RealWaste

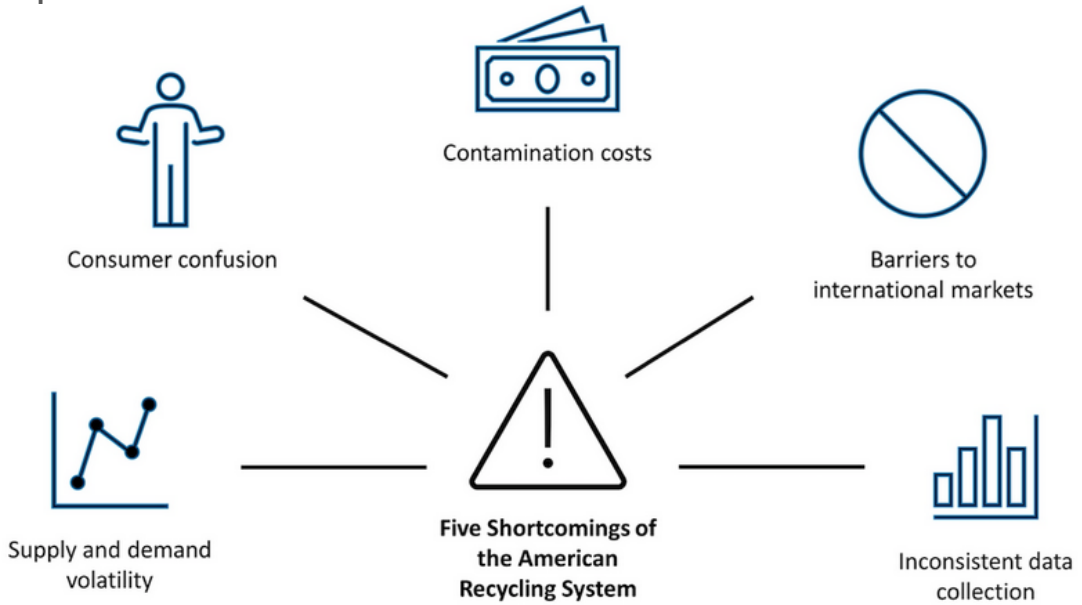
Computer Vision Material Classification

Holden Gill, Jerry Gonzalez, Hans Hernandez, Angie Jaimes

Berkeley
UNIVERSITY OF CALIFORNIA

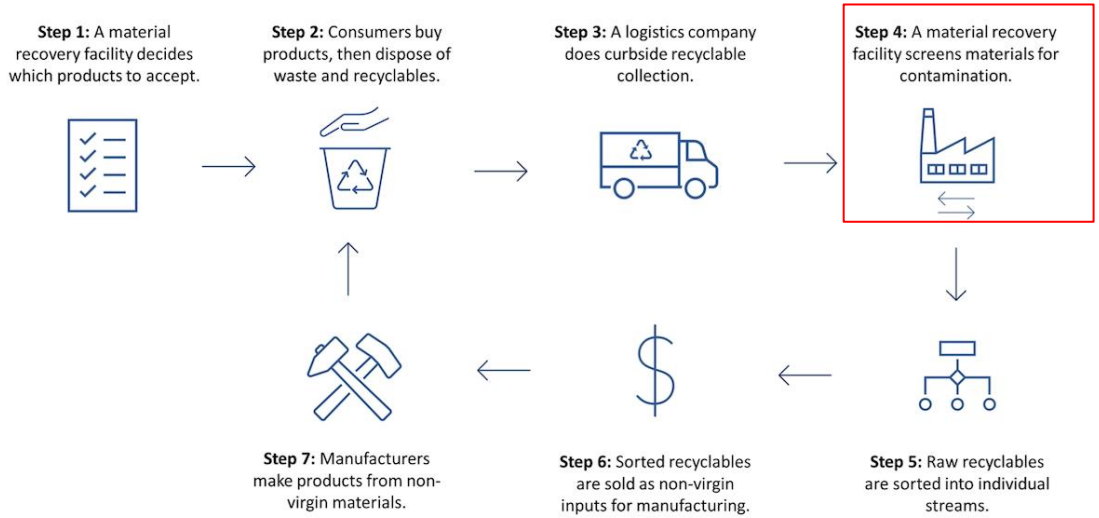
Problem

- The **percentage of recycling that actually gets recycled** is both surprising and disconcerting (35%).
- Traditional methods like visual inspection and manual sorting have limitations such as subjectivity and high labor requirements.



