### AA 274A Principles of Robot Autonomy I

Open-source Automated Driving Stack "Autoware"





### Today's lecture

- Aim
  - Overview Autoware (Autoware.Al, Autoware.Auto), software architecture
  - Simulation environments for Autoware
  - Integration of Autoware into a research vehicle
  - Hands-on
    - Installation, development environment
    - Demos: Localization, object detection, path planning
- Readings
  - <u>https://www.autoware.org/</u>
  - <a href="https://gitlab.com/autowarefoundation/autoware.ai/autoware/wikis/Installation">https://gitlab.com/autowarefoundation/autoware.ai/autoware/wikis/Installation</a>
  - <a href="https://gitlab.com/autowarefoundation/autoware.ai/autoware/wikis/home">https://gitlab.com/autowarefoundation/autoware.ai/autoware/wikis/home</a>

### **Overview Autoware**

- Other Automated driving stacks
- Autoware.Al (ROS1), Autoware.Auto (ROS2)
- Software architecture
  - General overview
  - Localization
  - Object detection
  - Path planning

### Autonomous stack / Motivation

	 Product			User Application	System Integration	Application	Release		
		$\langle \rangle$	$\diamond$	Algorithmic Software	2D+3D Perception, Tracking, Class.	AI/ML based Scene Understanding	Localization	Route Planning, Decision Making	Motion Planning and Control
	On-Board	$\langle \rangle$	$\bigcirc$	Framework Software	Abstraction of hardware, middleware, OS, interfaces	Middleware	Safety Support	Security Support	Diagnostics
	Software	$\langle \rangle$	$\bigcirc$	Operating System	Kernel	Scheduler	Driver		
		$\langle \rangle$	$\bigcirc$	Functional Safety	Regulations, Homologation	Security	Safety	Verification	Validation
	Methodologies	$\langle \rangle$	$\bigcirc$	Testing	Unit tests	Regression Tests	Integration Tests	SIL/HIL Tests	Vehicle Tests
۔ م		$\langle \rangle$	$\bigcirc$	Design	User Experience	Interior Interaction Design	Exterior Interaction Design		
Full Stack		$\langle \rangle$	$\bigcirc$	Development Tools	Development Environment	Visualization	Simulation		
đ		$\langle \rangle$	$\bigcirc$	Data Processing	Data Recording	Data Playback	Data Annotation	Data Management and Analytics	
	Off-Board Software and Data	$\langle \rangle$	$\bigcirc$	Operations	Fleet Management	Fleet Routing	Tele-Operation	Remote Diagnostics	
	and Data	$\langle \rangle \rangle$	$\bigcirc$	Mapping	Creation	Annotation	Update	Distribution	
		$\langle \rangle$	$\bigcirc$	Maps	Topological Layer	Relational Layer	Physical Layer		
		$\langle \rangle$		Sensors	GNSS	INS/IMU	Lidar	Camera	Radar
	Hardware Stack	$\langle \rangle$	$\bigcirc$	Components	Computing	Cloud Connectivity	In-Vehicle Connectivity	Data Recorder	Data Storage
				Vehicle	Interfaces to:	Drive Train	Braking System	Steering System	Electronics
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### Autonomous software stack solutions

Most relevant software stacks in 2019

- DriveWorks (Nvidia)\*
- Apollo\*
- Autoware
- EB robinos & EB robinos Predictor (Elektrobit)
- OpenPilot (comma.ai)

