

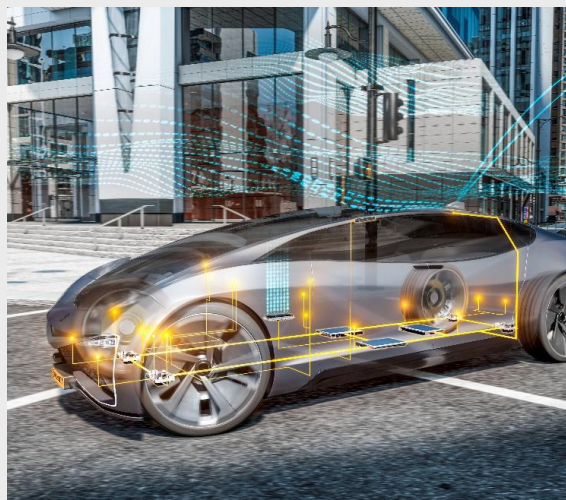
Engineering, Fielding & Operating Complex Mobility Solutions

Model-Driven Engineering challenges & trends in the automotive industry
Or How much systems modeling do I really need in the era of the Software-Defined-Vehicle?

Maged Khalil | MDENet Symposium 2023. Dec. 6th, 2023. London, UK

Continental Group

Leading the Way for Your Mobility



A leading player
in **autonomous
mobility**

First to market
with **software-
defined**
vehicle architecture

Industry-benchmark
in **tires**

199,038
talented and
dedicated
employees

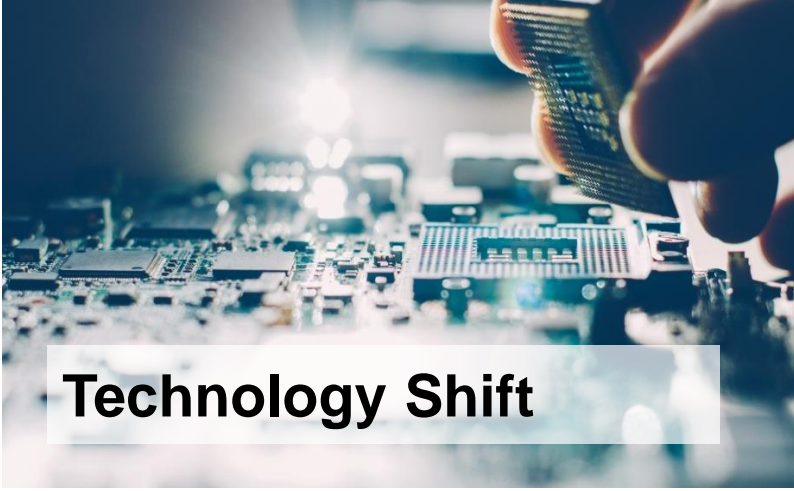


Digitalization



Sustainability

Our Opportunities and Challenges



Technology Shift



Competitive Environment



Speed

Continental Group

Overview 2022



€**39.4** billion
sales

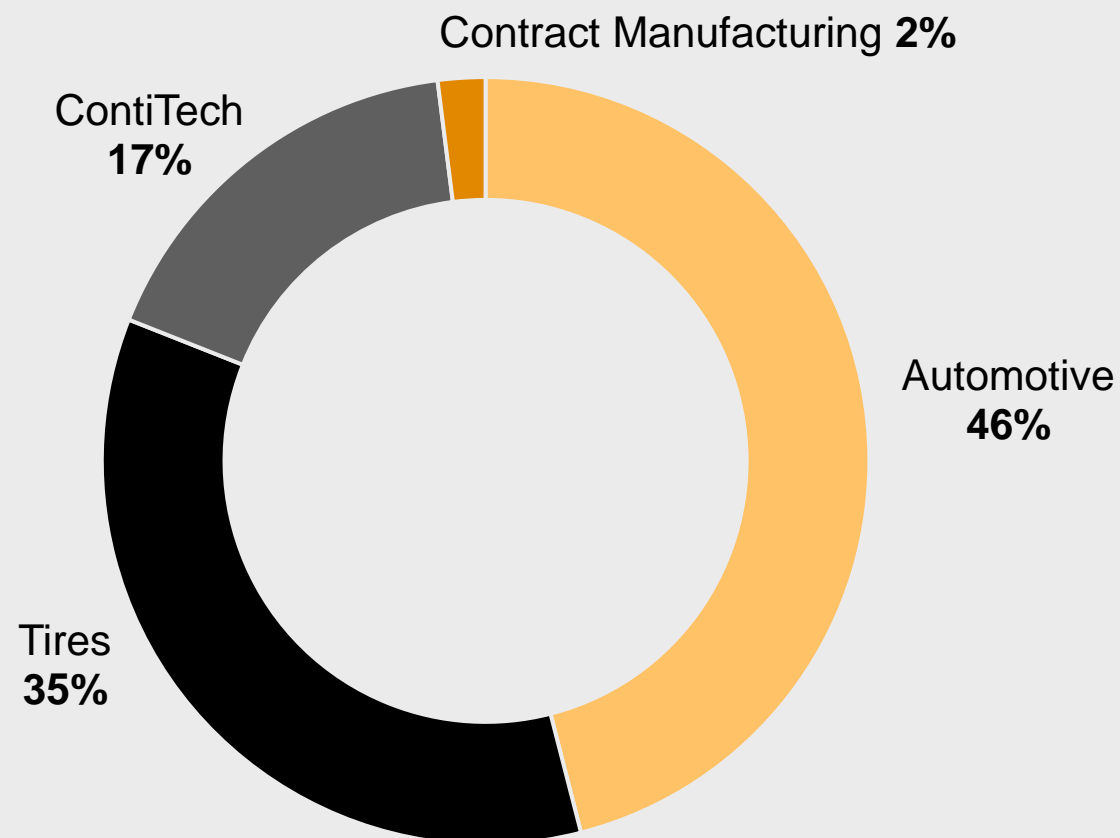


199,038
employees



519 locations
in 57 countries

Sales by group sector



As at: Dec. 31, 2022

About me...

