Error Analysis of Object Detection Models with Interactive User Interfaces

DAYEON OH

Computer vision

Oregon State University
College of Engineering

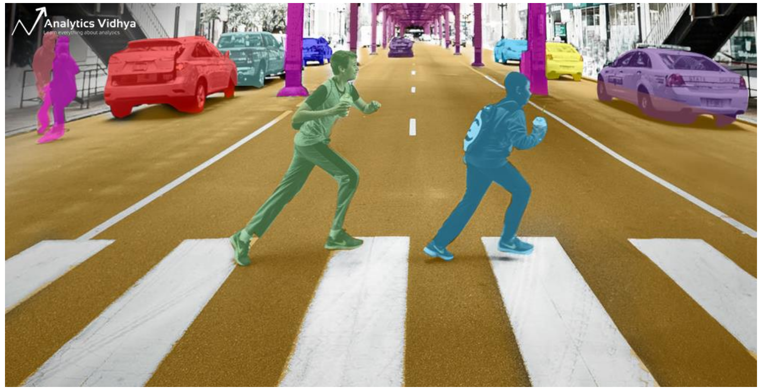


Image segmentation

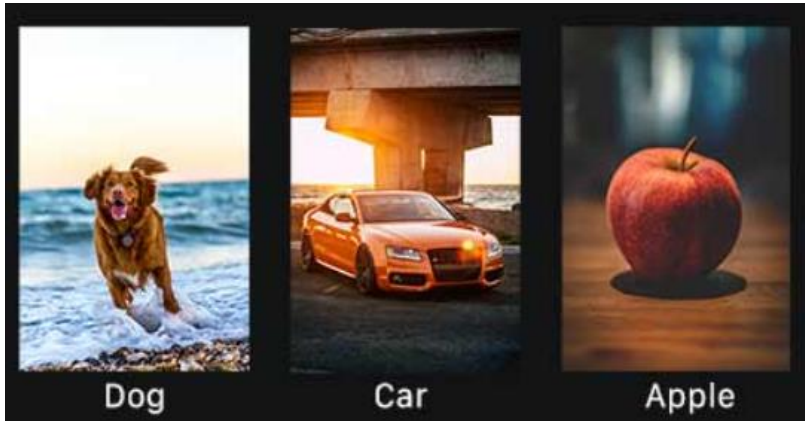
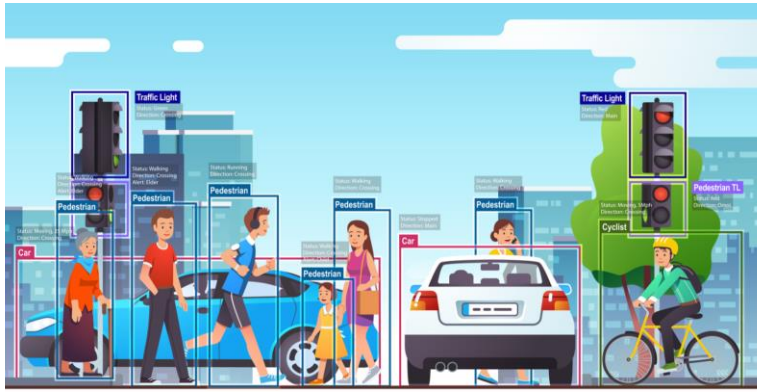
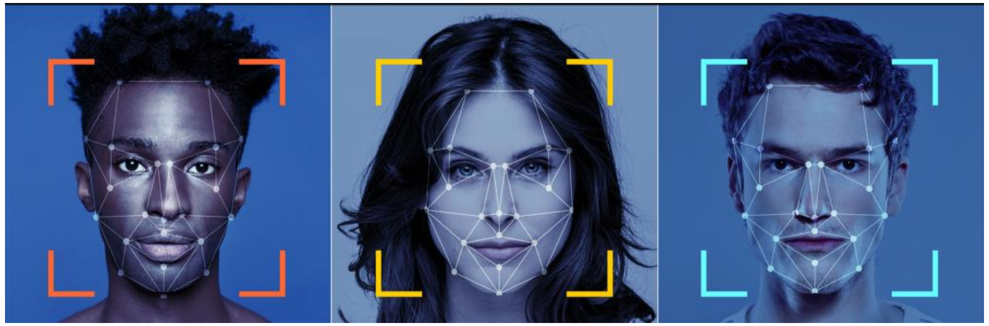


Image classification

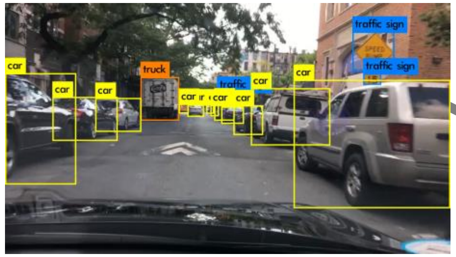


Object detection

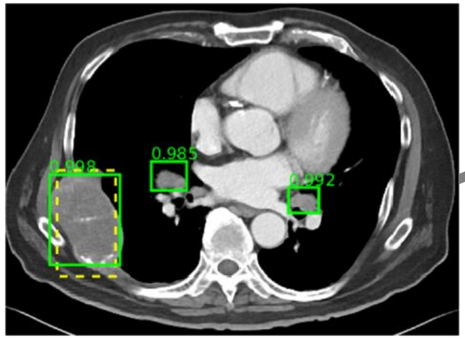


Facial recognition

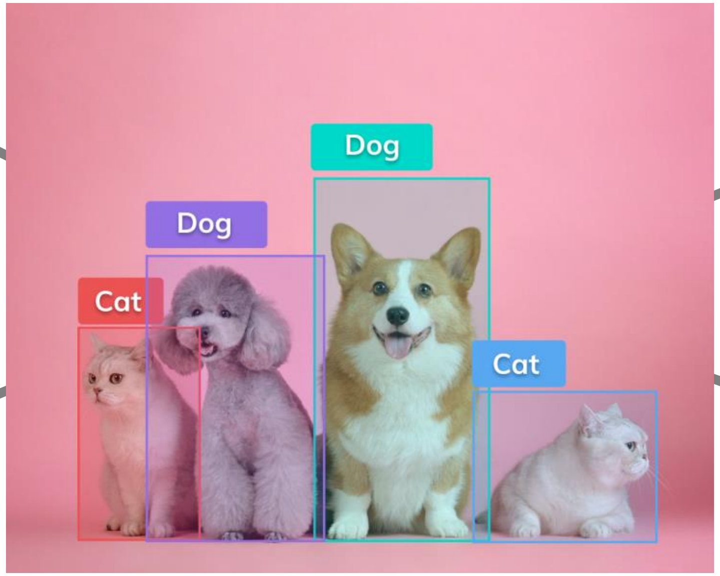
Object detection



Self-driving cars



Cancer and tumor detection

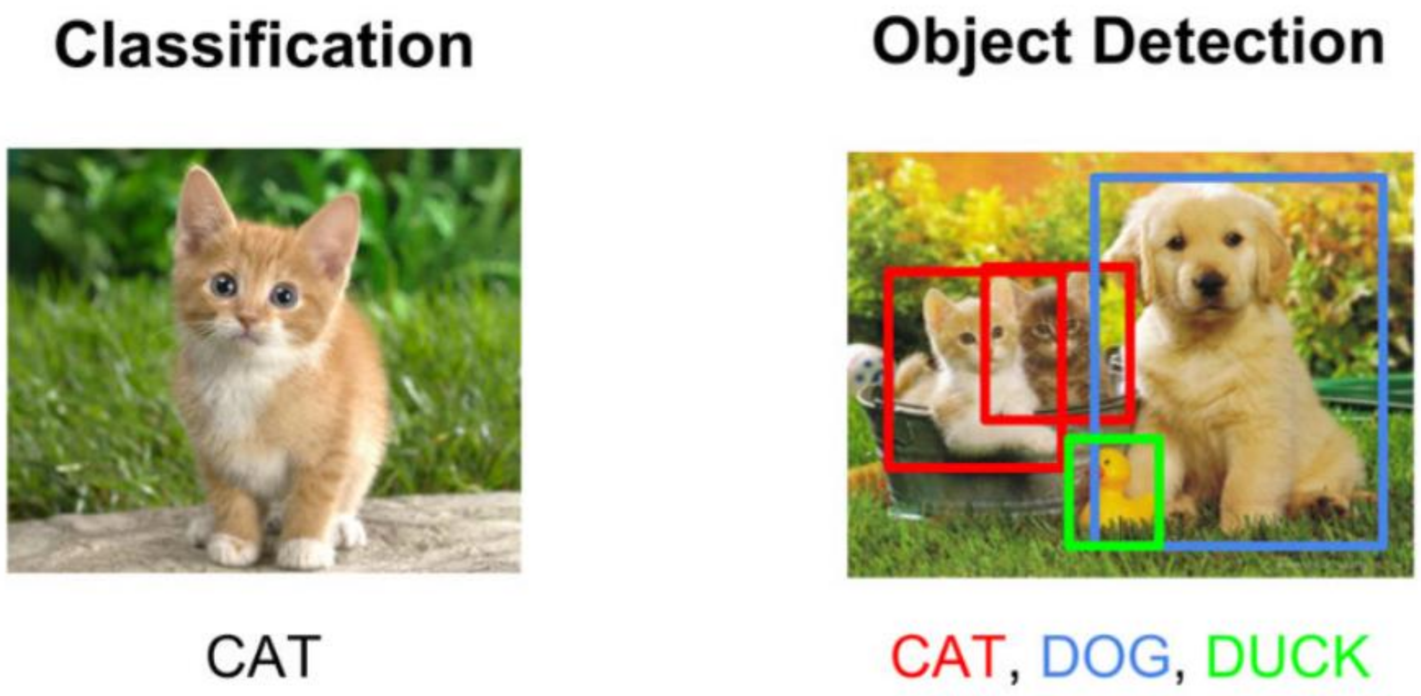


Object Detections

Construction management

Drones and robots

Object detection model evaluation



Most of the images have several objects to be detected

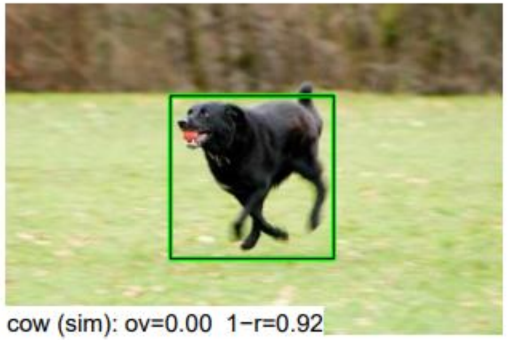
Oregon State University
College of Engineering

Errors of object detection models

Not fully detecting the whole object

Detecting the background

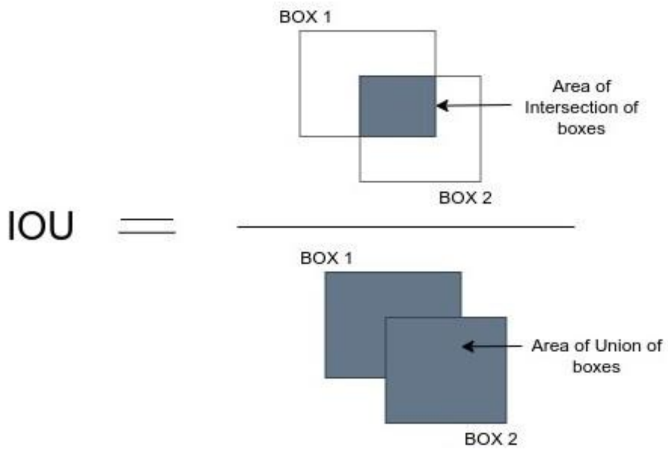
Incorrectly classifying and not fully detecting the object