\* will be briefly introduced

### Nvidia DriveWorks

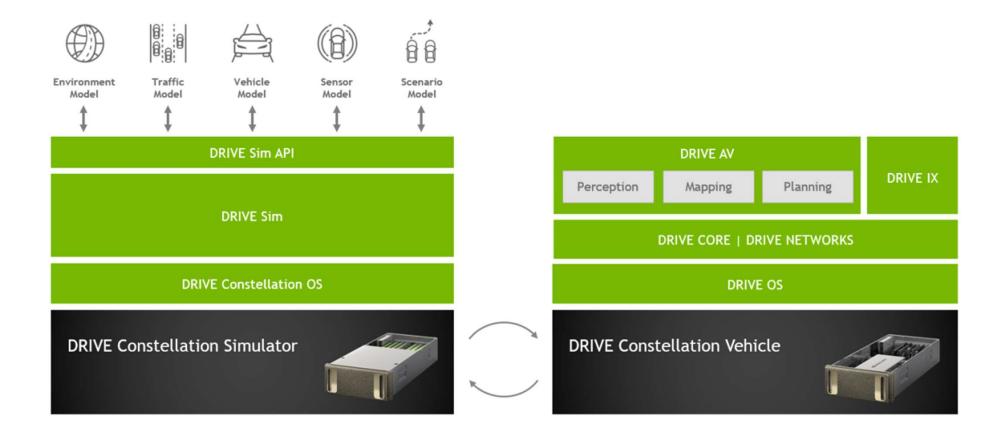


DRIVE AV	DRIVE IX												
DRIVE Planning Route Lane Behavior	Visualization AI CoPilot AI Assistant Confidence View Driver Monitoring Speech System												
DRIVE Mapping Localization MapStream MapServices	AV Visualization Neural Networks Gesture DMS Visualization Plugins Face ID												
DRIVE Perception Obstacle Path Wait Conditions	Camera Calibration tool												
DRIVEWORKS													
DRIVE Networks       DriveNet     OpenRoadNet     LaneNet       MapNet     PathNet     SignNet       LightNet     WailNet     ClearSightNet	DRIVE Calibration Egomotion Self-Calibration Calibration Tools												
DRIVE Core													
Sensor Abstraction Layer + Plugins Vehicle IO Image Processing	Point Cloud Processing DNN Framework Tools (Recorder)												
DRIVE OS													
NVMedia CUDA	TensorRT Developer Tools												
DRIVE AGX DEVELOPER KITS (Xavier/Pegasus)	DRIVE HYPERION DEVELOPER KIT												

https://developer.nvidia.com/drive/drive-software

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### Nvidia Drive Constellation Architecture



### Apollo

### apollo

#### Android of the autonomous driving industry, but more open and powerful.

2017.4		2017.7		2017.9		2018.1		2018.4		2018.7		2019.1		2019.7		2021			
				• •		• •				• •		•		• •		• • • • • • • • • • • • • • • • • • • •			
Hello Apollo		Apollo 1.0		Apollo 1.5		Apollo 2.0		Apollo 2.5		Apollo 3.0		Apollo 3.5		Apollo 5.0		Highway and			
Apollo Platform		Closed Venue		Simple City Roads		Autonomous		Geo-fenced		Production-level		Urban Road		Volume		Urban Road			
Anno	Announced		Autonomous		Autonomous		Driving for		Highway		Closed Venue		Autonomous		Production		Full Autonomy		
			Driving		Driving		Simple Urban		Autonomous		Autonomous		Driving		Geo-fenced				
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### Apollo / Software modules



- Data Pipeline
- Perception
- Planning
- Control
- Prediction
- Map Engine
- Simulation

Apollo 5.0 Cloud Production components Simulation HD Map ΟΤΑ DuerOS V2X Service Security Platform **Data Pipeline** Map Engine Localization Perception Prediction Planning Control HMI Open V2X Software **Apollo Cyber RT** Adapter Platform RTOS Hardware Ultrasonic HMI Black Computing Development GPS/IMU LIDAR Radar ASU AXU V2X OBU Camera Unit Box Sensor Device Platform **Open Vehicle** Certification Certified Apollo Compatible Drive-by-wire vehicle **Open Vehicle Interface Standard** Platform **New Service Offering Feature Update** 

### Apollo in action



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### Autoware

- Autoware was started 2015 by Shinpei Kato at Nagoya University.
- "All-in-One" open-source software for autonomous driving technology.
- Autoware Foundation launched in 2018.



