RRPN: Radar Region Proposal Network for Object Detection in Autonomous Vehicles

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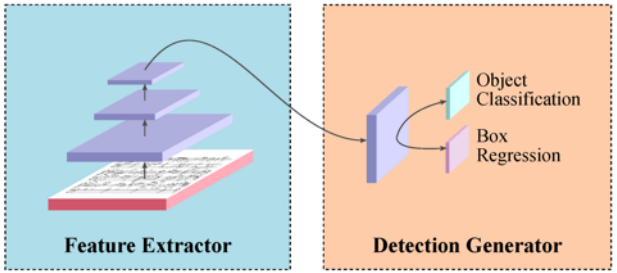
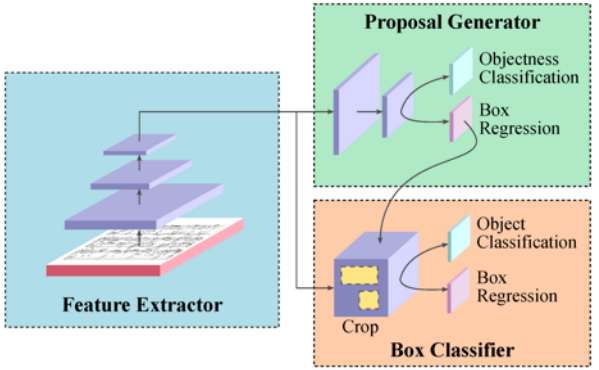
2D Object Detection

- One-Stage Detectors



(a) Basic architecture of a one-stage detector.

- Two-Stage Detectors

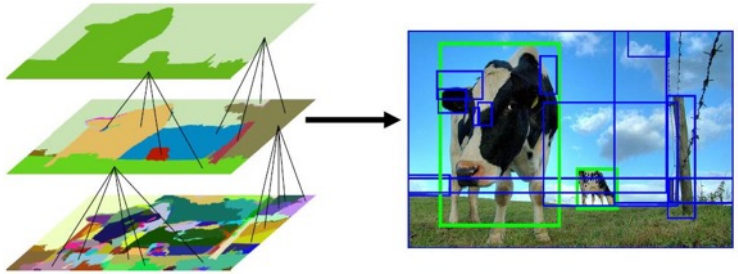


(b) Basic architecture of a two-stage detector.

Images from: A Baseline for General Music Object Detection with Deep Learning, Alexander Pacha et. al

Proposal Generation

- Task: Find candidate regions containing object
  - **Selective Search**[1]: hierarchical grouping of similar regions based on color, texture, size and shape compatibility.



1. Segmentation as Selective Search for Object Recognition, K. E. A. van de Sande et. al

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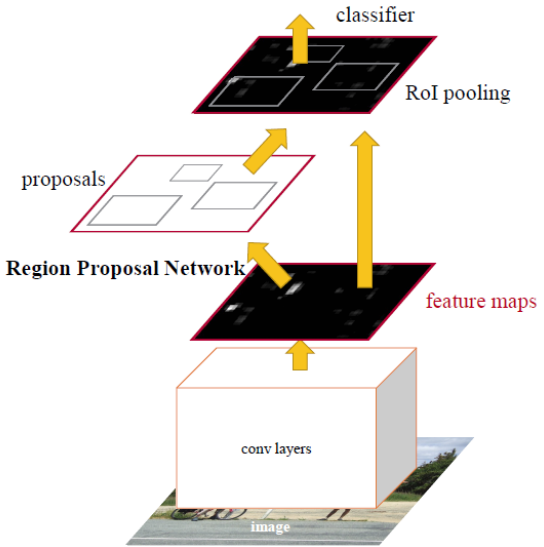

