Deep Learning Concepts and Datasets for Image Recognition: Overview 2019

Case Study: Pedestrian Detection

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Our goal is to detect pedestrians on images from on-board camera (Advanced driver-assistance systems)



SSD-Lite-Pedestrian-detection with MobileNet v2 as feature extractor on Mixed Dataset

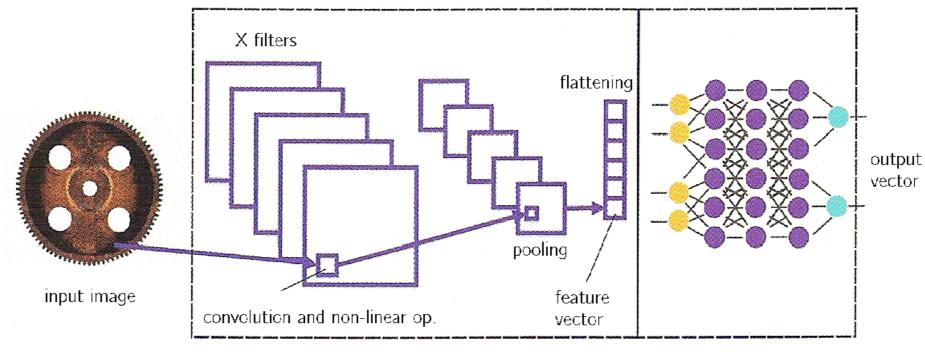
There is a lot of different architectures of Convolutional Neural Networks designed for image recognition:

Objects detectors:

- R-CNN family Region-based CNN (R-CNN, Fast R-CNN, Faster R-CNN, R-FCN, Mask R-CNN) \bullet
- SSD Single Shot MultiBox Detector ${}^{\bullet}$
- YOLO You Only Look Once ${\color{black}\bullet}$
- RetinaNet uses ResNet as backbone ۲

Objects classifiers:

- AlexNet
- VGG16
- GoogleNet
- ResNet Residual Neural Network \bullet

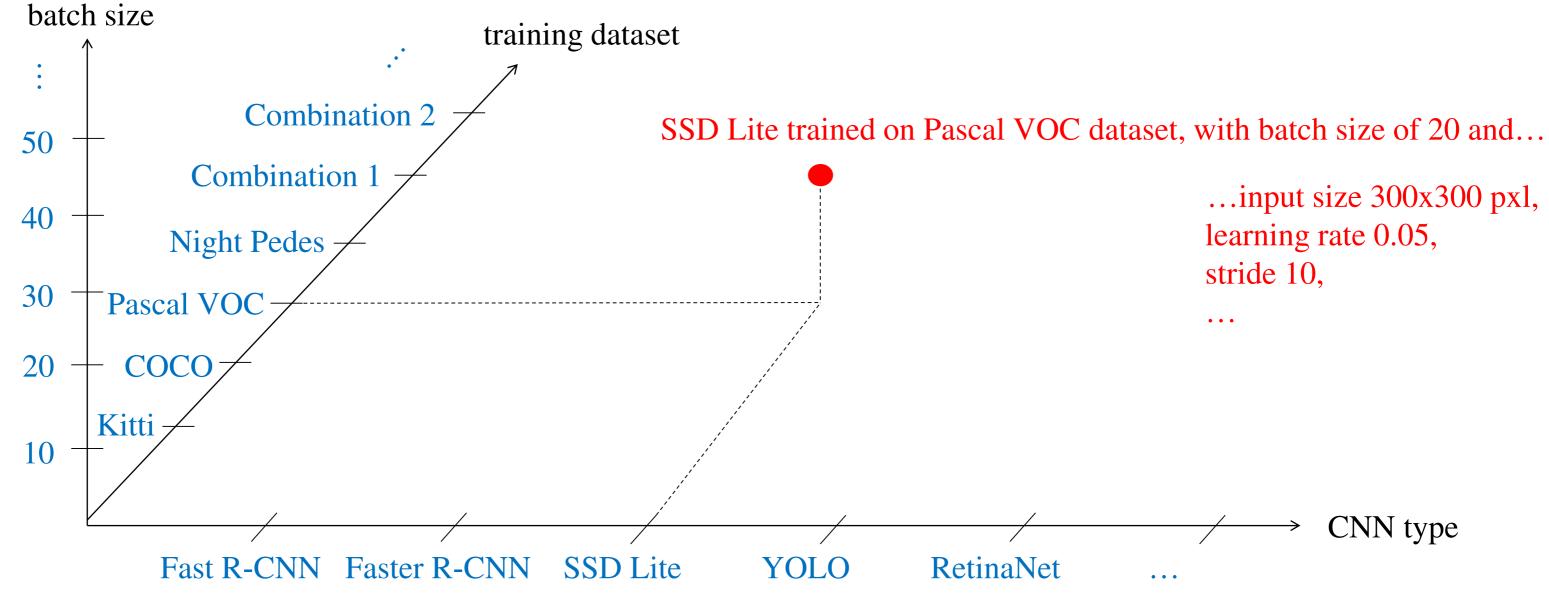


N convolution layers

neural network

Q: How to choose the proper one?

A: Find solution of **optimization problem** – searching of unknown parameters in **high-dimensional** space.



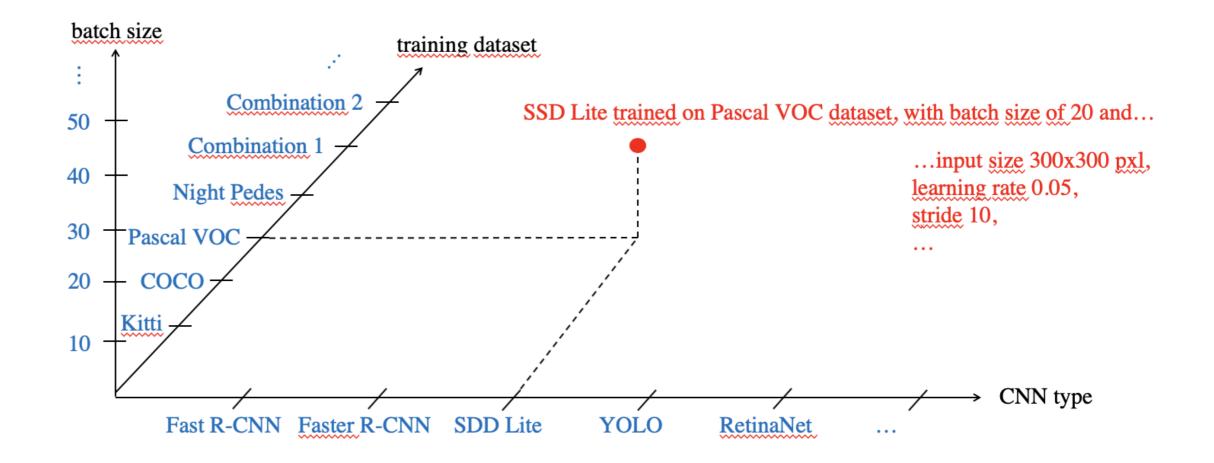
Only three dimensions are displayable here, nevertheless we have much more than only these to analyse!

...input size 300x300 pxl,

We know how to solve optimization tasks, but two problems arise:

1. Principal (theoretical) problem of solution: adjoining items on axes does not create neither sequential nor linear space (e.g. as ordinal numbers 1, 2, 3, ...) => not measured values (combinations) can not be interpolated or estimated => only **brute force** optimization can be used.