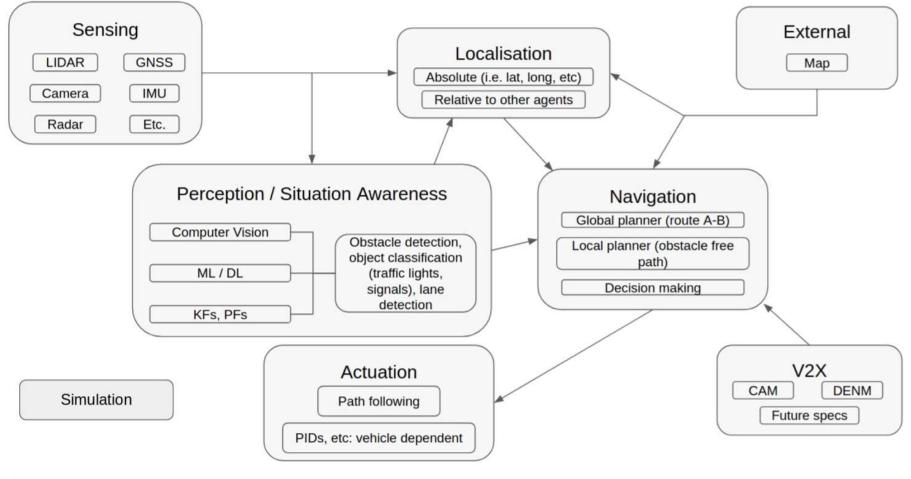
 Non-profit organization supporting open-source projects enabling self-driving mobility.





- It is based on ROS 1 and available under Apache 2.0 license
- It contains the following modules:
  - Localization is achieved by 3D maps and SLAM algorithms in combination with GNSS and IMU sensors.
  - **Detection** uses cameras and LiDARs with sensor fusion algorithms and deep neural networks.
  - **Prediction** and **Planning** are based on probabilistic robotics and rule-based systems, partly using deep neural networks as well.
- The output of Autoware to the vehicle is a twist of velocity and angular velocity (yaw rate).

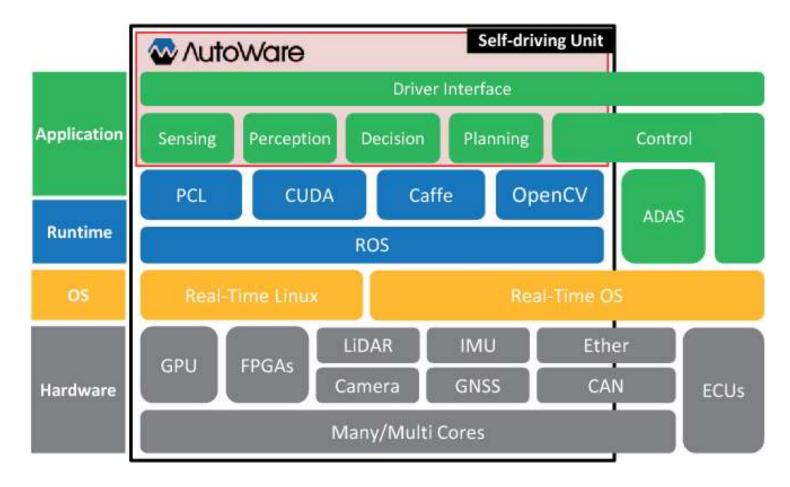
### Software modules



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### Abstraction layers



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- An interface project for Autoware to be extended with proprietary software and third-party libraries in a reliable manner.
- Include device drivers for sensors, by-wire controllers for vehicles, and hardware-dependent programs for SoC boards.
- Provides a hardware reference platform with tools, unified interface design and test framework.
- Enables the integration of member company's solutions onto platforms which support the Autoware.Auto and Autoware.Al software stack.

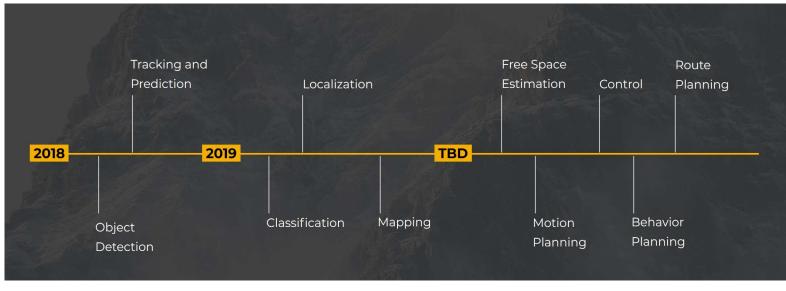


### AUTOWARE.AUTO

- Re-implementation of Autoware.Al
- ROS2 based
- Cleary defined APIs and interfaces for the different modules
- State of the Art development process CI/CD
  - Pull request reviews, pull request builds
  - Comprehensive documentation
  - 100% code coverage
  - Coding style guide
  - Managed by an open source community manager



- Will initially address Autonomous Valet Parking and Autonomous Depot Maneuvering as example uses cases.
- Autoware.Auto will allow mapping of a parking lot, creation of a map for autonomous driving and autonomous driving on the parking lot.