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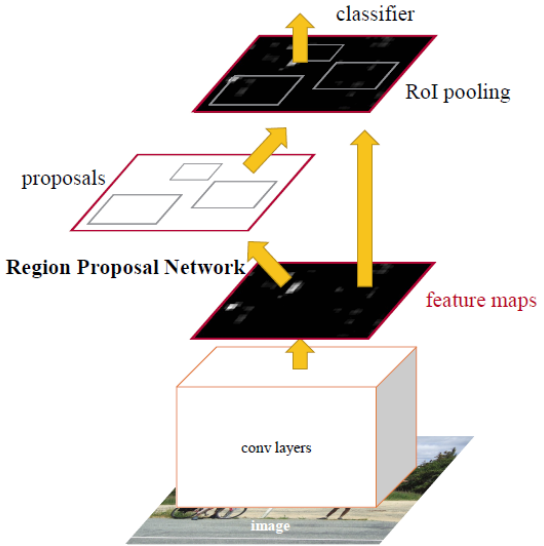
  - **RPN**[3]: fully convolutional network that simultaneously predicts object bounds and objectness scores
- Proposal generation is usually the bottleneck in two-stage algorithms



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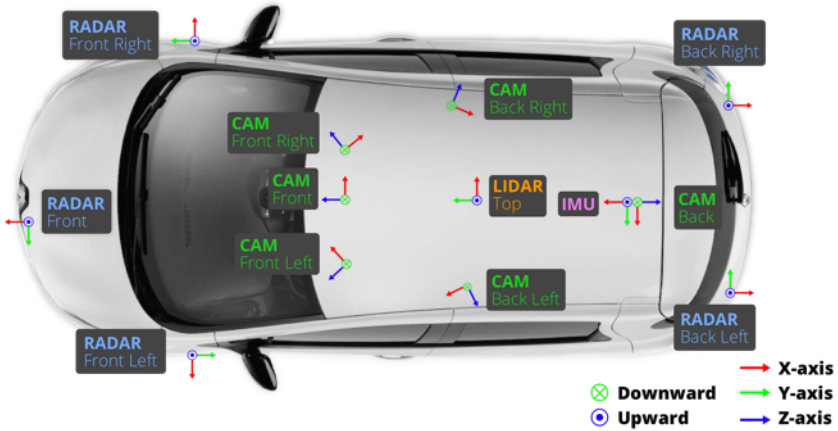
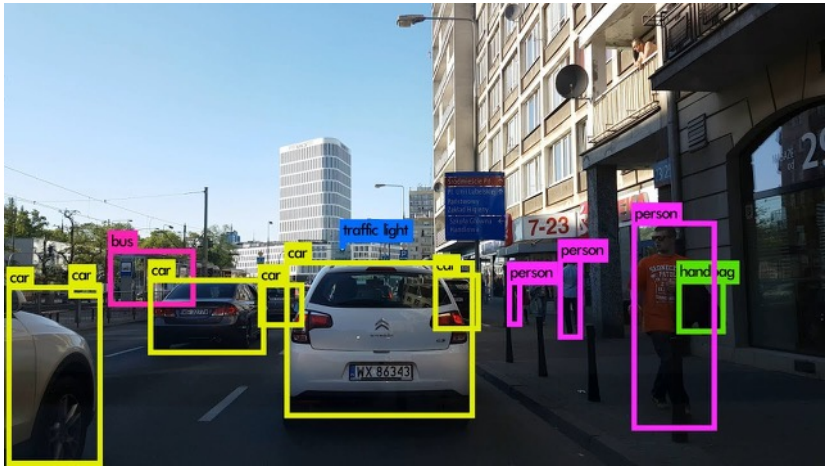
Object Detection for Autonomous Vehicles

- Autonomous vehicles require real-time object detection
- Multiple sensors available on vehicle (camera, Radar, LIDAR, ...)
- Large areas of image usually do not contain any object of interest