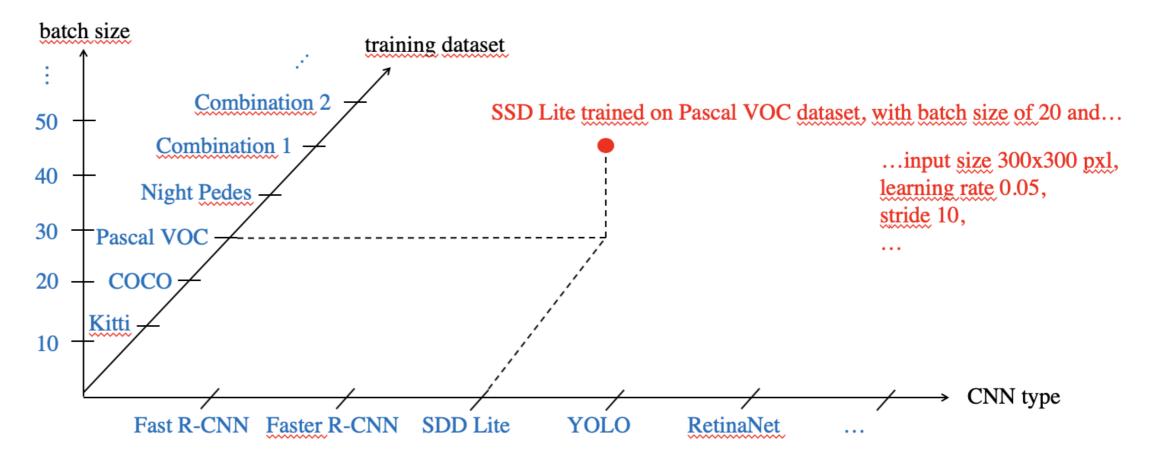
Unfortunately, brute force solution necessarily creates the other one problem...



We know how to solve optimization tasks, but two problems arise:

2. Practical problem of solution: measuring (= training) each type of the CNN on each available dataset (lots of variants and even more combinations of them) with each admissible value of each parameter (batch size, input size, learning rate, stride, networks structure,...) is not computable neither on any current hardware nor cloud!

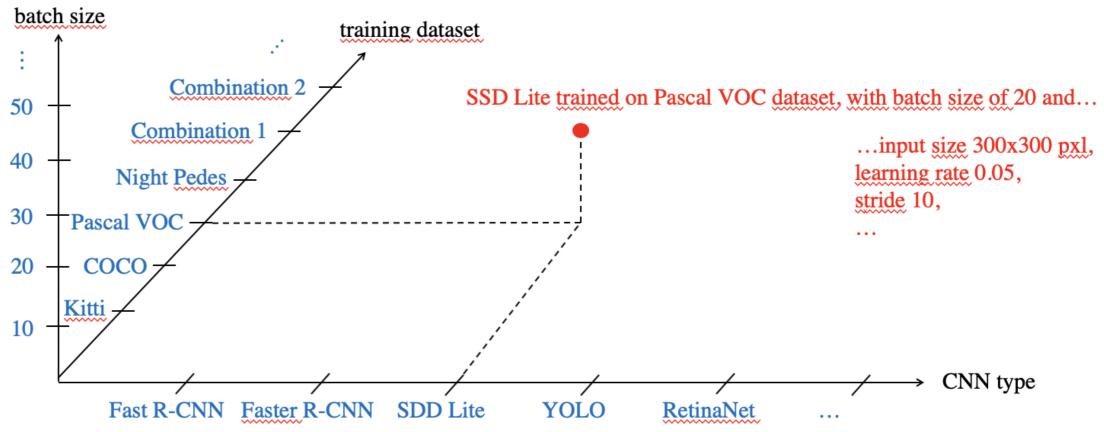
Try to estimate number of all solution in this space and time needed to train: tens of CNNs x hundreds of datasets x thousands of parameters values =~ 10⁸ solutions and above => almost 4000 years of computing!



Chosen "enforced" solution:

Best practise = use pretrained network to fix some parameters at least (mainly CNNs structure and basic parameters as stride and learning rate).

What dimensions remained to optimize? CNN type, datasets and their combinations, input size, dataset volume (we evaluated 10, 100, 500, 800, 2k and 5k images sets).



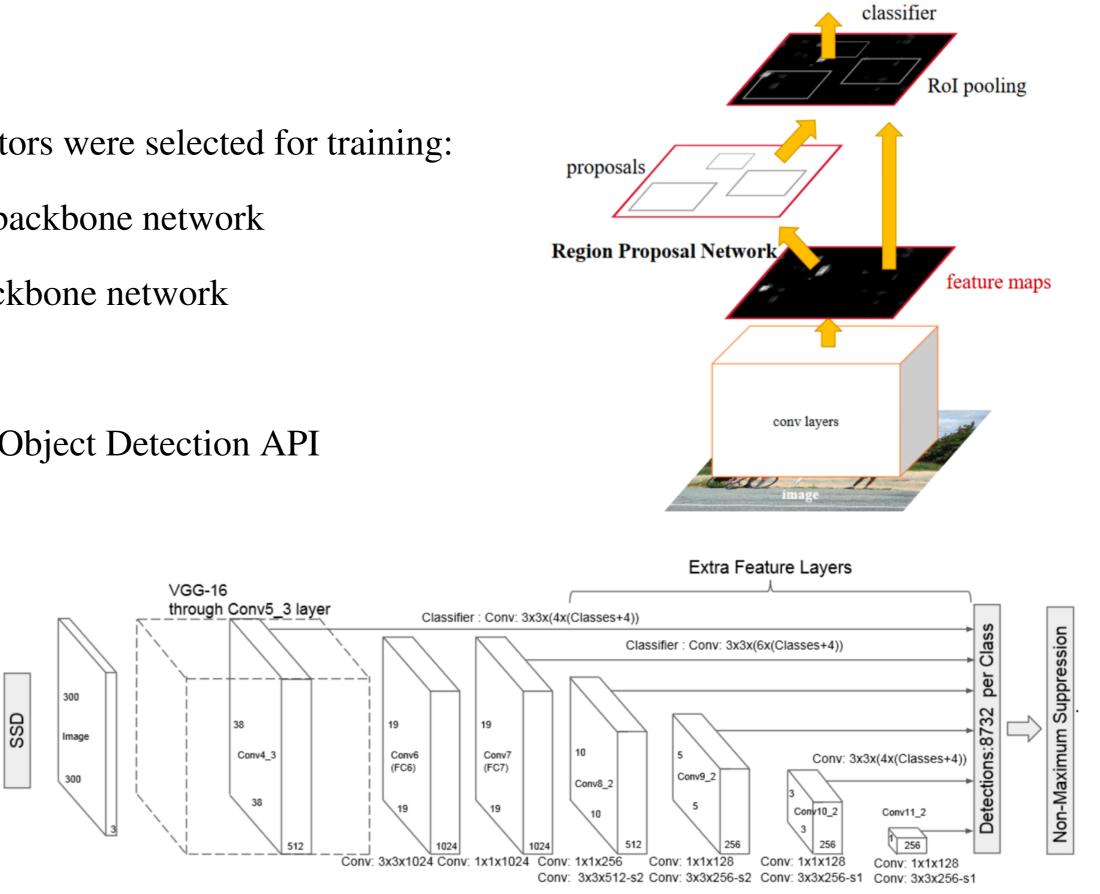
Implementation Details

Two meta-architectures of objects detectors were selected for training:

- a) Faster R-CNN with Resnet101 as a backbone network
- b) SSD Lite with Mobilenet v2 as a backbone network

Libraries used: TensorFlow-gpu 1.12 + Object Detection API

GPU used for training phase: Nvidia GeForce MX 150 v1/2 GB Nvidia Titan X - 12 GB



Datasets Used – Publicly Available

COCO (used for testing, not training): contains 328k images in 80 categories, 250k labelled people



Kitti (complex dataset of 2D, 3D and Bird's eye views): contains 15k images, 2k labelled pedestrians

Pascal VOC: 20 categories





CityShapes: contains 25k images in 30 categories, 3.5k labelled persons (+metadata: temperature and GPS)

Datasets Used – Proprietary Ad-hoc Dataset

Because of not any night images are present in the previous datasets at all, we have created the one: Night Pedestrian: contains 227 images in one category of persons, 815 labelled pedestrians.