### Autoware outlook - commercial use - APEX.AI



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### Simulation environments for Autoware

- Carla
- LGSVL
- Gazebo
- Autoware simulator

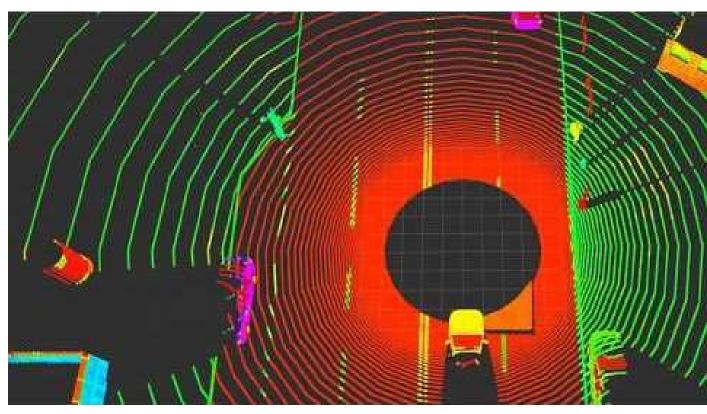


- Camera, lidar, GPS, ground truth
- Autoware, Apollo interface
- Unreal Engine
- Open Drive
- Scenario modelling
- Detailed camera model



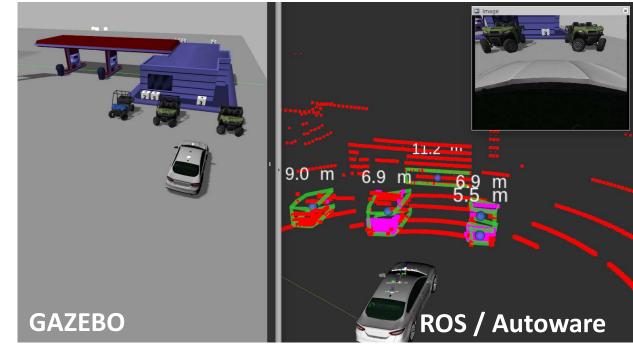


- Camera, lidar, GPS, ground truth
- Autoware, Apollo interface
- Unity engine
- Road editor
- Radar simulation
- GPU optimized lidar model





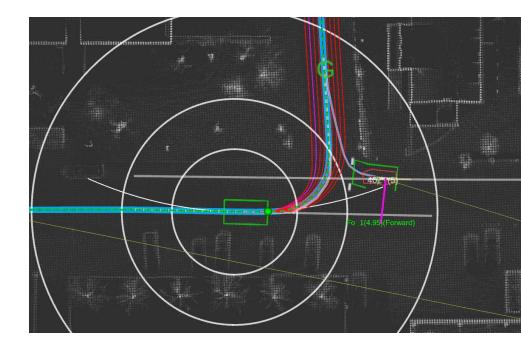
- Willow garage project, since 2012 Open Source Robotics Foundation
- ROS Interface
- Different sensor models
  - Camera
  - Lidar
- Vehicle model
- + not automotive specific
- + large community
- custom engine
- modelling other traffic participants



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### Autoware Simulator

- Focus: Path Planning algorithms
- Function development only based on ground truth data
- Simulation of 5 other vehicles
- Simple vehicle models



