

Challenges of Autonomous Vehicle Development for Motorsports

MIT-Pitt Autonomous
GTC 2021



Agenda

1

Our Team's Approach

2

Overview of Controls

3

Overview of Planning

4

Perception Deep Dive



robotics&automation
society

Our Team's Approach



Single Race at Indy 500
Multi Agent checkered flag race
Date: October 23rd



ROBORACE

Multiple Track Racing Series
Single Agent time trials with metaverse
Date: Ongoing, next race on __

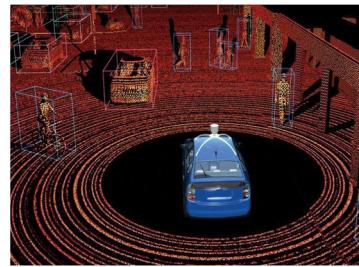
Our Team's Approach

Robotics is Interdisciplinary by Nature



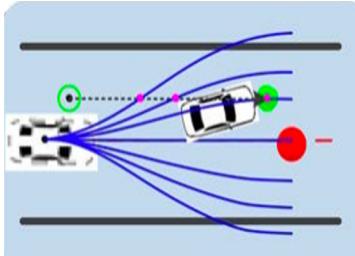
Perception

How do we see and interpret the world?



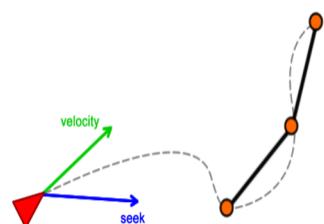
Localization

Where do we believe we are?



Motion Planning

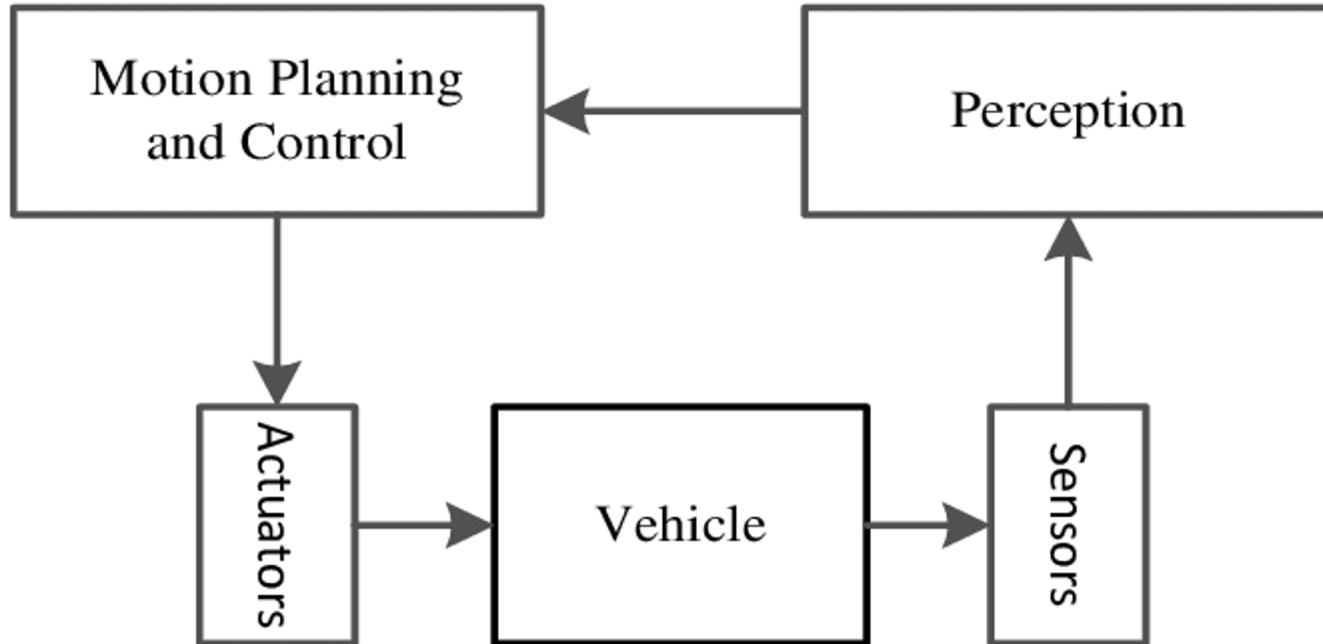
How can we find the best path to our goal?



Controls

How do we get from one point to another?