My roles are...

Principal Expert Mobility Systems Architectures

Head of “Systems Engineering for SDV” Dept.

Model-Based Systems Engineering (MBSE) Expert, Qualification Definer & Trainer

In-House Consultant on (System of) Systems Engineering

PC-member Systems Engineering Qualification program + Global Conference @Continental

I started working for Continental in...

April 2016 (Lead Architect for AD)

I started working in the Automotive Industry in...

2005 (dSPACE, BHTC, Ford, ZF)

My background is..

M.Eng. Mechatronics, B.Sc. Elec. Engineering

15+ years Automotive Systems & Safety Engineering (Aut. Dr./ADAS, Hybrid Drives, Climate Control, Steering)

5 years Applied Research in MBSE, Domain-adequate Architectures, Design Patterns, Reuse, Safety-critical development, DSLs/ADLs

Doctoral work on model-based reuse of safety-critical solutions (Hopefully done before 2050!)



Topics

1

Drivers for change

2

Technology Trends

3

Impact on Engineering

4

Continental's Software-Defined-Vehicle Offerings

5

About the modeling

6

Looking to the future..

1

Drivers for change



The “Revolution” of Automotive Industry

Automotive megatrends

CONNECTED

2030

There will be **700 million connected cars**



AUTONOMOUS

2030

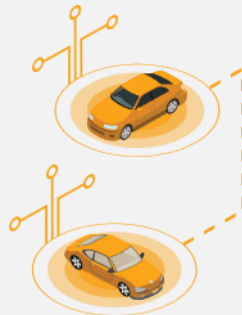
Autonomous miles driven in US: 13%



SHARED

2040

Shared mobility at ~80% of miles driven



ELECTRIC

2024

600 new electric models



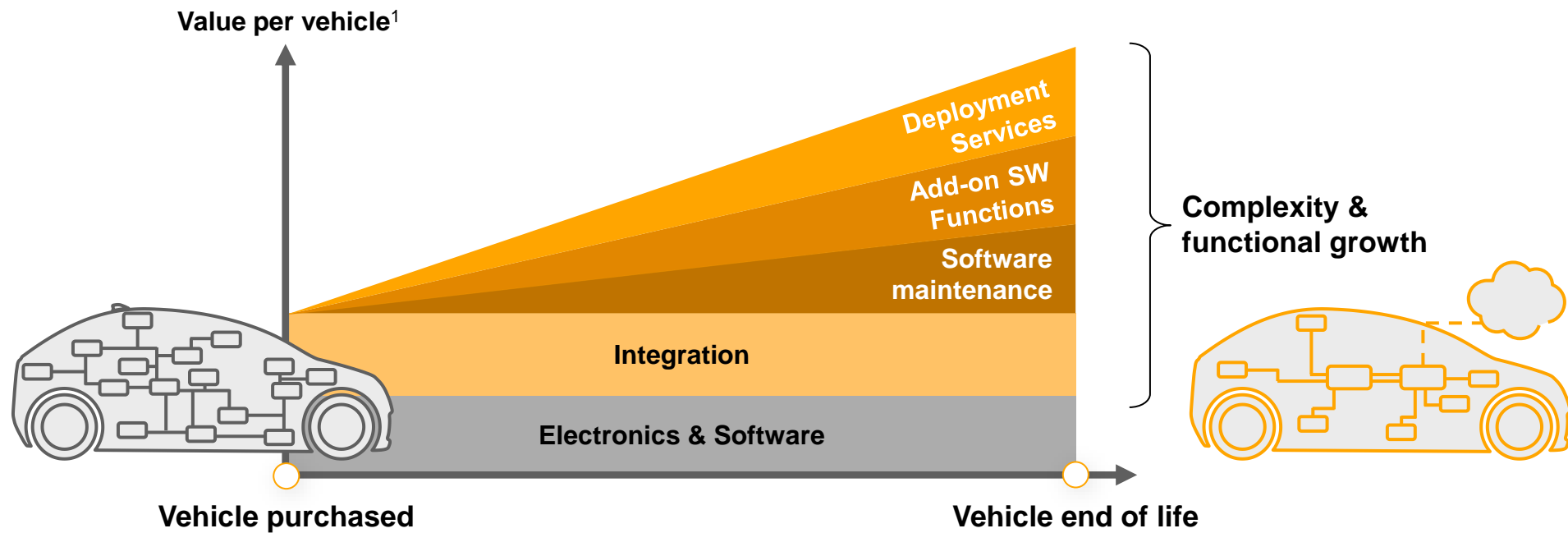
Sources: Forbes, Deloitte

Software Defined Vehicle

New value streams across lifecycle

Up2now

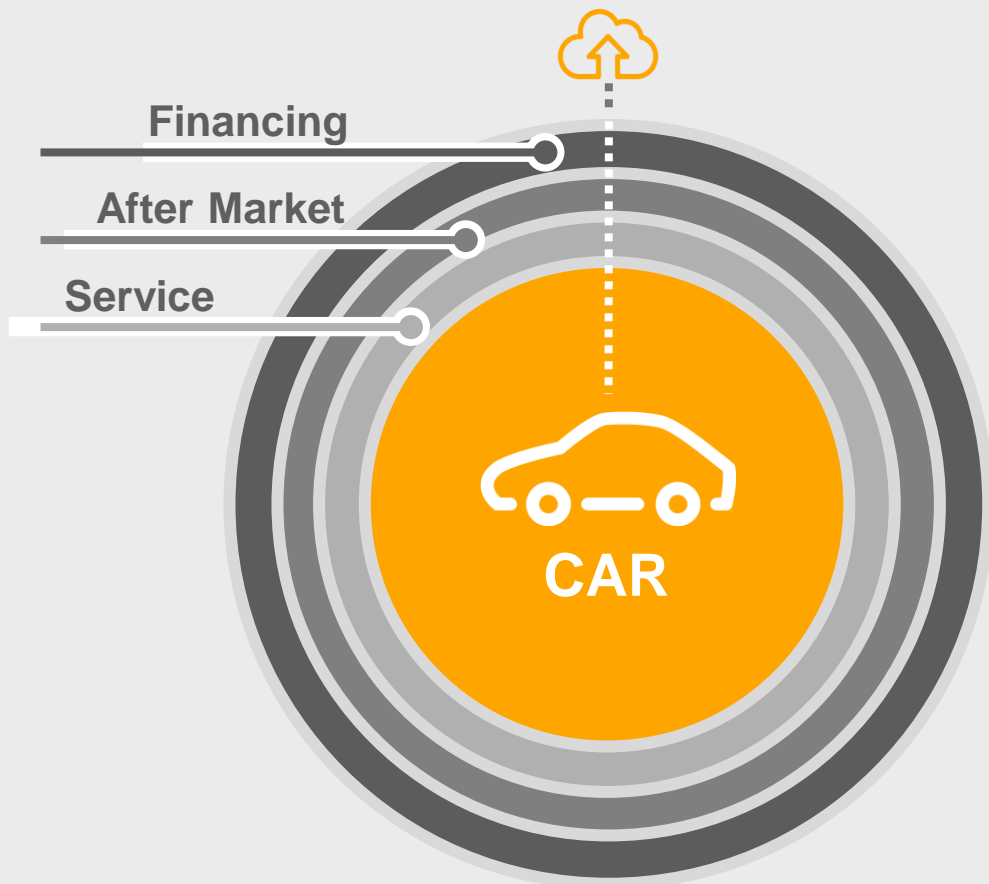
Going forward



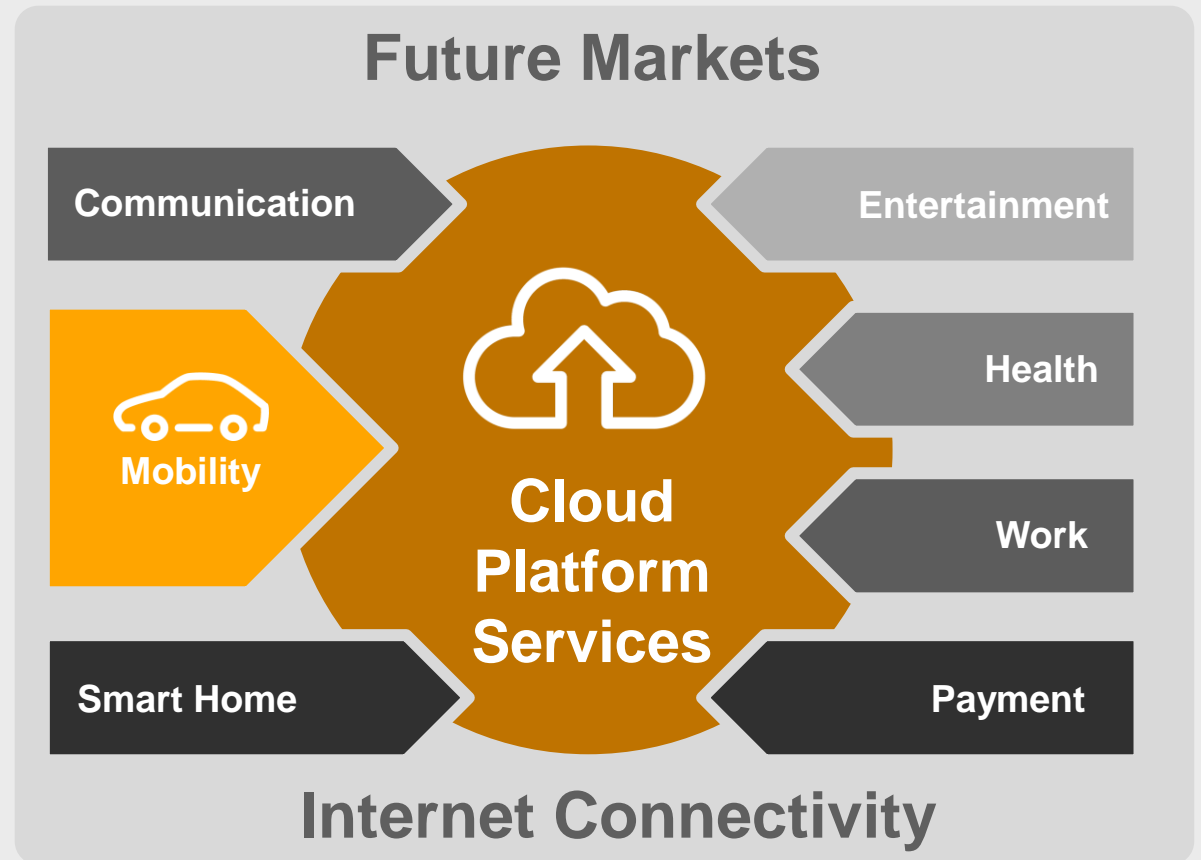
¹ Not to scale; for illustrative purposes only

