Institute of Automotive Technology
TUM School of Engineering and Design
Technical University of Munich

Open Source Software for Teleoperated Driving

Tagung Automatisiertes Fahren, March 30, 2022

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Frank Diermeyer, Dr.-Ing.

Teleoperation of Vehicles

Full Video: https://youtu.be/bQZLCOpOAQc

What do we need it for?

Domain-specific **Limitations of Automated Vehicle** (AV).

AV achieves **risk-minimal State** when Operational Design Domain (ODD) is left.

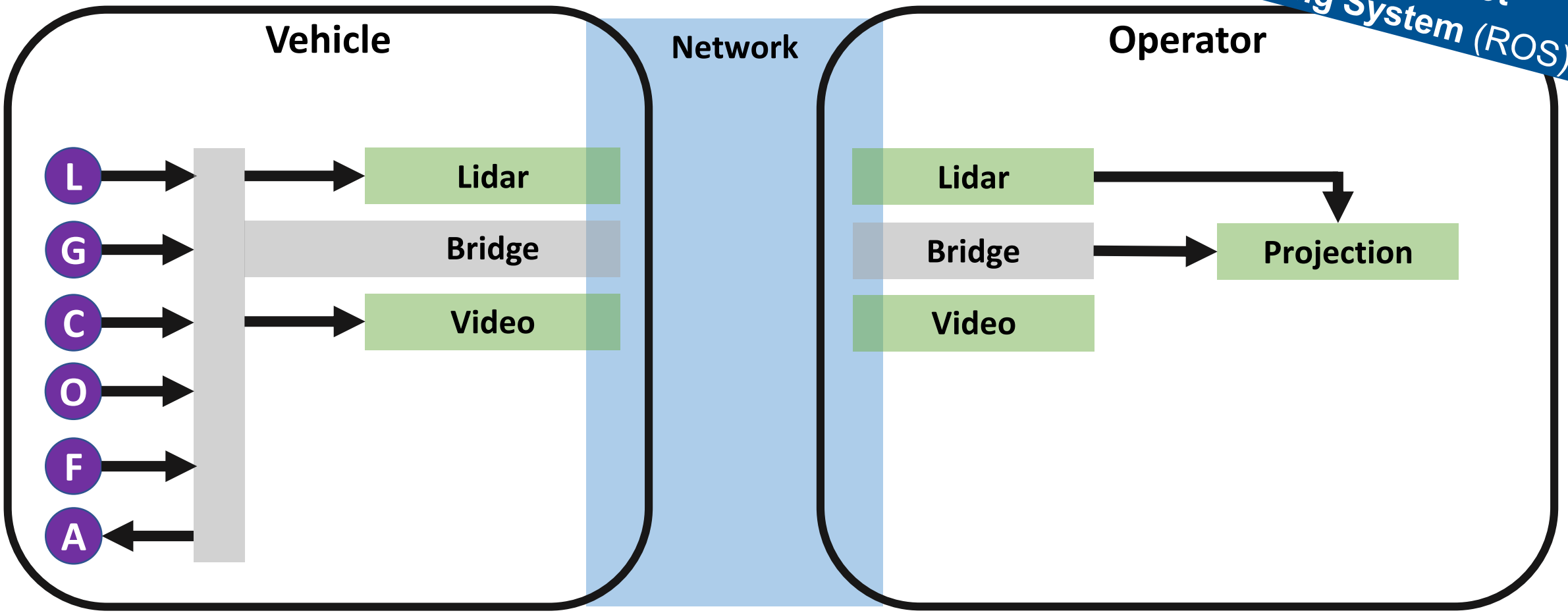
AV is **brought back into its ODD via Teleoperation**.

[1]

[2]

Software Architecture

Based on Robot Operating System (ROS)



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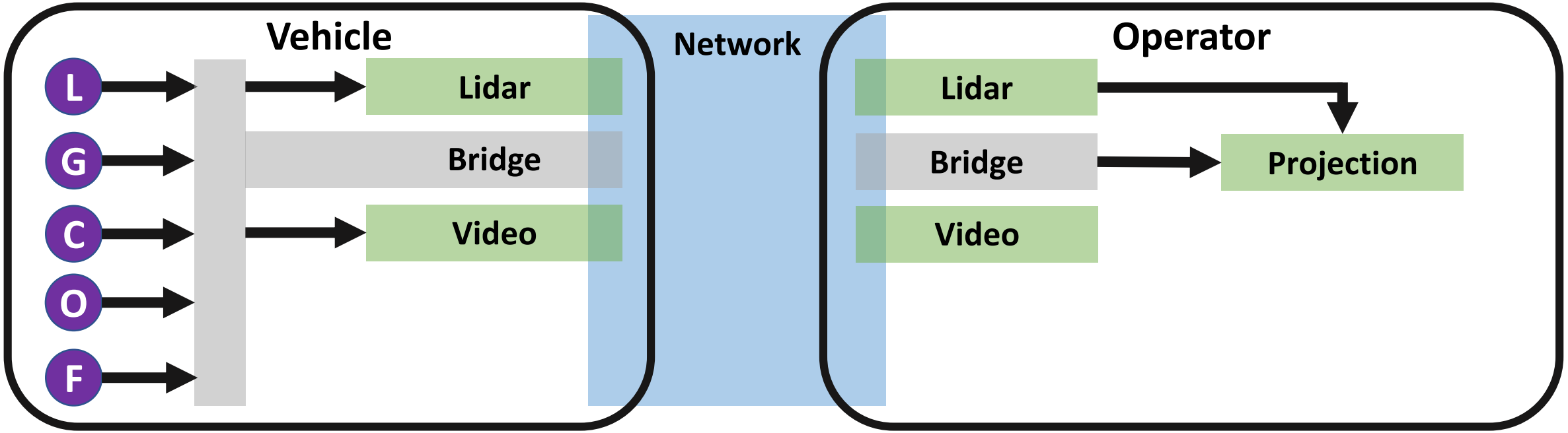


Perception for Teleoperation

Processing, Compression, Transmission & Preparation of Sensor Data for Human Operator

