Layer-based Multi-sensor Fusion Architecture for Cooperative and Automated Driving Application Development

TNO, integrated vehicle safety (IVS), the Netherlands

dr.ir. Maurice Kwakkernaat
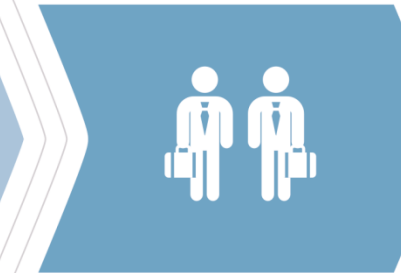**dr.ir. Tjerk Bijlsma**
ir. Frank Ophelders

Our mission

TNO connects people and knowledge to create innovations that boost the sustainable competitive strength of industry and well-being of society.
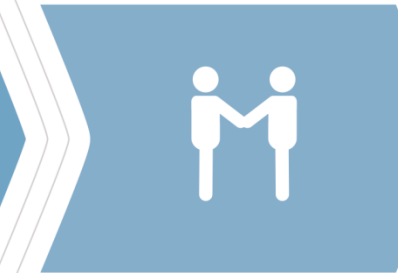
DEVELOPING FUNDAMENTAL KNOWLEDGE

KNOWLEDGE DEVELOPMENT

KNOWLEDGE APPLICATION
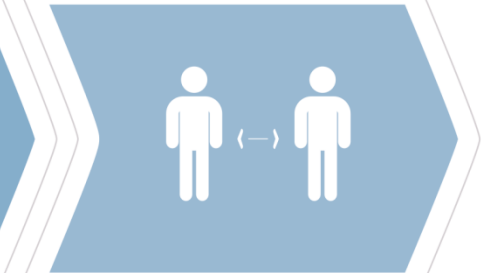
KNOWLEDGE EXPLOITATION

With universities

With partners in the golden triangle
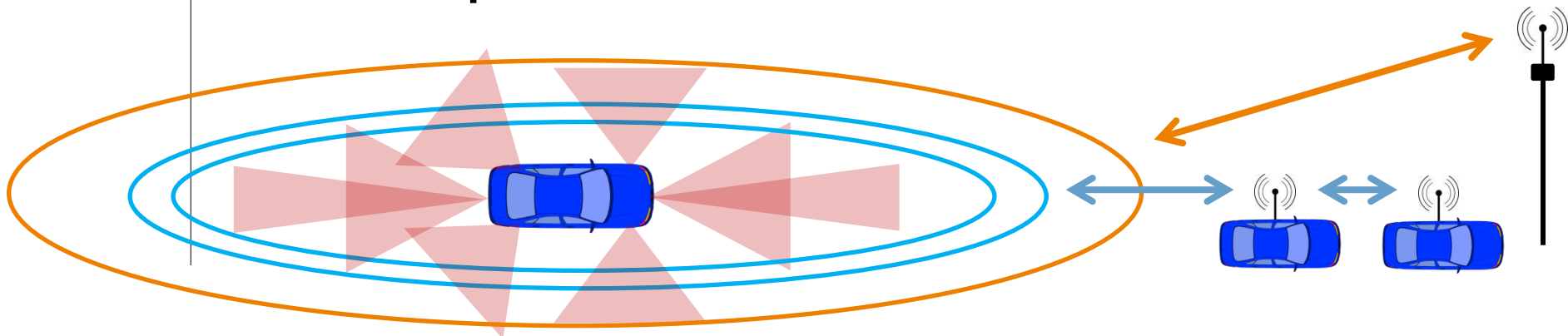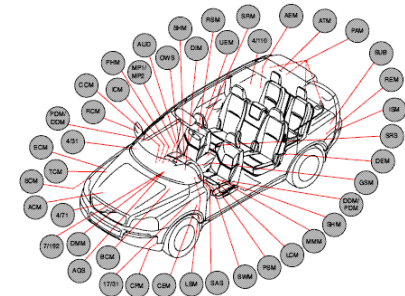
Contract research for and with customers

Embedding in the market (with TNO companies)