Vehicle Business Transformation

Change of Perspective

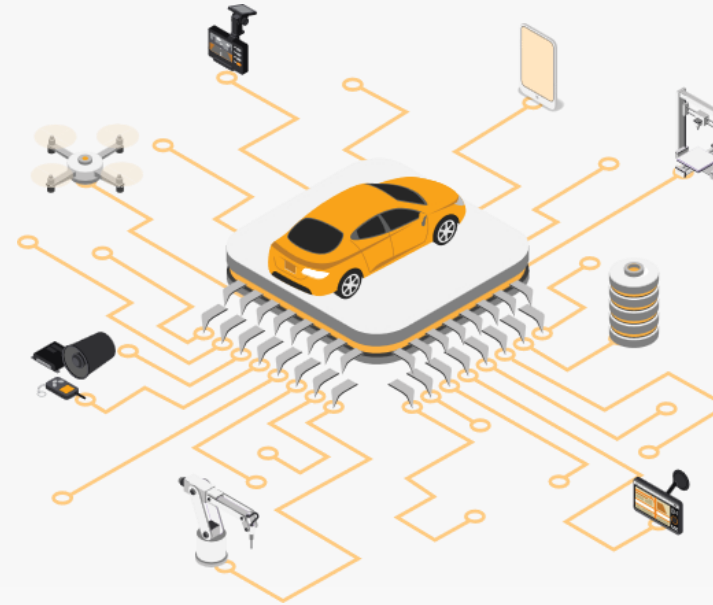


Traditional Automotive



2

Technology Trends

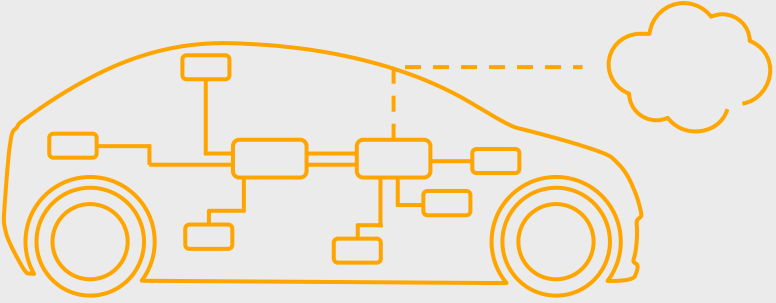
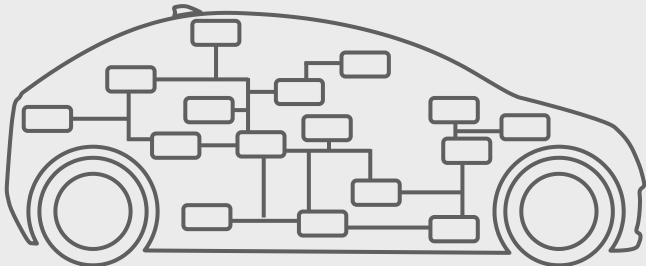


Vehicle Architecture Transformation

Scalable Compute Platforms – Enabler for Smart IoT Mobility

Up2now

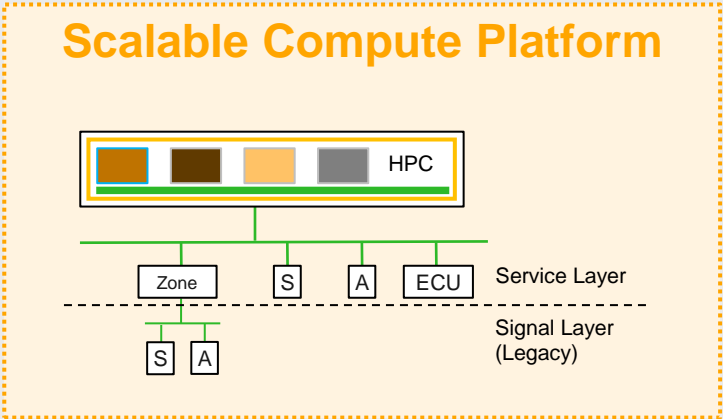
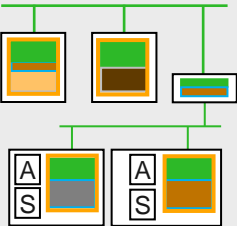
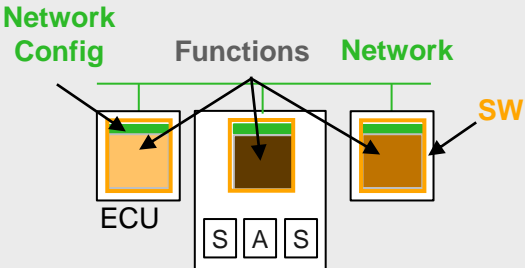
Going forward