Lidar

Clustering, Grid Map, Object Detection

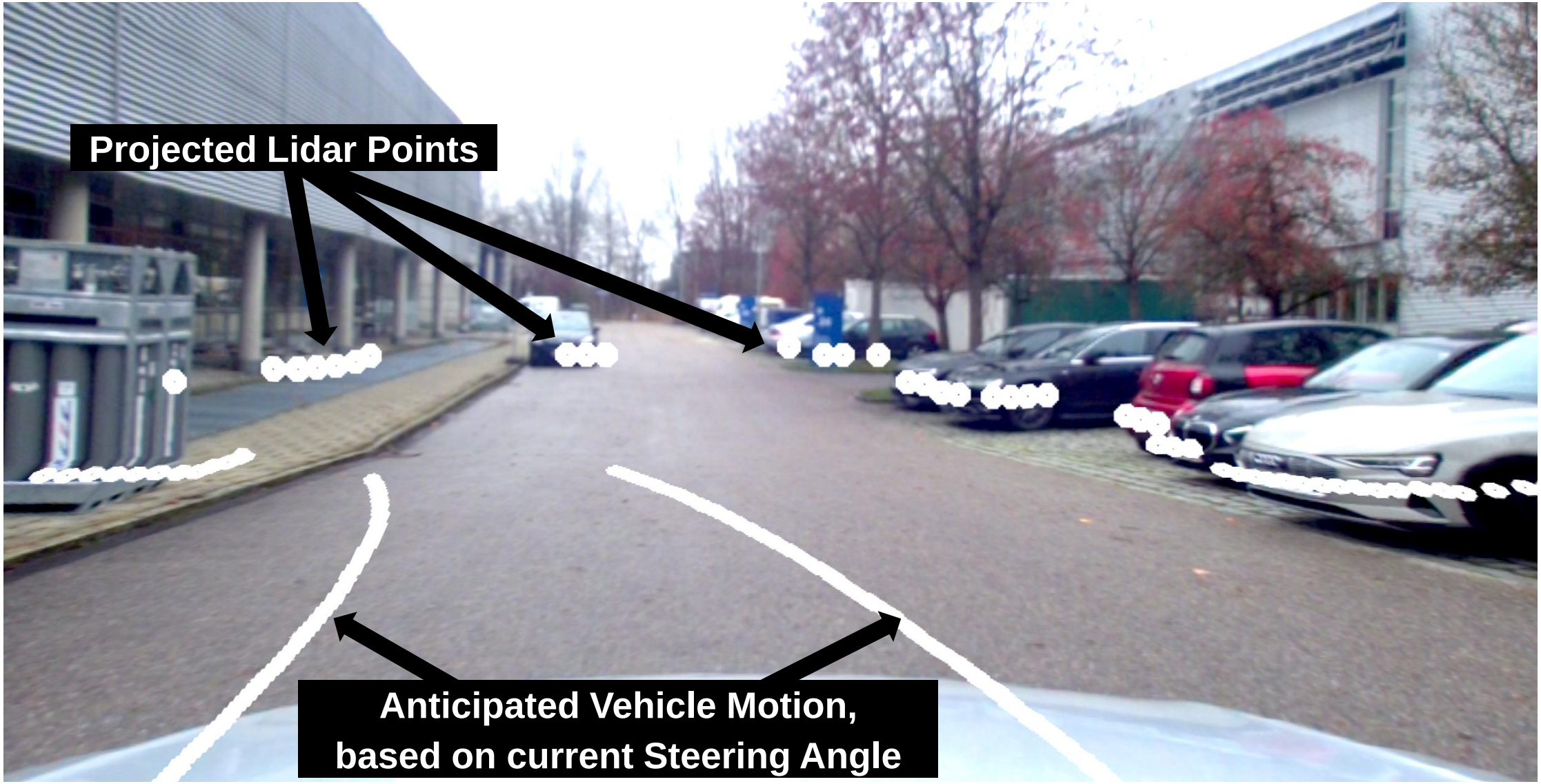
Video

Framework for Adaptation [3] based on GStreamer [4]

Projection

Preparation for Visualization

Projection of Elements on Video Stream



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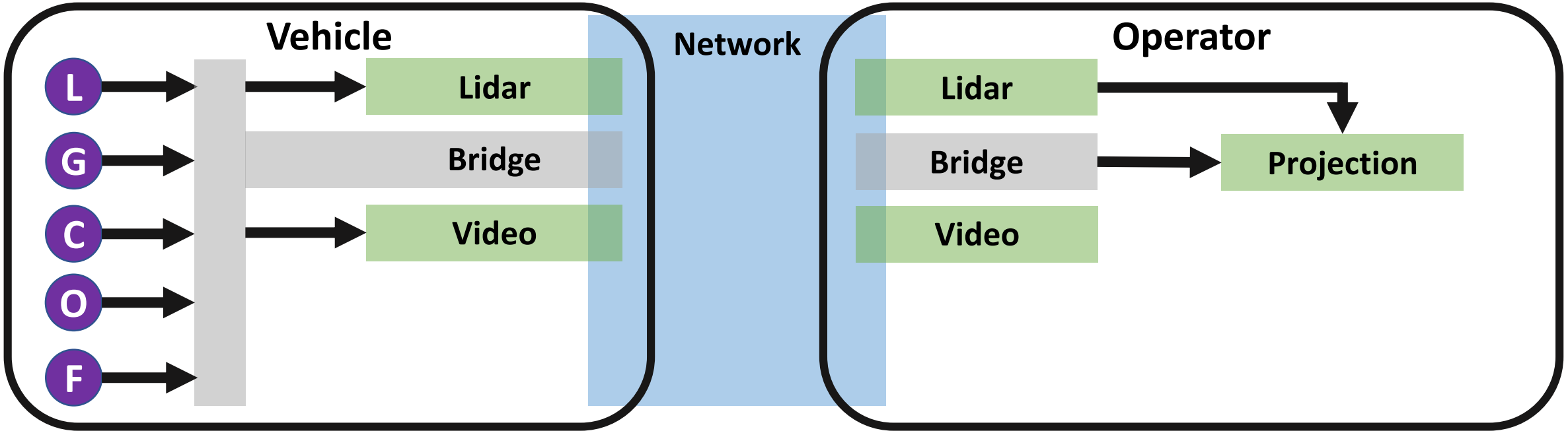