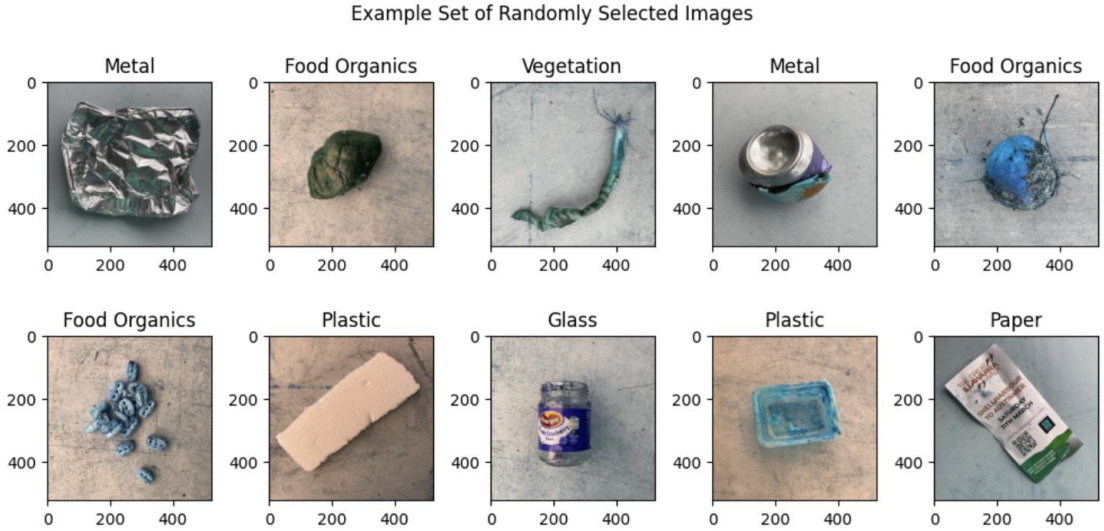
Goal

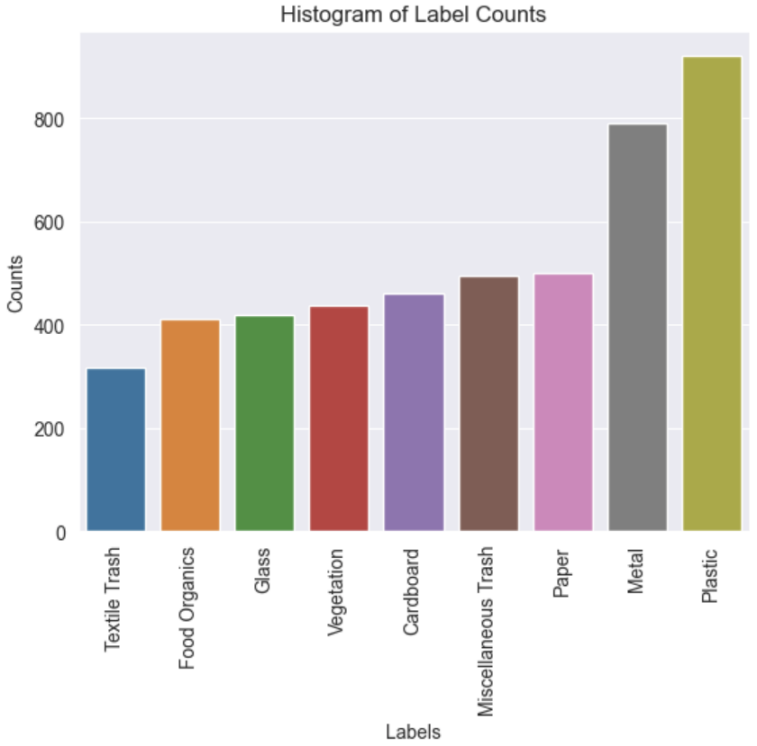
- To develop a computer vision based classification tool to:
  a. Remove, or at least minimize need of human intervention to sort waste
  b. Improve speed of which waste can be sorted



Dataset (RealWaste 2023 Image Set)

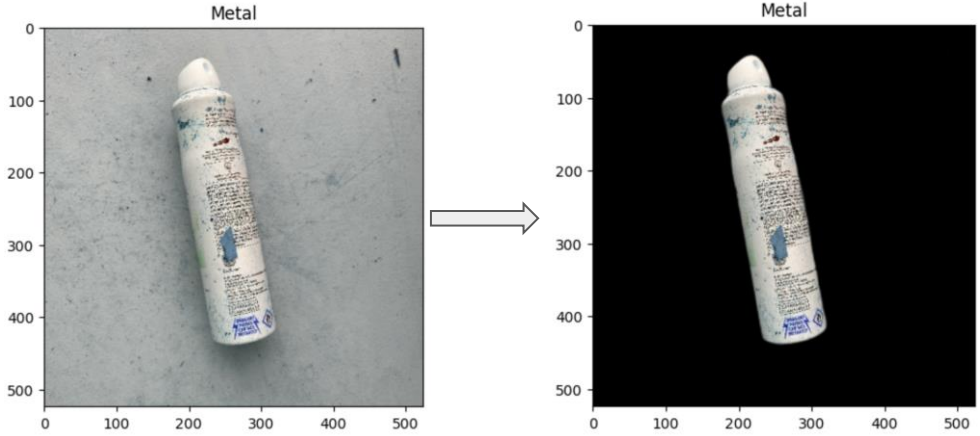
- 4,752 images, 9 material classes
  - Single item per image
  - 525 x 524 x 3 (RGB)

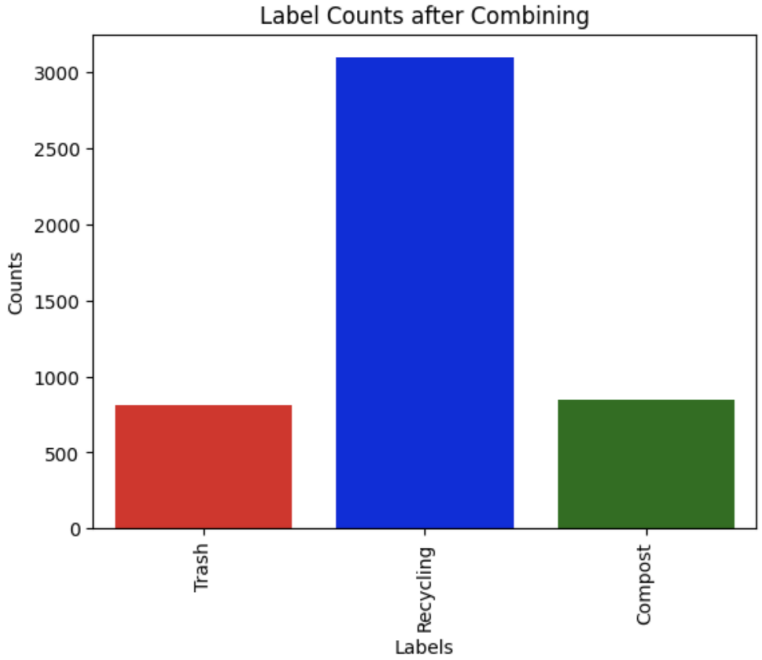




Process

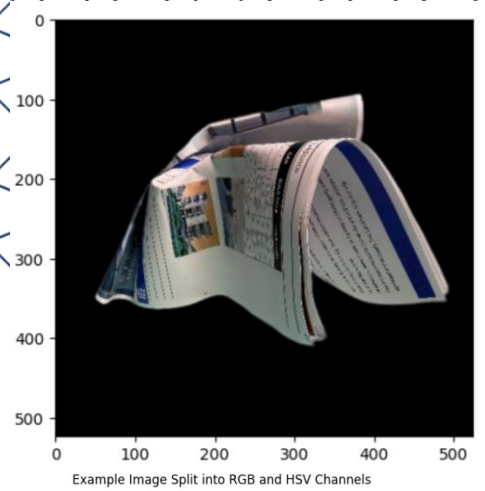
- Relabel images into: **trash, recyclable, compost**
  - Glass, Cardboard, Paper, Metal, Plastic = **recyclable**
  - Food Organics, Vegetation = **compostable**
  - Textile Trash, Miscellaneous Trash = **trash**
- Remove Background (RemBG tool) which 0's out backgrounds
- Split into Train/Test
- Investigate/Pick Features
- Classify (optimize)