Incorrectly classifying the object

Different types of errors in object detection models

Object detection evaluation metrics



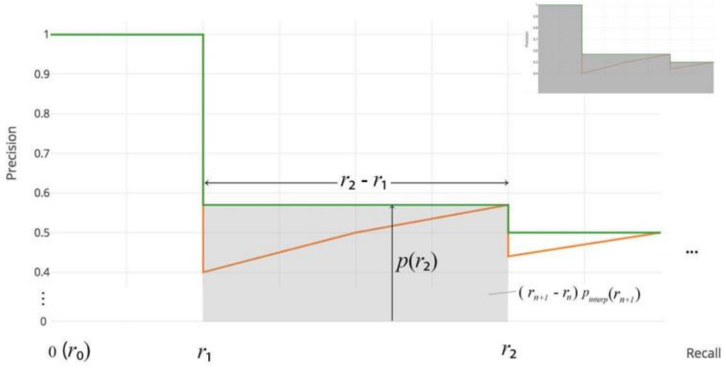
Intersection of Union

$$F_1 = 2 \cdot \frac{precision \cdot recall}{precision + recall}$$

$$precision = \frac{TP}{TP + FP}$$

$$recall = \frac{TP}{TP + FN}$$

Precision and Recall



Mean average precision

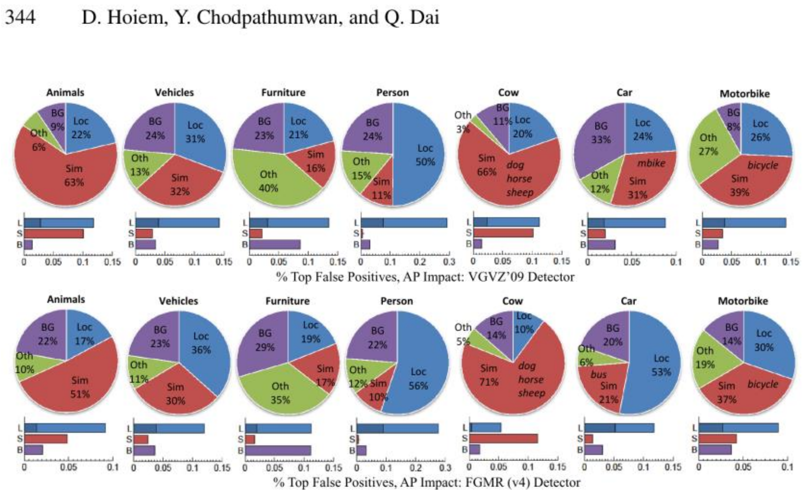
Motivation

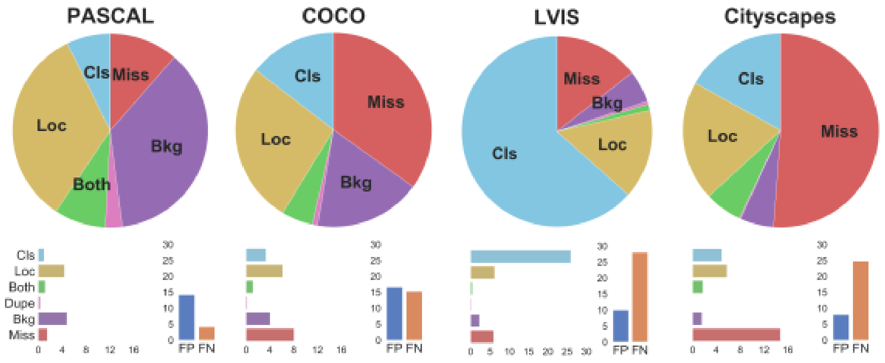
- Evaluating the performance of the object detection model is more complicated than other computer vision models such as image classification models.
- Most of the images have several objects to be detected, and the types of detections and their errors can be categorized in several different ways.

↓

- An effective performance evaluation method for the object detection model is needed.

Related works





(a) Object Detection

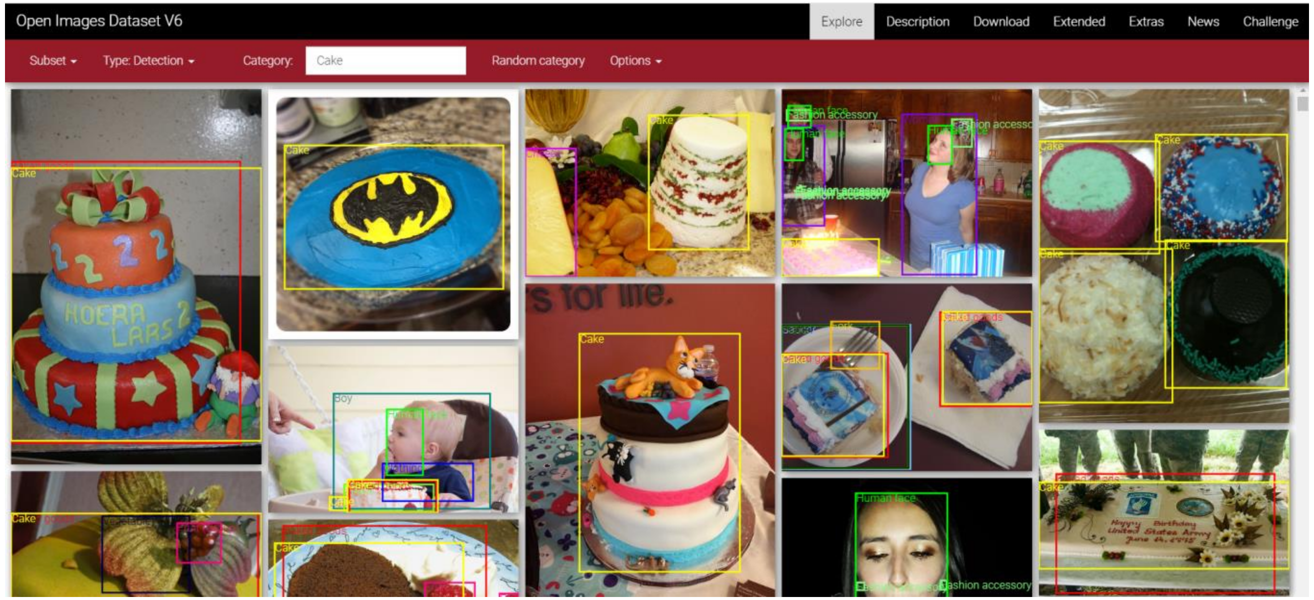
Diagnosing errors in object detectors
Hoiem, D., Chodpathumwan, Y., Dai, Q.: Diagnosing error in object detectors. In: ECCV (2012)

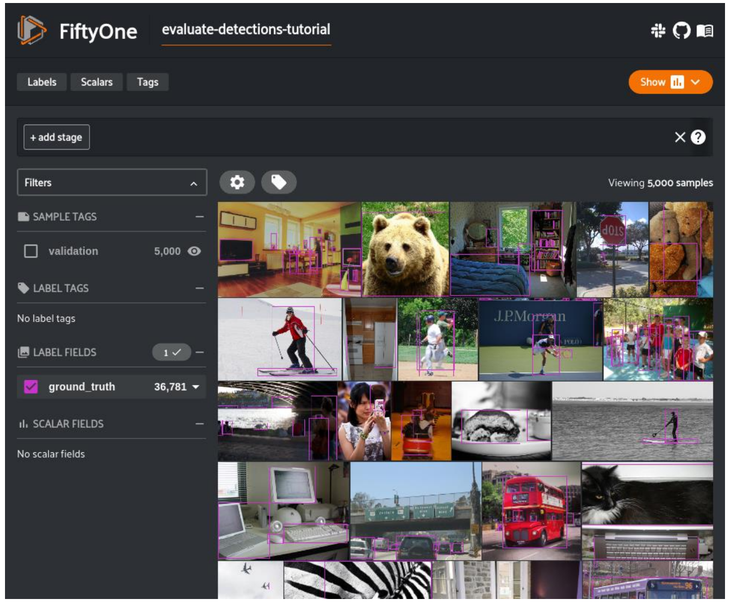
TIDE: A general toolbox for identifying object detection errors
Boyla D., Foley S., Hays J., Hoffman J.: TIDE: A General Toolbox for Identifying Object Detection Errors. In: ECCV (2020)

Categorized the errors into different types and visualized the result with charts

Oregon State University
College of Engineering

Related works





Google Open Images Dataset V6
https://storage.googleapis.com/openimages/web/index.html

Voxel 51
https://voxel51.com/
.

Showing individual images based on the filters like class

Related works

4 different false-positive error types and 6 error types do not contain all the detection result which limit the explanation of the results.

Showing summarized results with the chart is easy to check the percentage of each error type, but it is difficult to immediately check in detail which images and under what circumstances each error occurs.

Research Objectives

- **The goal of this project is to develop a tool that enables browsing object detection models and verifies the features of the tool.**
  - **Design the tool as an interactive web application with the features to analyze and evaluate the object detection results.**
  - **Evaluate the function/features of the tool with a realistic user scenario.**

↓

- **Understand and evaluate the result of the object detection model.**
- **Helping users to make more critical decisions based on the results.**

Oregon State University
College of Engineering

Object detection error explorer

Error Report

Result Summary detection

class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	backdetect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	26	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3961	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
train	0.000	0	15	0	0	0	0	0	0	0
truck	0.381	2869	4243	1602	512	97	296	3	151	208

Score Distributions

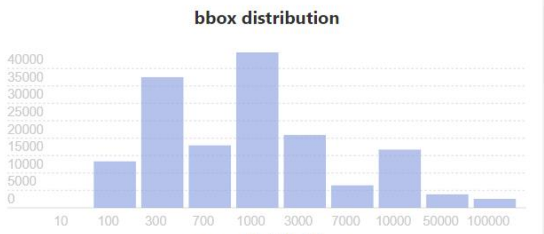
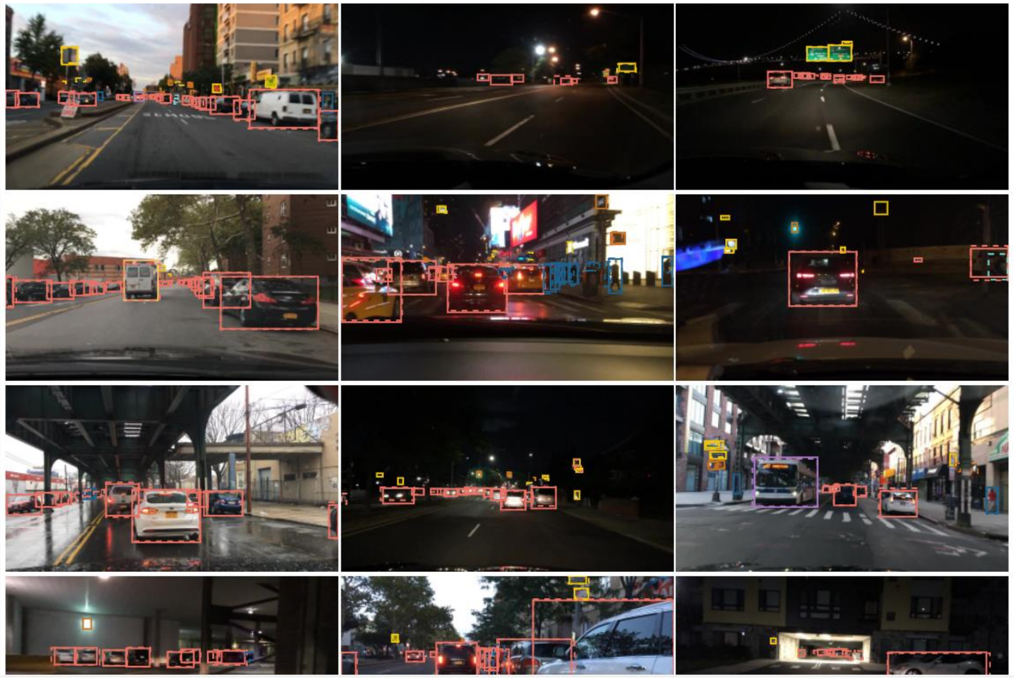