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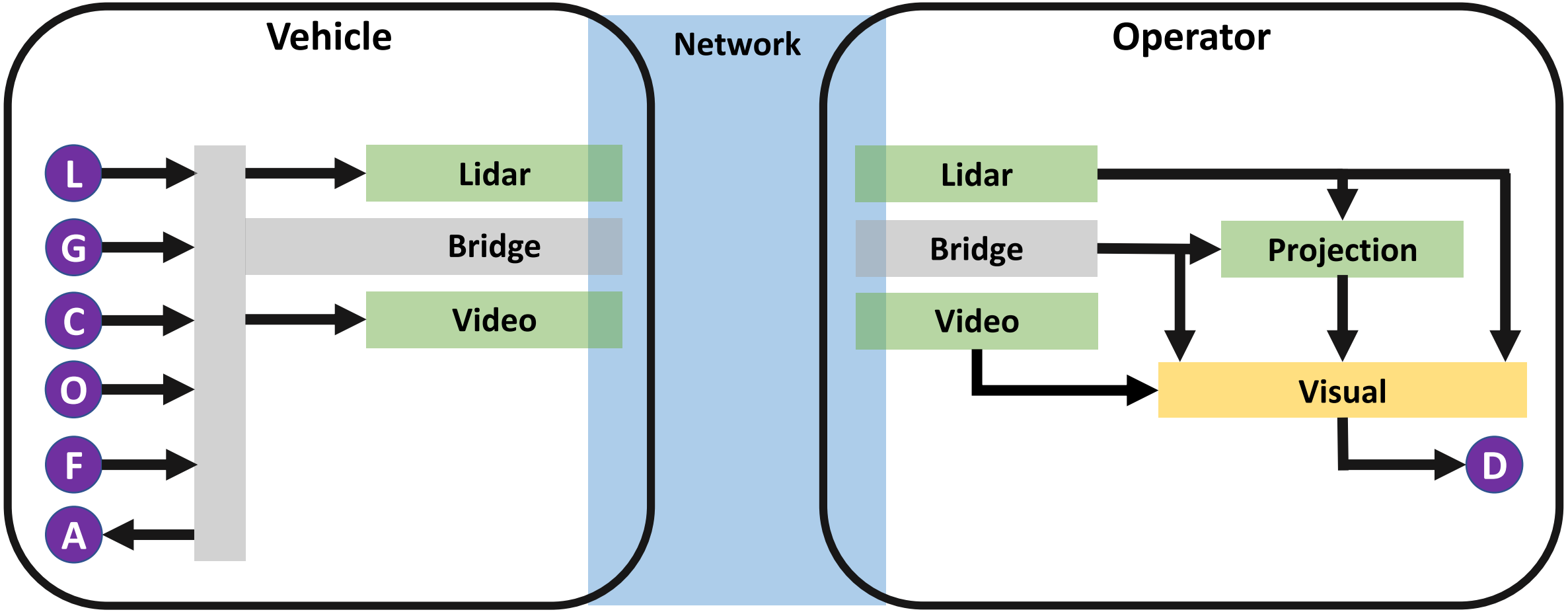

Visualization for Human Operator

Visual

Function-Rich and **Flexible Human-Machine-Interface**

Providing Human Operator with **Immersive Visualization of Vehicle Surroundings**

Construction of **3D World**, inspired by Open Source Game Engine *Hazel* [5]

Use of **Entity Component System** (ECS) design pattern through *entt* library [6]

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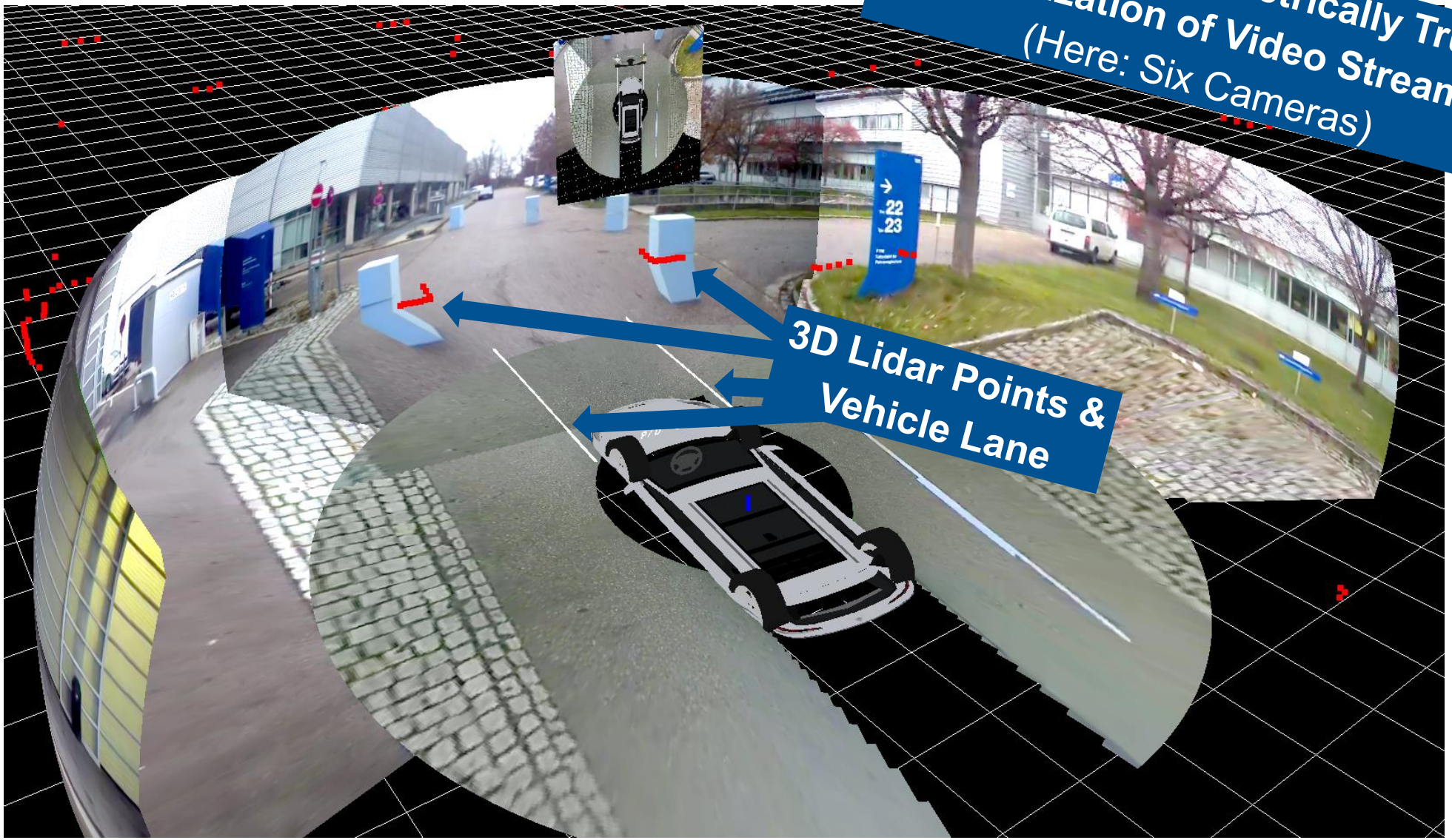