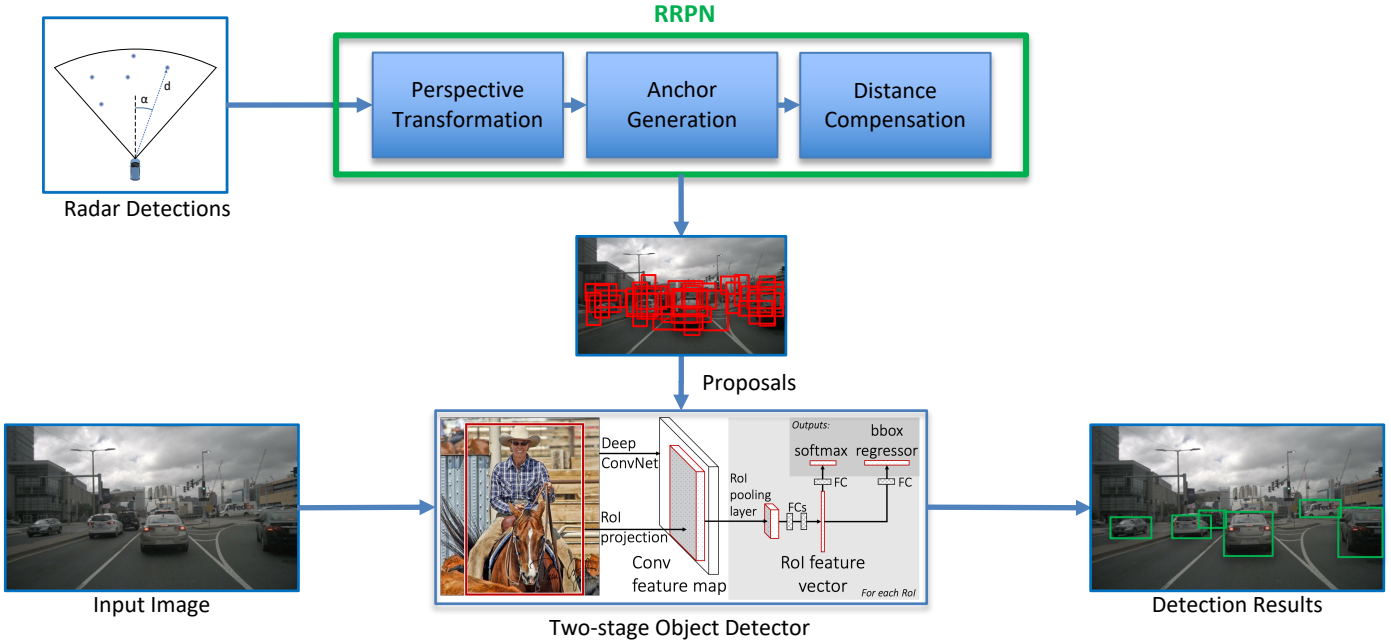




Left image: https://www.nuscenes.org
Right image: https://github.com/karolmajek/darknet

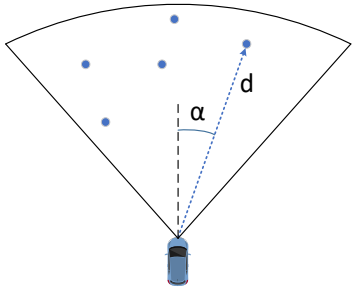
Radar Region Proposal Network (RRPN)

- Real-time algorithm generating object proposals from Radar detections



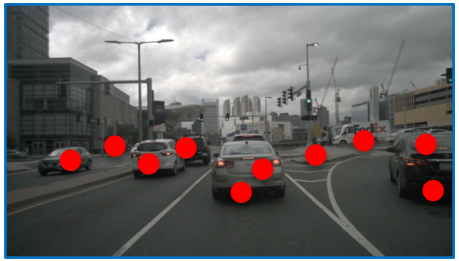
Radar Region Proposal Network (RRPN)

- Perspective Transformation
  - Radar detections are reported in Bird's Eye View (BEV) format
  - Detections need to be projected to the image coordinate system
  - Projection is done using a projection matrix H
  - H is obtained from calibrating the Radar and camera