Distributed

Domain-Centralized

Scalable Compute Platform



ADAS

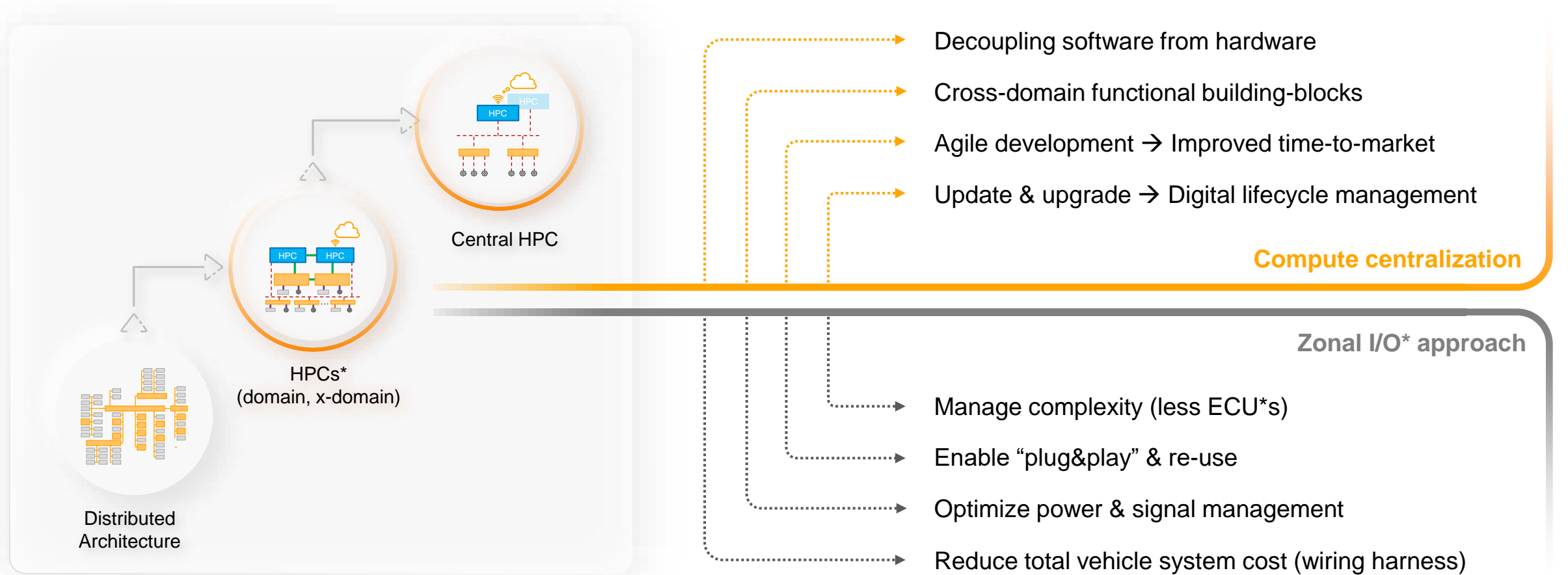
Safety & Motion

Cockpit

Body

Architecture Trends

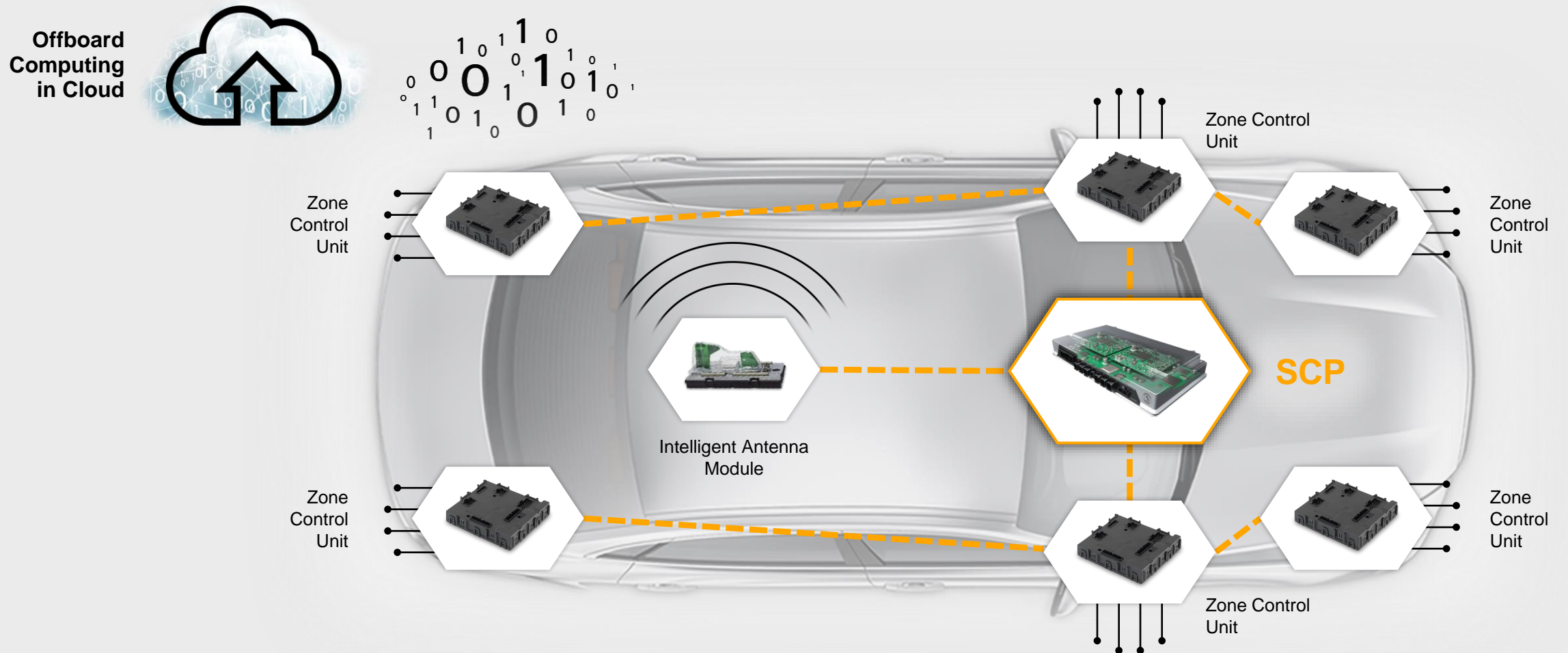
A radical shift in the automotive industry