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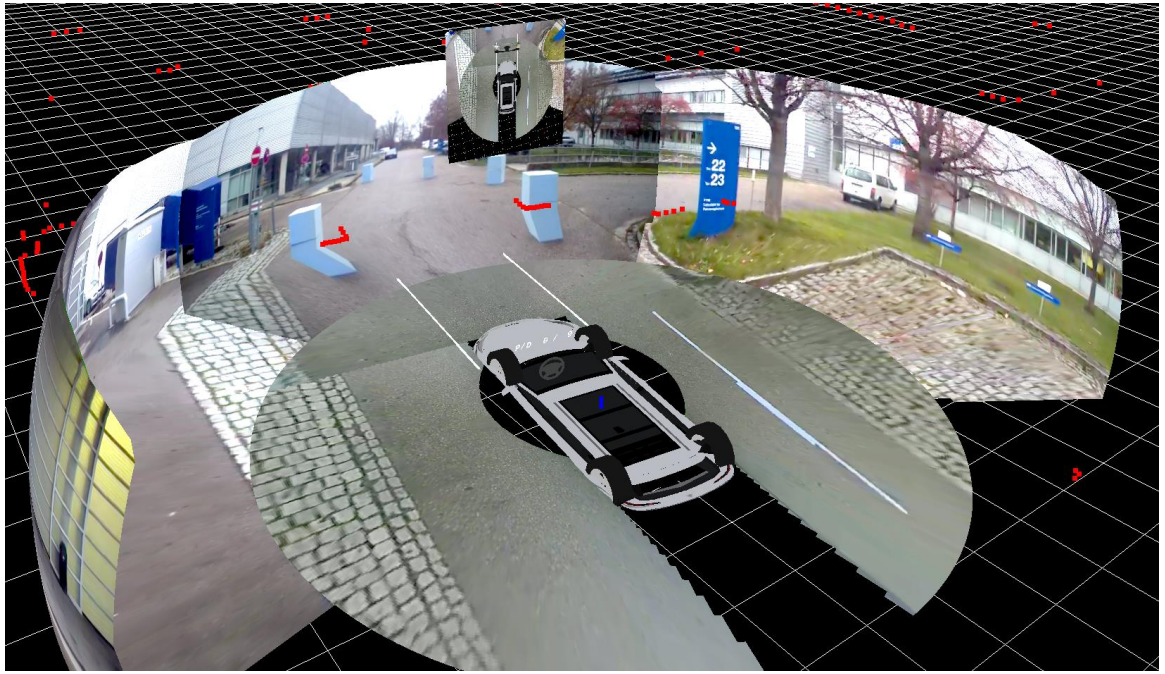
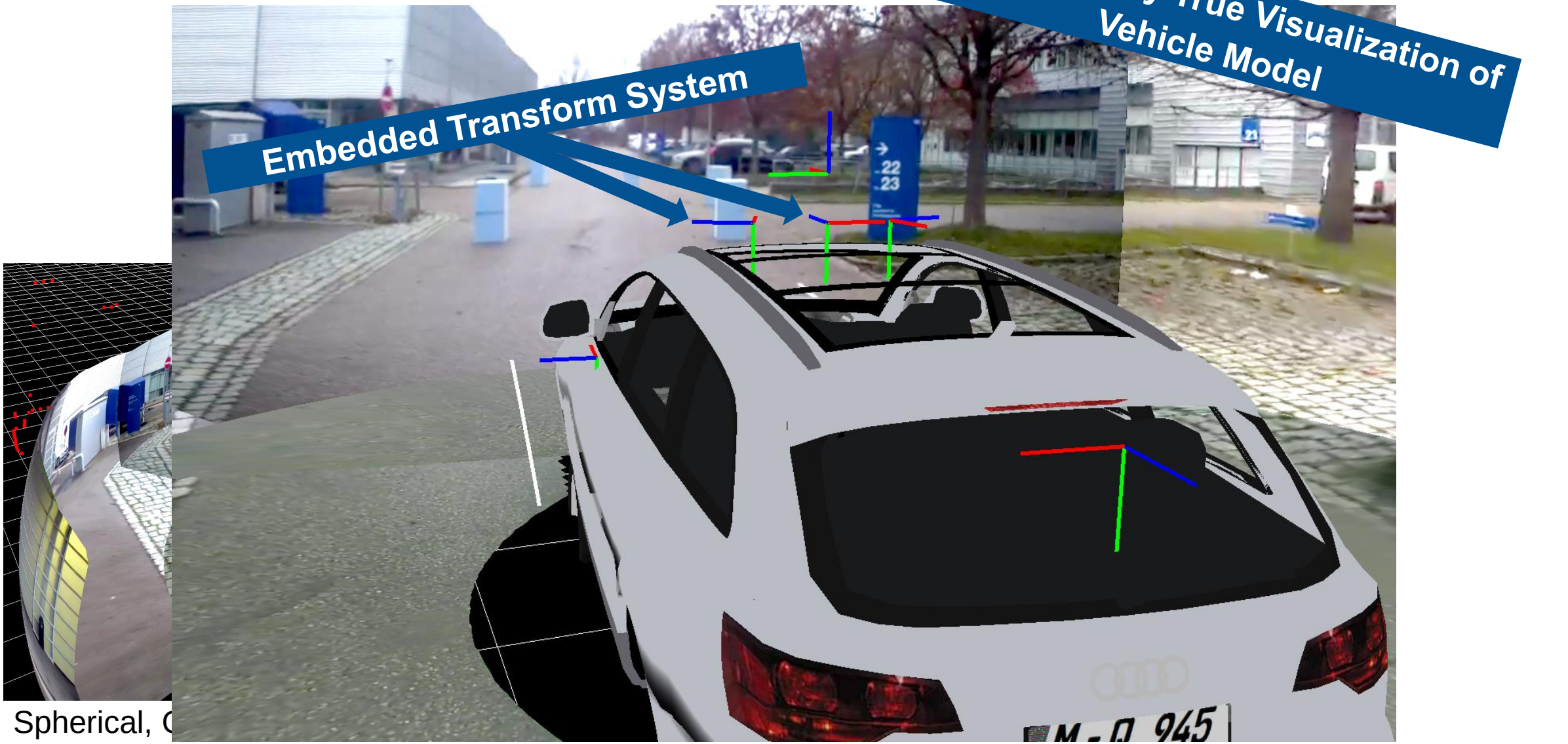


