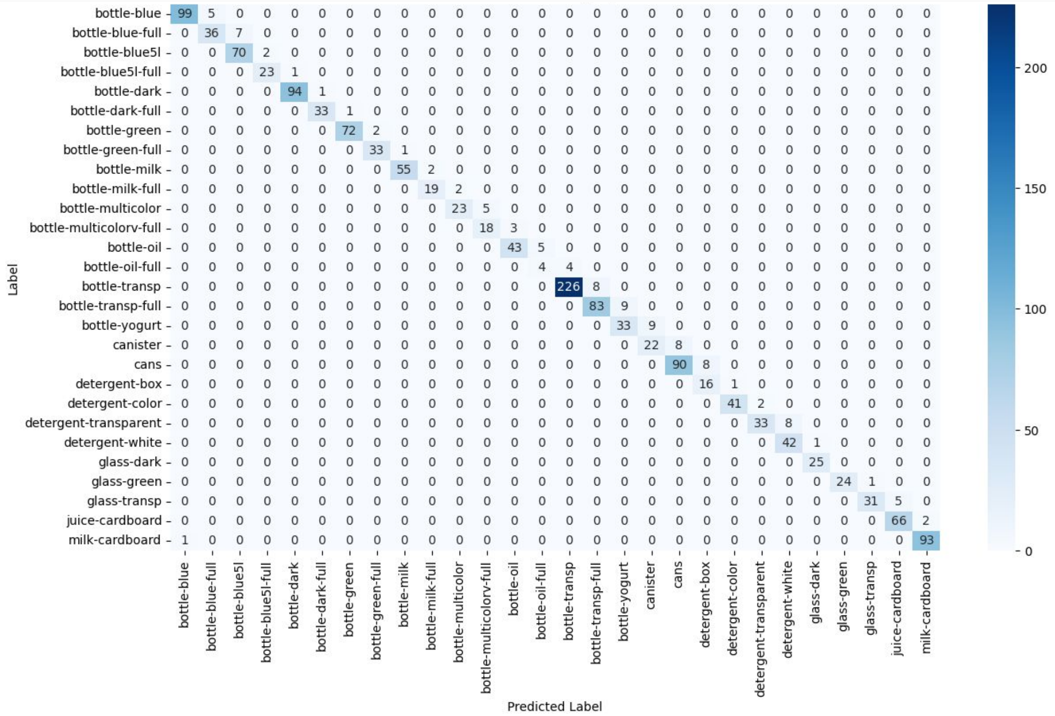


Performances

Model performance @ top-5



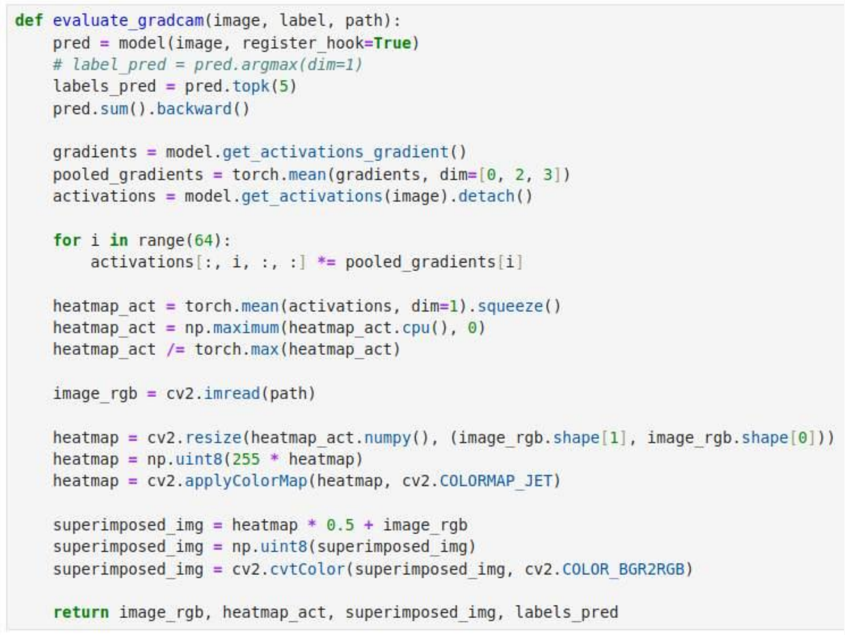
```
                         precision    recall  f1-score   support

             bottle-blue       0.99      0.95      0.97       104
        bottle-blue-full       0.88      0.84      0.86        43
           bottle-blue5l       0.91      0.97      0.94        72
      bottle-blue5l-full       0.92      0.96      0.94        24
             bottle-dark       0.99      0.99      0.99        95
        bottle-dark-full       0.97      0.97      0.97        34
            bottle-green       0.99      0.97      0.98        74
       bottle-green-full       0.94      0.97      0.96        34
             bottle-milk       0.98      0.96      0.97        57
        bottle-milk-full       0.90      0.90      0.90        21
       bottle-multicolor       0.92      0.82      0.87        28
 bottle-multicolorv-full       0.78      0.86      0.82        21
              bottle-oil       0.93      0.90      0.91        48
         bottle-oil-full       0.44      0.50      0.47         8
           bottle-transp       0.98      0.97      0.97       234
      bottle-transp-full       0.91      0.90      0.91        92
           bottle-yogurt       0.79      0.79      0.79        42
                canister       0.71      0.73      0.72        30
                    cans       0.92      0.92      0.92        98
           detergent-box       0.67      0.94      0.78        17
         detergent-color       0.98      0.95      0.96        43
   detergent-transparent       0.94      0.80      0.87        41
         detergent-white       0.84      0.98      0.90        43
              glass-dark       0.96      1.00      0.98        25
             glass-green       1.00      0.96      0.98        25
            glass-transp       0.97      0.86      0.91        36
         juice-cardboard       0.93      0.97      0.95        68
          milk-cardboard       0.98      0.99      0.98        94

                accuracy                           0.93      1551
               macro avg       0.90      0.90      0.90      1551
            weighted avg       0.94      0.93      0.93      1551
```