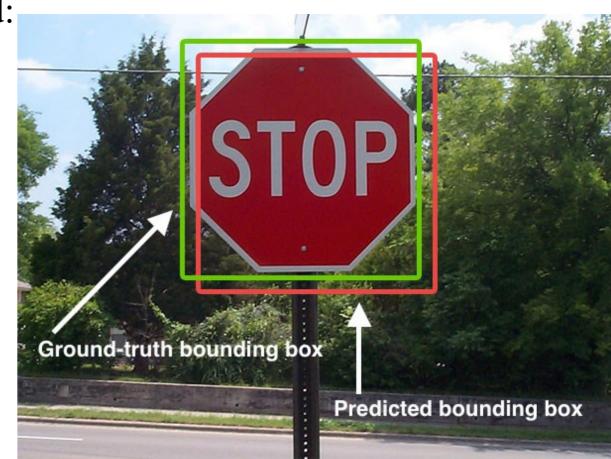


Note the LabelIMG tool has been used to manual annotations of pedestrians.

Detector Accuracy – object hit or missed and how much?

Problem: practically, any detector does not predict exact pixel position (caused by pooling, stride, pyramid scale, etc.) – difference between detectors (results in position) and classifiers (results in labels).
Q: How to evaluate an accuracy of the detector once it is trained?
A: Intersection of Union (IoU) method = an evaluation metric used to measure the accuracy of an object detector on a particular dataset.

Requirements: in order to apply IoU to evaluate the object detector we need:
1. The ground-truth bounding boxes (i.e., the hand labelled bounding boxes from the testing dataset that specify where our object is in the image).
2. The predicted bounding boxes by the detector.

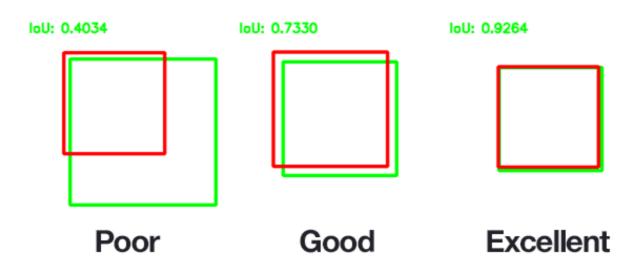


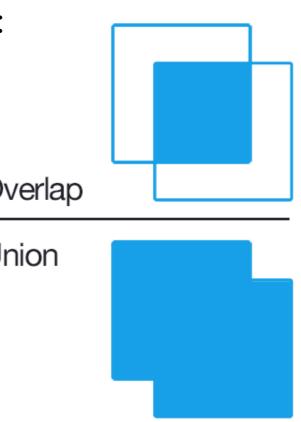
Detector Accuracy – object hit or missed and how much?

Intersection over Union is simple overlapping ratio - score (i.e. one number):

IoU = Area of Overlap Area of Union

Good practise: Intersection over Union score > 0.5 is normally considered a "good" prediction.





Detectors Efficiency

As soon as we know **score**, we know if prediction corresponds to the ground-truth box (by means of given threshold for score):