Spherical, Geometrically True Visualization of Videos

Visualization for Human Operator



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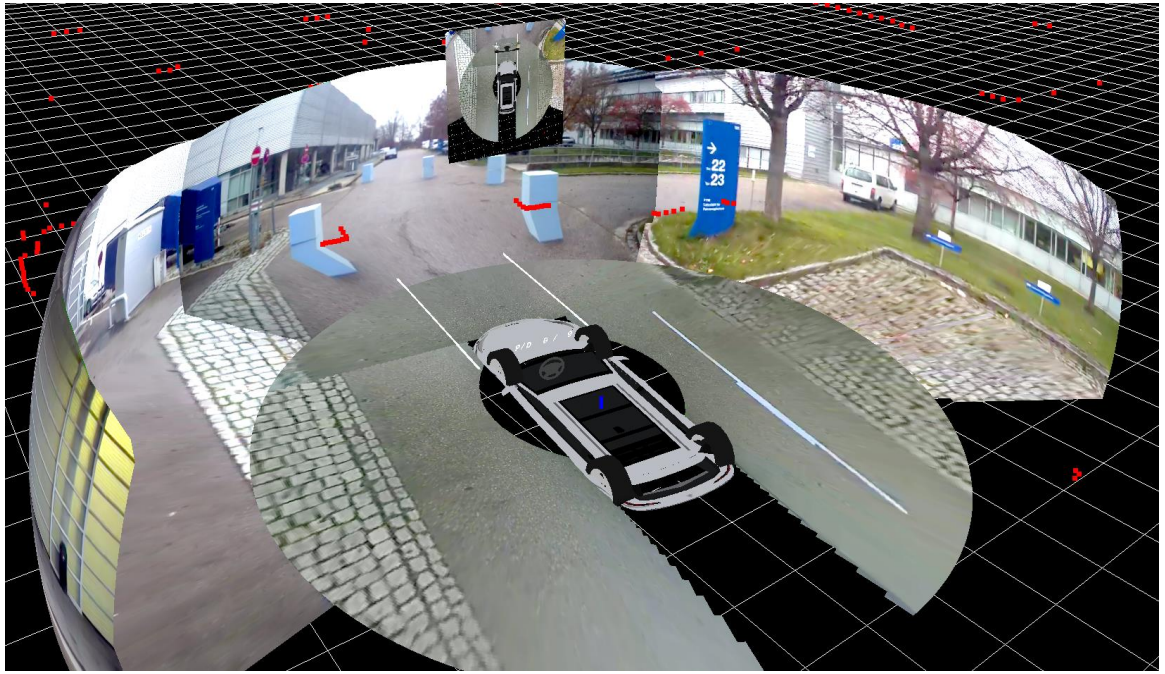

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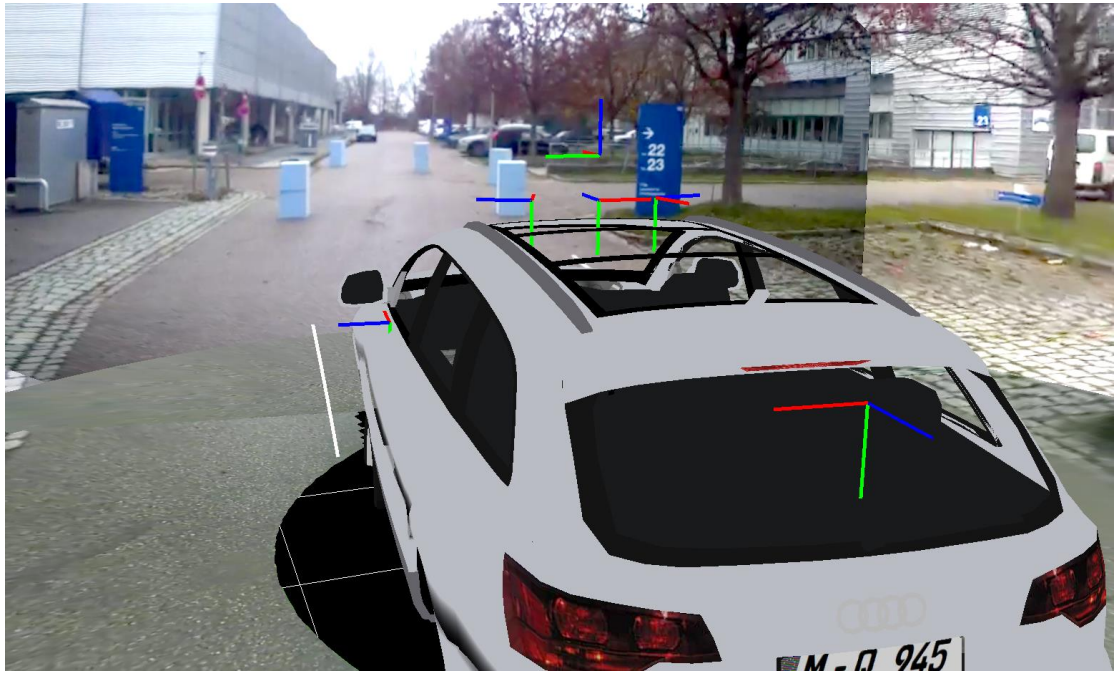
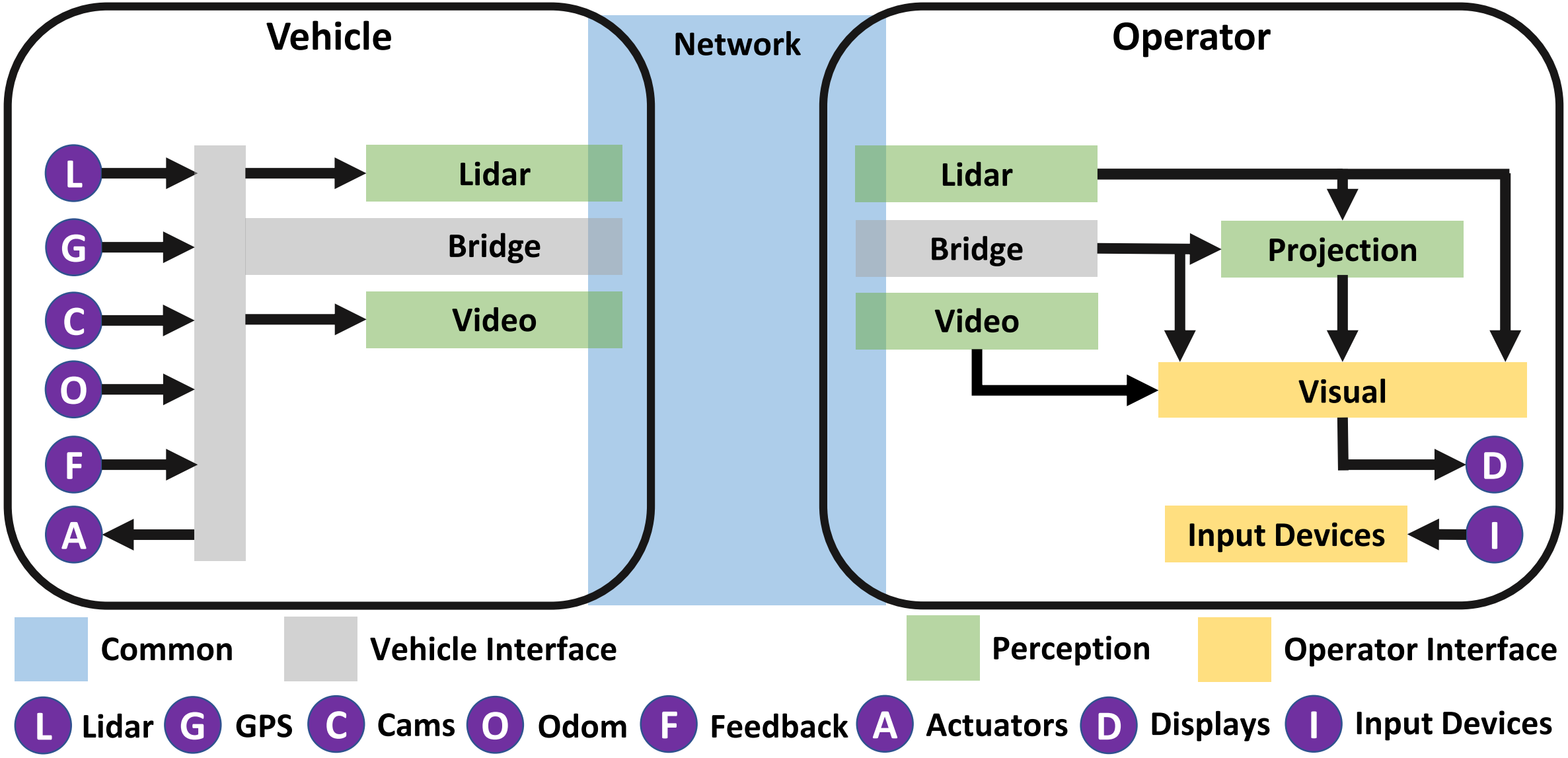