Our Team's Approach



Our Team's Approach

Planning

Controls

State
Estimation

Perception

Infrastructure

Simulation

1

Our Team's Approach

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Perception Deep Dive



Overview of Controls

Driver Inputs



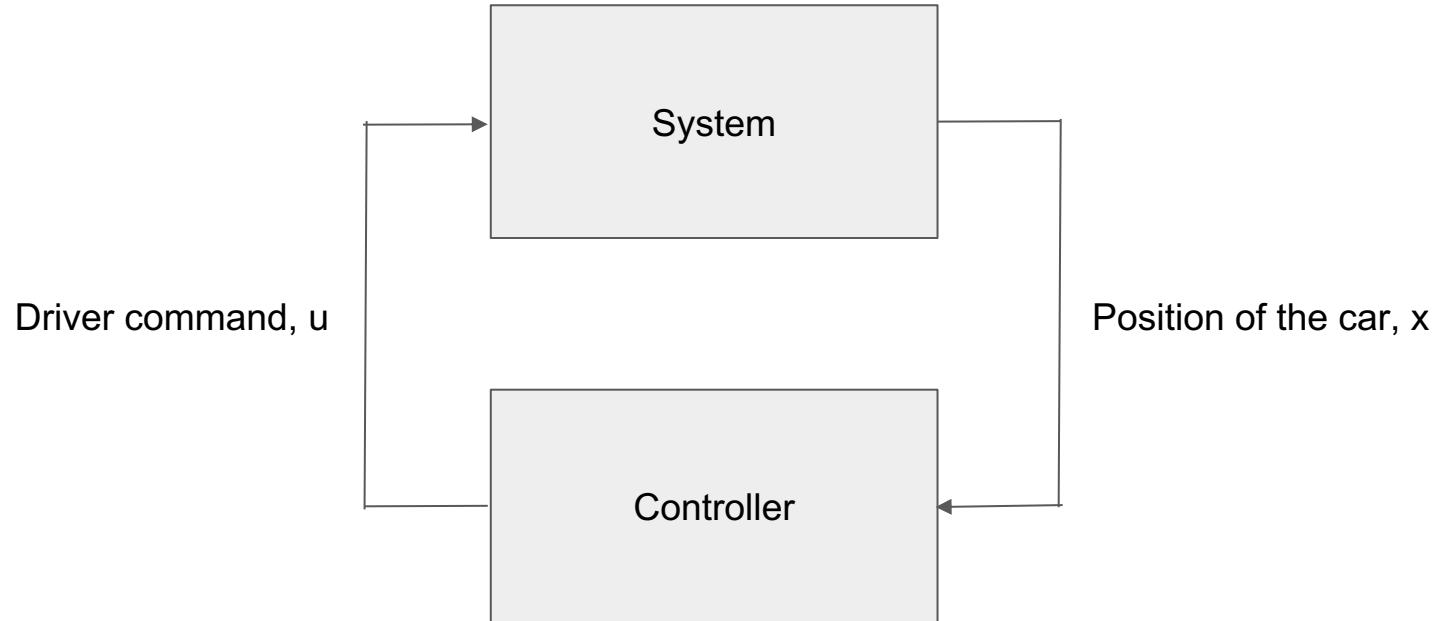
Steering



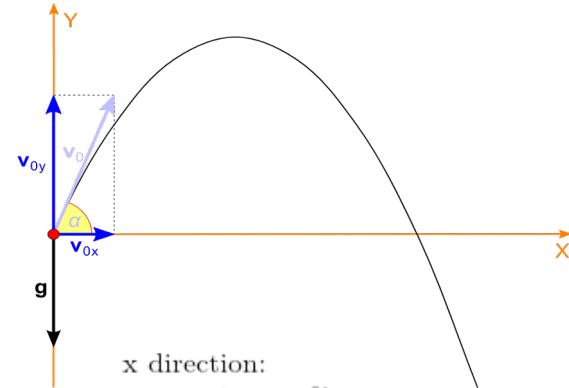
Acceleration



Overview of Controls



Overview of Controls

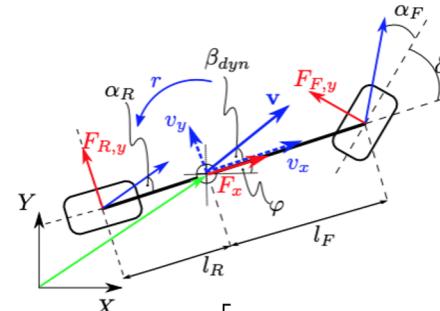


x direction:
$$x = x_0 + v_0 \cos \theta t$$

y direction:
$$y = y_0 + v_0 \sin \theta t + \frac{1}{2} a t^2$$

Given the current state of an object, the forces acting on it, and inputs to the system, can we determine its future state?

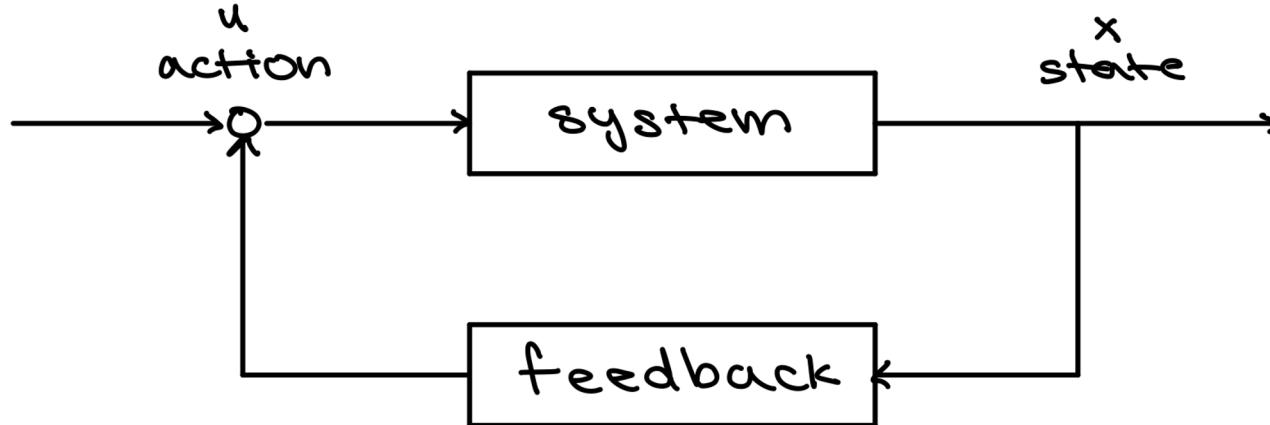
Overview of Controls



$$\dot{\mathbf{x}} = \begin{bmatrix} v_x \cos \varphi - v_y \sin \varphi \\ v_x \sin \varphi + v_y \cos \varphi \\ r \\ \frac{1}{m}(F_x - F_{F,y} \sin \delta + mv_y r) \\ \frac{1}{m}(F_{R,y} + F_{F,y} \cos \delta - mv_x r) \\ \frac{1}{I_z}(F_{F,y} l_F \cos \delta - F_{R,y} l_R + \tau_{TV}) \\ \Delta \delta \\ \Delta T \end{bmatrix}$$

Given the current state of an object, the forces acting on it, and inputs to the system, can we determine its future state?