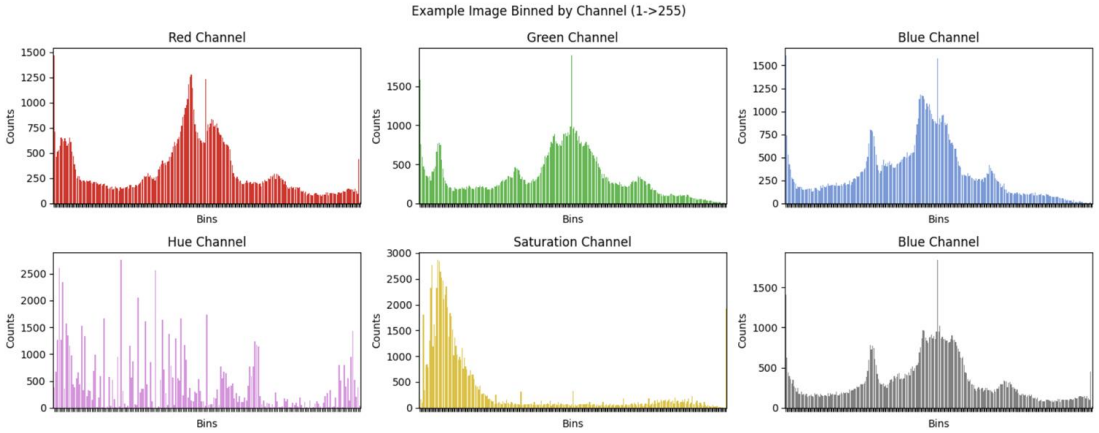


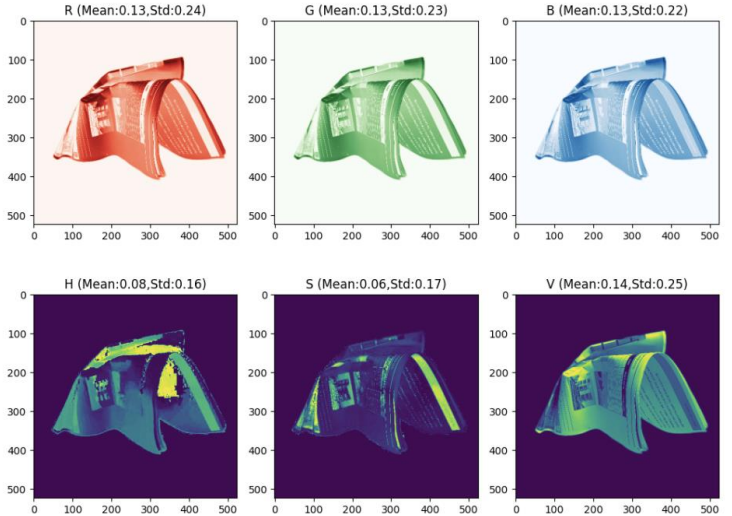


Features - Color Distributions

Count of values within each channel of the image (1-255) for both RGB and HSV channels



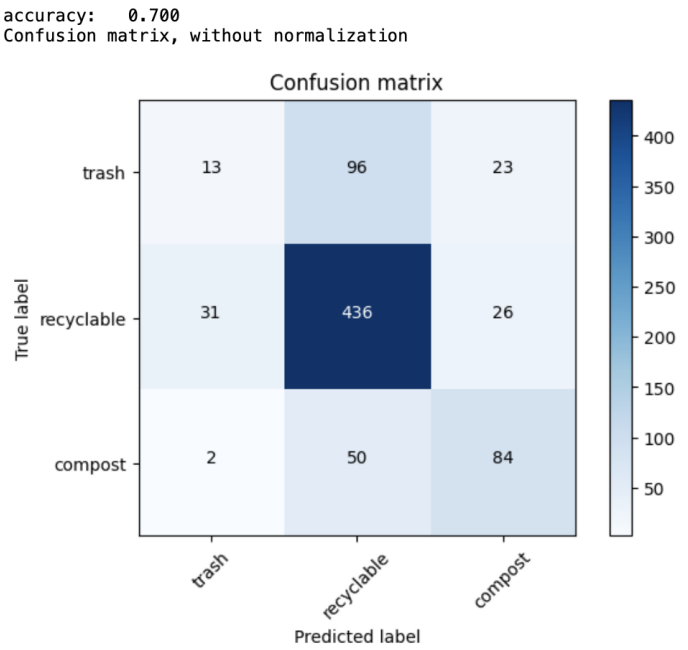


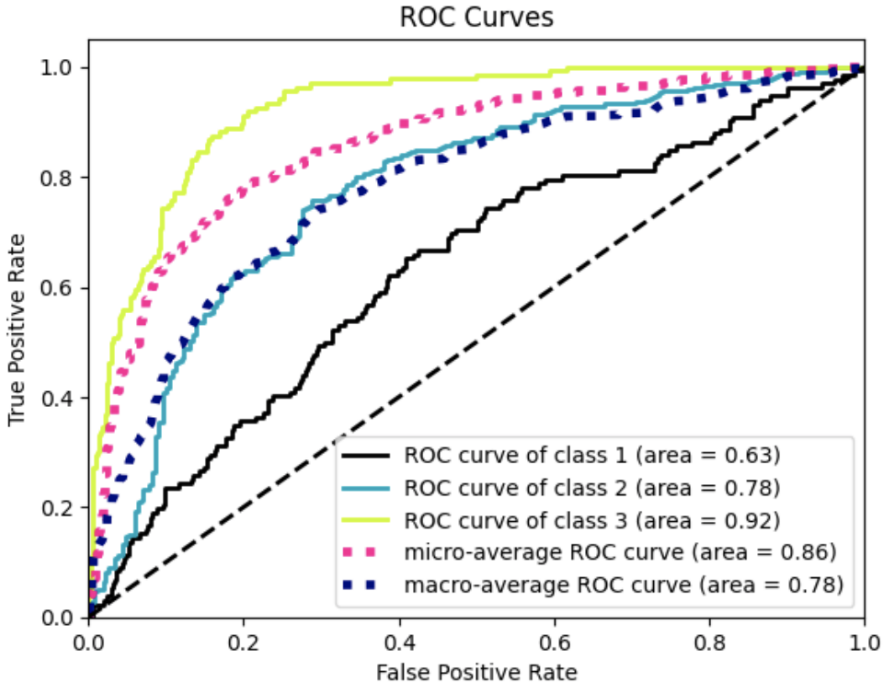


Features - Color Distributions

RGB combined (765 features)