Vehicle Model and Transform System

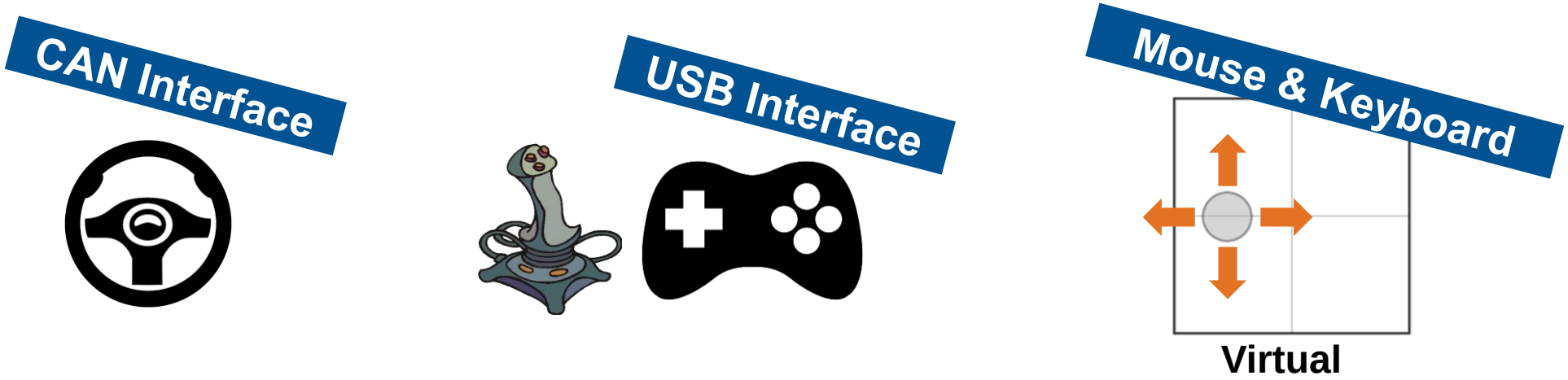
Software Architecture



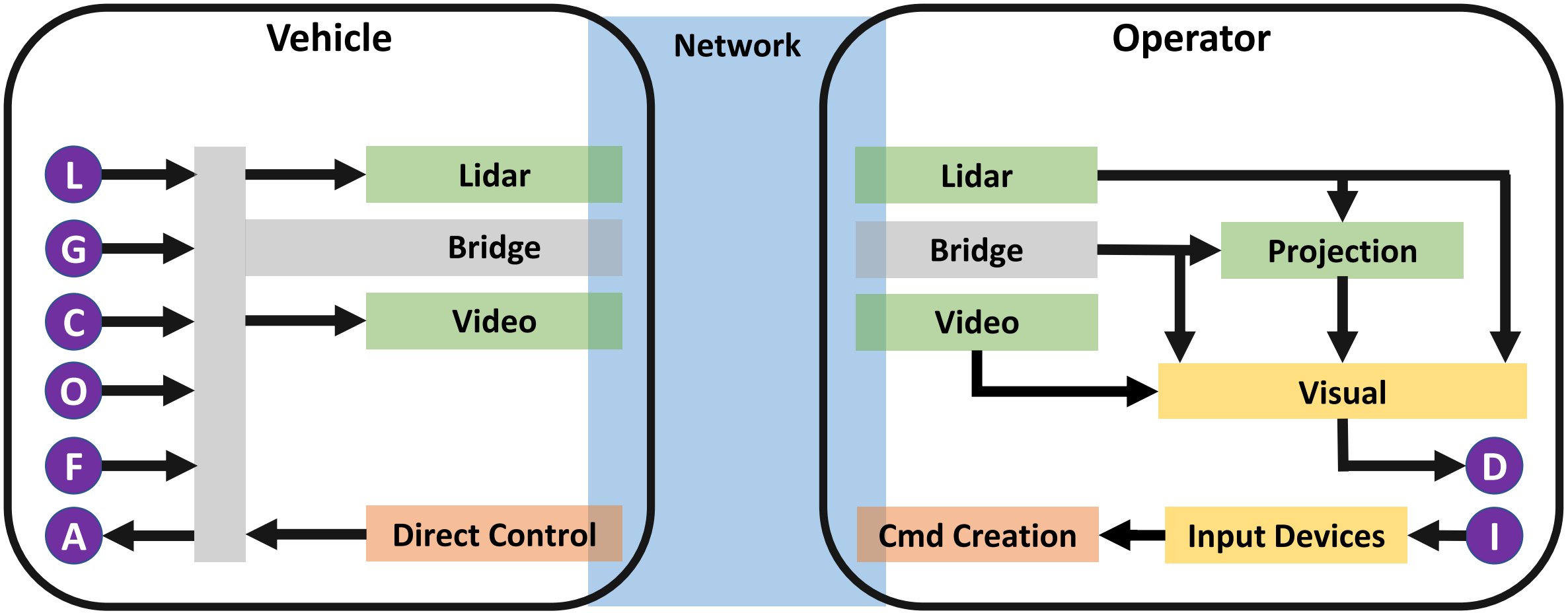
Support for Multiple Input Devices

Input Devices

Different Devices, Common Interface



Software Architecture



Challenges of Teleoperation

Latency
[8, 9]