1. score > thr \Box increase value of TP

2. score \leq thr \Box increase value of FP

3. for all ground-truth boxes never detected

increase value of FN

Note TN does not apply: background detection

and the second sec	NN 10														
							test			val	val	- confusion	matrix - sc	ore 0.7+ loU	0.5
Г	TP	FP	FN	TN	mAP@0.5-0.95	mAP@0.5	mAP small	mAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
SNPD	55	39	108	0				1		0,3272	0,272277	0,727723	0,337423	0,585106	0,428016
Kitti	1170	605	1822	0	0,0775	0,2481	0,0109	0,0714	0,1923	0,3851	0,325271	0,674729	0, 3 91043	0,659155	0,490875
CityPed	382	355	2775	0						0,1265	0,10877	0,89123	0,121001	0,518318	0,196199
Faster R-CN	NN 100														
							test			val		val - o	confusion m	natrix	
	TP	FP	FN	TN	mAP@0.5-0.95	mAP@0.5	mAP small	mAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
SNPD	95	81	68	0						0,5864	0,3893	0,6107	0,5828	<i>,</i>	-
Kitti	1455	1073	1537	0	0,1506	0,3794	0,0106	0,1209	0,3524	-,	0,3579		0,4863	,	-
CityPed	733	1026	2424	0						0,2818	0,1752	0,8248	0,2322	0,4167	0,2982
Faster R-CN	NN 500					_	1t	_	_		_				
E F	TP	FP	FN	TN	mAP@0.5-0.95	mAP@0.5	test mAP small	mAP med	mAP large	val mAP@0.5	200111201	-		precision	F1-score
CNIDD					map@0.5-0.95	map@0.5		map med	map large		accuracy 0,4352	error	recall 0,5767	0,6395	0,6065
SNPD Kitti	94 1772	53 868	69 1220	0	0,3062	0,6453	0,0762	0,2269	0,4832	0,2487	0,4352	0,5648 0,5409		0,6395	0,6063
CityPed	569	235	2588	0	0,5002	0,0455	0,0702	0,2205	0,4032	0,2145	0,4331	0,8323		,	0,8293
Faster R-CN		200	2500							0,2110	0,2077	0,002.0	0,1001	ojrorr	0/2010
							test			val		val - d	confusion m	natrix	
Г	TP	FP	FN	TN	mAP@0.5-0.95	mAP@0.5	mAP small	mAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
SNPD	117	91	46	0						0,7071	0,4606	0,5394		-	
Kitti	1664	665	1328	0	0,2058	0,4518	0,0154	0,1828	0,4343		0,4550	-		0,7145	0,6254
CityPed	724	578	2433	0						0,2714	0,1938	0,8062	0,2293	0,5561	0,3247
Faster R-CN	NN 2k														
				-			test			val		val - o	confusion m	natrix	
	TP	FP	FN	TN	mAP@0.5-0.95	mAP@0.5	mAP small	mAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
SNPD	113	72	50	0						0,6944	0,4809	0,5191	0,6933	0,6108	-
Kitti	1892	553	1100	0	0,3027	0,5518	0,0970	0,2856	0,5418		0,5337	0,4663	0,6324	-,	,
CityPed	792	518	2365	0						0,2725	0,2155	0,7845	0.2509	0,6046	0,3546
Faster R-CN	NN 5k						test			ual			confusion m		
Paster K-CN		FP	FN	TN	mAP@0 5-0 95	mΔP@0.5	test mAP small	mAP med	m AP large	val			confusion m	natrix	F1-score
	ТР	FP	FN 44	TN	mAP@0.5-0.95	mAP@0.5	test mAP small	mAP med	mAP large	mAP@0.5	accuracy	error	recall	natrix precision	F1-score
SNPD	TP 119	40	44	0	mAP@0.5-0.95	mAP@0.5	mAP small			mAP@0.5 0,7617	accuracy	error 0,4138	recall 0,7301	precision	0,7391
	ТР			0			mAP small	mAP med 0,5327		mAP@0.5	accuracy 0,5862 0,8943	error 0,4138 0,1057	recall 0,7301	natrix precision 0,7484 0,9771	0,7391 0,9442
SNPD Kitti	TP 119 2733 1137	40 64	44 259	0			mAP small			mAP@0.5 0,7617 0,9559	accuracy 0,5862 0,8943	error 0,4138 0,1057	recall 0,7301 0,9134	natrix precision 0,7484 0,9771	0,7391 0,9442
SNPD Kitti CityPed	TP 119 2733 1137	40 64	44 259	0			mAP small			mAP@0.5 0,7617 0,9559	accuracy 0,5862 0,8943	error 0,4138 0,1057 0,7101	recall 0,7301 0,9134	natrix precision 0,7484 0,9771 0,5978	0,7391 0,9442
SNPD Kitti CityPed	TP 119 2733 1137	40 64	44 259	0			mAP small 0,2981		0,6959	mAP@0.5 0,7617 0,9559 0,3699	accuracy 0,5862 0,8943	error 0,4138 0,1057 0,7101	recall 0,7301 0,9134 0,3602	natrix precision 0,7484 0,9771 0,5978	0,7391 0,9442
SNPD Kitti CityPed	TP 119 2733 1137 NN 5k HD	40 64 765	44 259 2020	0	0,5101	0,7515	mAP small 0,2981 test mAP small	0,5327	0,6959	mAP@0.5 0,7617 0,9559 0,3699 val	accuracy 0,5862 0,8943 0,2899	error 0,4138 0,1057 0,7101 val - 0	recall 0,7301 0,9134 0,3602 confusion m	natrix precision 0,7484 0,9771 0,5978 natrix	0,7391 0,9442 0,4495
SNPD Kitti CityPed Faster R-CN SNPD Kitti	TP 119 2733 1137 NN 5k HD TP 131 2834	40 64 765 FP 83 22	44 259 2020 FN 32 158	0	0,5101	0,7515 mAP@0.5	mAP small 0,2981 test mAP small	0,5327	0,6959 mAP large	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472	natrix precision 0,7484 0,9771 0,5978 natrix precision 0,6121 0,9923	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed	TP 119 2733 1137 NN 5k HD TP 131 2834 1213	40 64 765 FP 83	44 259 2020 FN 32	0	0,5101 mAP@0.5-0.95	0,7515 mAP@0.5	mAP small 0,2981 test mAP small	0,5327 mAP med	0,6959 mAP large	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472	natrix precision 0,7484 0,9771 0,5978 natrix precision 0,6121	0,7391 0,9442 0,4495 F1-score 0,6950
SNPD Kitti CityPed Faster R-CN SNPD Kitti	TP 119 2733 1137 NN 5k HD TP 131 2834 1213	40 64 765 FP 83 22	44 259 2020 FN 32 158	0	0,5101 mAP@0.5-0.95	0,7515 mAP@0.5	mAP small 0,2981 test mAP small 0,3489	0,5327 mAP med	0,6959 mAP large	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842	natrix precision 0,7484 0,9771 0,5978 natrix precision 0,6121 0,9923 0,5807	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed	TP 119 2733 1137 NN 5k HD TP 131 2834 1213	40 64 765 FP 83 22 876	44 259 2020 FN 32 158 1944	0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398	0,7515 mAP@0.5 0,7639	mAP small 0,2981 test mAP small 0,3489 test	0,5327 mAP med 0,5540	0,6959 mAP large 0,7166	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 confusion m	atrix precision 0,7484 0,9771 0,5978 atrix precision 0,6121 0,9923 0,5807	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 0 TP	40 64 765 FP 83 22 876 FP	44 259 2020 FN 32 158 1944 FN	0	0,5101 mAP@0.5-0.95	0,7515 mAP@0.5	mAP small 0,2981 test mAP small 0,3489	0,5327 mAP med	0,6959 mAP large 0,7166	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 confusion m recall	natrix precision 0,7484 0,9771 0,5978 natrix precision 0,6121 0,9923 0,5807 natrix precision	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 D TP 14	40 64 765 FP 83 22 876 FP 13	44 259 2020 FN 32 158 1944 FN 149	0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95	0,7515 mAP@0.5 0,7639 mAP@0.5	mAP small 0,2981 test mAP small 0,3489 test mAP small	0,5327 mAP med 0,5540 mAP med	0,6959 mAP large 0,7166 mAP large	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795	error 0,4138 0,1057 0,7101 val - o error 0,4675 0,0597 0,6992 val - o error 0,9205	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 confusion m recall	natrix precision 0,7484 0,9771 0,5978 natrix precision 0,6121 0,9923 0,5807 natrix precision natrix	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 D TP 14 1039	40 64 765 FP 83 22 876 FP 13 786	44 259 2020 FN 32 158 1944 FN 49 1953	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398	0,7515 mAP@0.5 0,7639	mAP small 0,2981 test mAP small 0,3489 test	0,5327 mAP med 0,5540	0,6959 mAP large 0,7166 mAP large	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5 0,1122 0,2826	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error 0,9205 0,7250	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 confusion m recall 0,0859 0,3473	natrix precision 0,7484 0,9771 0,5978 natrix precision 0,6121 0,9923 0,5807 natrix precision 0,5185 0,5693	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314
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SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 D TP 14 1039 59	40 64 765 FP 83 22 876 FP 13 786	44 259 2020 FN 32 158 1944 FN 49 1953	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95	0,7515 mAP@0.5 0,7639 mAP@0.5	mAP small 0,2981 test mAP small 0,3489 test mAP small	0,5327 mAP med 0,5540 mAP med	0,6959 mAP large 0,7166 mAP large	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5 0,1122 0,2826	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error 0,9205 0,7250 0,9819	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 confusion m recall 0,0859 0,3473	natrix precision 0,7484 0,9771 0,5978 natrix precision 0,6121 0,9923 0,5807 natrix precision 0,5185 0,5693 0,3491	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti CityPed	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 D TP 14 1039 59	40 64 765 FP 83 22 876 FP 13 786	44 259 2020 FN 32 158 1944 FN 49 1953	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95	0,7515 mAP@0.5 0,7639 mAP@0.5	mAP small 0,2981 test mAP small 0,3489 test mAP small 0,0308	0,5327 mAP med 0,5540 mAP med	0,6959 mAP large 0,7166 mAP large 0,2932	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5 0,1122 0,2826 0,0246	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error 0,9205 0,7250 0,9819	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 confusion m recall 0,0859 0,3473 0,0187	natrix precision 0,7484 0,9771 0,5978 natrix precision 0,6121 0,9923 0,5807 natrix precision 0,5185 0,5693 0,3491	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti CityPed	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 0 TP 14 1039 59 0	40 64 765 FP 83 22 876 FP 13 786 110	44 259 2020 FN 32 158 1944 FN 1944 1953 3098	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277	0,7515 mAP@0.5 0,7639 mAP@0.5 0,3321	mAP small 0,2981 test mAP small 0,3489 test mAP small 0,0308	0,5327 mAP med 0,5540 mAP med 0,1197	0,6959 mAP large 0,7166 mAP large 0,2932	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val 0,1122 0,2826 0,0246	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795 0,2750 0,0181	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error 0,9205 0,7250 0,9819 val - 0	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 confusion m recall 0,0859 0,3473 0,0187 confusion m	natrix precision 0,7484 0,9771 0,5978 natrix precision 0,6121 0,9923 0,5807 natrix precision 0,5185 0,5693 0,3491 natrix precision	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314 0,0355