# Integration of Autoware into a research vehicle





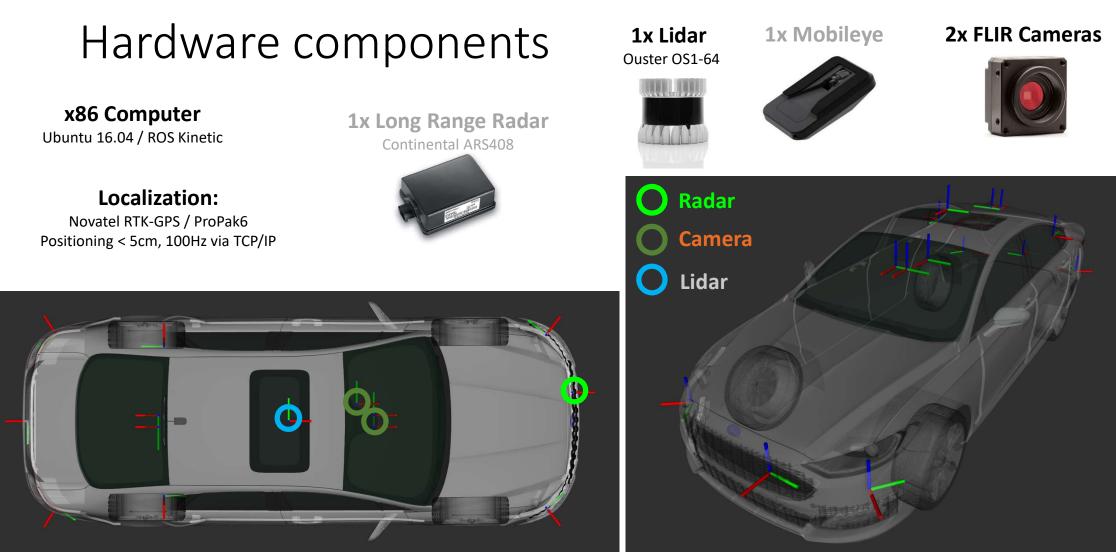
# Integration of Autoware into a research vehicle

- Vehicle hardware components
- Mapping of road network
- Required software components from Autoware