Image View



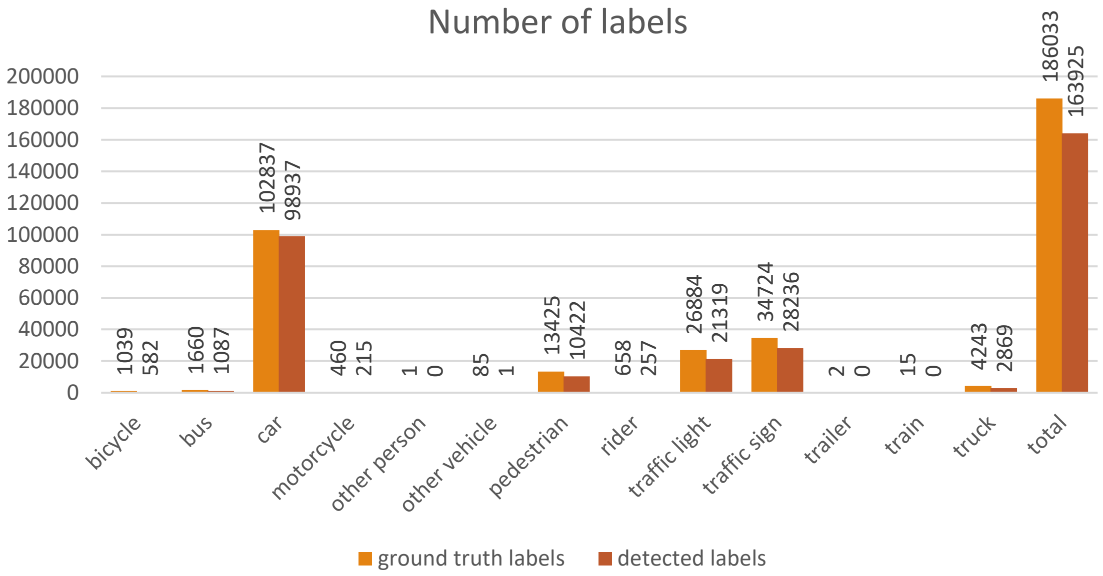
An interactive tool that supports the evaluation and analysis of the results of the detection model

Oregon State University
College of Engineering

Dataset and model

BDD 100k dataset

Training (70K), validation (10K), and testing (20K)
Number of classes: 13



Oregon State University
College of Engineering

Dataset and model

Faster R-CNN

Image object detection

faster_rcnn/resnet50_v1_640x640

Faster R-CNN with Resnet-50 V1 Object detection model, trained on COCO 2017 dataset with trainning images scaled to 640x640.

Publisher: TensorFlow License: Apache-2.0

Architecture: Faster R-CNN

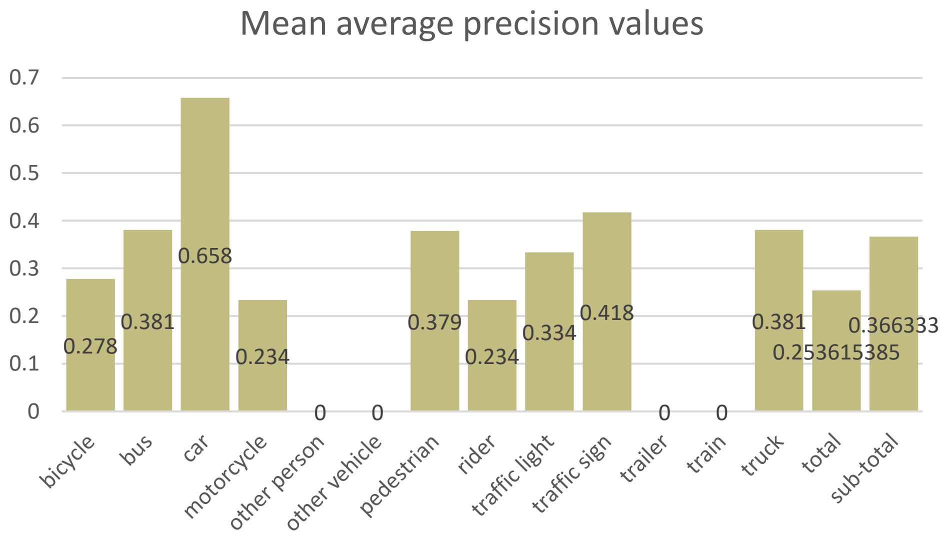
Dataset: COCO 2017

Overall usage data

4.3k Downloads

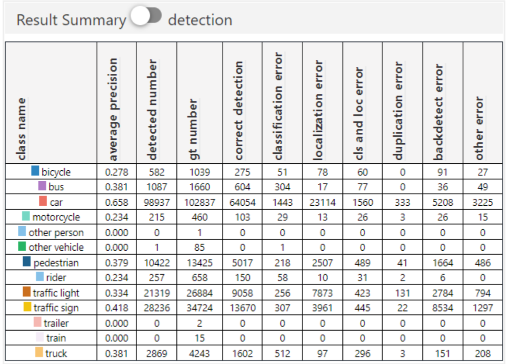
Metric	Value
mAP on COCO 2017 test set	29.3

Trained on COCO 2017
Fine-tuned with BDD 100K training data (70K)
Used BDD 100K validation data (10K) for the experiment
mAP on COCO : 29.3, mAP on fine-tuned: 25.3, 36.6



Oregon State University
College of Engineering

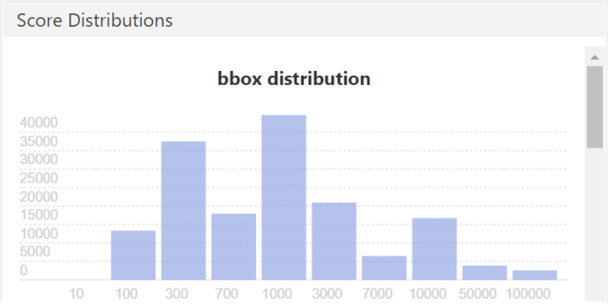
Object detection error explorer



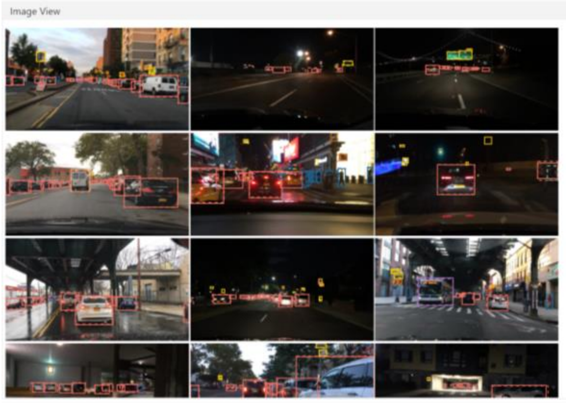
Result Summary detection

class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	backdetect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	26	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3961	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
train	0.000	0	15	0	0	0	0	0	0	0
truck	0.381	2869	4243	1602	512	97	296	3	151	208