- R 255 counts + G 255 counts + B 255 counts
- PCA to 100 components (99.5% Variance explained)



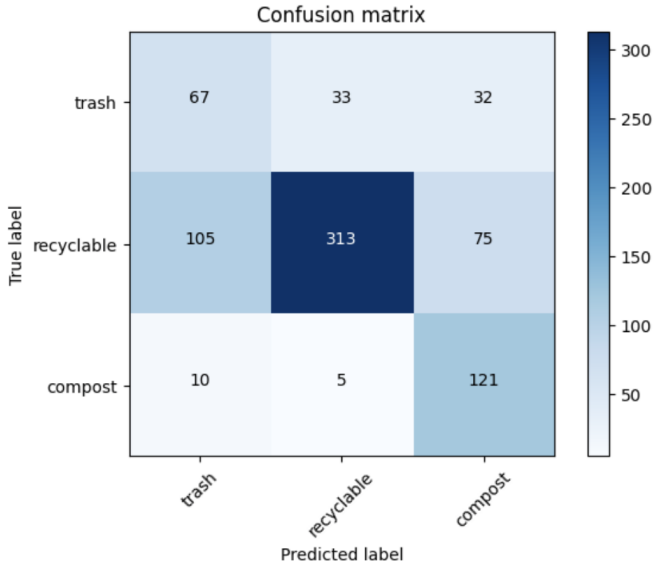


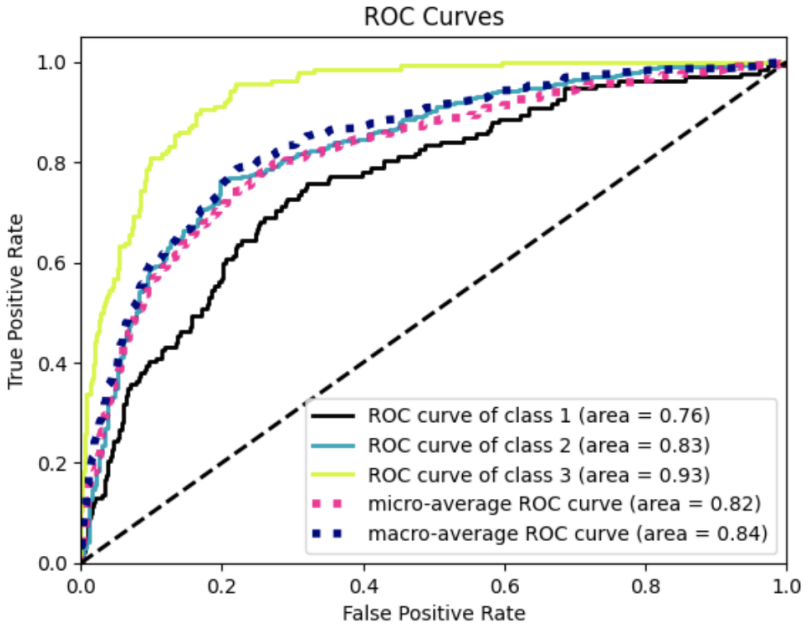
Features - Color Distributions

HSV combined (689 features)

- H 179 counts + S 255 counts + V 255 counts
- PCA to 100 components (99.5% Variance explained)

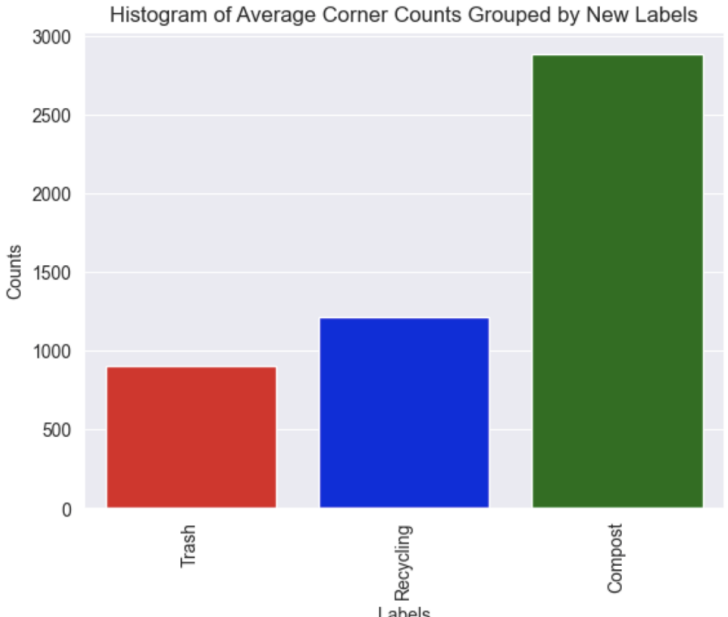
```
accuracy:   0.658
Confusion matrix, without normalization
```