	bottle-blue	bottle-blue-full	bottle-blue5l	bottle-blue5l-full	bottle-dark	bottle-dark-full	bottle-green	bottle-green-full	bottle-milk	bottle-milk-full	bottle-multicolor	bottle-multicolorv-full	bottle-oil	bottle-oil-full	bottle-transp	bottle-transp-full	bottle-yogurt	canister	cans	detergent-box	detergent-color	detergent-transparent	detergent-white	glass-dark	glass-green	glass-transp	juice-cardboard	milk-cardboard
bottle-blue	99	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-blue-full	0	36	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-blue5l	0	0	70	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-blue5l-full	0	0	0	23	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-dark	0	0	0	0	94	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-dark-full	0	0	0	0	0	33	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-green	0	0	0	0	0	0	72	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-green-full	0	0	0	0	0	0	0	33	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-milk	0	0	0	0	0	0	0	0	55	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-milk-full	0	0	0	0	0	0	0	0	0	19	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-multicolor	0	0	0	0	0	0	0	0	0	0	23	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-multicolorv-full	0	0	0	0	0	0	0	0	0	0	0	18	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-oil	0	0	0	0	0	0	0	0	0	0	0	0	43	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-oil-full	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
bottle-transp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	226	8	0	0	0	0	0	0	0	0	0	0	0	0
bottle-transp-full	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	83	9	0	0	0	0	0	0	0	0	0	0	0
bottle-yogurt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	9	0	0	0	0	0	0	0	0	0	0
canister	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	8	0	0	0	0	0	0	0	0	0
cans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	8	0	0	0	0	0	0	0	0
detergent-box	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	1	0	0	0	0	0	0	0
detergent-color	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	2	0	0	0	0	0	0
detergent-transparent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	8	0	0	0	0	0
detergent-white	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	1	0	0	0	0
glass-dark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0
glass-green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	1	0	0
glass-transp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	5	0
juice-cardboard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66	2
milk-cardboard	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93