*HPC = High Performance Computer (Server), *I/O = Input/output, *ECU = Electronic Control Unit

Vehicle Architecture Transformation

Scalable Compute Platforms – Enabler for Smart IoT Mobility



Towards IoT Ecosystem Integration

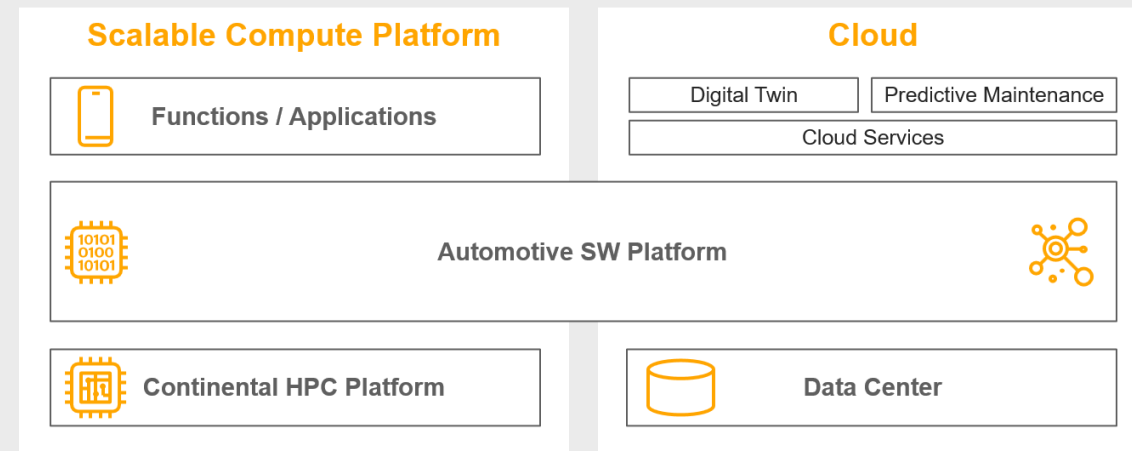
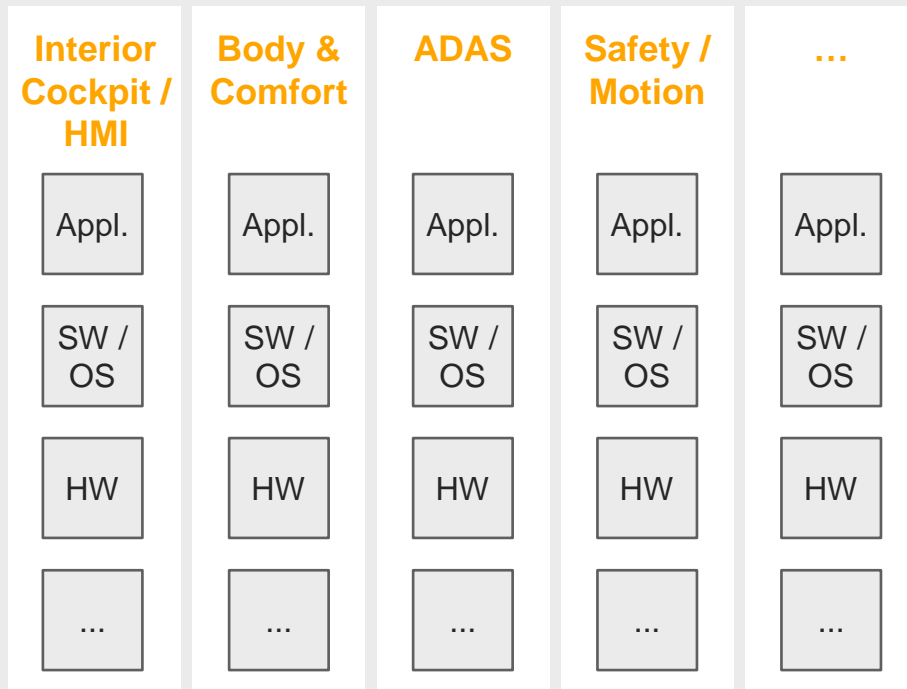
From domains to function & service orientation