Transport and mobility is one of TNO's 7 innovation areas
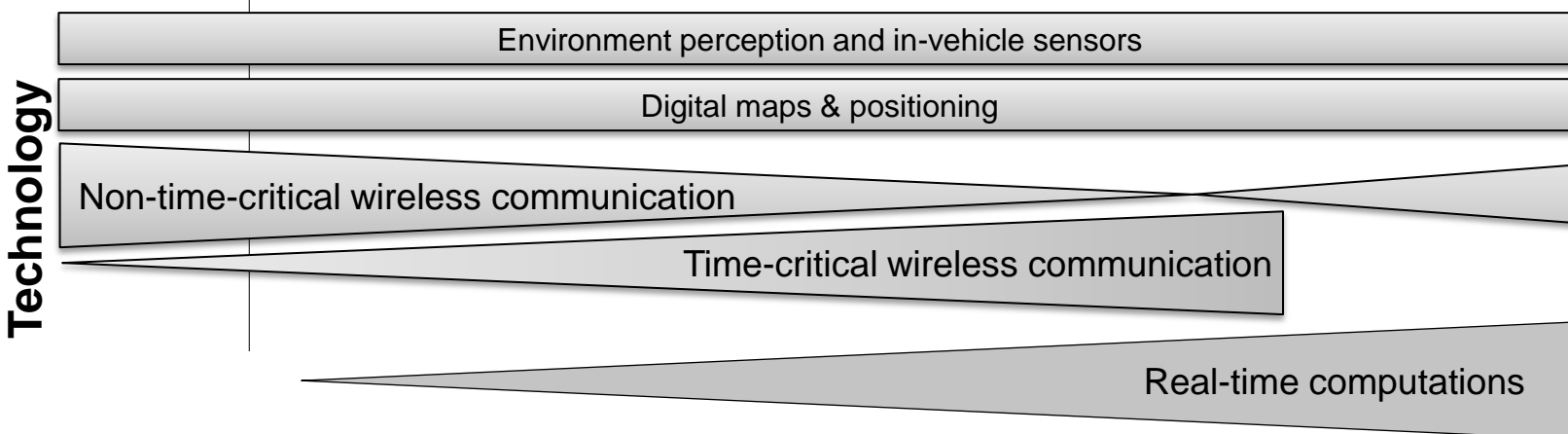
Introduction

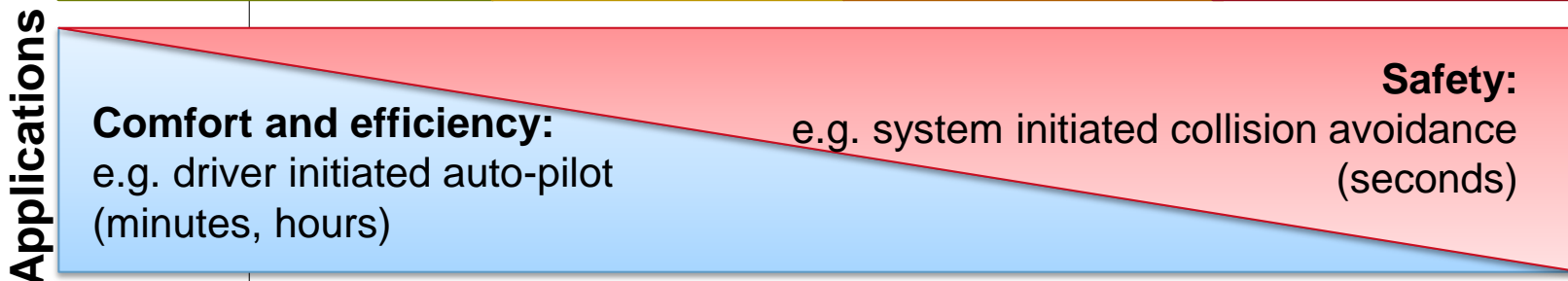› Current ADAS

  › Single functionality, independent operation
  › Limited information sources

› Next generation cooperative and automated ADAS

  › Multi-functionality, more sensors, communication, information
  › Shared resources, information and functions
  › Safe, comfortable and efficient driving

› **Development, prototyping and testing becomes much more complex and takes much more time!**

Introduction

| Normal driving | Critical situation | Crash imminent | Crash unavoidable | Post-crash |