Summary of whole data



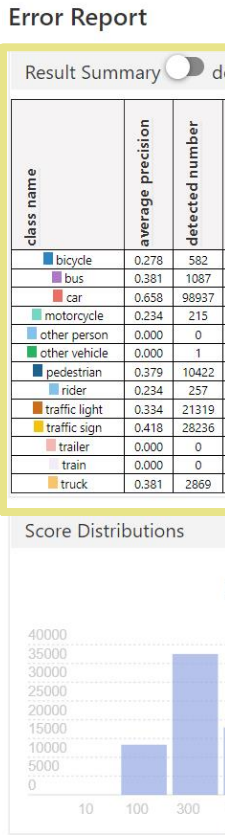
Summary of class and detection type

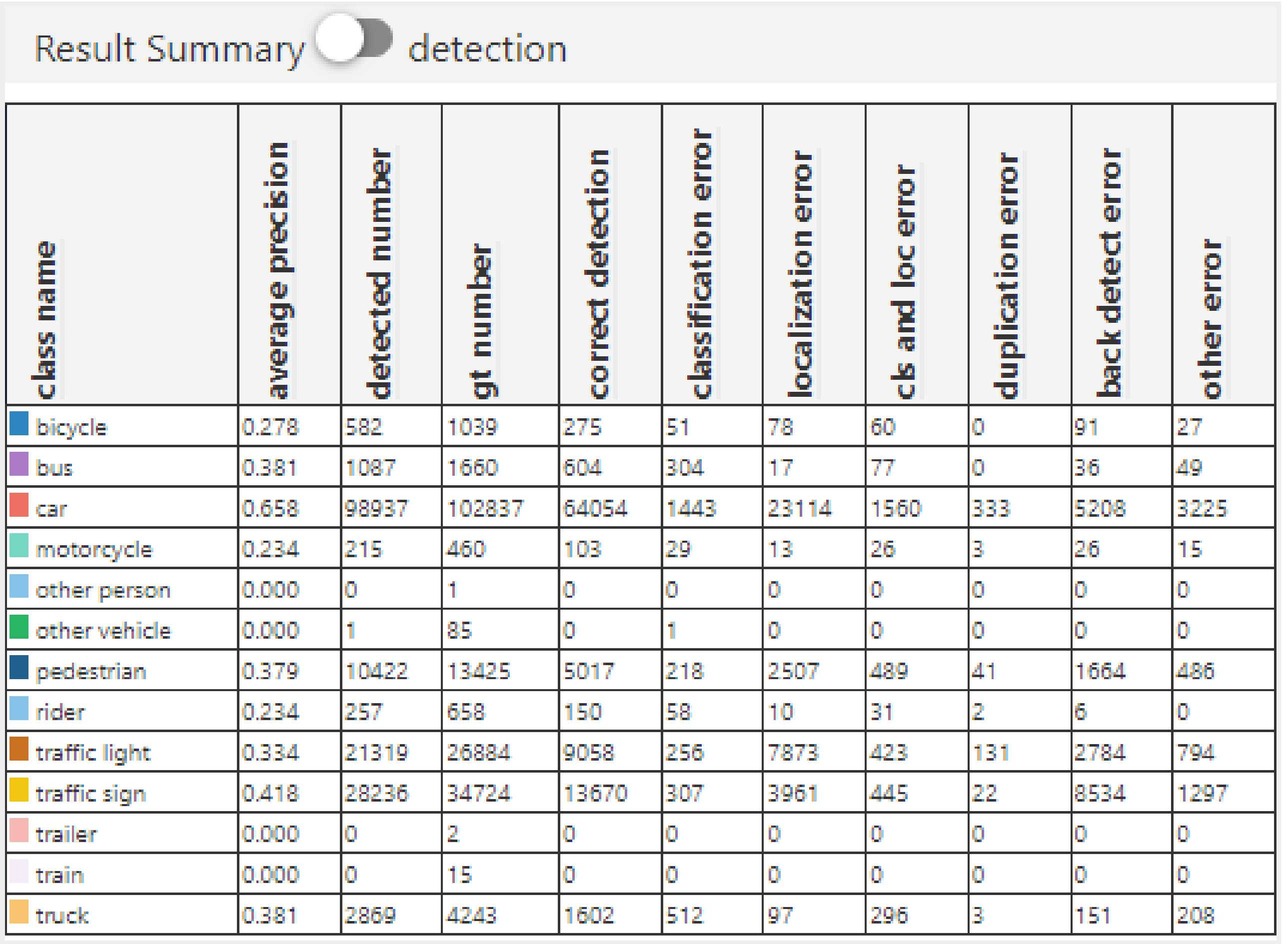


Individual image display

Oregon State University College of Engineering

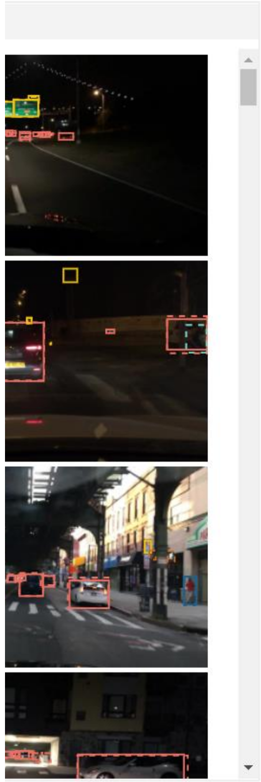
Summary view panel





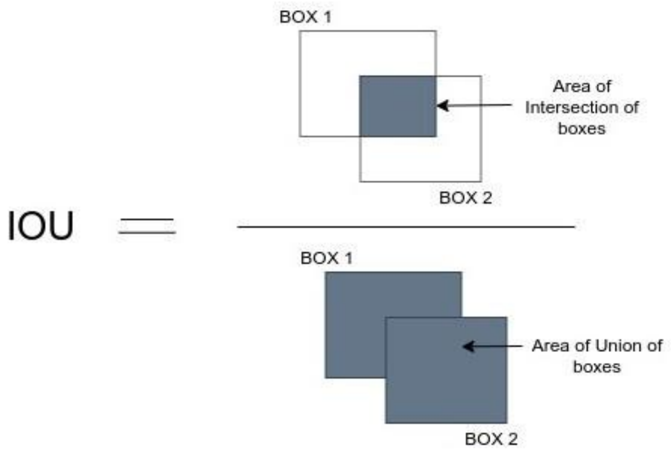
Result Summary detection

class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	back detect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	26	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3961	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
train	0.000	0	15	0	0	0	0	0	0	0
truck	0.381	2869	4243	1602	512	97	296	3	151	208

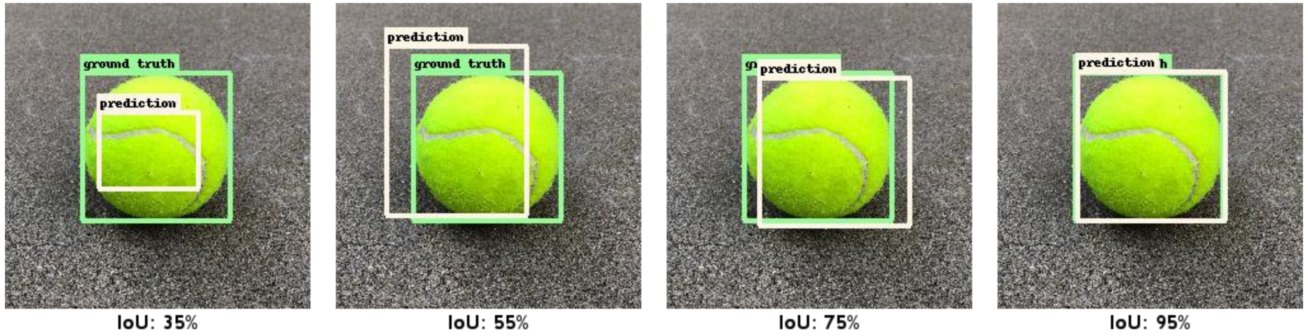


Oregon State University College of Engineering

Object detection evaluation metrics



Intersection over Union



Examples of different IoU score

IoU Thresholds:

A value used in object detection to measure the overlap of a predicted versus actual bounding box for an object.

Thresholds for object detection result analyzer:

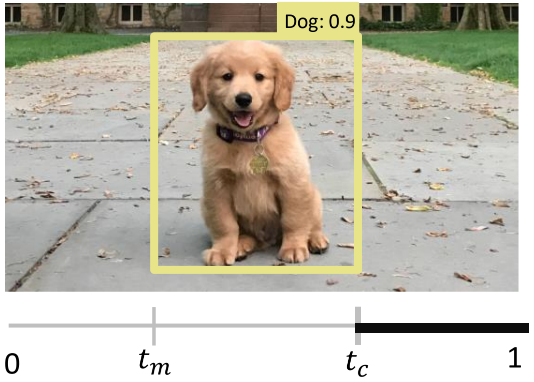
Correct threshold (0.5): if higher than 0.5, consider as correct overlapping

Minimum threshold (0.1): if lower than 0.1, consider a non-meaningful overlapping

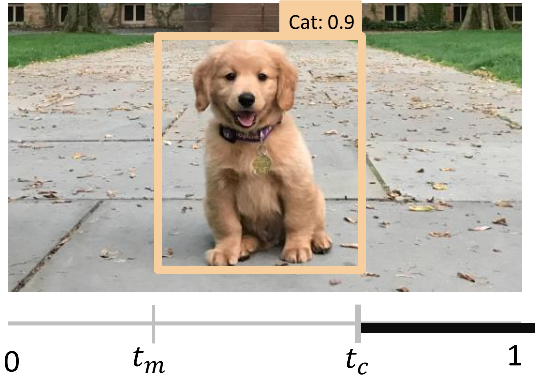
Background threshold (0): if the score is 0, consider non-overlapping

Detected labels categories

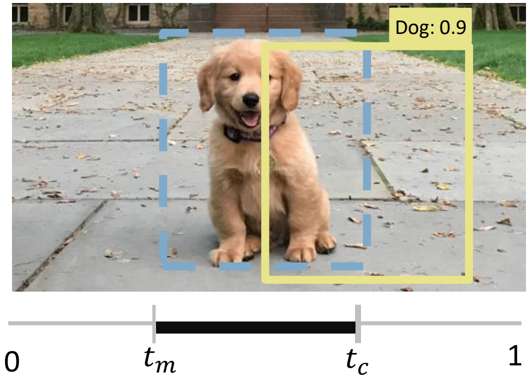
Correctly detected



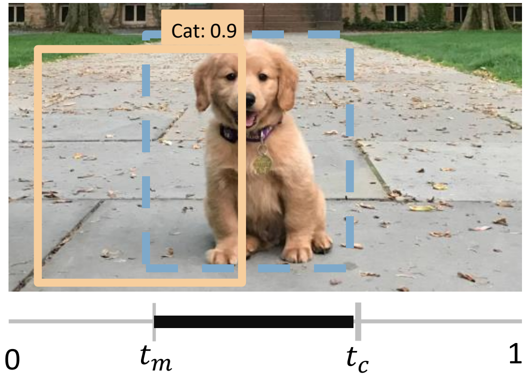
Classification error



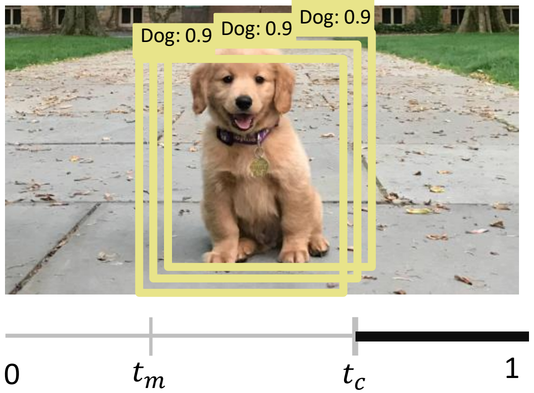
Localization error



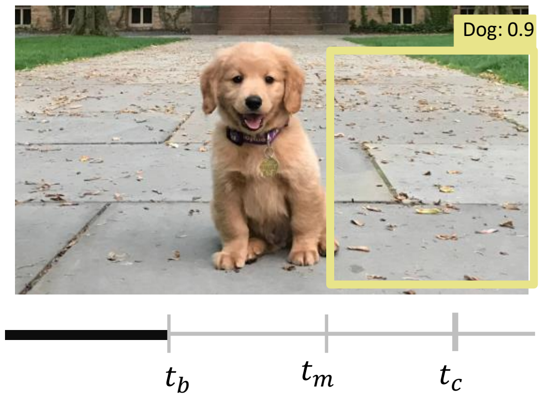
Classification + localization error



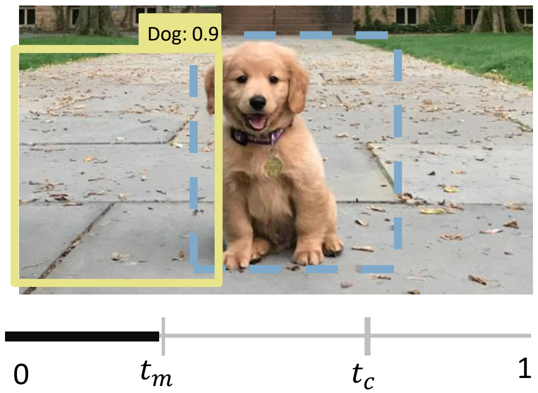
Duplicate detected error



Background detect error



Min-overlap error

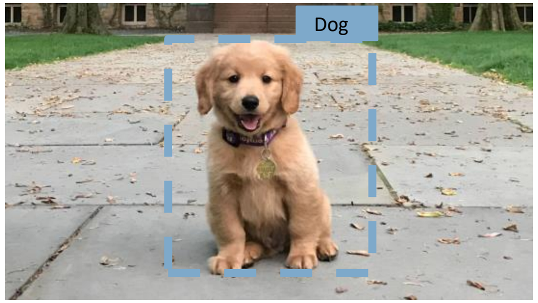


$t_c: 0.5, t_m: 0.1, t_b: 0$

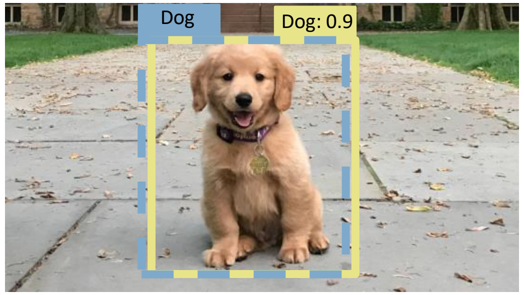
Ground truth labels categories

None or one matching label between the ground truth label and the detected label

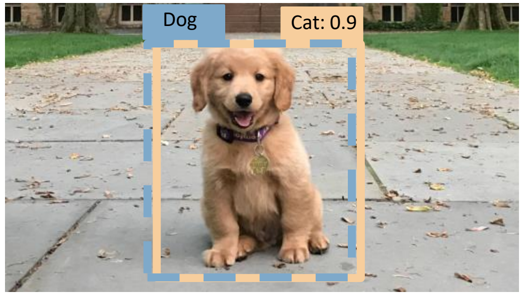
No matching label
Missed detected error



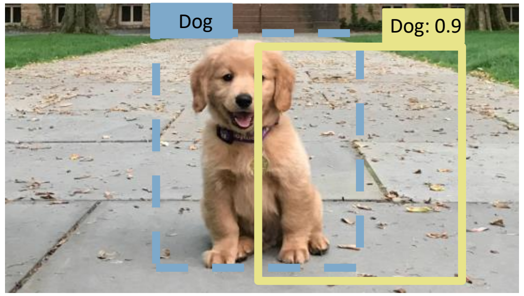
Only one match
with correct detection



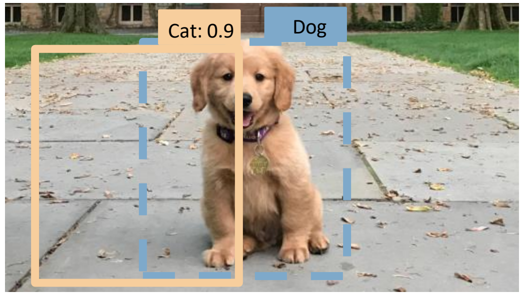
Only one match
with classification error