Overview of Controls



The question remains, how do we solve for optimal steer angle and acceleration?
LQR, MPC, or other?

1

Our Team's Approach

2

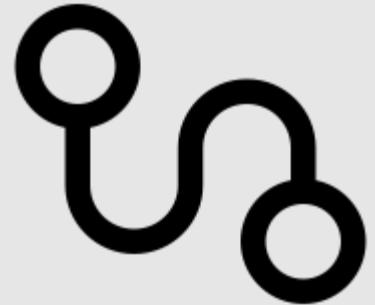
Overview of Controls

3

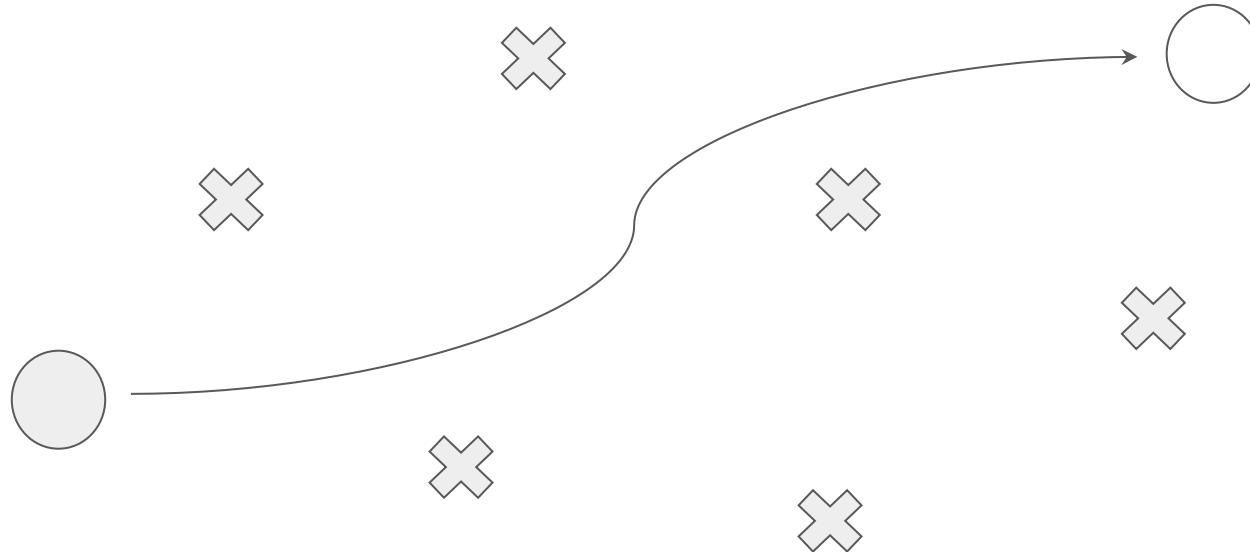
Overview of Planning

4

Perception Deep Dive

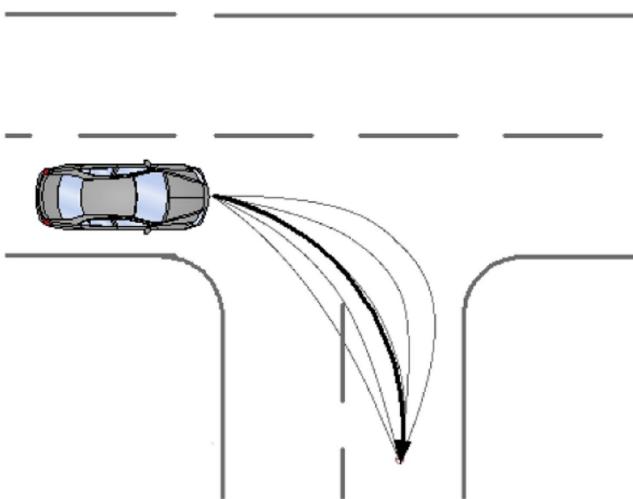


Overview of Planning



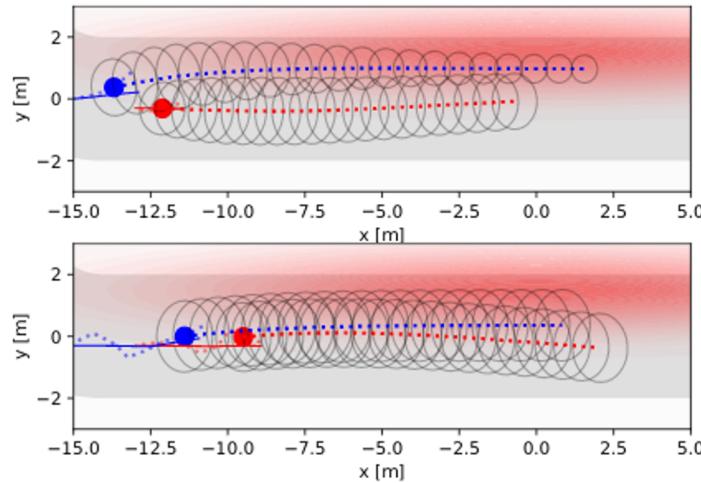
Given starting and goal positions, it is path planning's job to determine the optimal path between them