TTC = 3 s   1,5 s   500 ms   0 s

| Information zone | Warning zone | Avoidance zone | Pre-crash zone |

Applications

Comfort and efficiency:
e.g. driver initiated auto-pilot
(minutes, hours)

Safety:
e.g. system initiated collision avoidance
(seconds)

Technology

Environment perception and in-vehicle sensors

Digital maps & positioning

Non-time-critical wireless communication

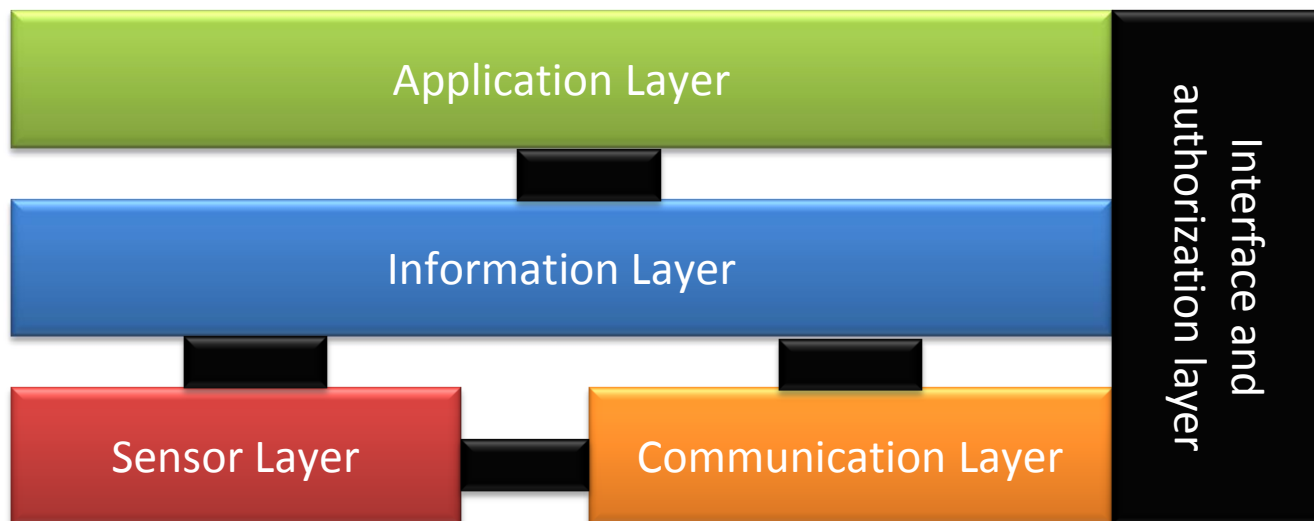Time-critical wireless communication

Real-time computations

Objectives

› Define development architecture for next generation ADAS
  › Prototyping, testing and evaluation in real-life pilots

› Implement a centralized safety awareness platform
  › Seamless handling, fusion and processing of information
    › A-priori data (e.g. digital maps)
    › Sensor data (e.g. vehicle sensors, radar, camera)
    › Communication data (e.g. 802.11p, ITS-G5, 3G)
  › Provide real-time situational awareness
  › Scalable, flexible, multiple interfaces and secure