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti CityPed SSDLite 800	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 D TP 14 1039 59 D	40 64 765 FP 83 22 876 786 110 FP	44 259 2020 FN 32 158 1944 FN 1949 1953 3098 FN	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277	0,7515 mAP@0.5 0,7639 mAP@0.5 0,3321	mAP small 0,2981 test mAP small 0,3489 test mAP small 0,0308	0,5327 mAP med 0,5540 mAP med 0,1197	0,6959 mAP large 0,7166 mAP large 0,2932	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5 0,1122 0,2826 0,0246	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795 0,0795 0,0795 0,0181	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error 0,9205 0,7250 0,9819 val - 0 error 0,9819	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 0,3842 0,0859 0,3473 0,0187 0,0187 0,0187	atrix precision 0,7484 0,9771 0,5978 atrix precision 0,6121 0,9923 0,5807 atrix precision 0,5185 0,5693 0,3491 atrix precision 0,3491	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314 0,0355 F1-score
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti CityPed SSDLite 800 SSDLite 800	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 D TP 14 1039 59 D TP 43	40 64 765 FP 83 22 876 876 110 FP 13 786 110	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277 mAP@0.5-0.95	0,7515 mAP@0.5 0,7639 mAP@0.5 0,3321	mAP small 0,2981 test mAP small 0,3489 test mAP small 0,0308	0,5327 mAP med 0,5540 mAP med 0,1197 mAP med	0,6959 mAP large 0,7166 mAP large 0,2932 mAP large	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5 0,1122 0,2826 0,0246	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795 0,2750 0,0181	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error 0,9205 0,7250 0,9819 val - 0 error 0,7713 0,7908	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 0,3842 0,0859 0,3473 0,0187 0,0187 0,0187 0,0187 0,0187 0,0187	natrix precision 0,7484 0,9771 0,5978 0,5978 0,5978 0,6121 0,9923 0,5807 0,5807 0,5807 0,5807 0,5185 0,5693 0,3491 0,6324 0,6692	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314 0,0355 F1-score 0,3723 0,3460
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti CityPed SSDLite 800 SSDLite 800 SSDLite 800	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 D TP 14 1039 59 D TP 43 698	40 64 765 FP 83 22 876 786 110 FP 25 345	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120 2294	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277 mAP@0.5-0.95	0,7515 mAP@0.5 0,7639 mAP@0.5 0,3321	mAP small 0,2981 test mAP small 0,3489 test mAP small 0,0308	0,5327 mAP med 0,5540 mAP med 0,1197 mAP med	0,6959 mAP large 0,7166 mAP large 0,2932 mAP large	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5 0,1122 0,2826 0,0246 0,0246	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795 0,0795 0,0795 0,0795 0,0181	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error 0,9205 0,7250 0,9819 val - 0 error 0,7713 0,7908	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 0,3842 0,0859 0,3473 0,0187 0,0187 0,0187 0,0187 0,0187 0,0187	natrix precision 0,7484 0,9771 0,5978 0,5978 0,5978 0,6121 0,9923 0,5807 0,5807 0,5807 0,5807 0,5185 0,5693 0,3491 0,6324 0,6692	0,7391 0,9442 0,4499 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314 0,0355 F1-score 0,3723
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti CityPed SSDLite 800 SNPD Kitti CityPed	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 1213 0 TP 14 1039 59 0 TP 43 698 252	40 64 765 FP 83 22 876 25 3786 110 FP 25 345 300	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120 2294	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277 mAP@0.5-0.95 0,0646	0,7515 mAP@0.5 0,7639 0,7639 0,3321 mAP@0.5 0,1928	mAP small 0,2981 test mAP small 0,3489 test mAP small 0,0308	0,5327 mAP med 0,5540 mAP med 0,1197 mAP med	0,6959 mAP large 0,7166 mAP large 0,2932 mAP large	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5 0,1122 0,2826 0,0246 0,0246	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795 0,0795 0,0795 0,0795 0,0181	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error 0,9205 0,7250 0,9819 val - 0 error 0,9205 0,7250 0,9819 val - 0 error	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 0,3842 0,0859 0,3473 0,0187 0,0187 0,0187 0,0187 0,0187 0,0187	natrix precision 0,7484 0,9771 0,5978 natrix precision 0,6121 0,9923 0,5807 natrix precision 0,5185 0,5693 0,3491 natrix precision 0,6324 0,6692 0,4565	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314 0,0355 F1-score 0,3723 0,3460
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti CityPed SSDLite 800 SNPD Kitti CityPed	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 D TP 14 1039 59 D TP 43 698	40 64 765 FP 83 22 876 786 110 FP 25 345	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120 2294	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277 mAP@0.5-0.95	0,7515 mAP@0.5 0,7639 mAP@0.5 0,3321	mAP small 0,2981 test mAP small 0,3489 test mAP small 0,0308 test mAP small 0,00063	0,5327 mAP med 0,5540 mAP med 0,1197 mAP med	0,6959 mAP large 0,7166 0,2932 mAP large 0,2140	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5 0,1122 0,2826 0,0246 0,0246	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795 0,0795 0,0795 0,0795 0,0181	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error 0,9205 0,7250 0,9819 val - 0 error 0,9205 0,7250 0,9819 val - 0 error	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 confusion m recall 0,0859 0,3473 0,0187 confusion m recall 0,2638 0,2333 0,0798 confusion m recall	atrix precision 0,7484 0,9771 0,5978 atrix precision 0,6121 0,9923 0,5807 atrix precision 0,5185 0,5693 0,3491 atrix precision 0,6324 0,6692 0,4565 atrix precision	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314 0,0355 F1-score 0,3723 0,3460 0,1359
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti CityPed SSDLite 800 SNPD Kitti CityPed	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 1213 0 TP 14 1039 59 0 TP 43 698 252	40 64 765 FP 83 22 876 110 FP 13 786 110 FP 25 345 300	44 259 2020 FN 32 158 1944 FN 1944 1953 3098 FN 120 2294 2905	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277 mAP@0.5-0.95 0,0646	0,7515 mAP@0.5 0,7639 0,3321 0,3321 0,1928 0,1938 0,19	mAP small 0,2981 test mAP small 0,3489 test mAP small 0,0308 test mAP small 0,0063 test mAP small mAP small test mAP small 0,0063 test mAP small	0,5327 mAP med 0,5540 0,1197 mAP med 0,0481	0,6959 mAP large 0,7166 mAP large 0,2932 mAP large 0,2140	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5 0,1122 0,2826 0,0246 0,0246 val 0,0246 0,0246	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795 0,2750 0,0181 accuracy 0,0181	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,6992 val - 0 error 0,9205 0,7250 0,9819 val - 0 error 0,7250 0,9819 val - 0 error 0,7250 0,7250 0,9819 val - 0 error 0,7250	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 confusion m recall 0,0859 0,3473 0,0187 confusion m recall 0,2638 0,2333 0,0798 confusion m recall	atrix precision 0,7484 0,9771 0,5978 atrix precision 0,6121 0,9923 0,5807 atrix precision 0,5185 0,5693 0,3491 atrix precision 0,6324 0,6692 0,4565 atrix precision 0,6324 0,6692	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314 0,0355 F1-score 0,3723 0,3460 0,1359 F1-score 0,3010
SNPD Kitti CityPed Faster R-CN SNPD Kitti CityPed SSDLite 500 SNPD Kitti CityPed SSDLite 800 SNPD Kitti CityPed SSDLite 5k	TP 119 2733 1137 NN 5k HD TP 131 2834 1213 D TP 14 1039 59 0 TP 43 698 252 TP	40 64 765 FP 83 22 876 110 FP 25 345 300 FP	44 259 2020 FN 32 158 1944 FN 1953 3098 FN 120 2294 2905 FN	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277 mAP@0.5-0.95 0,0646	0,7515 mAP@0.5 0,7639 0,3321 0,3321 0,1928 0,1938 0,19	mAP small 0,2981 test mAP small 0,3489 test mAP small 0,0308 test mAP small 0,0063 test mAP small mAP small test mAP small 0,0063 test mAP small	0,5327 mAP med 0,5540 0,1197 mAP med 0,0481	0,6959 mAP large 0,7166 mAP large 0,2932 mAP large 0,2140	mAP@0.5 0,7617 0,9559 0,3699 val mAP@0.5 0,7754 0,9703 0,3909 val mAP@0.5 0,1122 0,2826 0,0246 0,0246 val 0,0246 0,0246	accuracy 0,5862 0,8943 0,2899 accuracy 0,5325 0,9403 0,3008 accuracy 0,0795 0,2750 0,0181 accuracy 0,0181 accuracy 0,0287 0,2092 0,2092 0,0729	error 0,4138 0,1057 0,7101 val - 0 error 0,4675 0,0597 0,69922 val - 0 error 0,9205 0,7250 0,9819 val - 0 error 0,7713 0,7908 0,9271 val - 0 error 0,7708 0,9271	recall 0,7301 0,9134 0,3602 confusion m recall 0,8037 0,9472 0,3842 confusion m recall 0,0859 0,3473 0,0187 confusion m recall 0,2638 0,2333 0,0798 confusion m recall 0,2638 0,2333 0,0798 confusion m recall 0,2638	atrix precision 0,7484 0,9771 0,5978 atrix precision 0,6121 0,9923 0,5807 atrix precision 0,5185 0,5693 0,3491 atrix precision 0,6692 0,4565 atrix precision 0,6324 0,6692 0,4565	0,7391 0,9442 0,4495 F1-score 0,6950 0,9692 0,4624 F1-score 0,1474 0,4314 0,0355 F1-score 0,3723 0,3460 0,1359 F1-score 0,3010