Up2now

Domain-oriented

Going forward

Feature-driven & Service-oriented

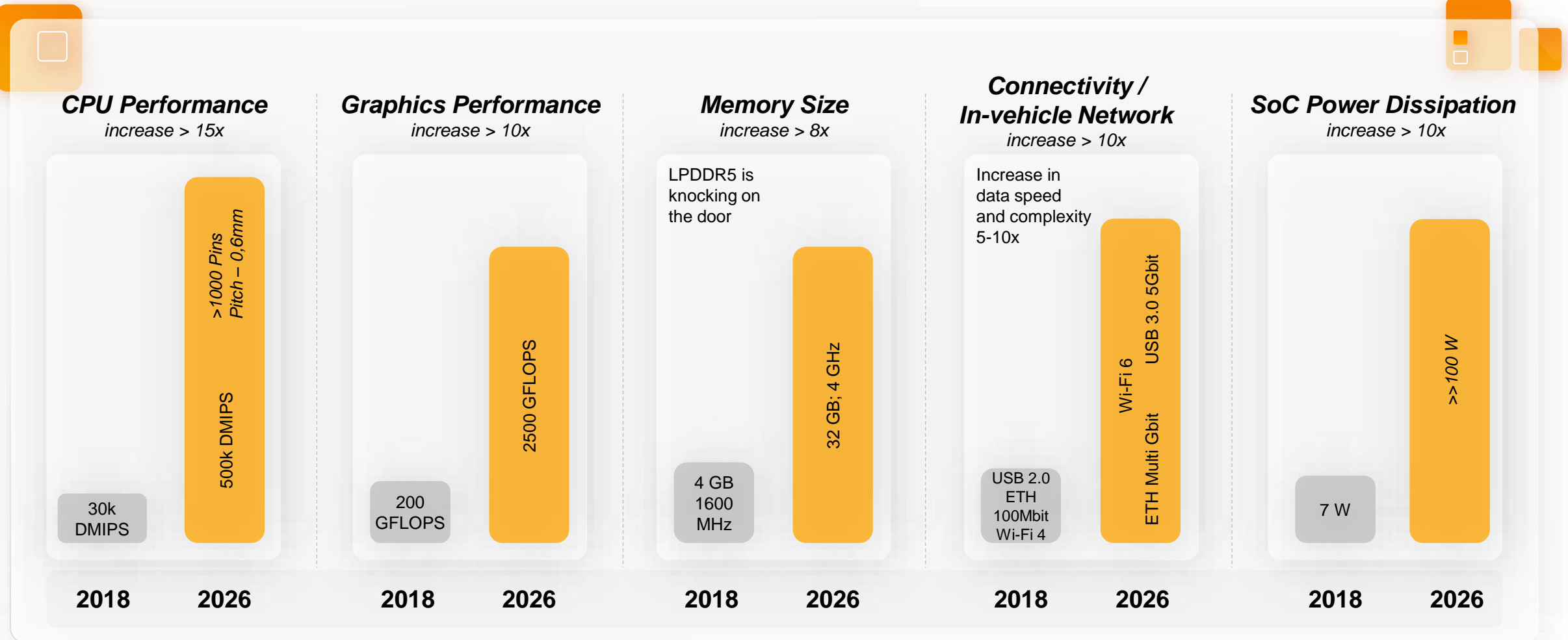


Horizontal Integration
synergies, reuse and maturity/quality

Vertical Integration
full solution/
stack that
OEM can
leverage

The Hardware Challenge

Performance boost on component side 2018 vs. 2026



*CPU = Central Processing Unit, SoC = System on Chip

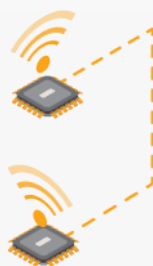
Continental: First Tier 1 to Launch HPC

An entirely new dimension of complexity

High-Performance Computer ("ICAS 1"²) for VW MEB Platform (SOP 2019)

Introduction of server-based architecture, one powerful HPC¹ replaces several ECUs

Agile approach with continuous customer communication



68

Links to other ECUs³



>30.000

Protocol messages in the vehicle



19

Companies working on the software for a single ECU



> 70,000

Stakeholder requirements



40

3rd party applications

¹HPC: High-Performance Computer, ² ICAS: InCar Application Server, ³ ECU: Electronic Control Unit