GradCAM

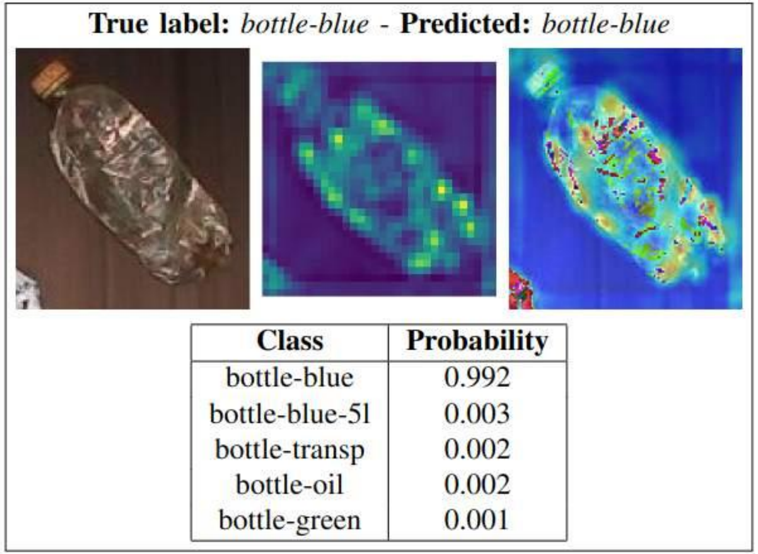
How to?!??!?!?



```
def evaluate_gradcam(image, label, path):
    pred = model(image, register_hook=True)
    # label_pred = pred.argmax(dim=1)
    labels_pred = pred.topk(5)
    pred.sum().backward()

    gradients = model.get_activations_gradient()
    pooled_gradients = torch.mean(gradients, dim=[0, 2, 3])
    activations = model.get_activations(image).detach()

    for i in range(64):
        activations[:, i, :, :] *= pooled_gradients[i]

    heatmap_act = torch.mean(activations, dim=1).squeeze()
    heatmap_act = np.maximum(heatmap_act.cpu(), 0)
    heatmap_act /= torch.max(heatmap_act)

    image_rgb = cv2.imread(path)

    heatmap = cv2.resize(heatmap_act.numpy(), (image_rgb.shape[1], image_rgb.shape[0]))
    heatmap = np.uint8(255 * heatmap)
    heatmap = cv2.applyColorMap(heatmap, cv2.COLORMAP_JET)

    superimposed_img = heatmap * 0.5 + image_rgb
    superimposed_img = np.uint8(superimposed_img)
    superimposed_img = cv2.cvtColor(superimposed_img, cv2.COLOR_BGR2RGB)

    return image_rgb, heatmap_act, superimposed_img, labels_pred
```