Detectors Efficiency

As soon as we know TP and FP values, the **mAP** (mean Average Precision) serves as a Detector efficiency indicator:

$$mAP = \frac{1}{|classes|} \sum_{c \in classes} \frac{\#TP(c)}{\#TP(c) + \#FP(c)}$$

	NN 10				
	TP	FP	FN	TN	mAP@0.5-0.95
SNPD	55	39	108	0	IIIAr@0.5-0.55
Kitti	1170	605	1822	0	0,0775
CityPed	382	355	2775	0	0,0775
Faster R-C		555	2775	0	
Faster R-C					
	TD	50	EN 1	Thi	
	TP	FP	FN	TN	mAP@0.5-0.95
SNPD	95	81	68	0	0.4505
Kitti	1455	1073	1537	0	0,1506
CityPed	733	1026	2424	0	
Faster R-C	NN 500				
	TP	FP	FN	TN	mAP@0.5-0.95
SNPD	94	53	69	0	
Kitti	1772	868	1220	0	0,3062
CityPed	569	235	2588	0	
Faster R-C	NN 800				
	TP	FP	FN	TN	mAP@0.5-0.95
SNPD	117	91	46	0	
Kitti	1664	665	1328	0	0,2058
CityPed	724	578	2433	0	
Faster R-C	NN 2k				
	TP	FP	FN	TN	mAP@0.5-0.95
SNPD	113	72	50	0	
Kitti	1892	553	1100	0	0,3027
CityPed	792	518	2365	0	-,
Faster R-C	NN 5k				
	ТР	FP	FN I	TN	mAP@0.5-0.95
SNPD	TP 119	FP 40	FN 44	TN	mAP@0.5-0.95
SNPD Kitti	119	40	44	0	
Kitti	119 2733	40 64	44 259	0	0,5101
Kitti CityPed	119 2733 1137	40 64	44	0	0,5101
Kitti	119 2733 1137	40 64	44 259	0	0,5101
Kitti CityPed	119 2733 1137 NN 5k HD	40 64 765	44 259 2020	0 0 0	0,5101
Kitti CityPed Faster R-C	119 2733 1137 NN 5k HD TP	40 64 765 FP	44 259 2020 FN	0 0 0 TN	0,5101
Kitti CityPed Faster R-C SNPD	119 2733 1137 NN 5k HD TP 131	40 64 765 FP 83	44 259 2020 FN 32	0 0 0 TN 0	0,5101 mAP@0.5-0.95
Kitti CityPed Faster R-C SNPD Kitti	119 2733 1137 NN 5k HD TP 131 2834	40 64 765 FP 83 22	44 259 2020 FN 32 158	0 0 0 TN 0 0	0,5101
Kitti CityPed Faster R-C SNPD Kitti CityPed	119 2733 1137 NN 5k HD TP 131 2834 1213	40 64 765 FP 83	44 259 2020 FN 32	0 0 0 TN 0	0,5101 mAP@0.5-0.95
Kitti CityPed Faster R-C SNPD Kitti	119 2733 1137 NN 5k HD TP 131 2834 1213	40 64 765 FP 83 22	44 259 2020 FN 32 158	0 0 0 TN 0 0	0,5101 mAP@0.5-0.95
Kitti CityPed Faster R-C SNPD Kitti CityPed	119 2733 1137 NN 5k HD TP 131 2834 1213 0	40 64 765 FP 83 22 876	44 259 2020 FN 32 158 1944	0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50	119 2733 1137 NN 5k HD TP 131 2834 1213 0 TP	40 64 765 FP 83 22 876 FP	44 259 2020 FN 32 158 1944 FN	0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 SNPD	119 2733 1137 NN 5k HD 131 2834 1213 0 TP 14	40 64 765 FP 83 22 876 FP 13	44 259 2020 FN 32 158 1944 FN 149	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 SNPD Kitti	119 2733 1137 NN 5k HD 131 2834 1213 0 TP 14 1039	40 64 765 FP 83 22 876 FP 13 786	44 259 2020 FN 32 158 1944 FN 1949 1953	0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 SNPD Kitti CityPed	119 2733 1137 NN 5k HD TP 131 2834 1213 0 TP 14 1039 59	40 64 765 FP 83 22 876 FP 13	44 259 2020 FN 32 158 1944 FN 149	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 SNPD Kitti	119 2733 1137 NN 5k HD TP 131 2834 1213 0 TP 14 1039 59	40 64 765 FP 83 22 876 FP 13 786	44 259 2020 FN 32 158 1944 FN 1949 1953	0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 SNPD Kitti CityPed	119 2733 1137 NN 5k HD 7P 131 2834 1213 0 7P 14 1039 59 0	40 64 765 FP 83 22 876 FP 13 786 110	44 259 2020 FN 32 158 1944 FN 149 1953 3098	0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 SNPD Kitti CityPed SSDLite 80	119 2733 1137 NN 5k HD 131 2834 1213 0 TP 14 1039 59 0 TP	40 64 765 FP 83 22 876 FP 13 786 110 FP	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN	0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 Kitti CityPed SSDLite 80 SSDLite 80	119 2733 1137 NN 5k HD TP 131 2834 1213 0 7 7 14 1039 59 0 7 7 9 0 7 7 4 3	40 64 765 FP 83 22 876 110 FP 13 786 110 FP 25	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 Kitti CityPed SSDLite 80 SSDLite 80 Kitti	119 2733 1137 NN 5k HD TP 131 2834 1213 0 7 7 14 1039 59 0 7 9 0 7 7 9 0 7 9 0 7 9 0	40 64 765 FP 83 22 876 876 110 FP 25 345	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120 2294	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 Kitti CityPed SSDLite 80 SNPD Kitti CityPed	119 2733 1137 NN 5k HD 131 2834 1213 0 TP 14 1039 59 0 TP 14 1039 59 0 7 7 8 43 698 252	40 64 765 FP 83 22 876 110 FP 13 786 110 FP 25	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 Kitti CityPed SSDLite 80 SSDLite 80 Kitti	119 2733 1137 NN 5k HD 131 2834 1213 0 TP 14 1039 59 0 TP 14 1039 59 0 7 7 8 43 698 252	40 64 765 FP 83 22 876 876 110 FP 25 345	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120 2294	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 Kitti CityPed SSDLite 80 SNPD Kitti CityPed	119 2733 1137 NN 5k HD TP 131 2834 1213 0 7 7 14 1039 59 0 7 7 9 0 7 7 9 0 7 7 9 0 7 9 0	40 64 765 FP 83 22 876 110 FP 13 786 110 FP 25 345 300	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120 2294 2905	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 Kitti CityPed SSDLite 80 SNPD Kitti CityPed SSDLite 5k	119 2733 1137 NN 5k HD TP 131 2834 1213 0 7 TP 14 1039 59 0 7 7 43 698 252 7 7 P	40 64 765 FP 83 22 876 110 FP 25 345 300 FP	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120 2294 2905 FN	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 Kitti CityPed SSDLite 80 SNPD Kitti CityPed SSDLite 5k SSDLite 5k	119 2733 1137 NN 5k HD TP 131 2834 1213 0 TP 14 1039 59 0 7 7 9 0 7 7 9 0 7 7 7 4 3 698 252 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	40 64 765 FP 83 22 876 110 FP 25 345 300 FP 12	44 259 2020 FN 32 158 1944 FN 1953 3098 FN 120 2294 2905 FN 132	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277 0,1277
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 SNPD Kitti CityPed SSDLite 80 SNPD Kitti CityPed SSDLite 5k SSDLite 5k SSDLite 5k Kitti	119 2733 1137 NN 5k HD TP 131 2834 1213 0 TP 14 1039 59 0 7 7 7 43 698 252 0 7 7 7 43 698 252	40 64 765 FP 83 22 876 110 FP 13 786 110 FP 25 345 300 FP 12 367	44 259 2020 FN 32 158 1944 FN 149 1953 3098 FN 120 2294 2905 FN 120 2294 2905	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277
Kitti CityPed Faster R-C SNPD Kitti CityPed SSDLite 50 Kitti CityPed SSDLite 80 SNPD Kitti CityPed SSDLite 5k SSDLite 5k	119 2733 1137 NN 5k HD TP 131 2834 1213 0 TP 14 1039 59 0 7 7 9 0 7 7 9 0 7 7 7 4 3 698 252 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	40 64 765 FP 83 22 876 110 FP 25 345 300 FP 12	44 259 2020 FN 32 158 1944 FN 1953 3098 FN 120 2294 2905 FN 132	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0,5101 mAP@0.5-0.95 0,5398 mAP@0.5-0.95 0,1277 0,1277