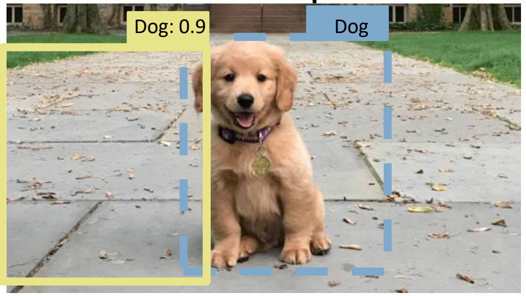
Only one match
with localization error



Only one match with
classification + localization error



Only one match with
Min-overlap error

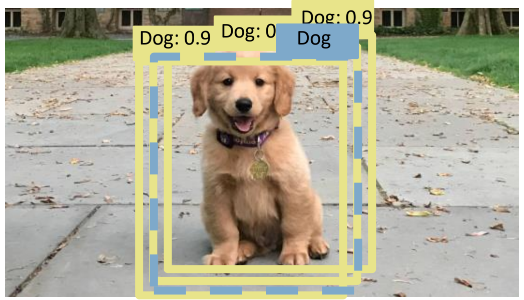


Oregon State University
College of Engineering

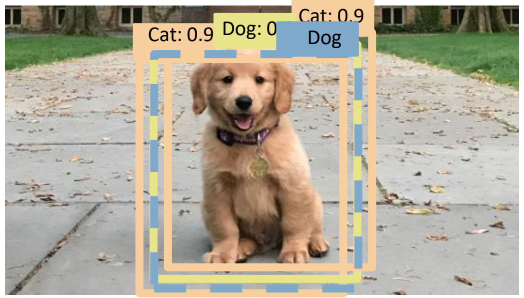
Ground truth labels categories

Multiple matching labels between the ground truth label and the detected label

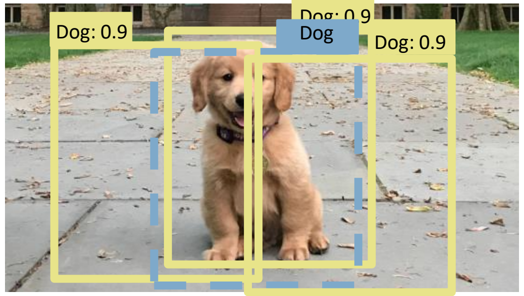
Multiple matches with
Correct and duplication



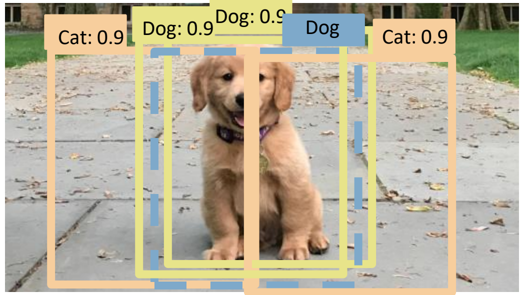
Multiple matches with
Correct and classification



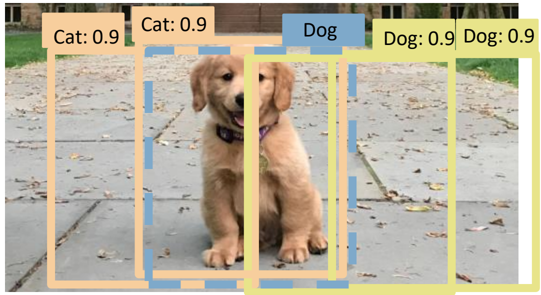
Multiple matches with
Correct and localization



Multiple matches with
errors and including correct



Multiple matches
and all incorrect



Oregon State University College of Engineering

Summary view panel

Detection result summary table

Result Summary detection

class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	back detect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	26	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3961	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
	0.000	0	15	0	0	0	0	0	0	0
	0.381	2869	4243	1602	512	97	296	3	151	208

Name and color of the classes

Ground truth summary table

Result Summary ground truth

Name of the categories

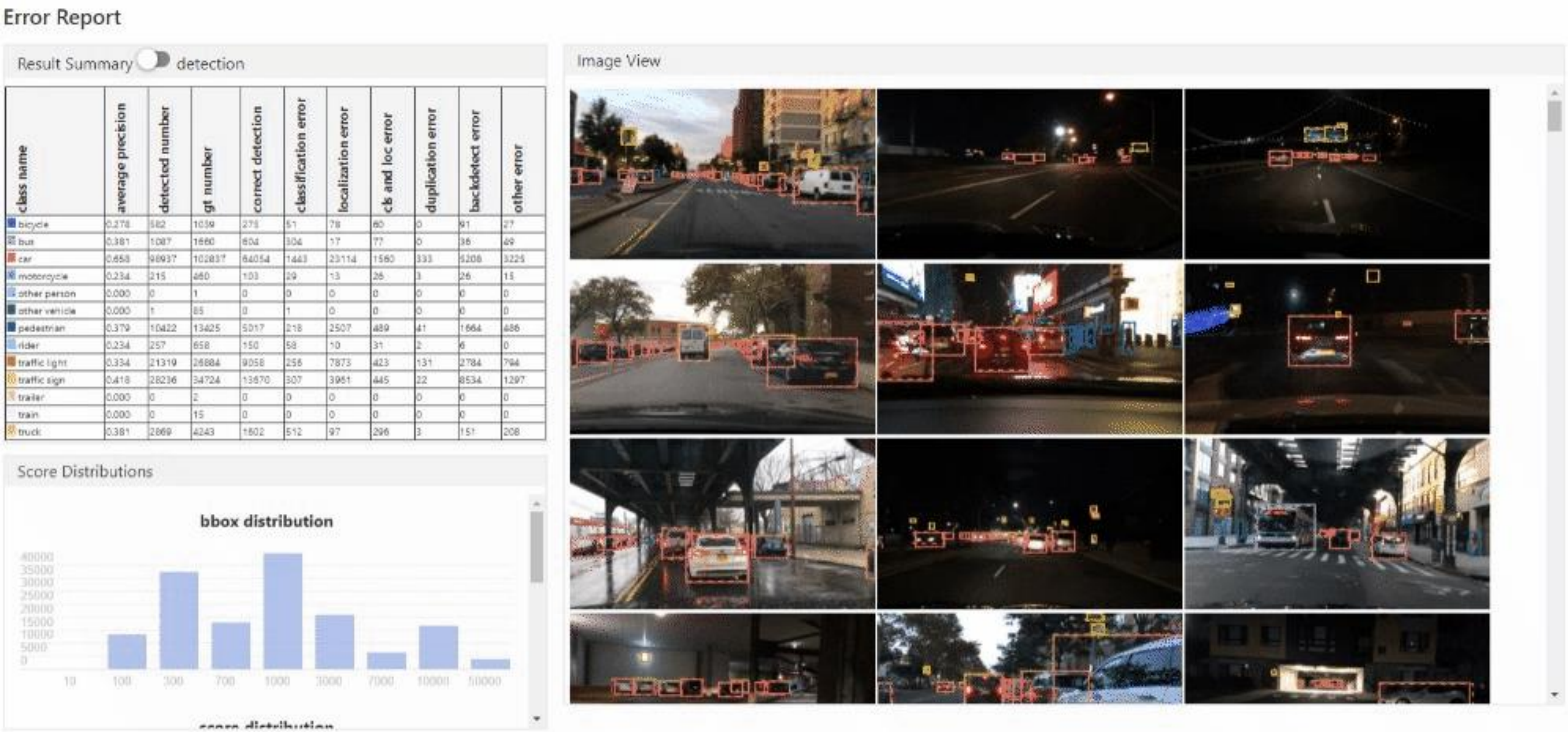
class name	number	match + correct	match + cls	match + loc	match + cls and loc	match + incorrect	matches + cor, dup	matches + cor, cls	matches + cor, loc	matches + with cor	matches + inco	missed detecte
bicycle	1039	239	70	56	88	14	0	0	16	16	10	530
bus	1660	558	408	9	170	25	0	0	3	43	64	380
car	102837	56783	469	15153	317	513	221	4	4232	2594	674	21877
motorcycle	460	93	91	11	65	4	2	0	0	8	19	167
other person	1	0	0	0	1	0	0	0	0	0	0	0
other vehicle	85	0	32	0	14	4	0	0	0	0	6	29
pedestrian	13425	4282	139	1632	351	133	24	0	519	180	97	6068
rider	658	140	114	8	83	12	1	0	0	9	13	278
traffic light	26884	7100	232	5062	317	257	60	0	1598	259	270	11729
traffic sign	34724	12743	265	3023	485	371	14	0	525	305	147	16846
trailer	2	0	1	0	0	0	0	0	0	0	1	0
train	15	0	2	0	3	3	0	0	0	0	0	7
truck	4243	1438	985	56	437	59	1	2	11			

Number of labels

Method and Design

Oregon State University
College of Engineering

Summary view panel



class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	backdetect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	26	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3961	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
train	0.000	0	15	0	0	0	0	0	0	0
truck	0.381	2869	4243	1602	512	97	296	3	151	208

Oregon State University College of Engineering

Potential user and User scenarios

- Amy
- Using object detection model for self-driving car research

User scenarios

- Finding similarities between certain errors
  - From localization errors
  - From classification errors
  - From background detection errors
- Finding example images for specific conditions
  - Misclassification cases between pedestrians and vehicles
  - Missed detection cases for pedestrians and vehicles

Demo

Findings

Similarities between errors

- Localization errors: small bounding boxes, densely located objects, or hard to observe
- Classification errors: small bounding boxes or misclassification between similar objects
- Background errors: frequently occurred in dark and blurry images

Find example images for specific conditions

- Misclassification between pedestrians and vehicles: small bounding boxes, hard to distinguish, overlaps between the objects, and labeling errors
- Missed detected pedestrians and vehicles: small bounding boxes, densely located objects, on the opposite side of the driveway or on the sidewalk

Discover labeling errors while browsing images

- Labeling errors between cars and pedestrians

Chart view panel

Oregon State University
College of Engineering

Error Report

Result Summary detection

class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	backdetect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	26	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3961	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
train	0.000	0	15	0	0	0	0	0	0	0
truck	0.381	2869	4243	1602	512	97	296	3	151	208