Overview of Planning



To find the optimal path, the algorithm must incorporate time and kinematic constraints of vehicle while planning

Overview of Planning



Game theoretic planning adds a further layer of complexity, considering the actions of other vehicles while planning

1

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2

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3

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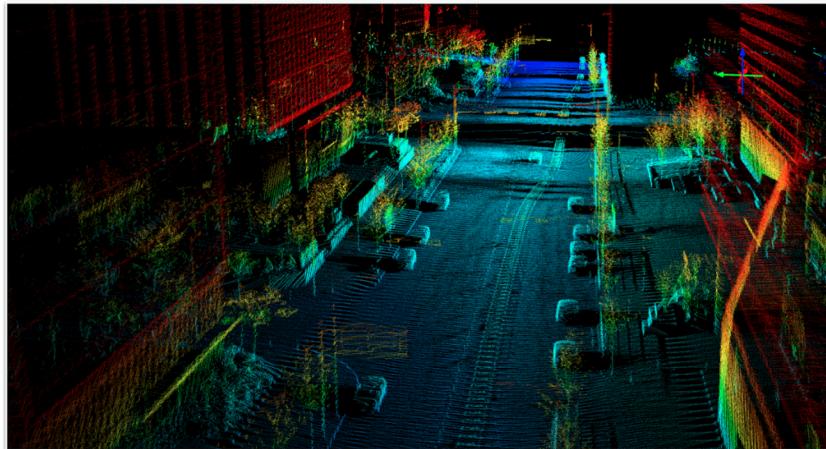
Perception Deep Dive



Perception Deep Dive



3D LiDAR Sensor

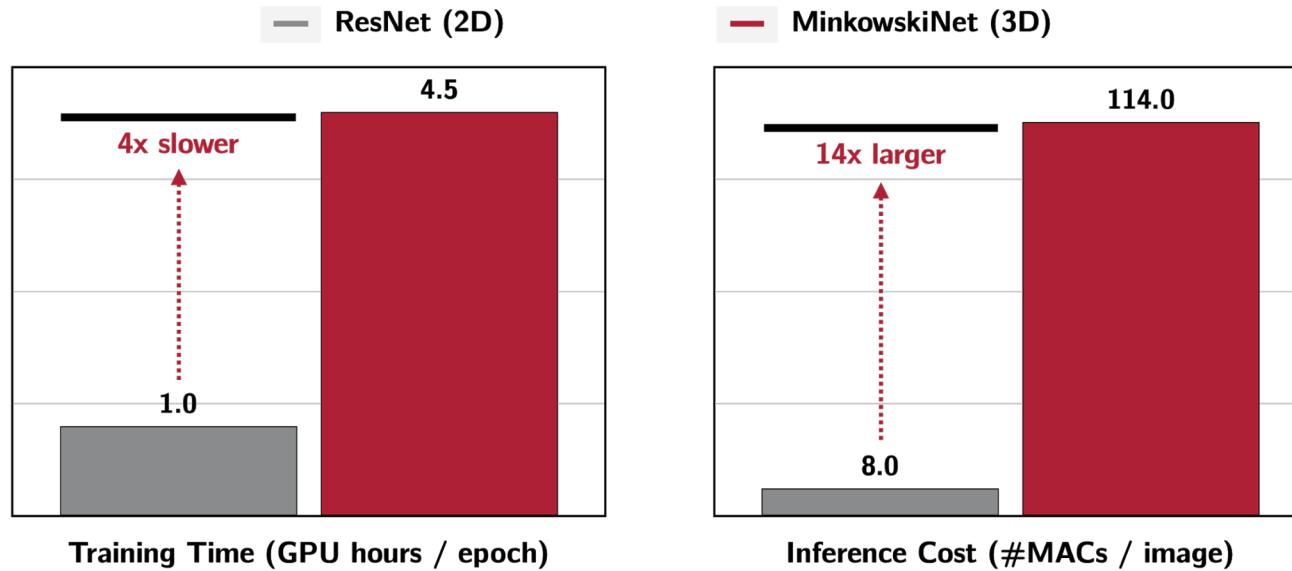


3D Point Cloud

500k+ points: (x, y, z, intensity)