› Provide generic information interface to application developers

› Efficiently develop and evaluate new applications in real-life
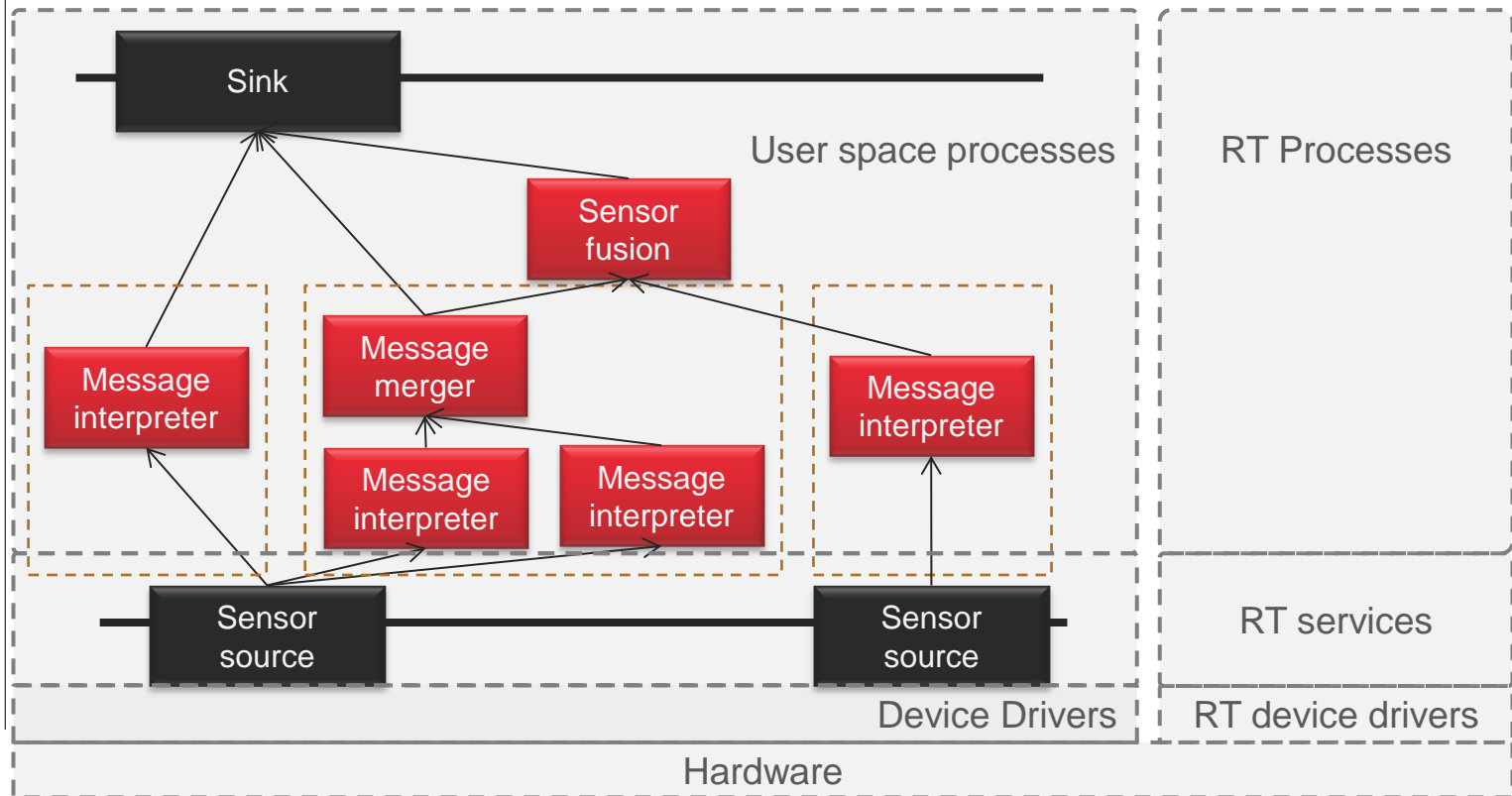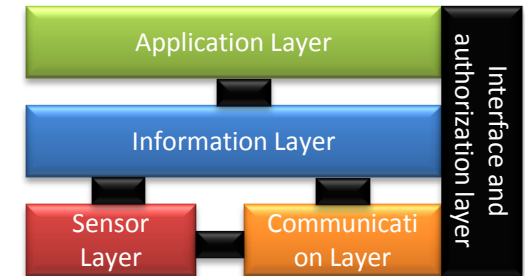
iVSP architecture