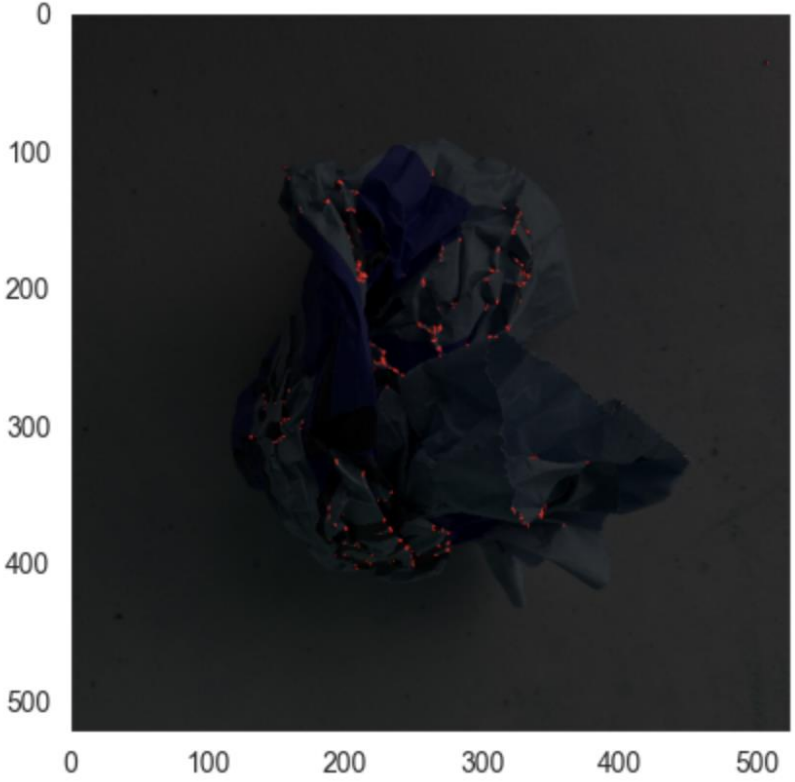




Features - Corner Counts

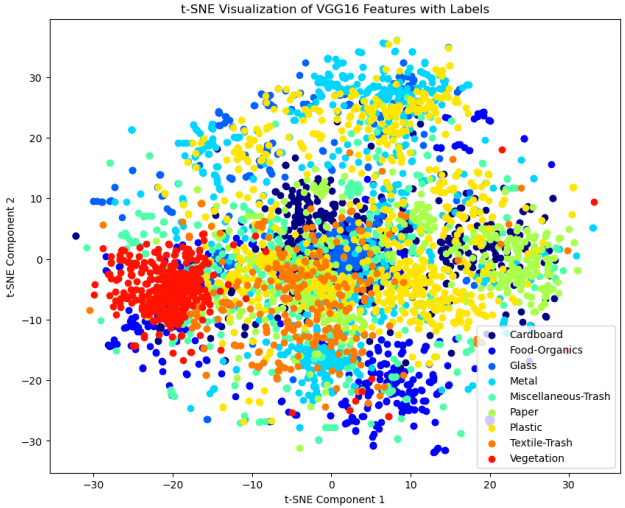
- Grayscale image -> bilateral filter blur -> harris corner detection -> count number of corners >0.01*max(corner)
- 1 Feature per image





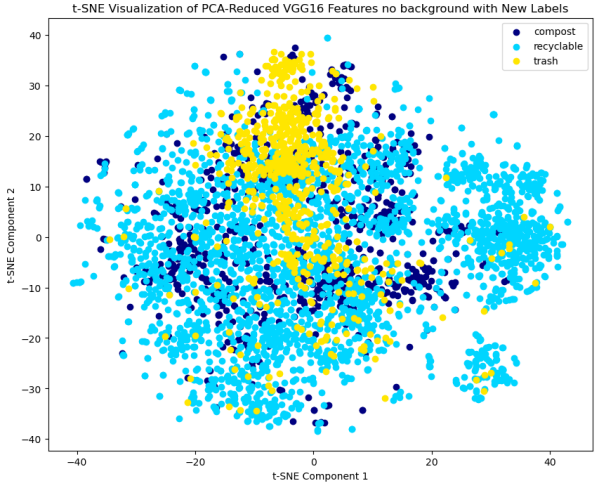
Features - Embeddings from pre-trained model VGG16