### Virtual Vehicle – Automated Drive Demonstrator

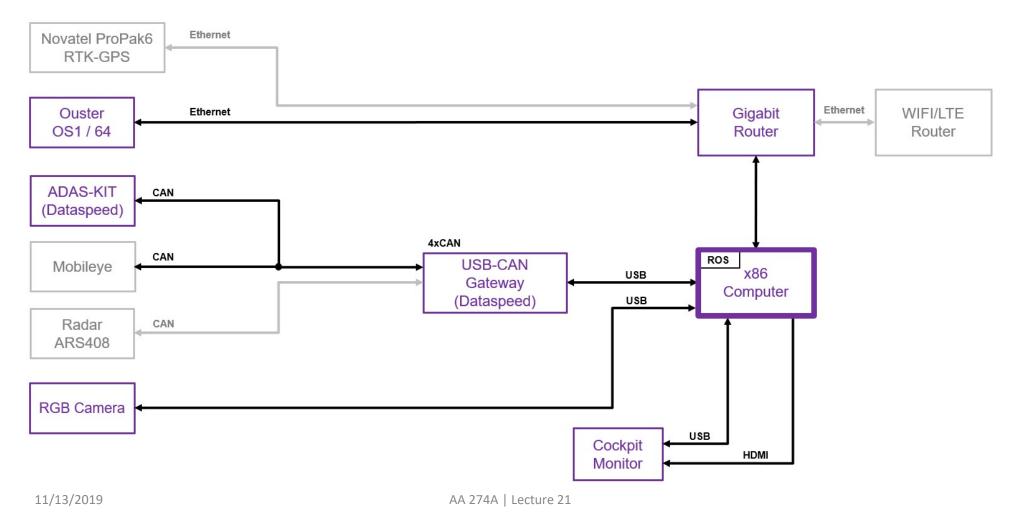


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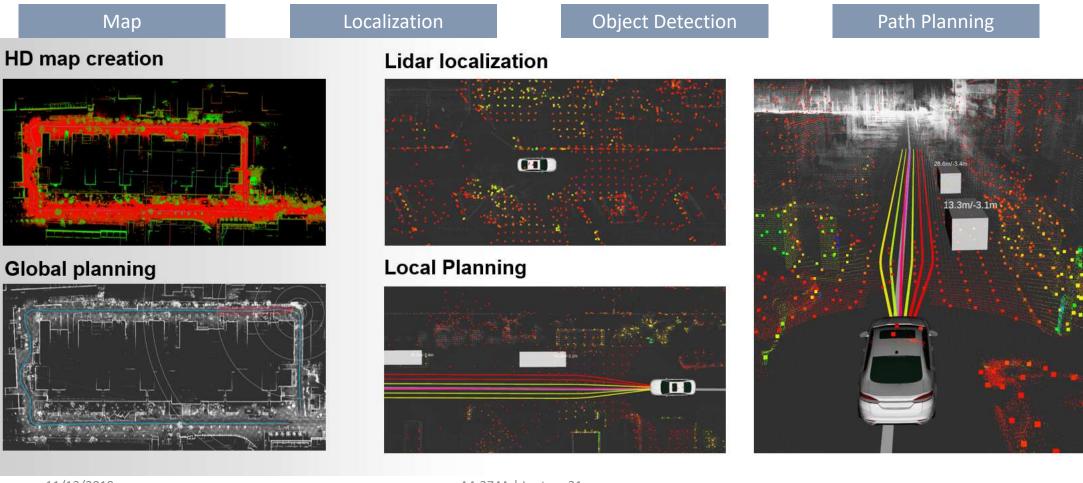


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### Hardware architecture



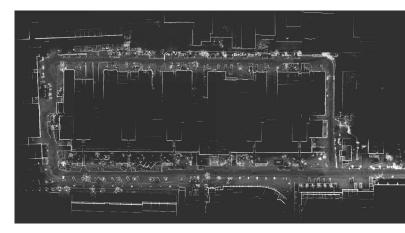
### Software components

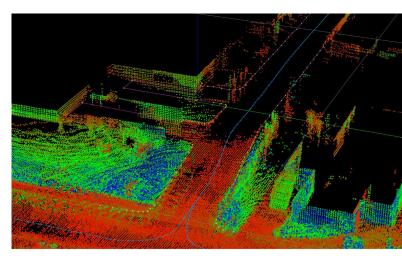


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### Mapping of Road Network

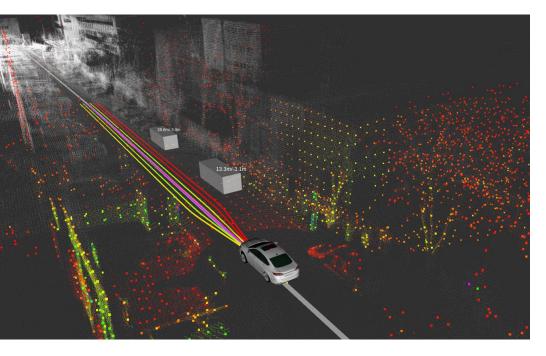
- Mapping for localization (without RTK-GPS)
  - Lidar with 64 layers (Ouster OS1-64)
  - NDT mapping
  - https://tools.tier4.jp/feature/vector\_map\_builder/
- HD map for path planning
  - Browser based tool for mapping (Tier IV)
  - Current data format: Asian Vector Map
  - Future data format: Lanelet2, OpenDrive

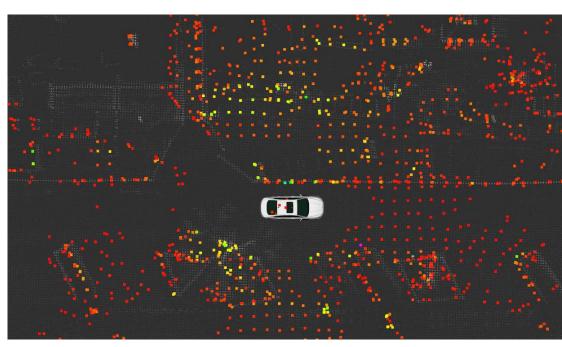




### Localization

- Normal distributions transform (NDT) matching
- Lidar based / 64 Layers / 20 Hz / Voxel Grid 1m