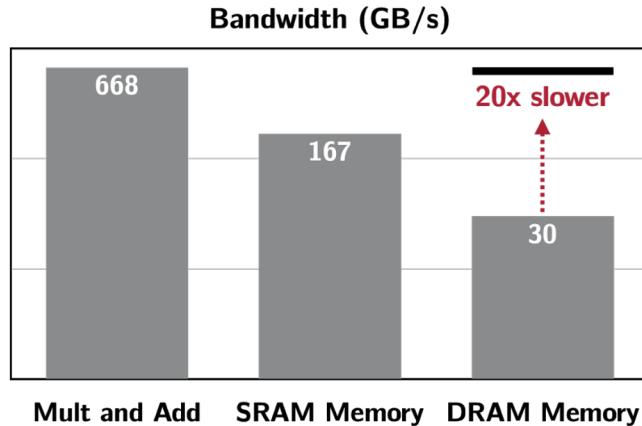
Perception Deep Dive

Efficient LiDAR Perception: Challenges

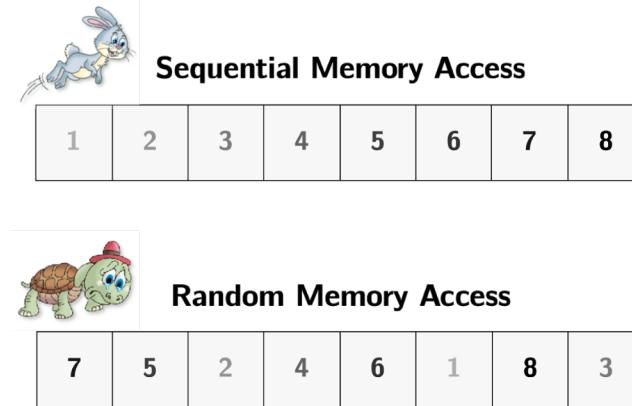


Perception Deep Dive

Efficient LiDAR Perception: Bottlenecks



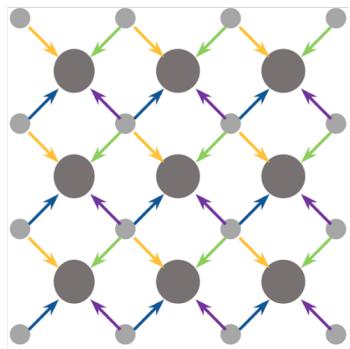
Off-chip DRAM access is much more expensive than arithmetic operation!



Random memory access is inefficient due to the potential bank conflicts!

Perception Deep Dive

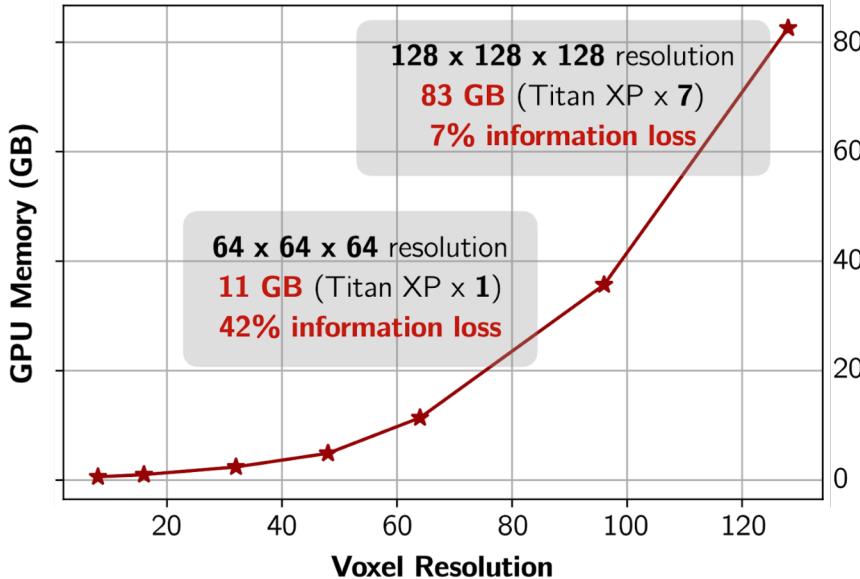
Voxel-Based Models: Cubically-Growing Memory



3D ShapeNets [CVPR'15]

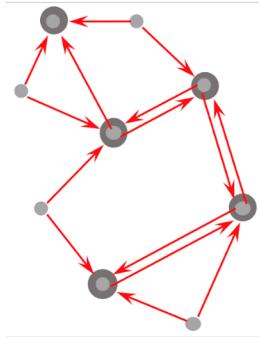
VoxNet [IROS'15]

3D U-Net [MICCAI'16]



Perception Deep Dive

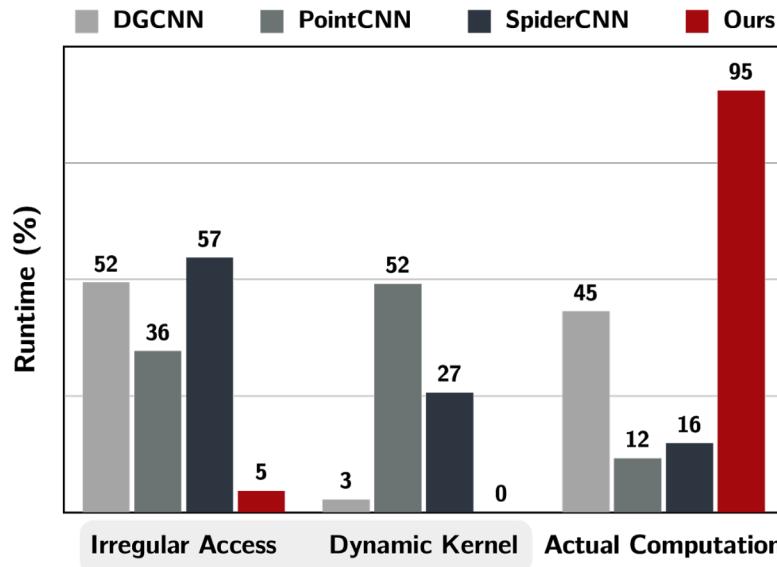
Point-Based Models: Sparsity Overheads



PointNet [CVPR'17]