Features before PCA: 25088



9 classes

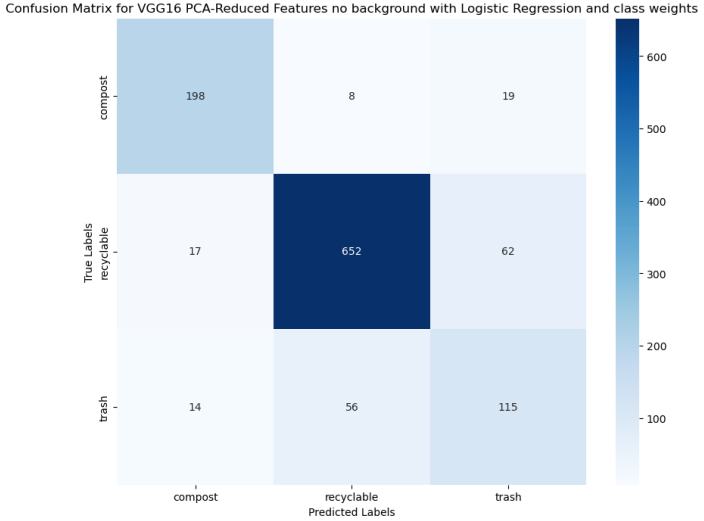
PCA to 1898 components



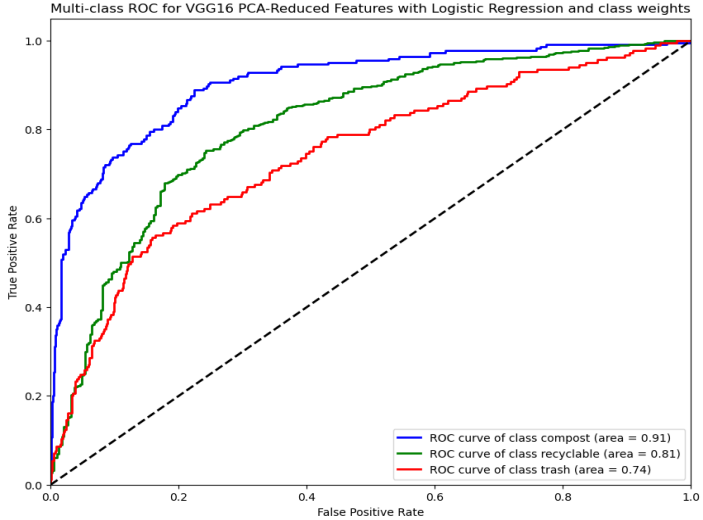
3 classes

Features - Embeddings from pre-trained model VGG16

PCA reduced Confusion Matrix



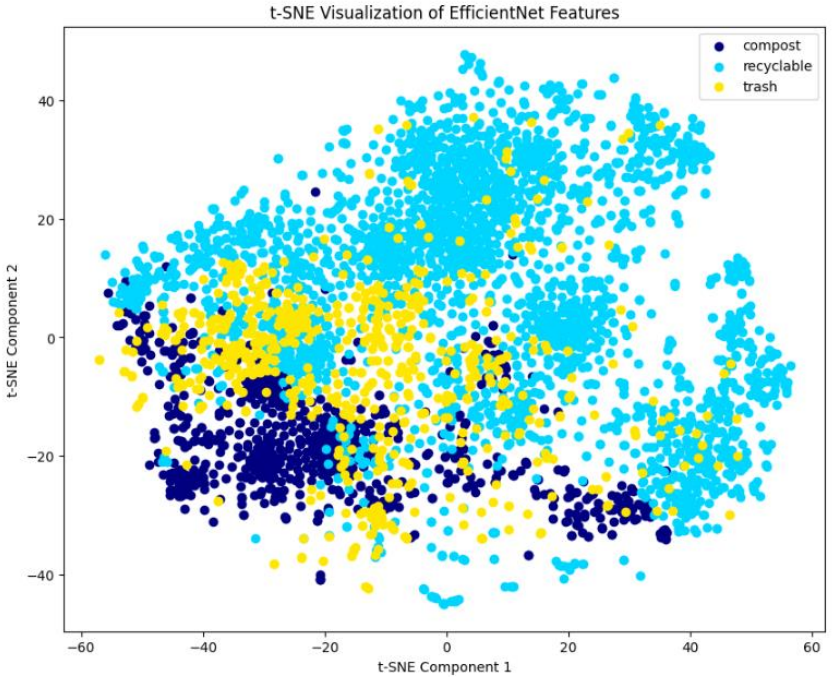
PCA reduced ROC Curves



Accuracy: 85%

F1 Score: 85%

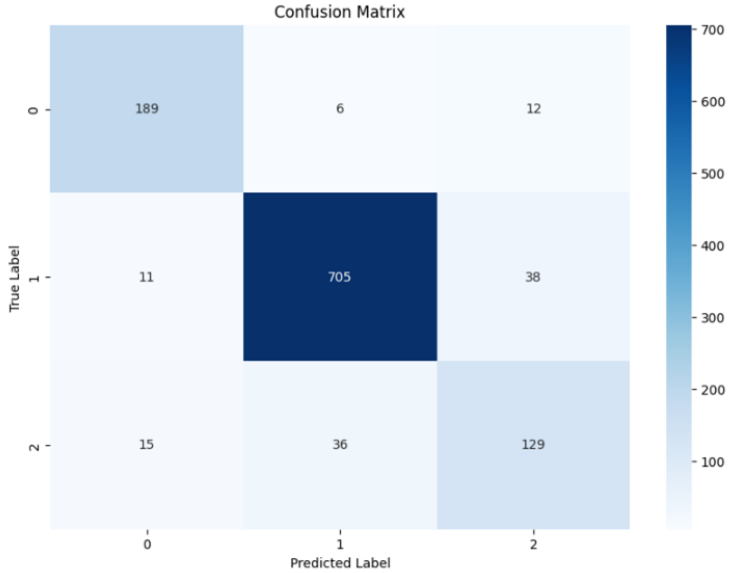
Features - Embeddings from pre-trained model EfficientNet

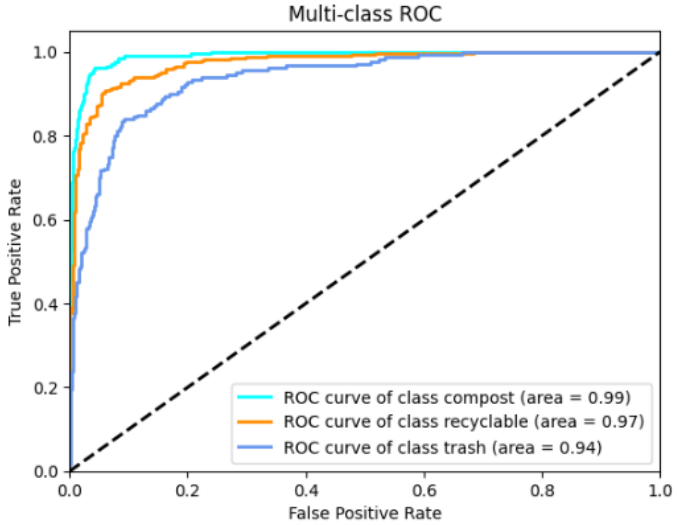


Features before PCA: 62720

Features after PCA: 2329

Features - Embeddings from pre-trained model EfficientNet

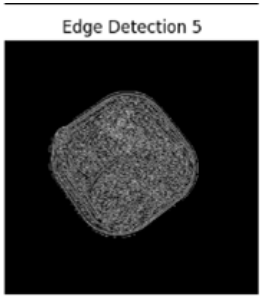


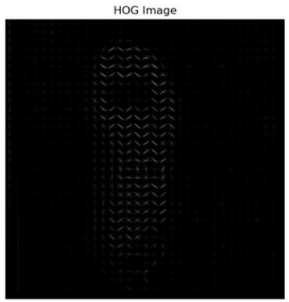


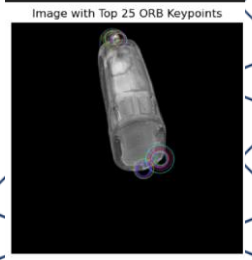
Accuracy: 89.7%
F1 Score: 90%

Unused Features

- Canny Edge Detector
  - Too many features for below average accuracy results
- Histogram of Gradients
  - Not useful on object detection, more useful for human face detection
- Orb
  - Overall low accuracy results
- RESNET50
  - EfficientNet and VGG16 provided better results