- › Five interconnected layers with own set of functionalities
  - › Object oriented approach
  - › Functionalities can be reused
  - › Security
- › Flexible sensor and communication interfaces, easily adaptable
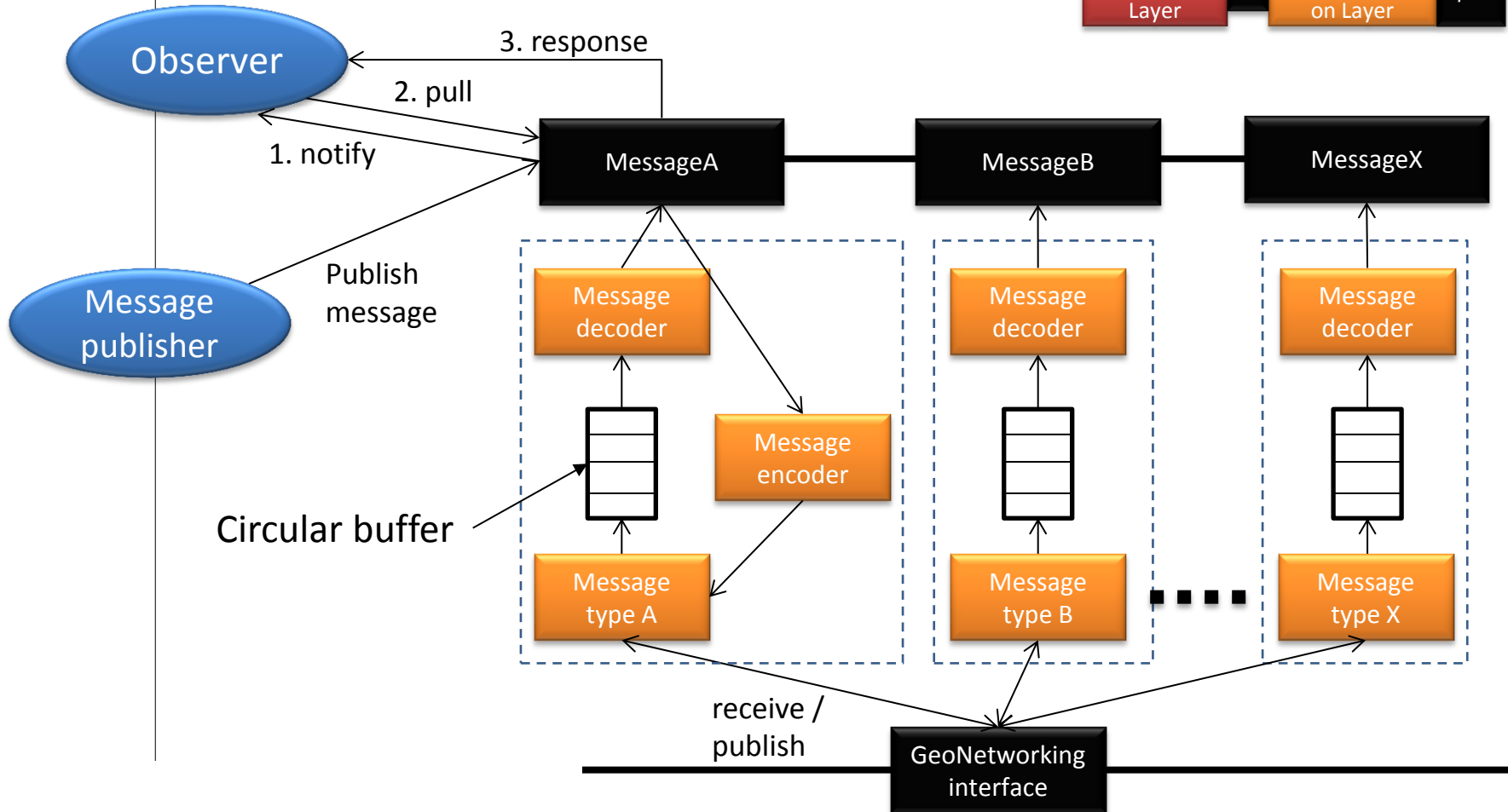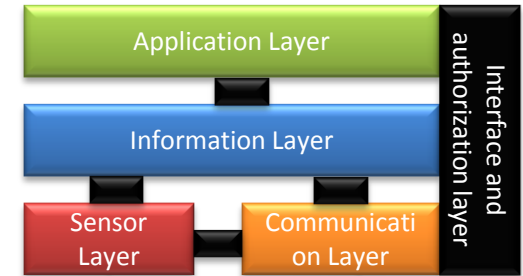- › Applications decoupled from low-level interfaces and processes