Processing, transmission and actuation delays

Situation Awareness
[10]

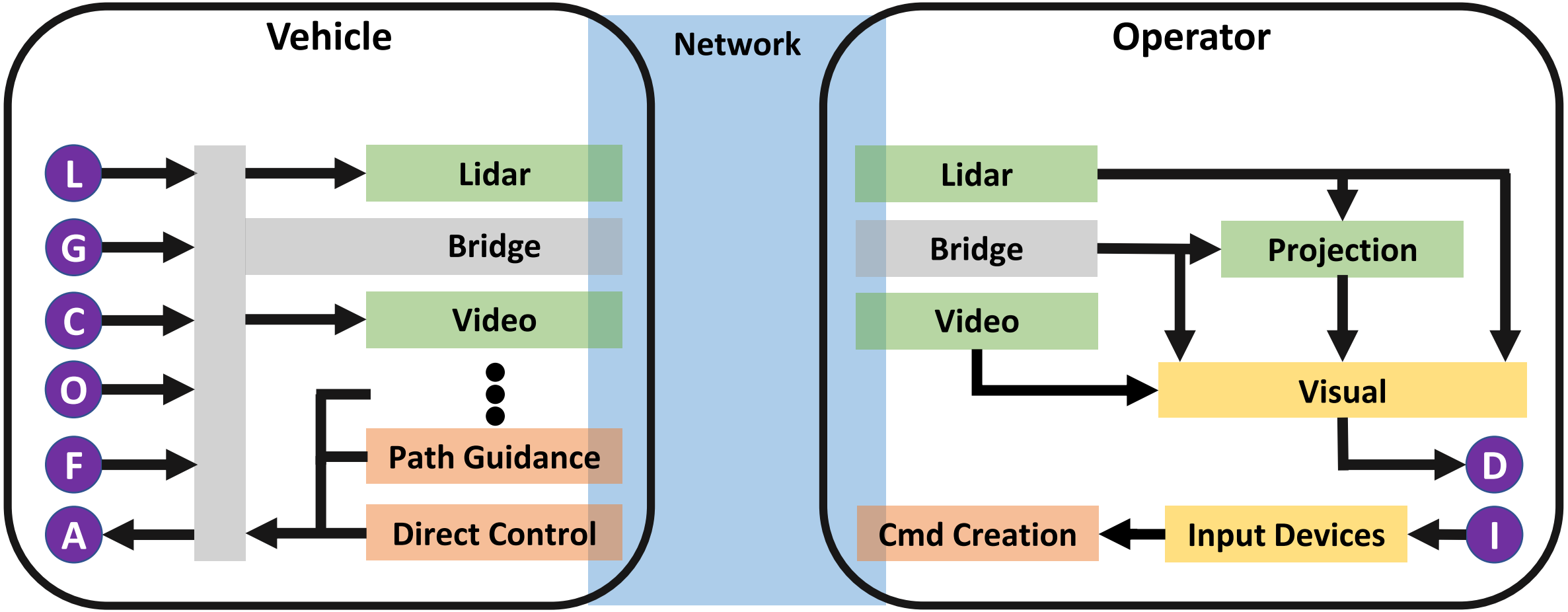
„Out-of-the-loop-syndrome“

Safety
[11]

Unstable network and risk of accidents

Assessment of different Teleoperation Concepts

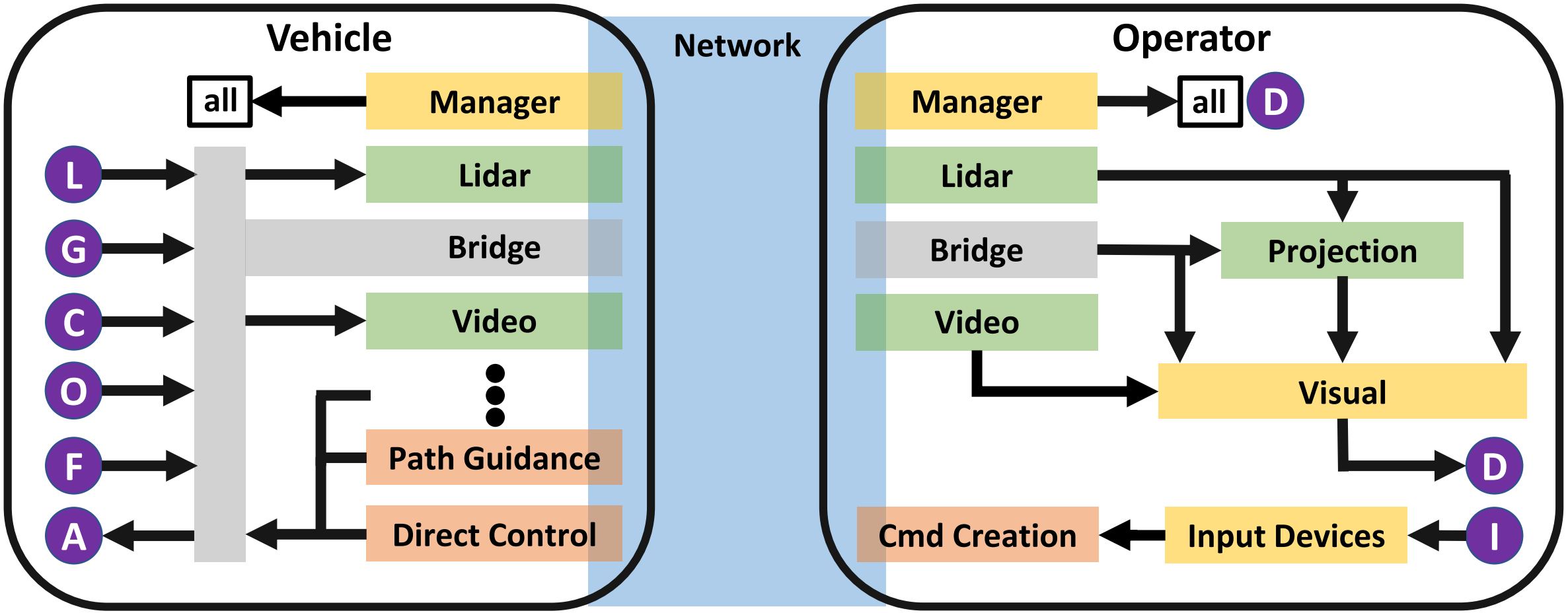
Software Architecture



Remote Path Guidance

(Playback Speed 2x)

Software Architecture



Vehicle Bridge defined through Set of Config Files

Vehicle Bridge

Configuration Files for

- Lists of Camera and Lidar Sensors
- Vehicle Transform Tree
- Vehicle Parameters (Dimensions, Steering Limit etc.)