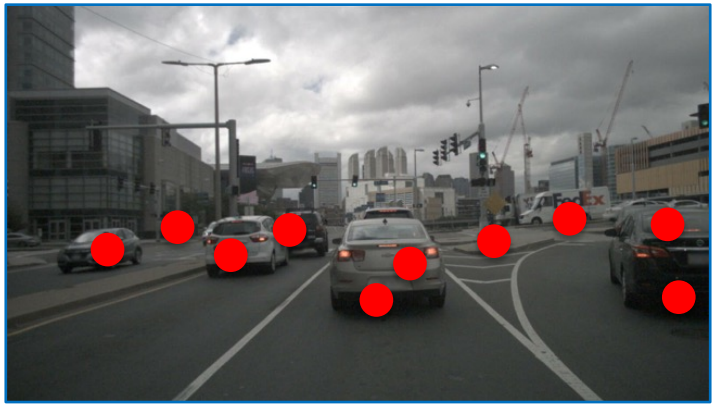
$$p = HP$$

$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \end{bmatrix}$$



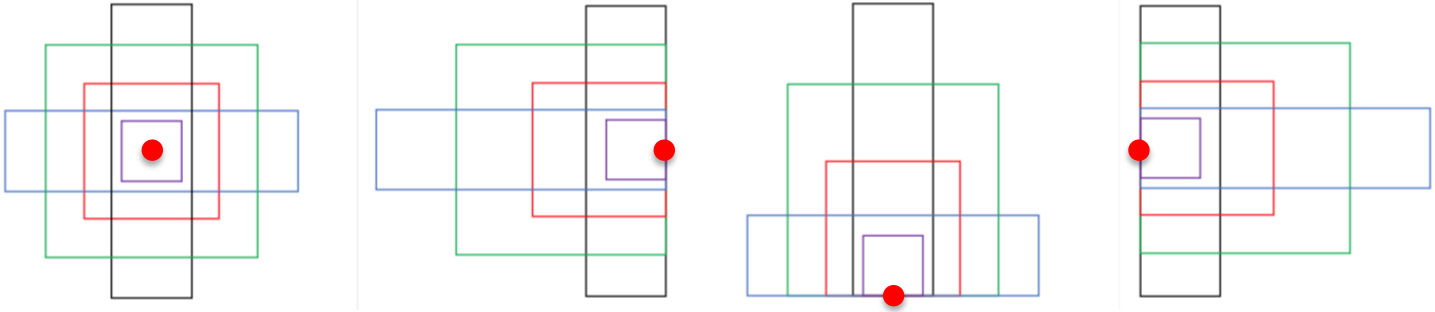
Radar Region Proposal Network (RRPN)

- Anchor Generation
  - Generate object proposals for every mapped Radar detection on image
  - Problems:
    - Radar detections are not always mapped to the center of objects
    - Radars usually do not report the size of the detected objects



Radar Region Proposal Network (RRPN)

- Anchor Generation
  - Generate multiple bounding boxes with different size and aspect ratios at each point



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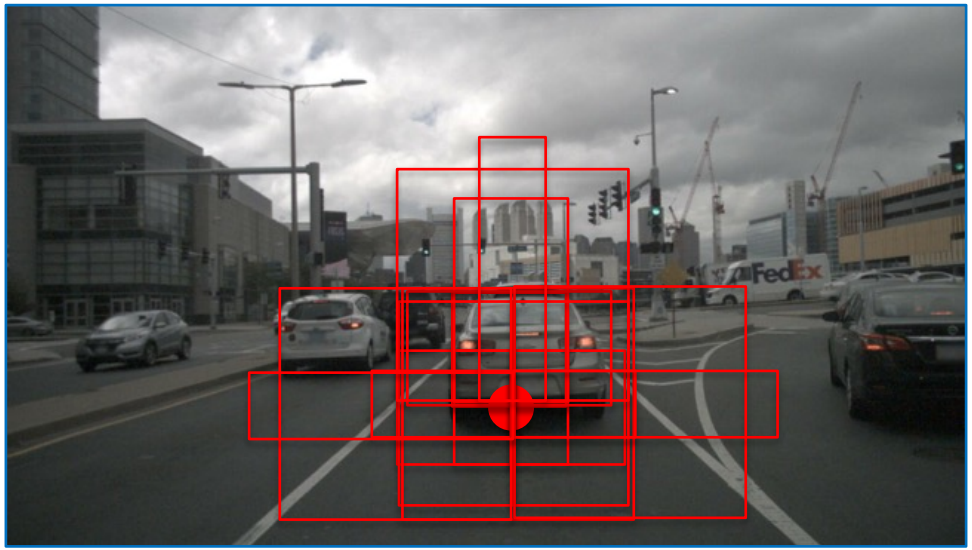