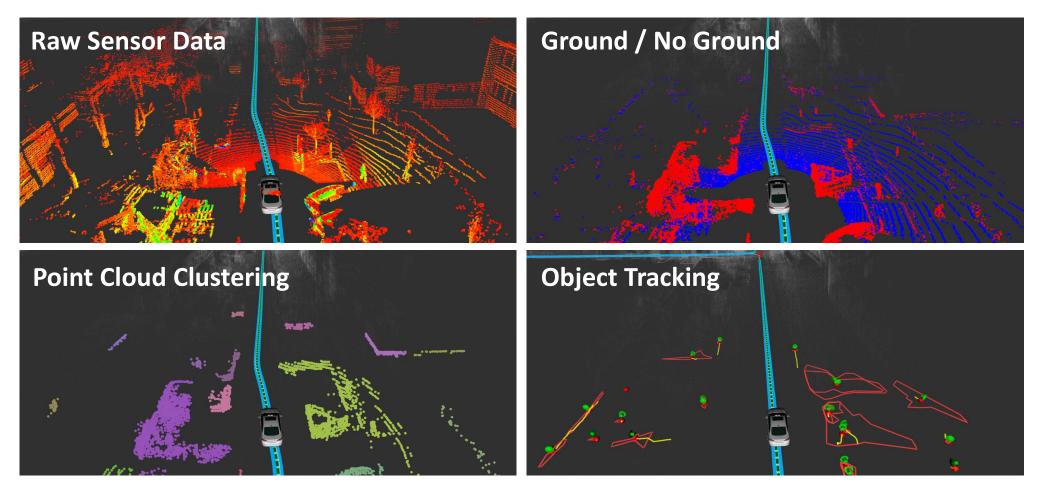




https://gitlab.com/autowarefoundation/autoware.ai/core\_perception/tree/master/lidar\_localizer/nodes/ndt\_matching

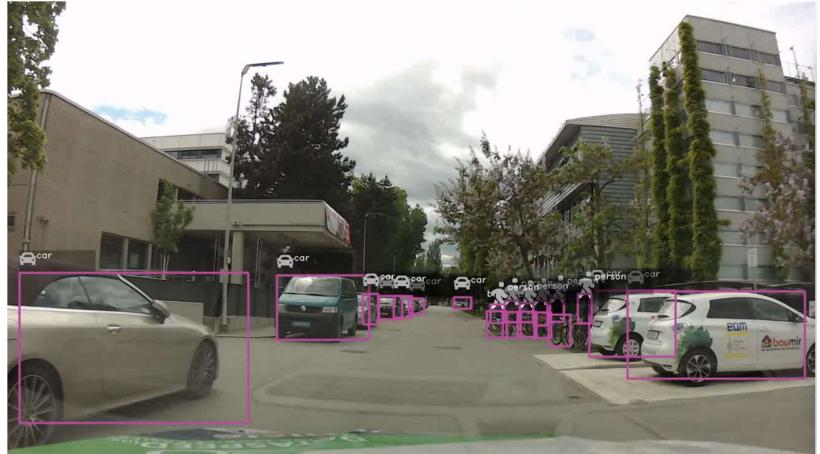
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### **Object Detection**



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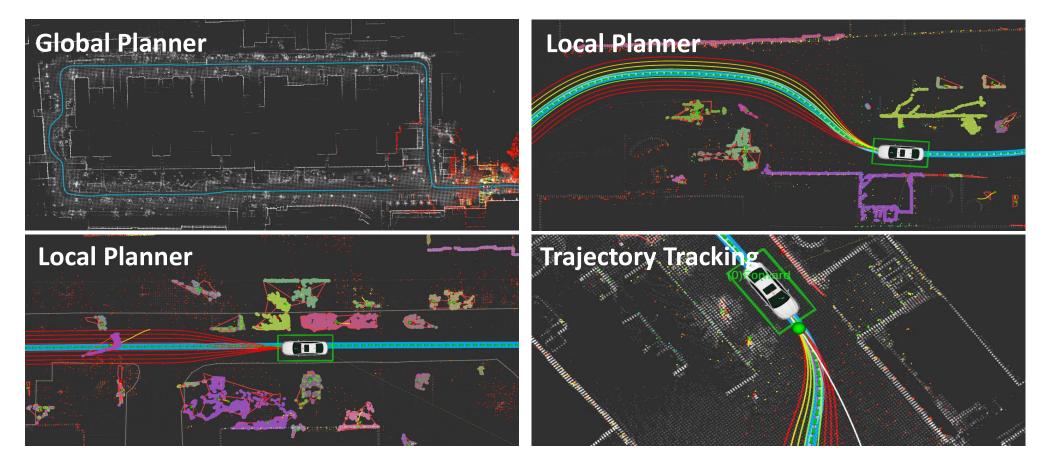
### **Object Detection / Classification**