Deployment of Software with minor Overheads
to **teleoperate arbitrary Ground Vehicle**

Teleoperation of 1:10-scale Vehicle Testbed

https://www.youtube.com/watch?v=bQZLCOpOAQc

Vehicle Bridge defined through Set of Config Files

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- Lists of Camera and Lidar Sensors
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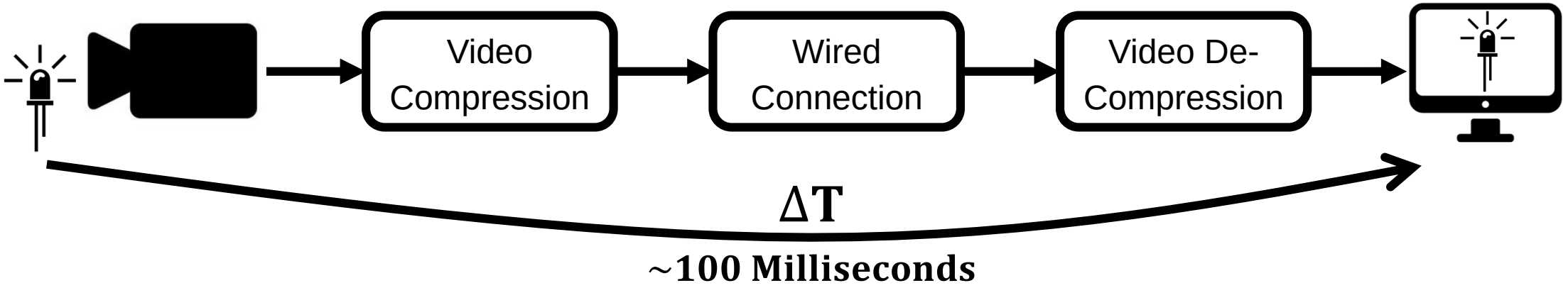
Deployment of Software with minor Overheads
to **teleoperate arbitrary Ground Vehicle**

3x **Full-scale Passenger Vehicle**	1x **1:10-scale Vehicle Testbed**	1x **Driving Simulator**	1x **Road Marking Machine**

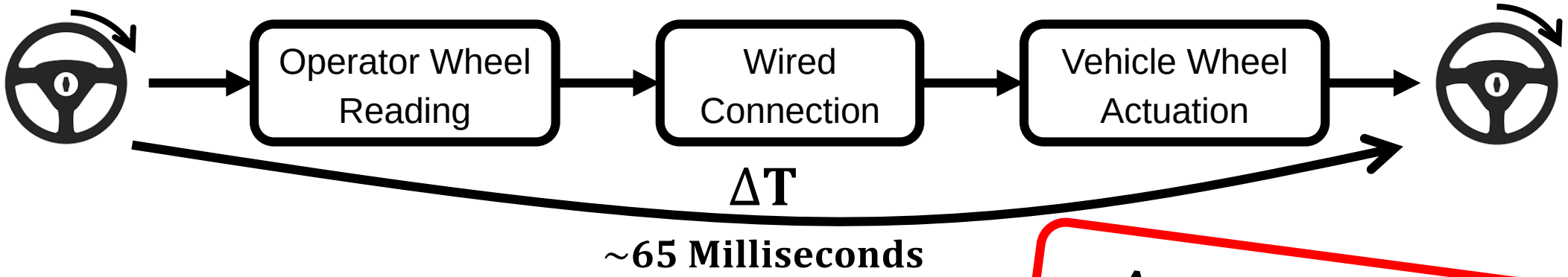
… more to come.

Latency Measurements with Passenger Vehicle

Uplink „Glass-to-Glass“ Latency



Downlink Actuation Latency



Analysis of Latencies *for* **Teleoperation** *System [9]*

Summary and Future Work

Summary

- Complete Software Stack for Teleoperated Driving
- Flexible and Usable through Conveniently Designed Vehicle Bridge and HMI
- Support to switch between different Teleoperation Control Modes and Input Devices

Future Work

- Further Improvements of HMI with Evaluation in Human Subject Studies
- Safety of Teleoperation
- Realization of Business Case through Remote Control Center

TUM FTM Teleoperated Driving Software Stack

available open source

https://github.com/TUMFTM/teleoperated_driving

References

[1] https://www.buschhueter.de/baustelle-rahlstedter-strasse-mitte-april-ist-erstmal-schluss/
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[3] A. Schimpe, S. Hoffmann, and F. Diermeyer, “Adaptive Video Configurationand Bitrate Allocation for Teleoperated Vehicles,” in Proc. of Workshop for Road Vehicle Teleoperation (RVT) at 2021 IEEE Intelligent Vehicles Symposium (IV21), 2021.
[4] GStreamer Team, “gstreamer - open source multimedia framework,” Accessed on: November 29, 2020. [Online]. Available: https://gstreamer.freedesktop.org/.
[5] Y. Chernikov, “Hazel Engine.” [Online]. Available: https://github.com/TheCherno/Hazel.
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[7] J. Feiler und F. Diermeyer, „The Perception Modification Concept to Free the Path of An Automated Vehicle Remotely,“ in VEHITS 2021 - 7th International Conference on Vehicle Technology and Intelligent Transport Systems
[8] J. F. Attig, Christiane Rauh, Nadine Franke, Thomas Krems, „System Latency Guidelines Then and Now -is Zero Latency Really Considered Necessary?,“ 2017.
[9] J.-M. Georg, J. Feiler, S. Hoffmann, and F. Diermeyer, “Sensor and Actuator Latency during Teleoperation of Automated Vehicles,” in Proc. of IEEE Intelligent Vehicles Symposium (IV), 2020, pp. 760–766.
[10] C. Mutzenich, S. Durant, S. Helman, and P. Dalton, “Updating our understanding of situation awareness in relation to remote operators of autonomous vehicles,” Cognitive Research: Principles and Implications, vol. 6, no. 1, p. 9, 2021.
[11] S. Hoffmann and F. Diermeyer, “Systems-theoretic Safety Assessment of Teleoperated Road Vehicles,” in 7th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2021). SciTePress, 2021, pp. 446–456.

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