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- Distance Compensation
  - Size of an object in image has an inverse relationship with distance
  - Radar detection has the range information for the detected object

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- Distance Compensation
  - Size of an object in image has an inverse relationship with distance
  - Radar detection has the range information for the detected object
  - This information is used to adjust the size of the proposed bounding boxes

$$S_i = \alpha \frac{1}{d_i} + \beta$$

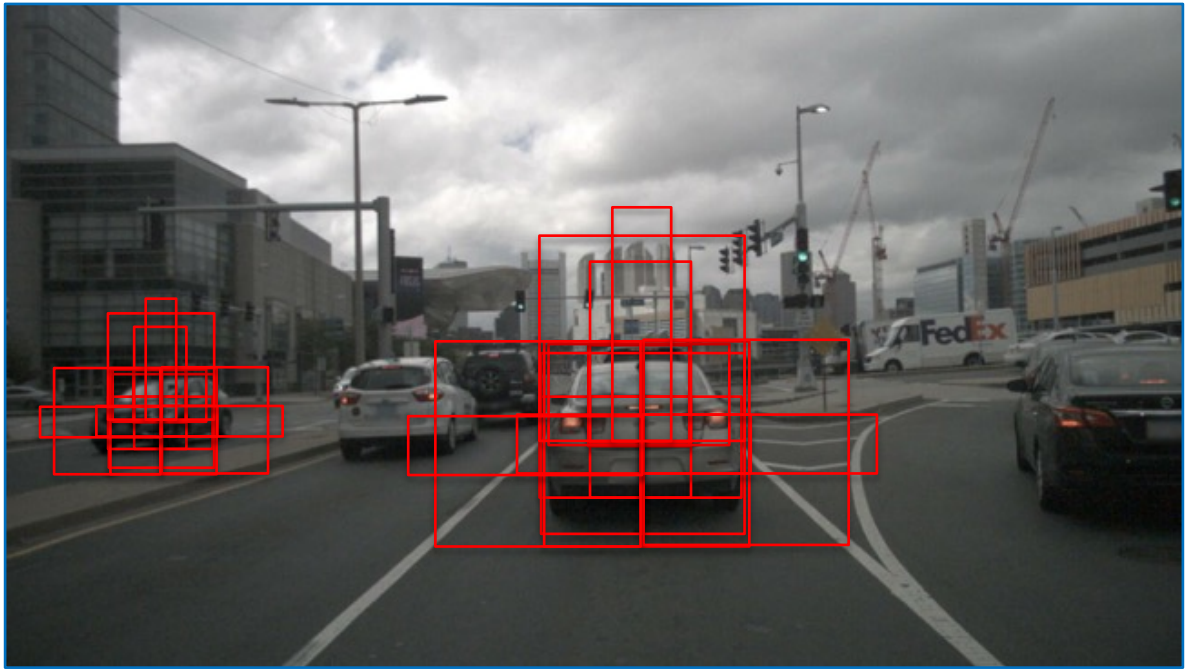
$$\underset{\alpha,\beta}{\operatorname{argmax}} \sum_{i=1}^{N} \sum_{j=1}^{M_i} \max_{1<k<A_i} IOU_{jk}^{i}(\alpha, \beta)$$

S_i : Scale factor for object i
d_i : Distance to object i
α, β: Parameters to adjust the scale

N : Number of training images
M_i : Number of ground truth bounding boxes in image i
A_i : Number of anchors generated in image i

Radar Region Proposal Network (RRPN)