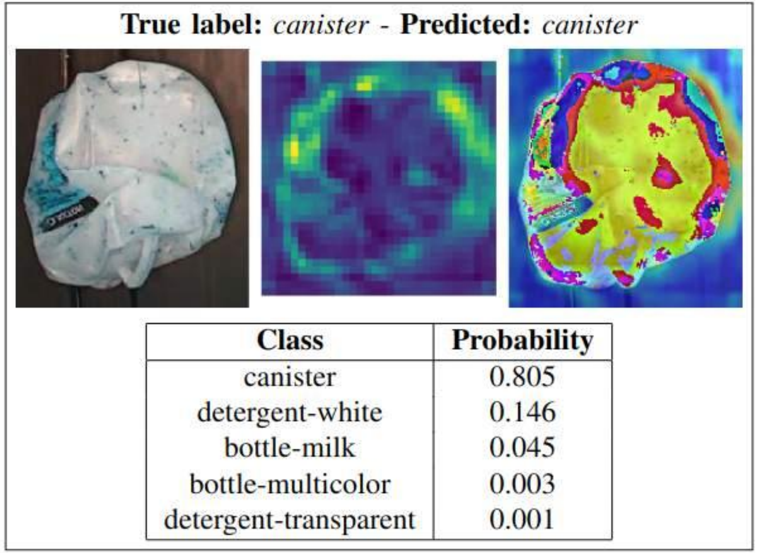
GradCAM

Correct predictions



True label: *bottle-blue* - **Predicted:** *bottle-blue*

Class	**Probability**
bottle-blue	0.992
bottle-blue-5l	0.003
bottle-transp	0.002
bottle-oil	0.002
bottle-green	0.001

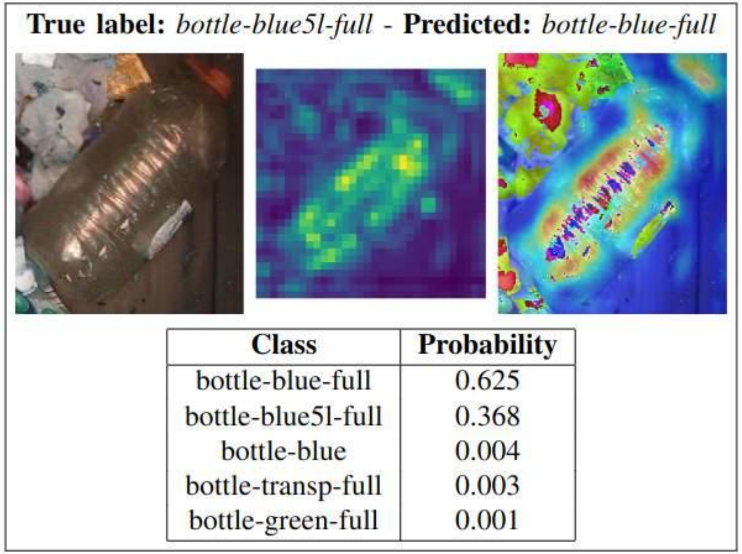


True label: *canister* - **Predicted:** *canister*

Class	**Probability**
canister	0.805
detergent-white	0.146
bottle-milk	0.045
bottle-multicolor	0.003
detergent-transparent	0.001

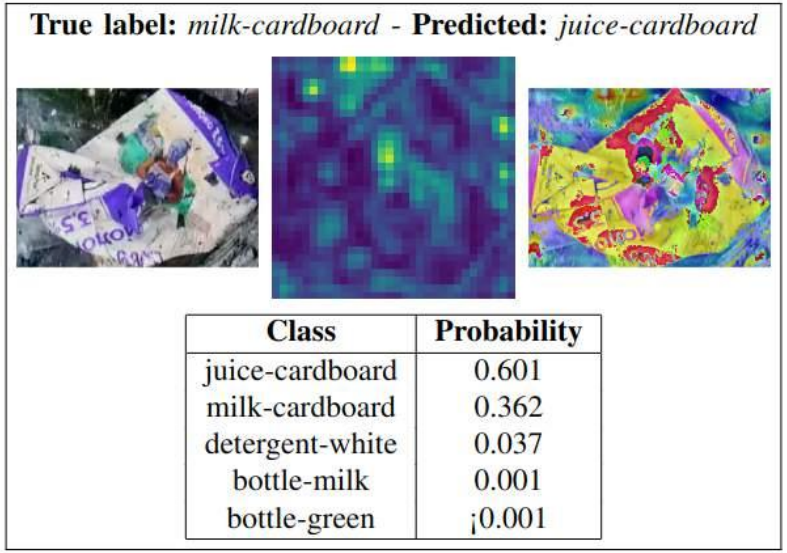
GradCAM

Incorrect predictions



True label: *bottle-blue5l-full* - **Predicted:** *bottle-blue-full*

Class	Probability
bottle-blue-full	0.625
bottle-blue5l-full	0.368
bottle-blue	0.004
bottle-transp-full	0.003
bottle-green-full	0.001