Sensor layer

> Data flow structure, acyclic event based
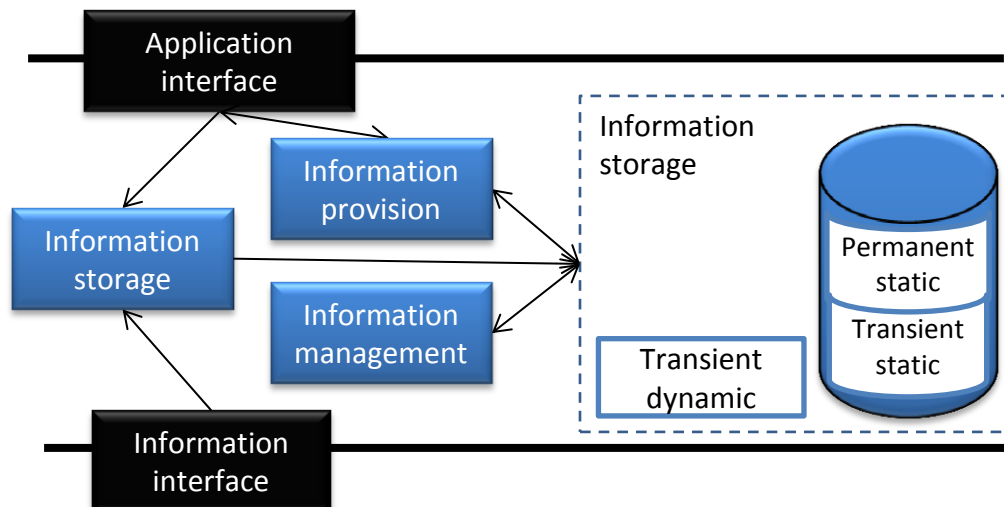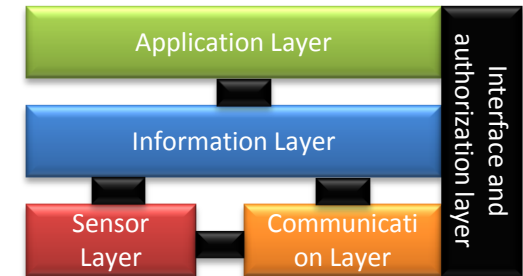> Easy addition of sensors and fusion processing (Matlab/Simulink)

Communication Layer

Application Layer

Interface and authorization layer

Information Layer

Sensor Layer

Communication Layer

Observer

3. response

2. pull

1. notify

Message publisher

Publish message

MessageA

MessageB

MessageX

Message decoder

Message decoder

Message decoder

Message encoder

Circular buffer

Message type A

Message type B

Message type X

receive / publish

GeoNetworking interface
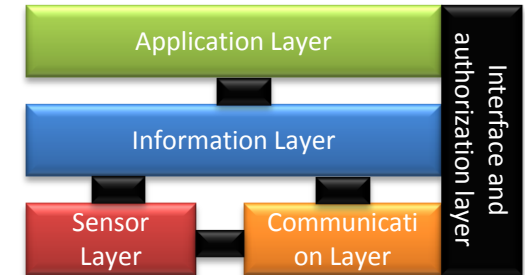
Information layer