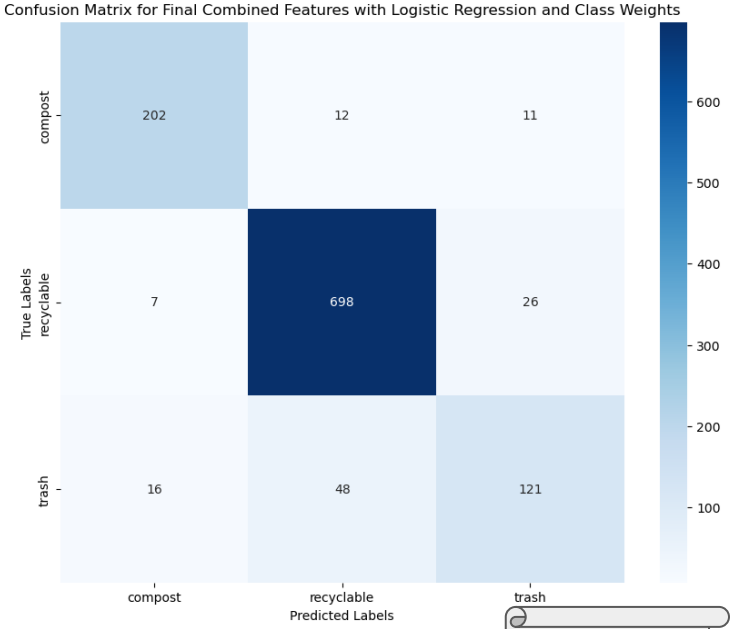
Model 1 - Logistic Regression

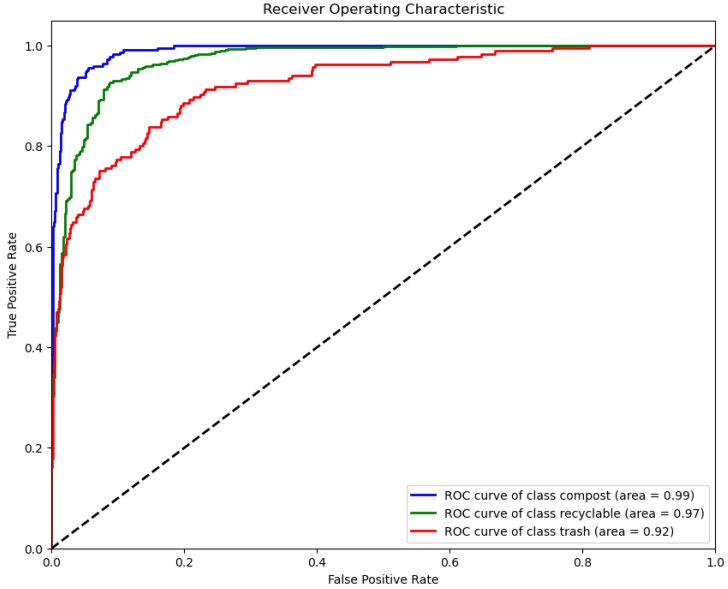
- **Feature Set Selection**

Corners	RGB Colors	HSV Colors	VGG	EfficientNet	Val. Acc.
yes	yes	no	yes	no	87
yes	yes	no	no	yes	87.8
yes	no	no	yes	yes	85.1
yes	yes	no	yes	yes	82
yes	**yes**	**yes**	**yes**	**yes**	**89**

Model 1 - Hyperparameter Tuning

Best parameters found: {'C': 0.3593813663804626, 'penalty': 'l1', 'solver': 'liblinear'}





Accuracy: 89%

F1 Score: 89%

Misclassifications

True Label: Trash / Predicted Label = Recyclable

True Label: Compost / Predicted Label = Recyclable

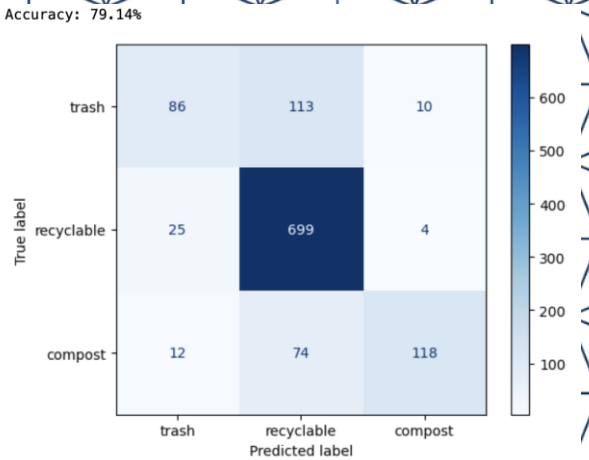
True Label: Trash / Predicted Label = Recyclable

Model 2 - Support Vector Machine
● Hyperparameter Optimization

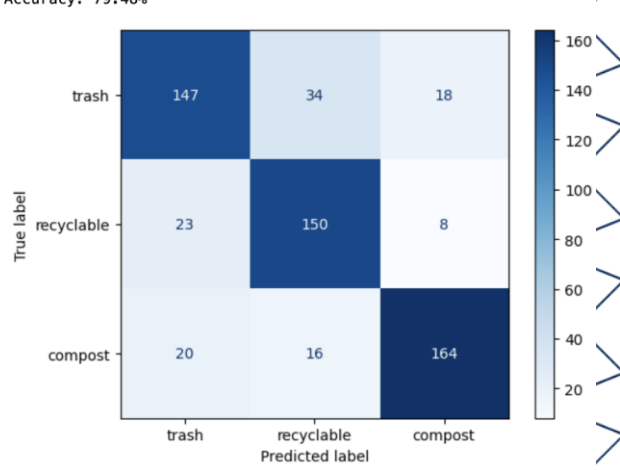
- Optimized on full feature set
  - Corners, RGB, HSV, VGG, EfficientNet
- 5-fold cross validation
- C (regularization parameter): [0.1,50]
- Kernel: linear, polynomial, rbf, sigmoid
- Gamma (kernel coefficient): [.00001,1]
- Weighting: {trash: 0.4, rec: 0.2, comp: 0.4}
  Vs. Downsampling (equal # images)

- Best parameters
  - Weighting: C=1, kernel=linear, gamma=0.1
  - Downsampling: C=4, kernel=rbf, gamma=0.00005