_		test	_		val	val	- confusion	matrix - scr	ore 0.7+ loU	0.5
m/				mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
					0,3272	0,272277	0,727723	0,337423	0,585106	0,428016
	0,2481	0,0109	0,0714	0,1923	0,3851	0,325271	0,674729	0,391043	0,659155	0,490875
	<u>, </u>		<u> </u>		0,1265	0 ,10877	0,89123	0,121001	0,518318	0,196199

	test				val		val - o	confusion m	atrix	
mAP@0.5	mAP small	m	nAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
					0,5864	0,3893	0,6107	0,5828	0,5398	0,5605
0,3794	0,0106		0,1209	0,3524	0,4842	0,3579	0,6421	0,4863	0,5756	0,5272
					0,2818	0,1752	0,8248	0,2322	0,4167	0,2982

	test			val		val - c	confusion m	atrix	
mAP@0.5	mAP small	mAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
				0,2487	0,4352	0,5648	0,5767	0,6395	0,6065
0,6453	0,0762	0,2269	0,4832	0,6192	0,4591	0,5409	0,5922	0,6712	0,6293
				0,2145	0,1677	0,8323	0,1802	0,7077	0,2873

test					val		val - o	confusion m	atrix	
mAP@0.5	mAP small	m/	AP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
					0,7071	0,4606	0,5394	0,7178	0,5625	0,6307
0,4518	0,0154		0,1828	0 <mark>,</mark> 4343	0,6154	0,4550	0,5450	0,5561	0,7145	0,6254
					0,2714	0,1938	0,8062	0,2293	0,5561	0,3247

	test			val		val - o	confusion m	atrix	
mAP@0.5	mAP sma	mAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
				0,6944	0,4809	0,5191	0,6933	0,6108	0,6494
0,5518	0,097	0 0,2856	0,5418	0,6862	0,5337	0,4663	0,6324	0,7738	0,6960
				0,2725	0,2155	0,7845	0,2509	0,6046	0,3546

	test			val		val - c	confusion m	atrix	
mAP@0.5	mAP small	mAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
				0,7617	0,5862	0,4138	0,7301	0,7484	0,7391
0,7515	0,2981	0,5327	0,6959	0,9559	0,8943	0,1057	0,9134	0,9771	0,9442
				0,3699	0,2899	0,7101	0,3602	0,5978	0,4495

	test			val	val - confusion matrix				
mAP@0.5	mAP small	mAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
				0,7754	0,5325	0,4675	0,8037	0,6121	0,6950
0,7639	0,3489	0,5540	0,7166	0,9703	0,9403	0,0597	0,9472	0,9923	0,9692
				0,3909	0,3008	0,6992	0,3842	0,5807	0,4624

	test						val		val - o	confusion m	atrix	
mAP@0.5	mAP small	m	nAP med	mΑ	P large		mAP@0.5	accuracy	error	recall	precision	F1-score
							0,1122	0,0795	0,9205	0,0859	0,5185	0,1474
0,3321	0,0308		0,1197		0,2932		0,2826	0,2750	0,7250	0,3473	0,5693	0,4314
						1	0,0246	0,0181	0,9819	0,0187	0,3491	0,0355

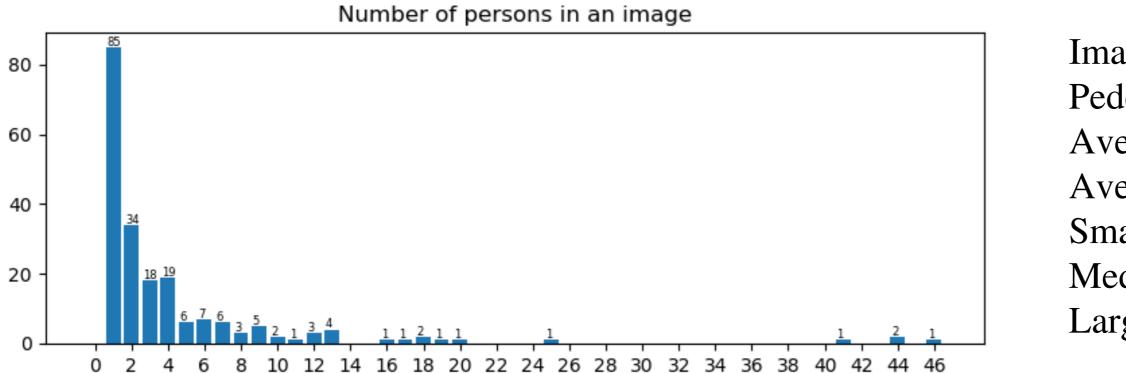
		test			val		val - o	confusion m	atrix	
m	AP@0.5	mAP small	mAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
					0,3660	0,2287	0,7713	0,2638	0,6324	0,3723
	0,1928	0,0063	0,0481	0,2140	0,3172	0,2092	0,7908	0,2333	0,6692	0,3460
					0,0858	0,0729	0,9271	0,0798	0,4565	0,1359

		test			val	val - confusion matrix				
mA	mAP@0.5 mAP small mAP med		mAP med	mAP large	mAP@0.5	accuracy	error	recall	precision	F1-score
					0,3730	0,1771	0,8229	0,1902	0,7209	0,3010
	0,2812	0,0163	0,0632	0,3091	0,4185	0,2617	0,7383	0,2938	0,7055	0,4148
					0,1599	0,1415	0,8585	0,1587	0,5661	0,2479