Score Distributions

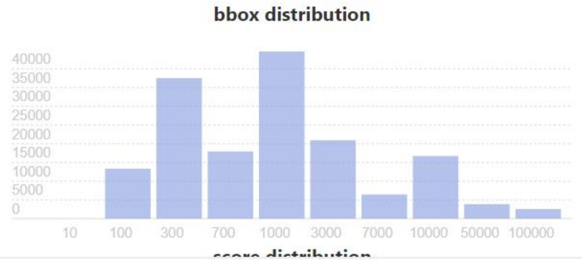


Image View

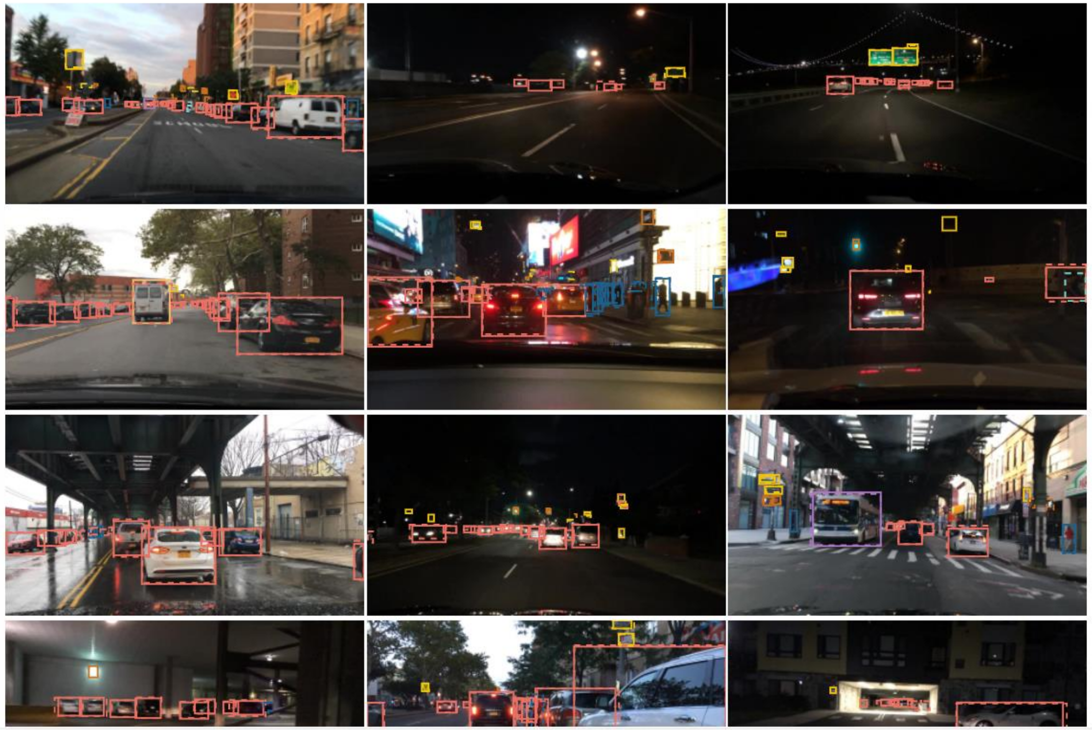
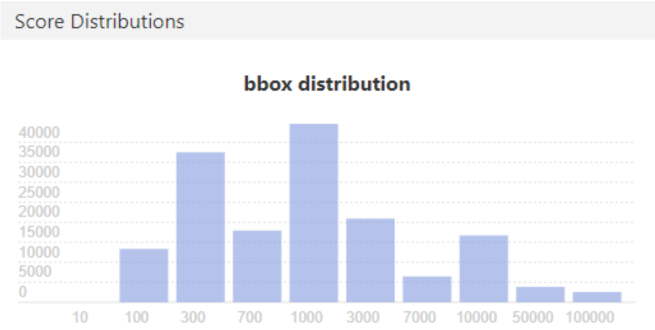
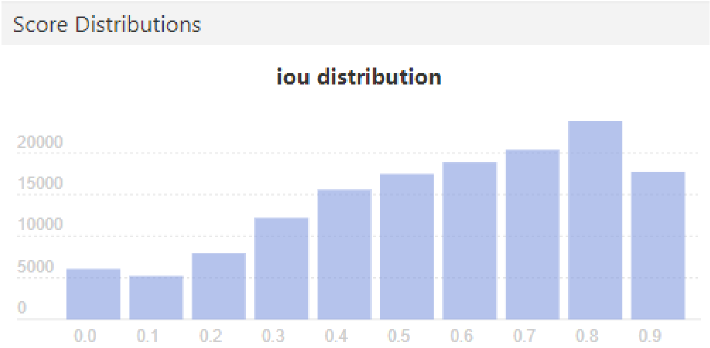


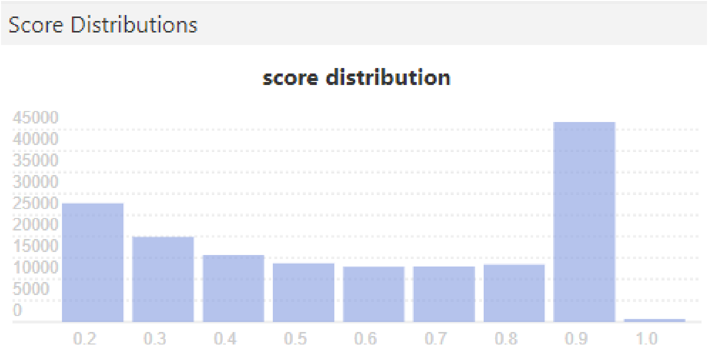
Chart view panel



Bounding box size distribution



IoU score distribution



Detection score distribution

- To find the relationship between the size of the bounding box, IoU score, detection score, and different detection types.
- To check the distribution difference between different detection types.

Oregon State University College of Engineering

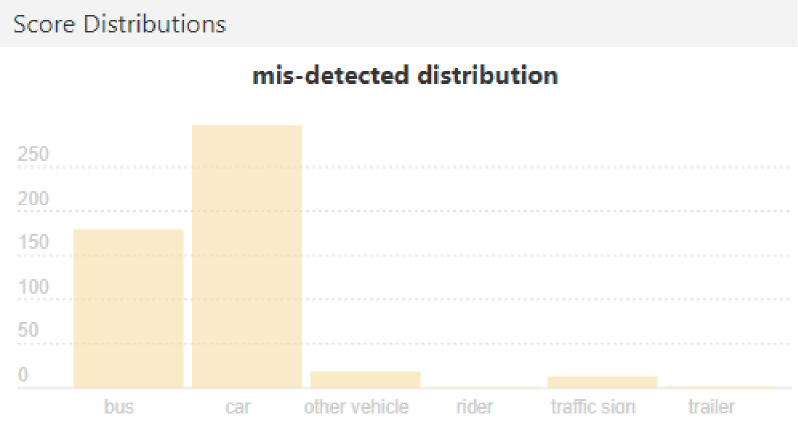
Chart view panel with detection type

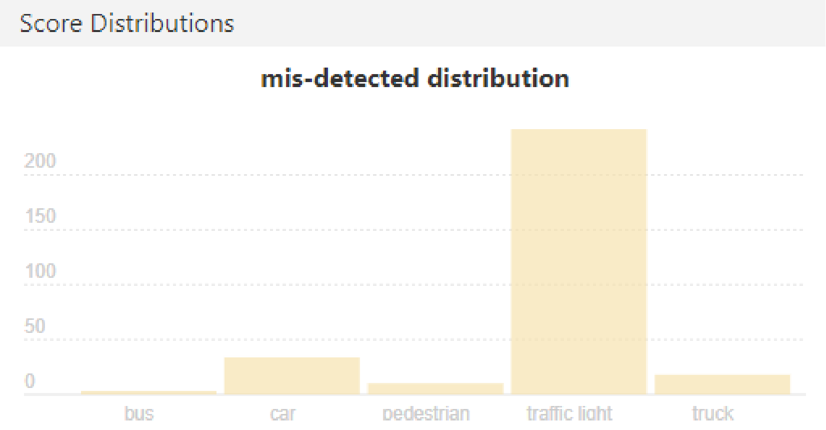
Classification error

- Distribution chart for incorrectly classified classes

Background detection error

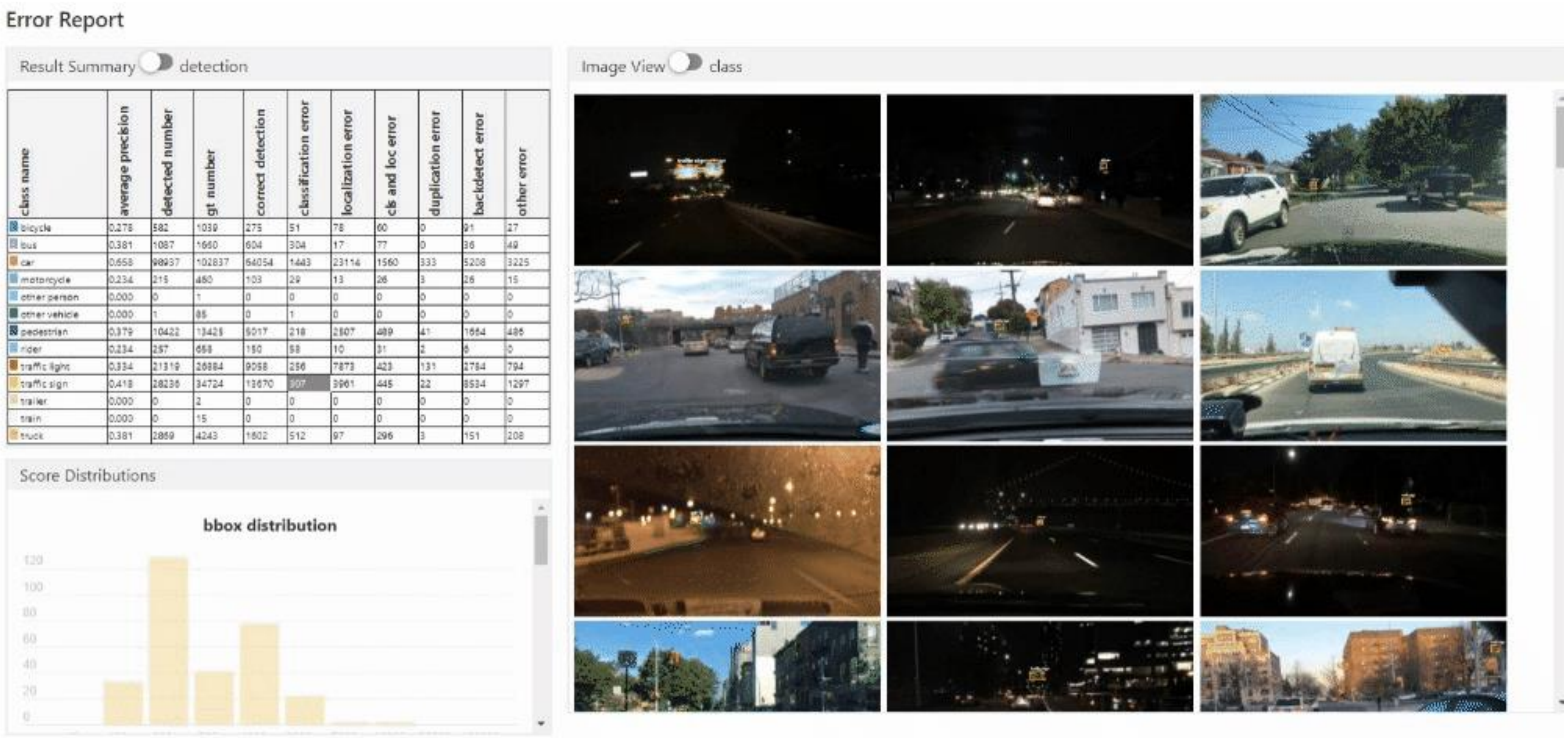
- Only bounding box size and detection score distribution charts