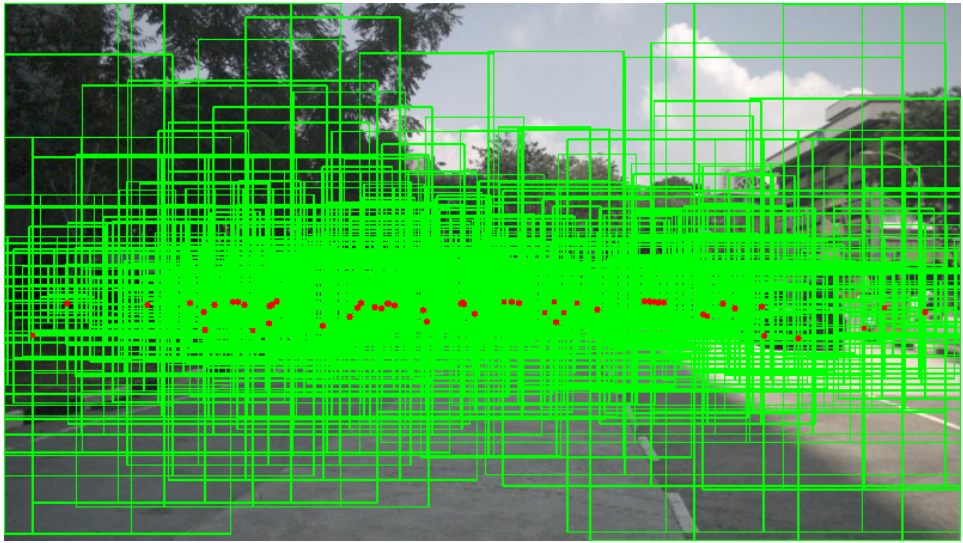
- Distance Compensation



Experiments and Results

- Simulation Setup:
  - Object Detection Network: Fast-RCNN
  - Backbone: ResNet-101 and ResNeXt-101
  - Dataset: NuScenes
  - Compared to: Selective Search
- Running time:
  - Up to 100x faster than Selective Search

Results



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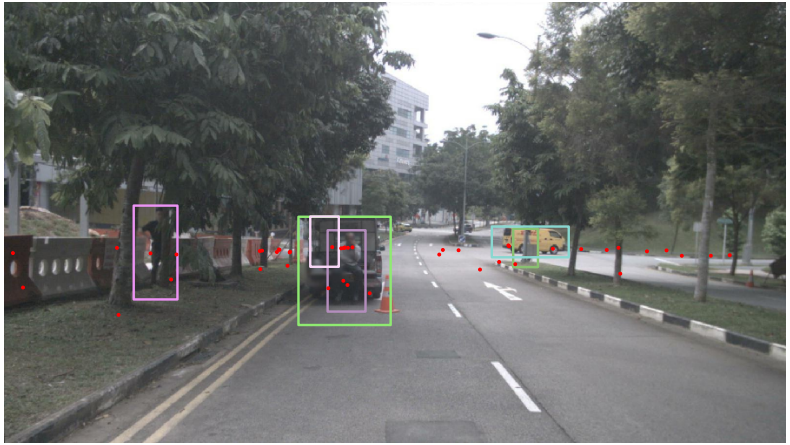
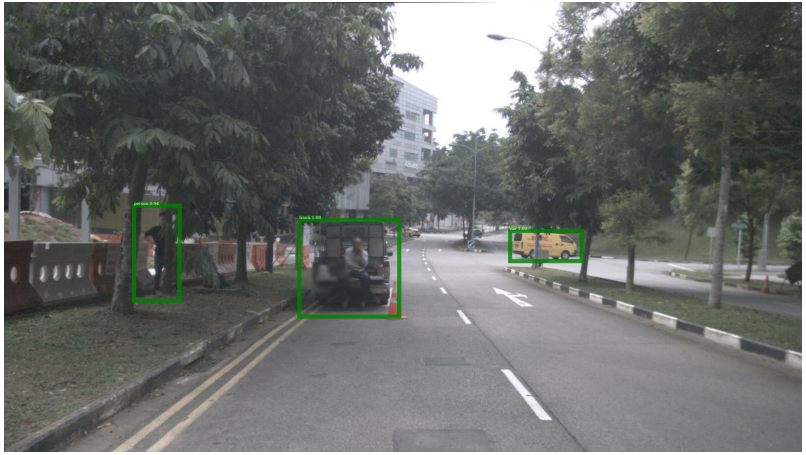
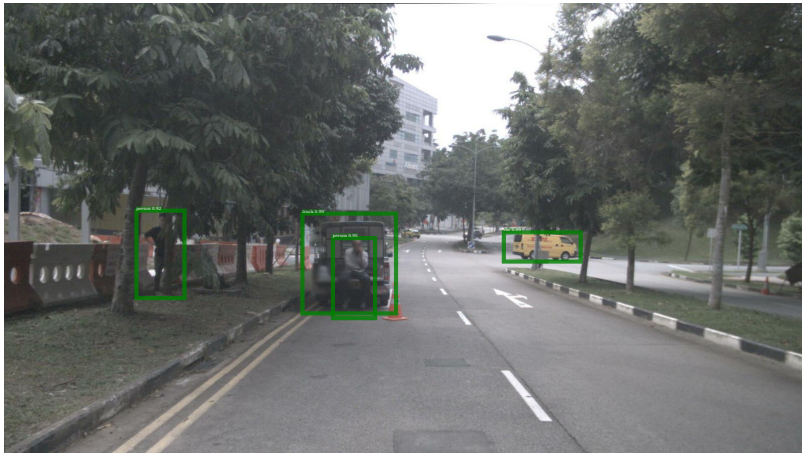