> Collects, stores and provides information
>> Transient dynamic (< sec) → volatile memory
>> Transient static (min - hours - days) → MySQL
>> Permanent static (months - years) → MySQL
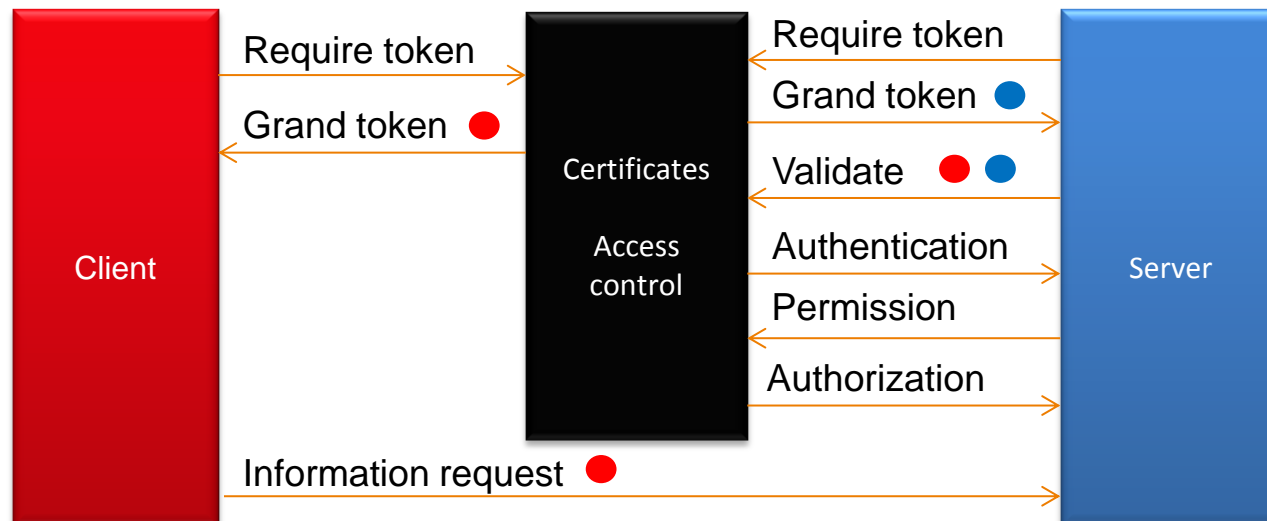> Authorization via interface and authorisation layer
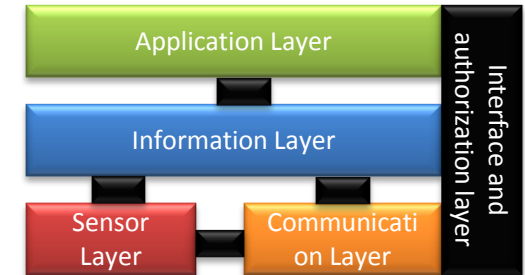
Interface and authorisation layer

› Communication between layers
  › Apache Thrift → C++, Java, Python, JavaScript
› Communication between different HW platforms
  › E.g. rapid control prototyping (RCP) platforms
› Authentication, authorization, security
  › Public key, certificates
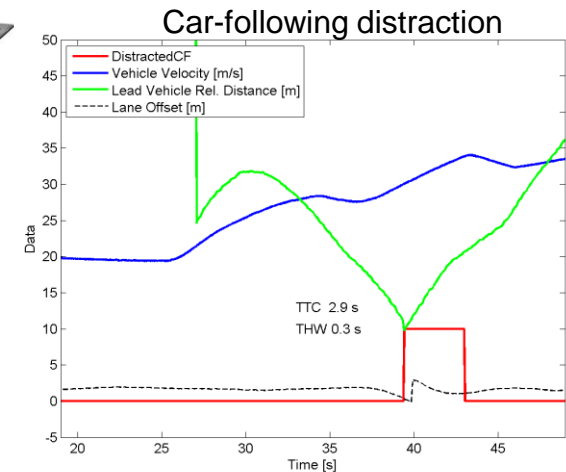 › Access control matrix

Application layer

> Application logic and algorithms

>> Interface to driver (HMI) and actuation of vehicle

> Application layer can run on separate platform

> Information layer provides generic information interface

>> Application decoupled from low-level interfaces

> Results of developed applications based on iVSP

>> DSPI: driving safety performance indicator

>> eMission: eco-mobility game

>> Compass4d: cooperative intersection and hazard warning

>> CAEB: Cooperative automated emergency braking

DSPI: Driving Safety Performance Indicator

› Detection of distraction based on insufficient driving performance

› Detect and log safety-critical events

› Single vehicle instrumented

  › Intel atom in-vehicle computer

    › iVSP HW platform

  › Sensor layer

    › Vehicle CAN-BUS

    › Mobileye C2-270

› Two driving tasks considered

  › Lane-keeping

  › Car-following (or approaching)

› 75% correct prediction of distraction

› Will be scaled-up to ~25 vehicles

Car-following distraction

eMission: eco-mobility game

› Reduce emissions by changing driving behavior via game

› 3 vehicles instrumented
  › Intel atom in-vehicle computer
    › iVSP HW platform
  › Sensor layer
    › Vehicle OBD2 interface
  › Application layer on mobile device
    › Interfaced via wifi
    › Performance indicator algorithm