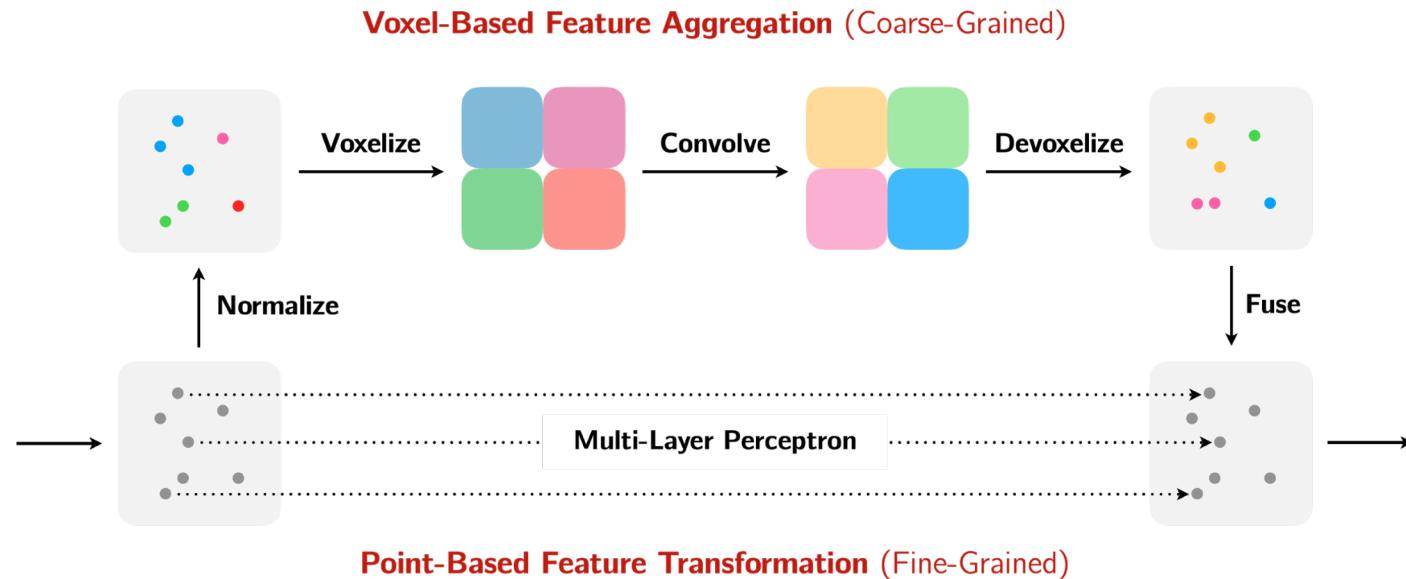
PointCNN [NeurIPS'18]

DGCNN [SIGGRAPH'19]



Perception Deep Dive

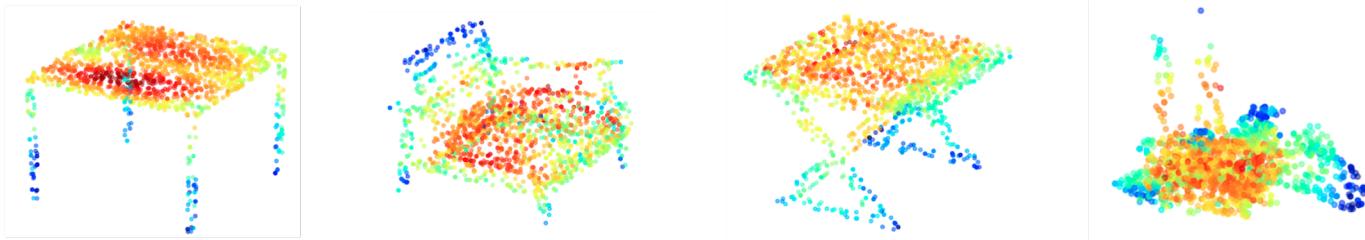
Point-Voxel Convolution (PVConv)



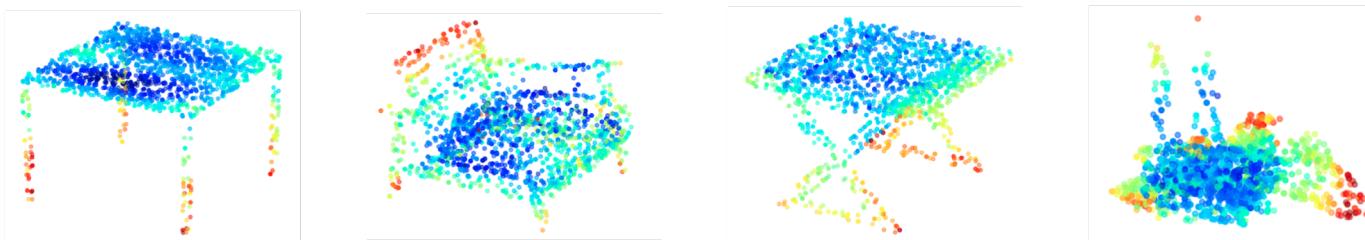
Perception Deep Dive

Attention Visualization for Small Objects

Features from **Voxel-Based Branch**:



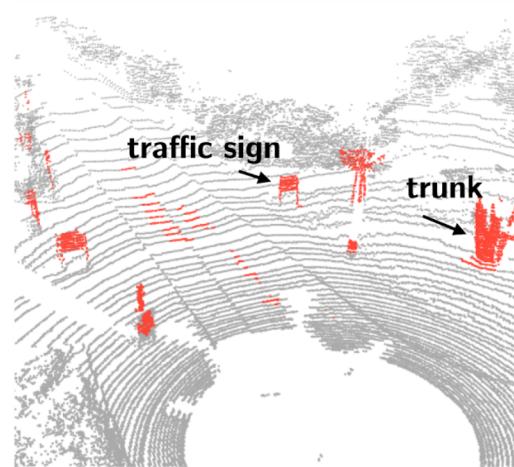
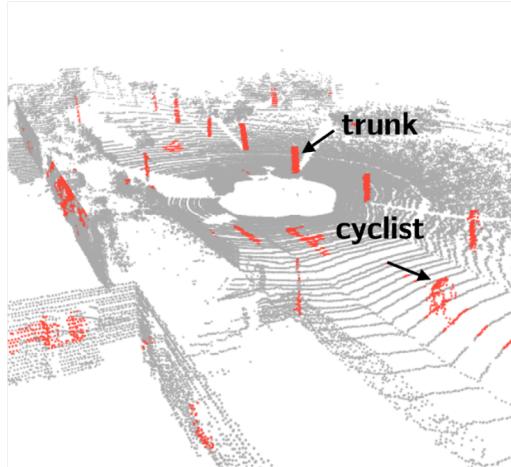
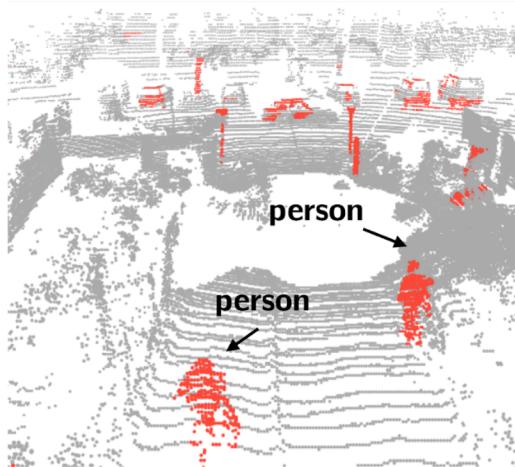
Features from **Point-Based Branch**:



Perception Deep Dive

Attention Visualization for Large Scenes

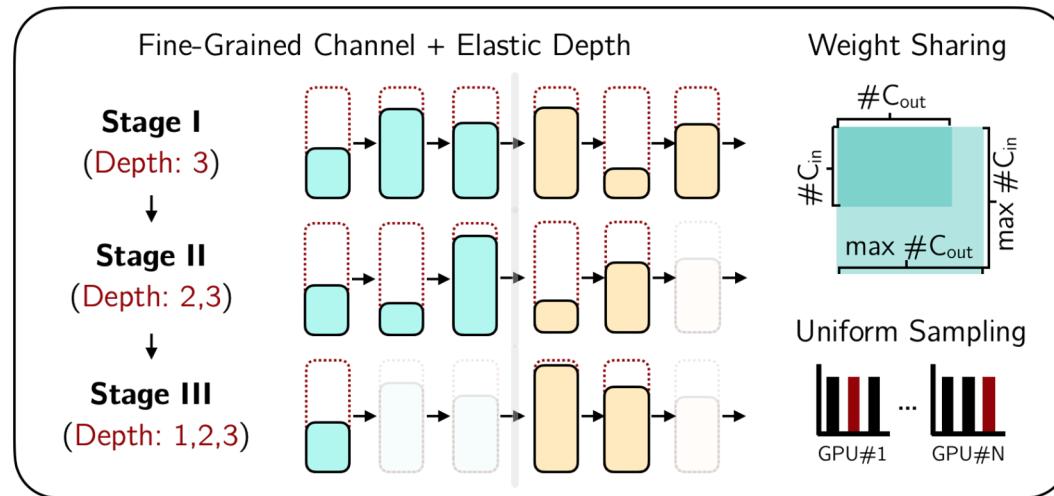
Features from **Point-Based Branch**:



Perception Deep Dive

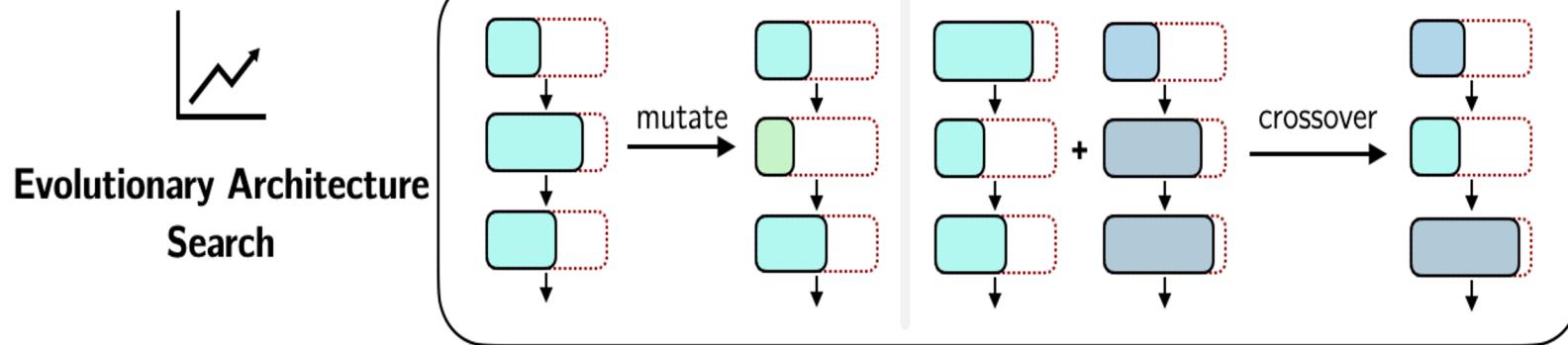
3D Neural Architecture Search (3D-NAS)