Ground Truth



Selective Search



RRPN

Results

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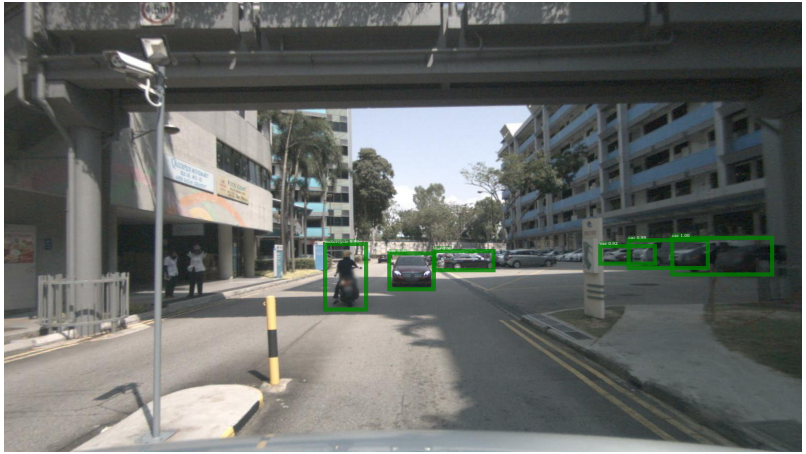

Selective Search

RRPN

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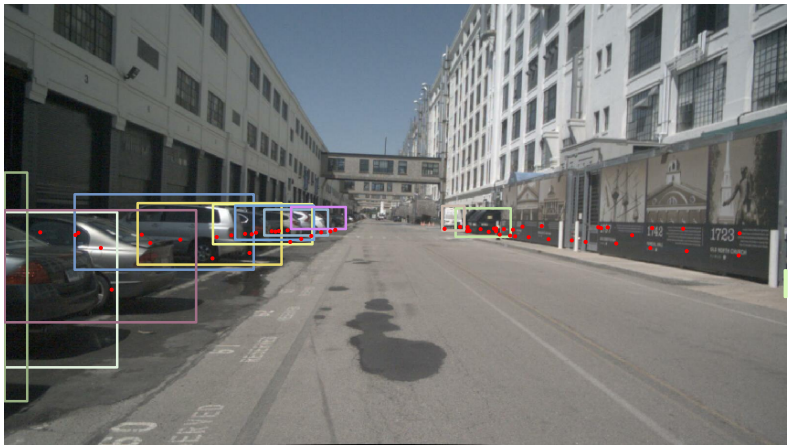