OBD2

Compass4d: cooperative intersection and hazard warning

› Cooperative services at 7 pilot sites in Europe (iVSP in 25 vehicles)
- › Energy Efficient Intersection Service
- › Road Hazard Warning
- › Red Light Violation Warning

› Sensor layer processes MobilEye C270 vision safety system

› Communication layer interprets latest (ETSI) message set
- › CAM, DENM, MAP, SPAT

› Information layer combines information

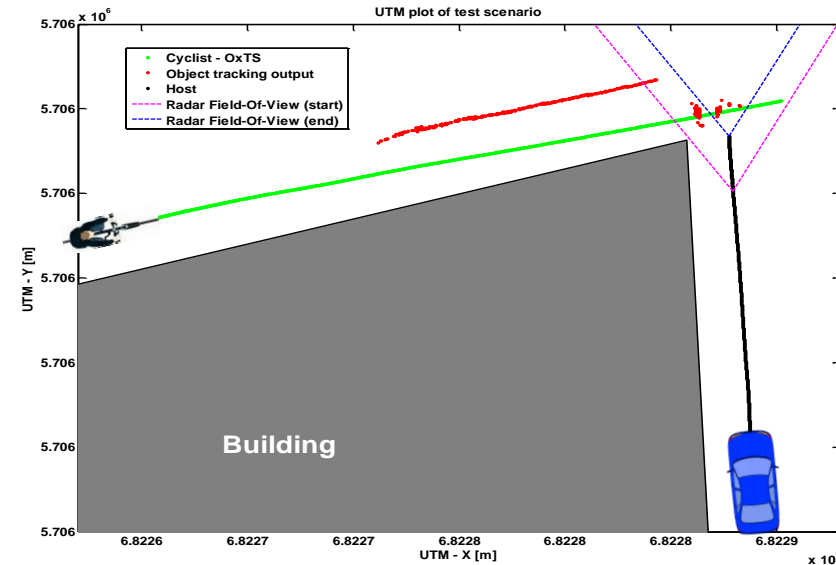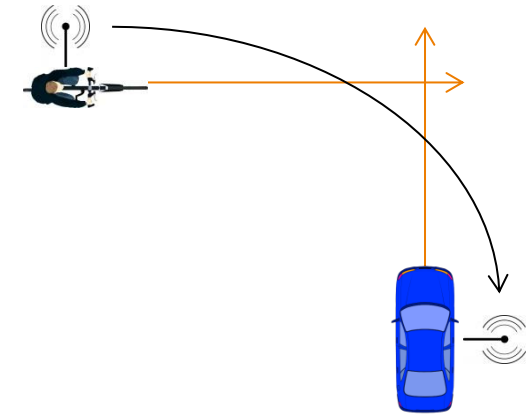› Application layer on Android device
- › Interfaced via wifi

CAEB: Cooperative automated emergency braking

› Collision avoidance using sensors and V2X
  › Sensor layer
    › GPS and motion sensors
    › Radar and camera sensor
  › Communication layer
    › ITS-G5 (ETSI CAM)
  › Information layer
    › Sensor fusion, object tracking
  › Application layer
    › AEB control algorithmic

UTM plot of test scenario

Legend:
- Cyclist - OxTS
- Object tracking output
- Host
- Radar Field-Of-View (start)
- Radar Field-Of-View (end)

Building

UTM - Y [m]

UTM - X [m]

Conclusions

› Architecture of a centralized safety awareness platform: iVSP
  › Data collection, processing, fusion and information exchange
  › Layer-based, scalable, flexible solution
› Provides efficient development, prototyping and evaluation of cooperative and automated driving applications
› Allows application developers to focus on application
› Easily adaptable for different type of applications
› Reduces complexity and time-to-market of new applications
› Provides cost effective solution
› iVSP approach successfully applied in several applications

Future work

› Distributed information exchange

› Real-time scheduling and bounded latency

› Functional safety

› Application of iVSP in automated driving applications

Thank you!

- Maurice Kwakkernaat
  - maurice.kwakkernaat@tno.nl
  - +31 (0) 888662442

- www.tno.nl