Weighted



Downsampling



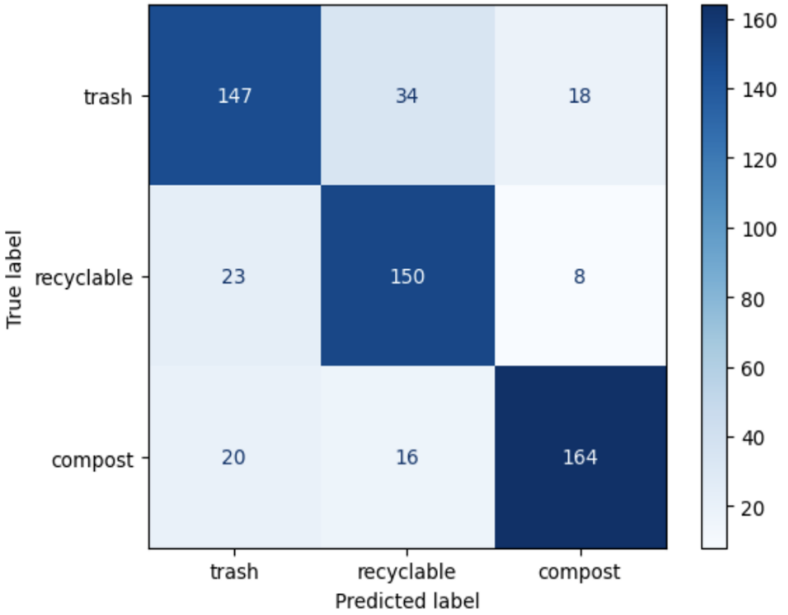
Model 2 - Support Vector Machine

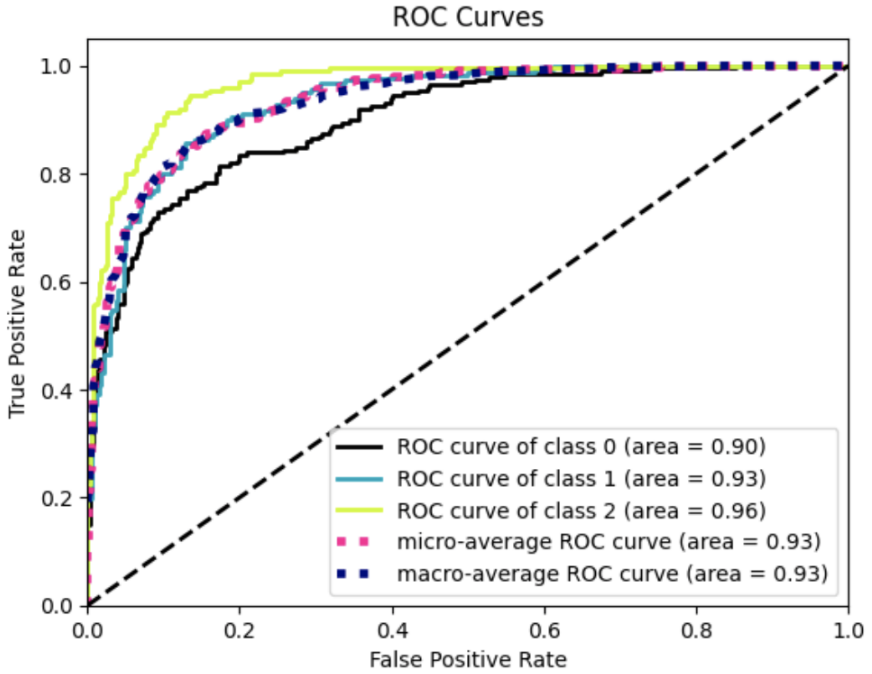
- **Feature Set Selection**

Corners	RGB Colors	HSV Colors	VGG	EfficientNet	Val. Acc.
yes	yes	no	yes	no	72.59
yes	yes	no	no	yes	68.79
yes	no	no	yes	yes	72.07
yes	yes	no	yes	yes	76.21
yes	**yes**	**yes**	**yes**	**yes**	**79.48**

Model 2 - Support Vector Machine

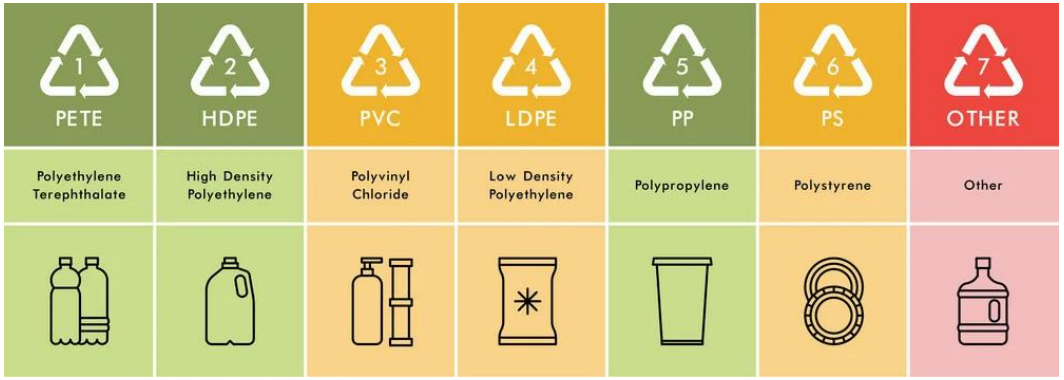
- **Final Validation Results**
  - All Features
    - Corners, RGB, HSV, VGG, Efficientnet
  - Accuracy - .795
  - F1 Score - .795

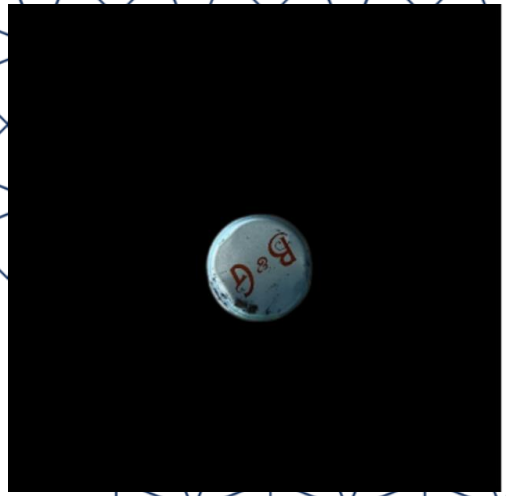




Model limitations

- Small dataset (~5k images)
- Grouped Classes Flawed
  - E.g. Plastic can be both trash and recyclable (nearly impossible to differentiate visually)
  - Greatly unbalanced dataset
- Remove background not perfect
- High variability within class objects and orientations
- Explore additional classification models
  - Eg. Random Forest, K-NN
- Limited computational resources





Conclusion

- Top features: Harris Corner Detection method, RGB and HSV color distributions, VGG-16, and EfficientNet

- Key Findings:
  - Deep learning embeddings with traditional image features provided a robust feature set.
  - Promising results that could significantly impact recycling rates and environmental sustainability

- Future Work
  - Refine our models and explore additional computational techniques to overcome current limitations

Q&A

Berkeley
UNIVERSITY OF CALIFORNIA