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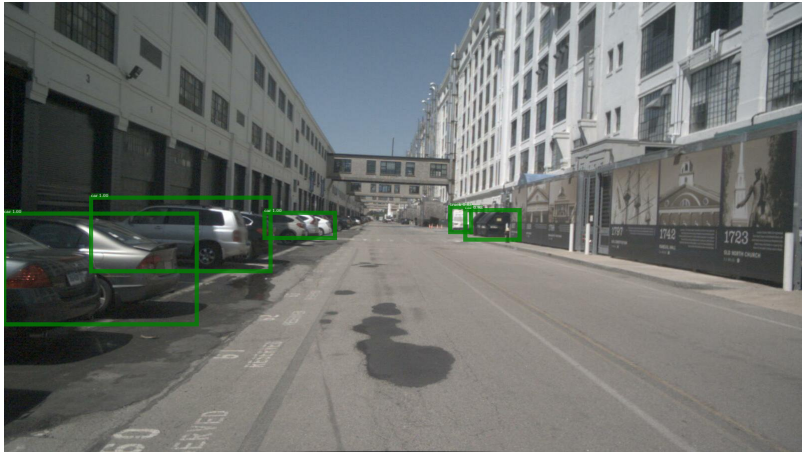

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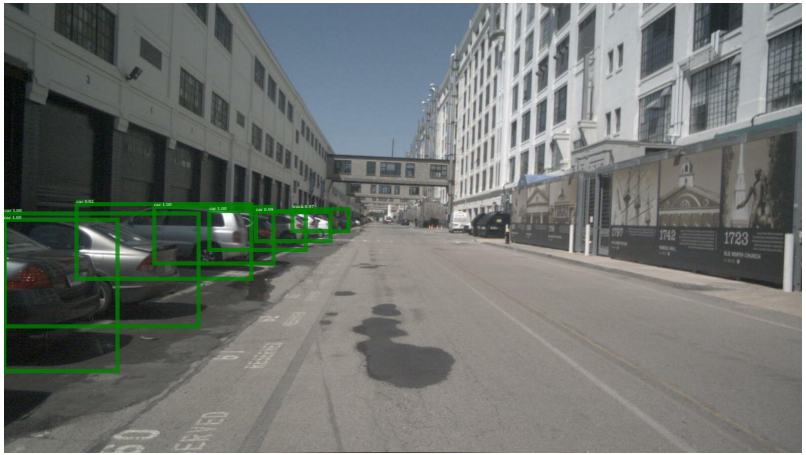

RRPN

Results

method	AP	AP50	AP75	AR	ARs	ARm	ARl
SS + X101 - F	0.368	0.543	0.406	0.407	0.000	0.277	0.574
SS + R101 - F	0.418	0.628	0.450	0.464	0.001	0.372	0.316
RRPN + X101 - F	0.419	**0.652**	0.463	0.478	**0.041**	0.406	0.573
RRPN + R101 - F	**0.430**	0.649	**0.485**	**0.486**	0.040	**0.412**	**0.582**
SS + X101 - FB	0.332	0.545	0.352	0.382	0.001	0.291	0.585
SS + R101 - FB	0.336	0.548	0.357	0.385	0.001	0.291	**0.591**
RRPN + X101 - FB	0.354	**0.592**	0.369	0.420	0.202	**0.391**	0.510
RRPN + R101 - FB	**0.355**	0.590	**0.370**	**0.421**	**0.211**	**0.391**	0.514

method	Car	Truck	Person	Motorcycle	Bicycle	Bus
SS + X101 - F	0.424	0.509	0.117	0.288	0.190	0.680
SS + R101 - F	**0.472**	**0.545**	0.155	0.354	0.241	**0.722**
RRPN + X101 - F	0.428	0.501	0.212	0.407	0.304	0.660
RRPN + R101 - F	0.442	0.516	**0.220**	**0.434**	**0.306**	0.664
SS + X101 - FB	0.390	0.415	0.122	0.292	0.179	0.592
SS + R101 - FB	0.392	0.420	0.121	0.291	0.191	**0.600**
RRPN + X101 - FB	0.414	**0.449**	**0.174**	0.294	**0.215**	0.579
RRPN + R101 - FB	**0.418**	0.447	0.171	**0.305**	0.214	0.572

F: Front camera only
FB: Front and back camera
SS: Selective Search

Questions?