Training Phase Example

Measured parameters of training phase on limited dataset (204 images) for Faster R-CNN and SSD Lite:

Architecture	Faster R-CNN					SSD Lite	
Speed [FPS]	7.52					47.3	
Dataset volume	10	100	800	2000	5000	800	5000
mAP [%] {small,medium,large}	24.81 {1, 7, 19}	37.94 {1, 12, 35}	64.53 {8, 22, 48}	55.18 {10, 29, 54}	75.15 {30, 53, 70}	19.28 {1, 5, 21}	28.12 {2, 6, 31}
Learning time [min]	351	411	378	(677)	(4946)	737	(1692)

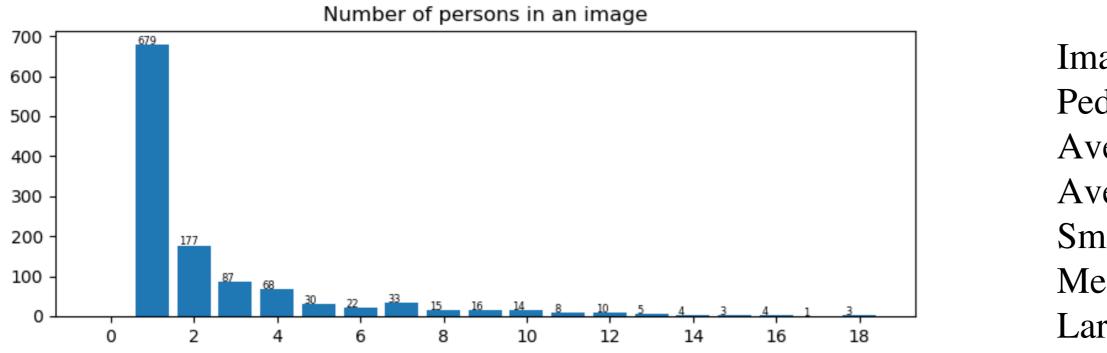


ages learned:	204
lestrians/image:	4.38
erage object width:	43.95 pxl
erage object height:	111.23 pxl
all objects:	68
edium objects:	420
rge objects:	405

Testing Phase – Kitti Dataset Validation

Now, we are interested much more in precision instead of in learning time:

	ТР	FP	FN	TN	Precision	Recall	F1-score
F.R-CNN 800	1664	665	1328	0	0.71	0.56	0.63
F.R-CNN 5k	2733	64	259	0	0.98	0.91	0.94
SSD Lite 800	698	345	2294	0	0.67	0.23	0.35
SSD Lite 5k	501	384	2656	0	0.57	0.16	0.25

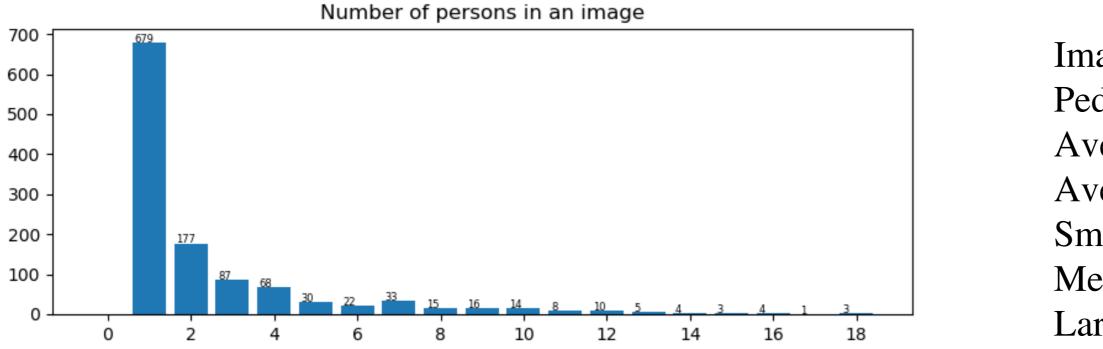


Images classified:1179Pedestrians/image:2.54Average object width:43.66 pxlAverage object height:103.21 pxlSmall objects:142Medium objects:1495Large objects:1355

Testing Phase – CityPersons Dataset Validation

Now, we are interested much more in precision instead of in learning time:

	ТР	FP	FN	TN	Precision	Recall	F1-score
F.R-CNN 800	724	578	2433	0	0.56	0.23	0.32
F.R-CNN 5k	1137	765	2020	0	0.60	0.36	0.45
SSD Lite 800	252	300	2905	0	0.46	0.08	0.14
SSD Lite 5k	501	284	2656	0	0.57	0.16	0.25



Images classified:39Pedestrians/image:7.9Average object width:47Average object height:11Small objects:21Medium objects:14Large objects:14

398 7.93 47.47 pxl 117.23 pxl 210 1457 1490

Results Evaluation

Conclusions:

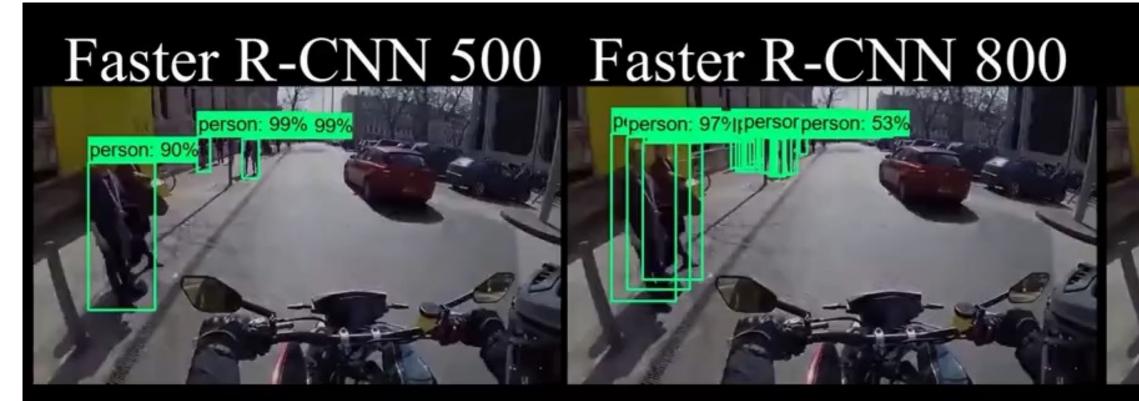
- Mixed training dataset (Kitti + Pascal VOC + CityPersons + Night Pedes) results in lower false positive lacksquaredetection in comparison with single Kitti dataset (video).
- Approx. 500 images are needed to train a model to **basic usable** level and 5k+ images for robust detection. ${}^{\bullet}$
- Detection speed on laptop with low-end GPU Nvidia GeForce MX 150 v1/2 GB:

a) Faster R-CNN 1.2 FPS

b) SSD Lite **12 FPS** (can be considered as real-time for ADAS)

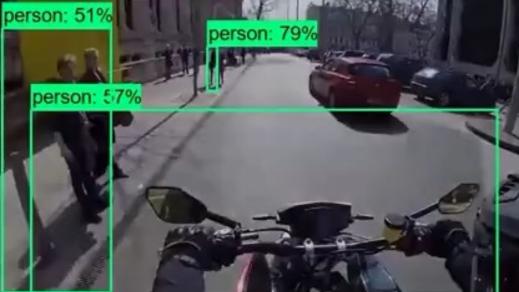
Dataset volume: 10, 100 and 500 are not enough => negligible mAP \bullet

Again, our goal was to detect pedestrians on images from on-board camera (Advanced driver-assistance systems)



SSDLite 500

SSDLite 800







SSDLite 5k