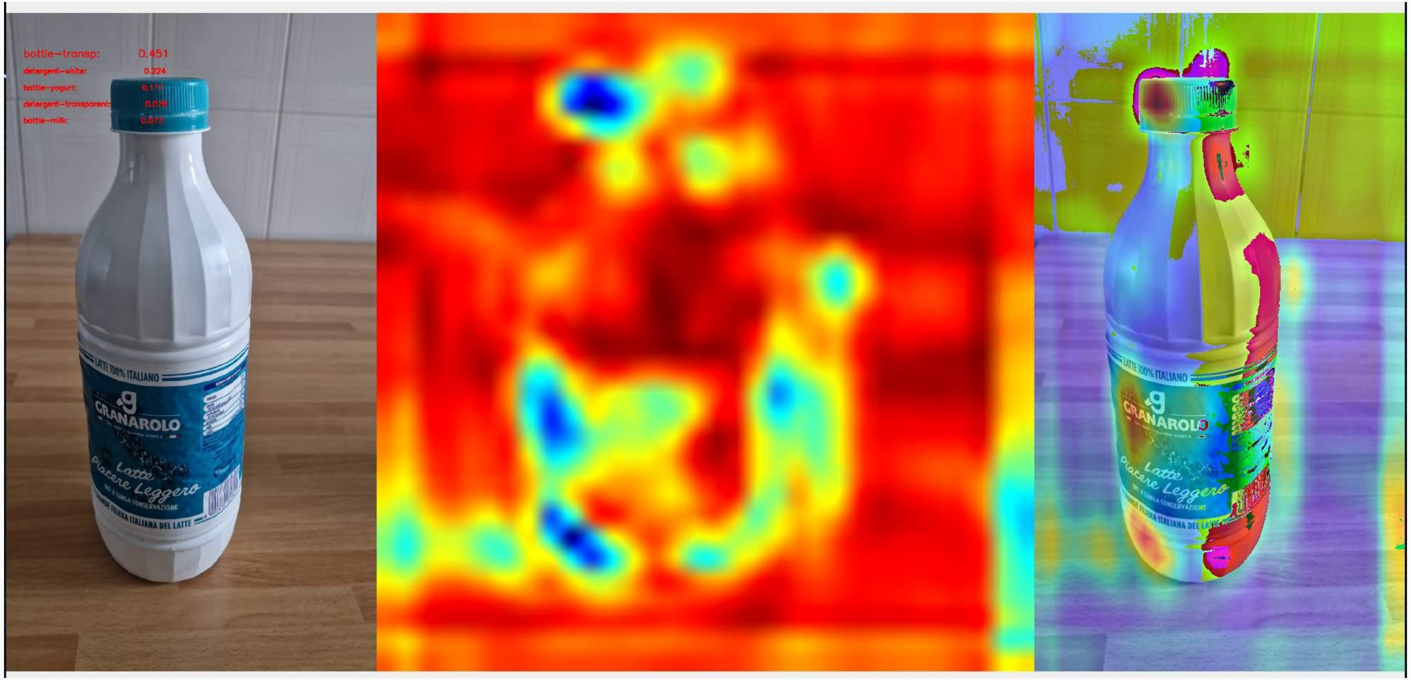


True label: *milk-cardboard* - **Predicted:** *juice-cardboard*

Class	Probability
juice-cardboard	0.601
milk-cardboard	0.362
detergent-white	0.037
bottle-milk	0.001
bottle-green	¡0.001

GradCAM on Video

Realtime GradCAM on Video



```
bottle-transp:           0.451
detergent-white:         0.224
bottle-yogurt:           0.177
detergent-transparent:   0.076
bottle-milk:             0.073
```

Grazie