Full HD RGB Camera / Yolo3: Neural Network for Object Detection

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### Path Planning / Trajectory Tracking



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### Vehicle Interface

- ADAS-Kit Dataspeed Inc.
- <u>Universal Lat/Lon Controller Interface</u>

Controller for drive-by-wire interface (exectution on Dataspeed ECUs)
 Velocity / yaw or curvature control (/twist\_cmd)





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### Hands-on

- Installation on PC
- Development environment
- Autoware Demos
  - Localization (with recorded data from TU/Stanford campus)
  - Object detection (with recorded data)
  - Path planning (with Autoware simulator)

### Installation

- Recommended System Specifications for complete stack
  - Number of CPU cores: 8, Nvidia GPU
  - RAM size: 32GB, Storage size: 64GB+

Depends extremely which components are used from the stack. Runs also in a virtual machine.

- Source Build
- Docker (recommended)

https://gitlab.com/autowarefoundation/autoware.ai/autoware/wikis/Installation

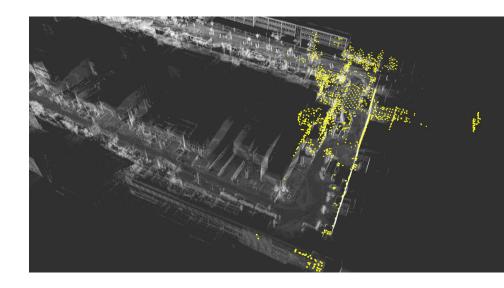
### Path planning

- Global planner [op\_global\_planner]
- Local planner [op\_trajectory\_generator, op\_motion\_predictor, op\_trajectory\_evaluator, op\_behavior\_selector]
  - Input: /tracked\_objects, /global\_path
  - Output: /final\_waypoints
- Trajectory Tracking [pure\_pursuit or mpc\_follower, twist\_filter]
  - Input: /final\_waypoints
  - Output: /twist\_cmd
- Autoware Simulator [wf\_simulator]
  - Input: /twist\_cmd
  - Output: /simulated\_objects

### Localization pipeline

- Map loader [points\_map\_loader]
  - PCD loader from map
- Voxel Grid Filter [voxel\_grid\_filter]
  - Downsampling lidar data
  - Leaf size: 2m (60MB/s  $\rightarrow$  ~1MB/s)
- Lidar based localization [ndt\_matching]
  - NDT matching
  - Input: /filtered\_points, /vehicle/twist
  - Output: /ndt\_pose
- EKF Localization Fusion [ekf\_localizer]
  - Input: /ndt\_pose, /vehicle/twist
  - Output: /ekf\_pose\_with\_covariance





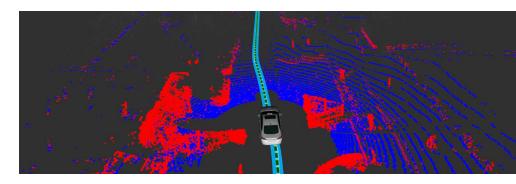
### Localization / Autonomous Racing Graz



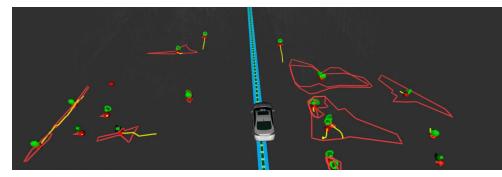
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### Object detection

- Ray ground filter [ray\_ground\_filter]
  - Separation ground / no ground
- Point cloud clustering [lidar\_euclidean\_cluster\_detect]
  - NDT matching
  - Input: /points\_no\_ground
  - Output: /points\_cluster
- Cluster tracker
   [lidar\_kf\_contour\_track]
  - Input: /points\_cluster
  - Output: /tracked\_objects







## Thanks for your attention! Questions?

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