Classification error class distribution

Chart view panel



class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	backdetect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	26	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3961	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
train	0.000	0	15	0	0	0	0	0	0	0
truck	0.381	2869	4243	1602	512	97	296	3	151	208

Image view panel

Error Report

Result Summary detection

class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	backdetect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	26	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3961	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
train	0.000	0	15	0	0	0	0	0	0	0
truck	0.381	2869	4243	1602	512	97	296	3	151	208

Score Distributions

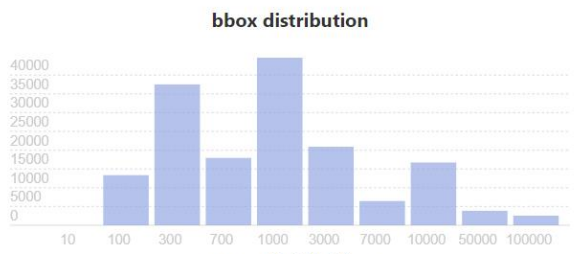


Image View

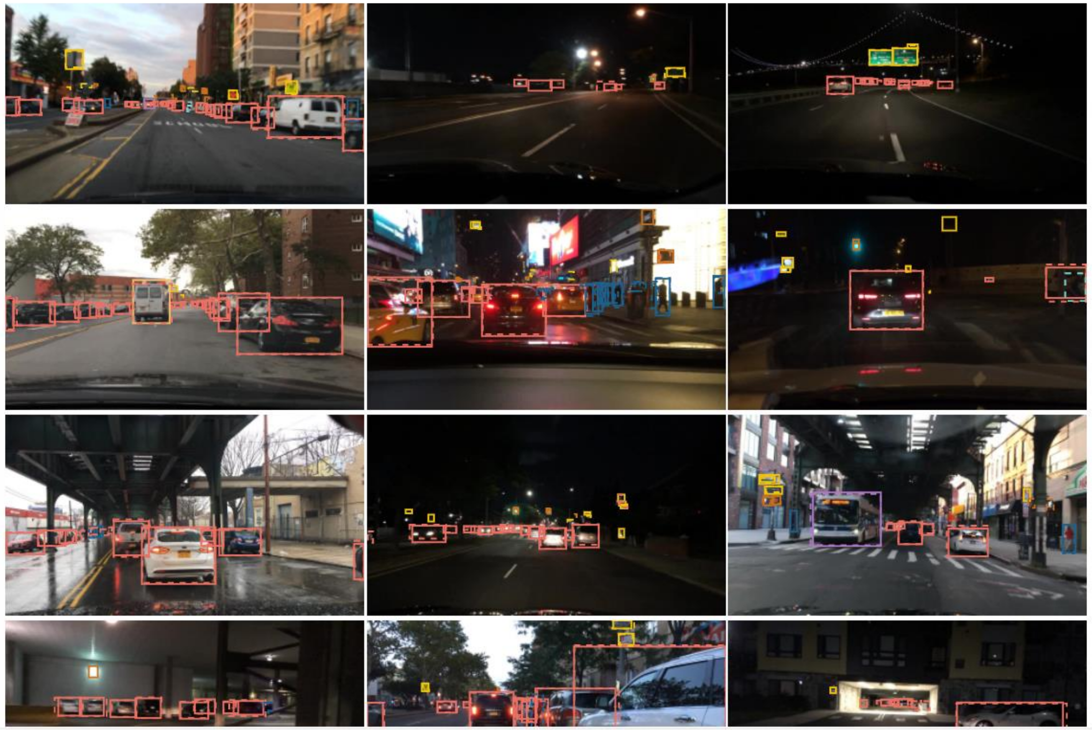


Image view panel

Error Report

Result Summary detection

class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	back detect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	26	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3961	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
train	0.000	0	15	0	0	0	0	0	0	0
truck	0.381	2869	4243	1602	512	97	296	3	151	208

Score Distributions

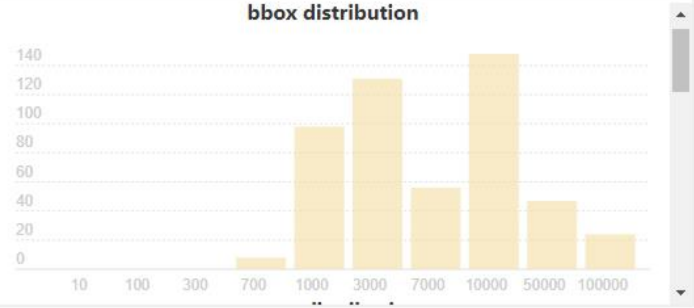
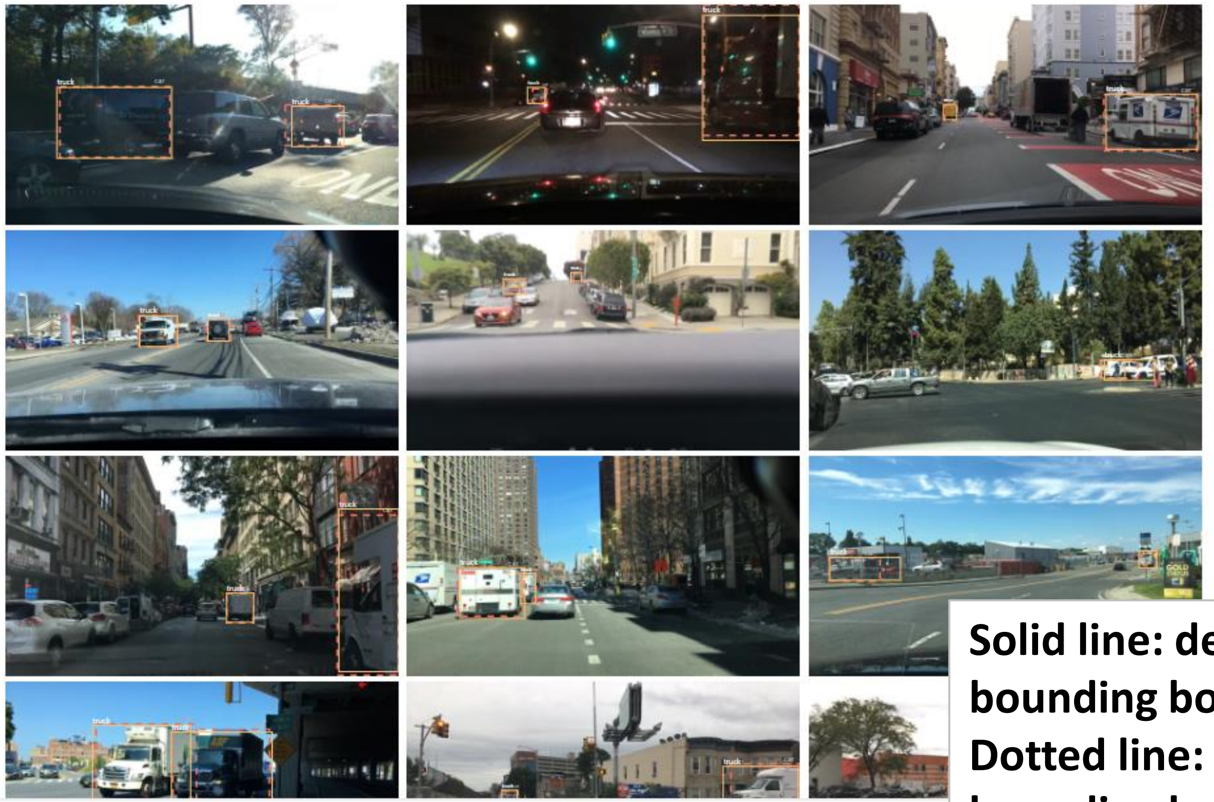
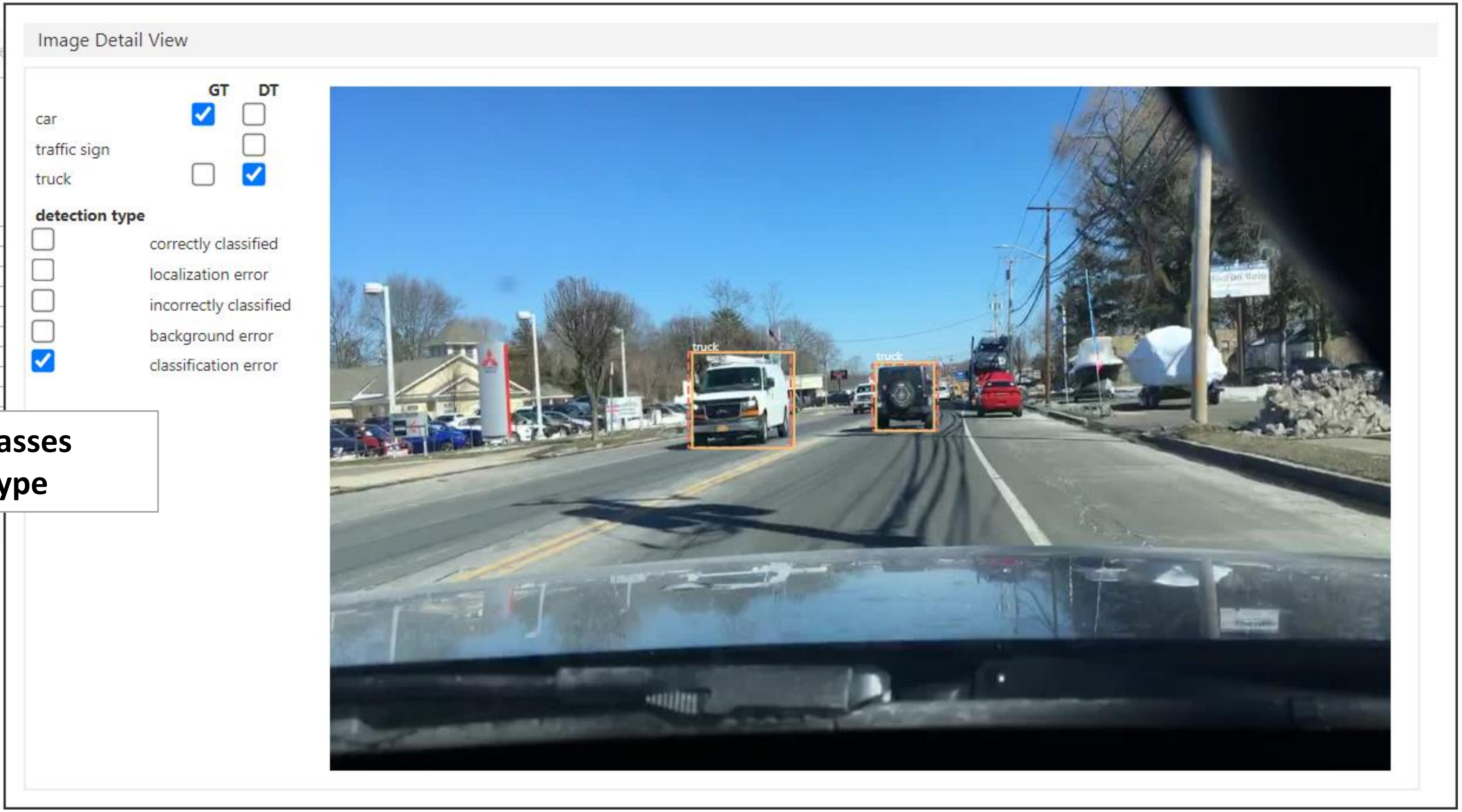