Train Super Network



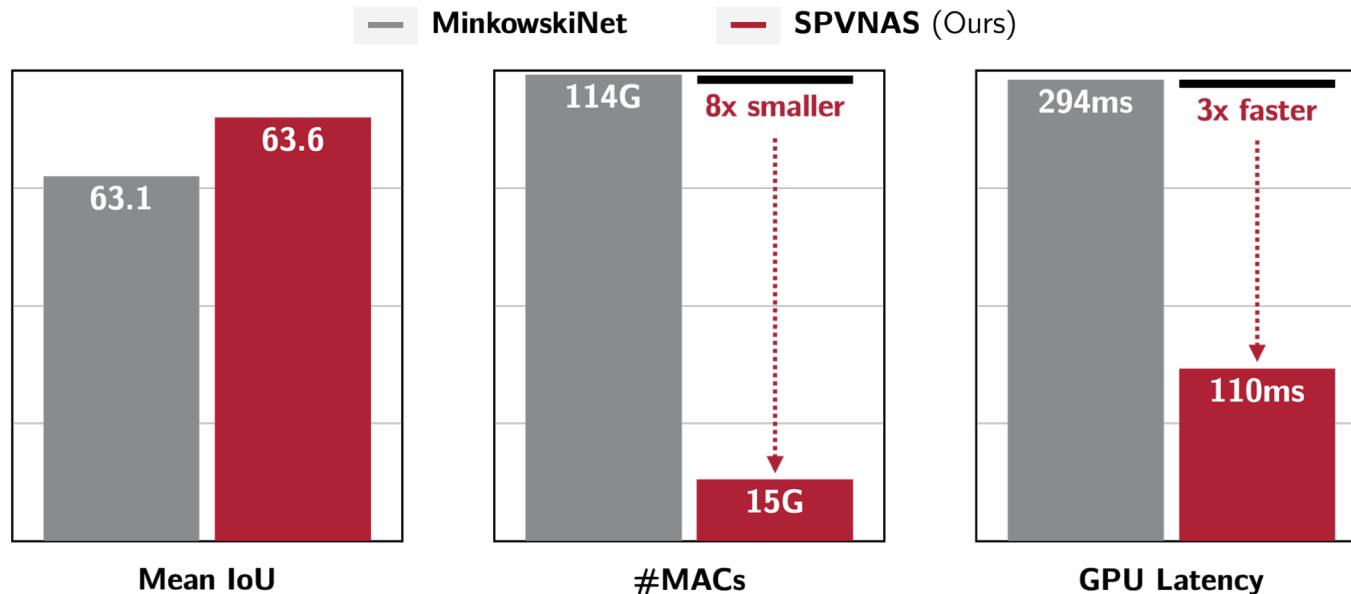
Perception Deep Dive

3D Neural Architecture Search (3D-NAS)



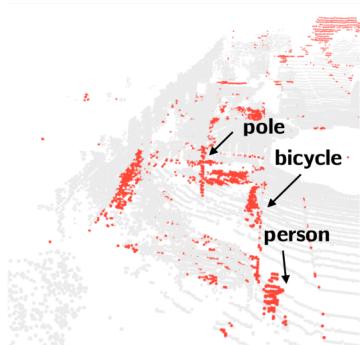
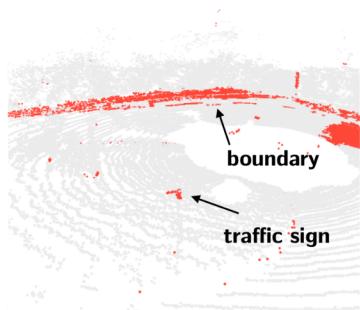
Perception Deep Dive

Results: 3D Outdoor Scene Segmentation

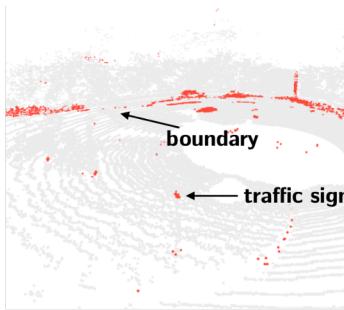


Perception Deep Dive

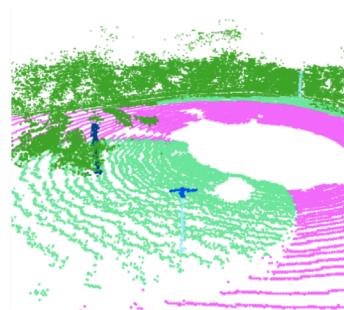
Results: 3D Outdoor Scene Segmentation



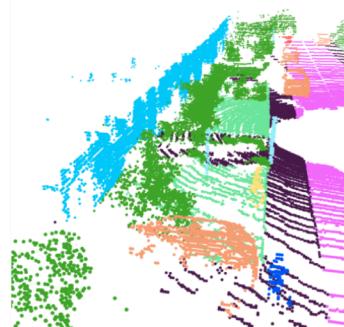
MinkowskiNet



SPVNas (Ours)



Ground Truth



Stay in Touch!



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pittras.org

Save the date!