Image View



Solid line: detected bounding box
Dotted line: ground truth bounding box

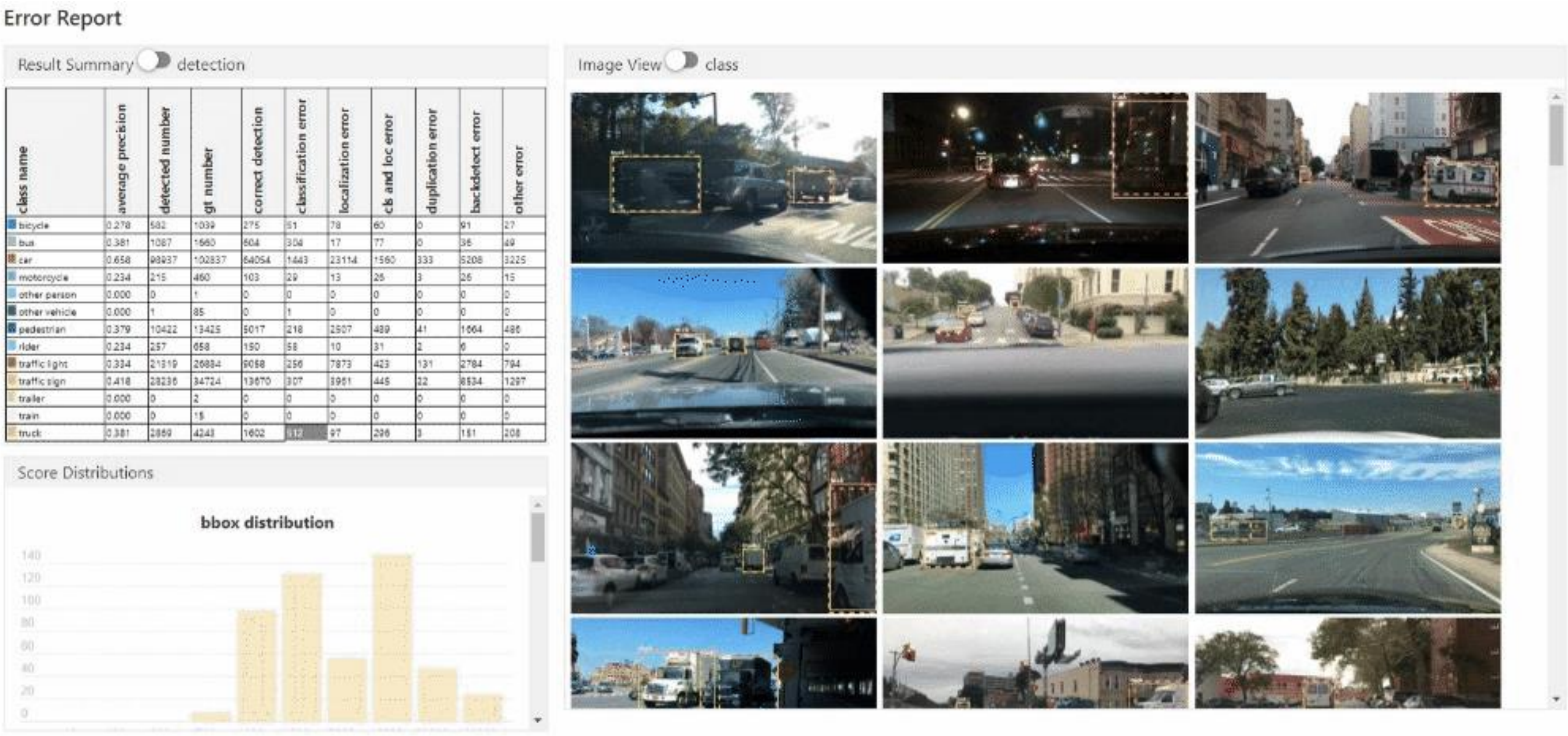
Image view modal window



Checkbox for classes and detection type

Oregon State University
College of Engineering

Image view panel



class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	backdetect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	25	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3951	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
train	0.000	0	15	0	0	0	0	0	0	0
truck	0.381	2869	4243	1602	512	97	296	3	151	208

Oregon State University College of Engineering

post-processing with results

Non-maximum suppression to reduce the duplicated detection bounding boxes

type 1	type 2	type 3	type 4	type 5	type 6	type 7	type 8
326	131	153	132	63	124	530	34
746	768	34	141	18	45	380	70
70443	2381	38930	2475	6142	6931	21877	4964
127	78	26	48	15	45	167	23
0	0	0	0	0	0	0	0
0	5	0	0	0	0	29	0
5902	366	4067	782	832	2123	6068	831
180	185	27	77	14	13	278	3
11643	366	13156	621	1789	3608	11729	1206
14977	432	7130	645	1399	10223	16846	1820
0	0	0	0	0	0	0	0
0	0	0	0	0	0	7	0
1973	1566	211	475	79	187	913	263

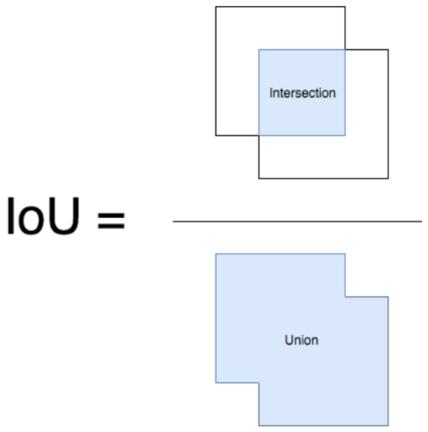
Before applying NMS methods

type 1	type 2	type 3	type 4	type 5	type 6	type 7	type 8
275	51	78	60	0	91	530	27
604	304	17	77	0	36	380	49
64054	1443	23114	1560	333	5208	21877	3225
103	29	13	26	3	26	167	15
0	0	0	0	0	0	0	0
0	1	0	0	0	0	29	0
5017	218	2507	489	41	1664	6068	486
150	58	10	31	2	6	278	0
9058	256	7873	423	131	2784	11729	794
13670	307	3961	445	22	8534	16846	1297
0	0	0	0	0	0	0	0
0	0	0	0	0	0	7	0
1602	512	97	296	3	151	913	208

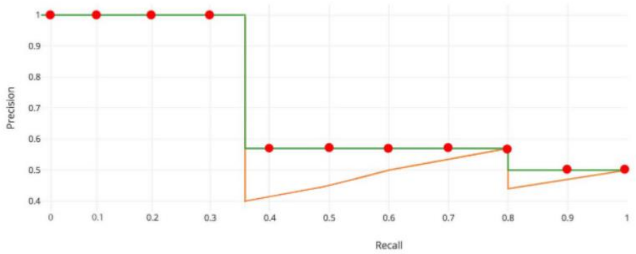
After applying NMS methods

Oregon State University College of Engineering

Post-processing with results



Intersection over Union



Result Summary detection

class name	average precision	detected number	gt number	correct detection	classification error	localization error	cls and loc error	duplication error	backdetect error	other error
bicycle	0.278	582	1039	275	51	78	60	0	91	27
bus	0.381	1087	1660	604	304	17	77	0	36	49
car	0.658	98937	102837	64054	1443	23114	1560	333	5208	3225
motorcycle	0.234	215	460	103	29	13	26	3	26	15
other person	0.000	0	1	0	0	0	0	0	0	0
other vehicle	0.000	1	85	0	1	0	0	0	0	0
pedestrian	0.379	10422	13425	5017	218	2507	489	41	1664	486
rider	0.234	257	658	150	58	10	31	2	6	0
traffic light	0.334	21319	26884	9058	256	7873	423	131	2784	794
traffic sign	0.418	28236	34724	13670	307	3961	445	22	8534	1297
trailer	0.000	0	2	0	0	0	0	0	0	0
train	0.000	0	15	0	0	0	0	0	0	0
truck	0.381	2869	4243	1602	512	97	296	3	151	208

Result Summary ground truth

class name	number	match + correct	match + cls	match + loc	match + cls and loc	match + incorrect	matches + cor, dup	matches + cor, cls	matches + cor, loc	matches + with cor	matches + incor	missed detected
bicycle	1039	239	70	56	88	14	0	0	16	16	10	530
bus	1660	558	408	9	170	25	0	0	3	43	64	380
car	102837	56783	469	15153	317	513	221	4	4232	2594	674	21877
motorcycle	460	93	91	11	65	4	2	0	0	8	19	167
other person	1	0	0	0	1	0	0	0	0	0	0	0
other vehicle	85	0	32	0	14	4	0	0	0	0	6	29
pedestrian	13425	4282	139	1632	351	133	24	0	519	180	97	6068
rider	658	140	114	8	83	12	1	0	0	9	13	278
traffic light	26884	7100	232	5062	317	257	60	0	1598	259	270	11729
traffic sign	34724	12743	265	3023	485	371	14	0	525	305	147	16846
trailer	2	0	1	0	0	0	0	0	0	0	1	0
train	15	0	2	0	3	3	0	0	0	0	0	7
truck	4243	1438	985	56	437	59	1	2	11	149	192	913

Calculate the IoU and average precision of detected labels

Categorized the labels into different types

Conclusion

Oregon State University
College of Engineering

CONCLUSION

- Develop an interactive tool that helps evaluate and analyze the results of the object detection model
- Can be helpful for non-computer science experts to evaluate the performance of the models and answer their research questions

FUTURE WORK

- Show the answers to ‘why’ with more enhanced explainability and interpretability
- Explore images intersecting with the ground truth and detected labels categories

References

[1] Boyla D., Foley S., Hays J., Hoffman J.: TIDE: A General Toolbox for Identifying Object Detection Errors. In: ECCV (2020)
[2] Hoiem, D., Chodpathumwan, Y., Dai, Q.: Diagnosing error in object detectors. In: ECCV (2012)
[3] Borji, A., Iranmanesh, S.M.: Empirical upper-bound in object detection and more. arXiv:1911.12451 (2019)
[4] Voxel 51. https://voxel51.com/.
[5] S. H. Naghavi, C. Avaznia and H. Talebi, "Integrated real-time object detection for self-driving vehicles," 2017 10th Iranian Conference on Machine Vision and Image Processing (MVIP), 2017, pp. 154-158, doi: 10.1109/IranianMVIP.2017.8342340.
[6] M. Vas and A. Dessai, "Lung cancer detection system using lung CT image processing," 2017 International Conference on Computing, Communication, Control and Automation (ICCUBEA), 2017, pp. 1-5, doi: 10.1109/ICCUBEA.2017.8463851.
[7] C. -C. Liu and J. J. -C. Ying, "DeepSafety: A Deep Learning Framework for Unsafe Behaviors Detection of Steel Activity in Construction Projects," 2020 International Computer Symposium (ICS), 2020, pp. 135-140, doi: 10.1109/ICS51289.2020.00036.
[8] M. Jain et al., "Object Detection and Gesture Control of Four-Wheel Mobile Robot," 2019 International Conference on Communication and Electronics Systems (ICCES), 2019, pp. 303-308, doi: 10.1109/ICCES45898.2019.9002323.
[9] Fisher et al.: BDD100K: A Diverse Driving Dataset for Heterogeneous Multitask Learning. arXiv: 1805.04687
[10] Ren S., He K., Girshick., Sun J.: Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks. arXiv: 1506.04197
[11] TF2.0 Faster R-CNN with Resent-50 V1 Object detection model:
[12] Google Open Image Dataset v6 https://storage.googleapis.com/openimages/web/index.html