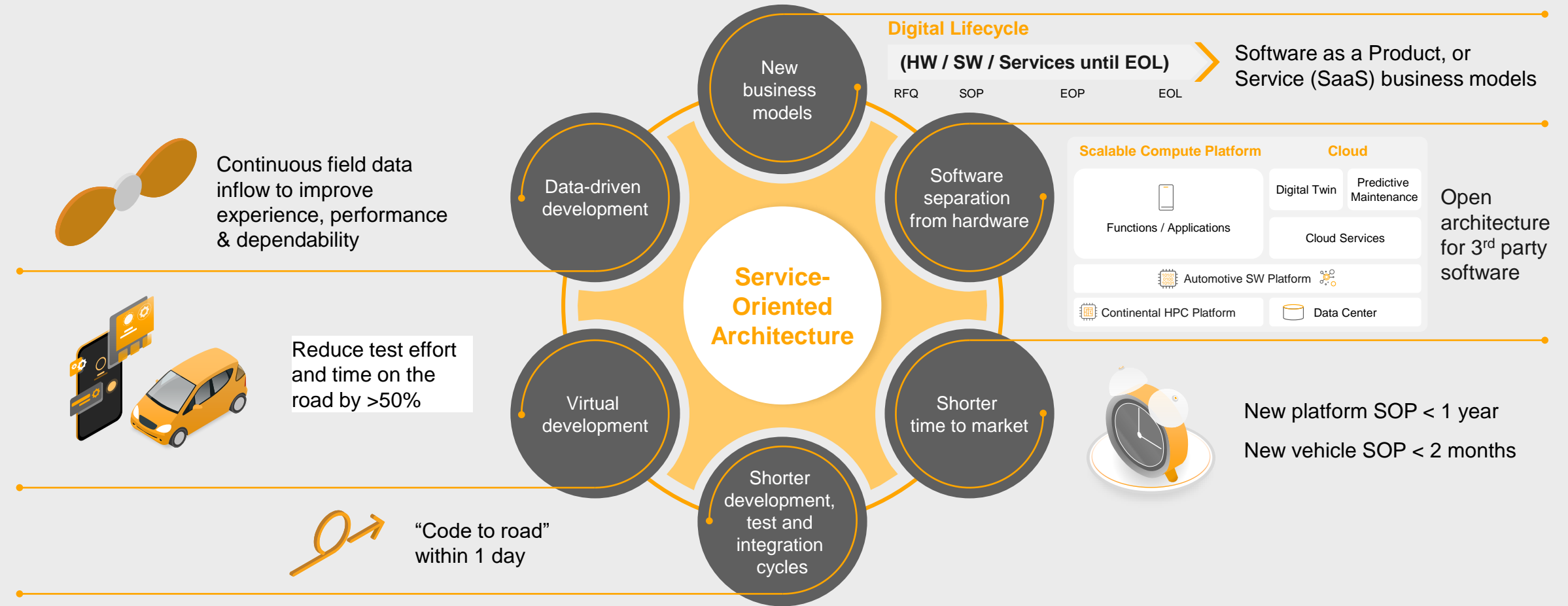
3

Impact on Engineering



The Software Defined Vehicle

Primary characteristics

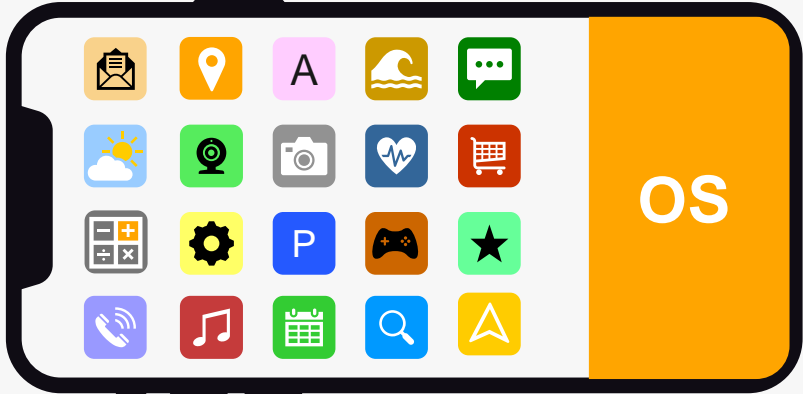


Software Defined Vehicle

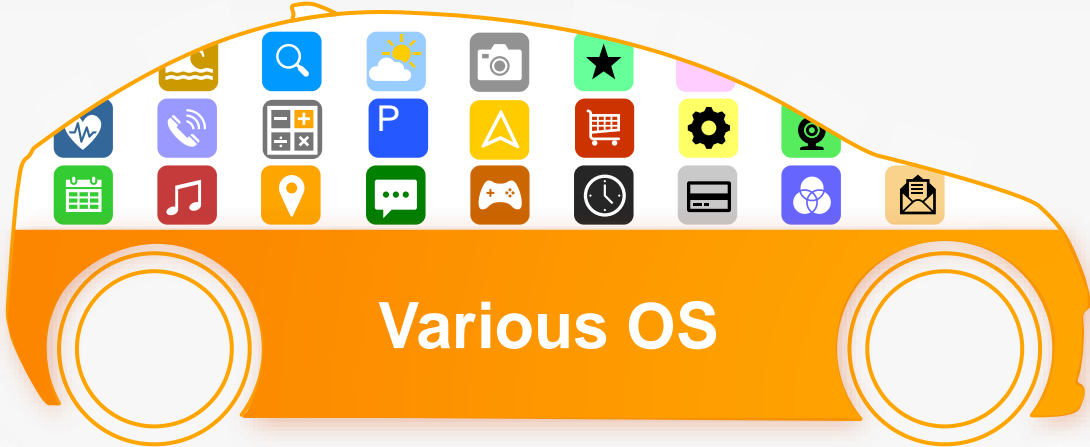
Facing numerous challenges

1 microprocessor	1 display	7 sensors
0.174 kg	1 OS	0 km/h

> 100 microcontrollers	> 10 displays	Hundreds of sensors
1,995 kg	4 OS	250 km/h ¹



Faulty software is **annoying**



Faulty software **can be fatal**

¹ Reference vehicle: German premium class vehicle in 2020

The Evolution of Products – The Civilization Builder Analogy

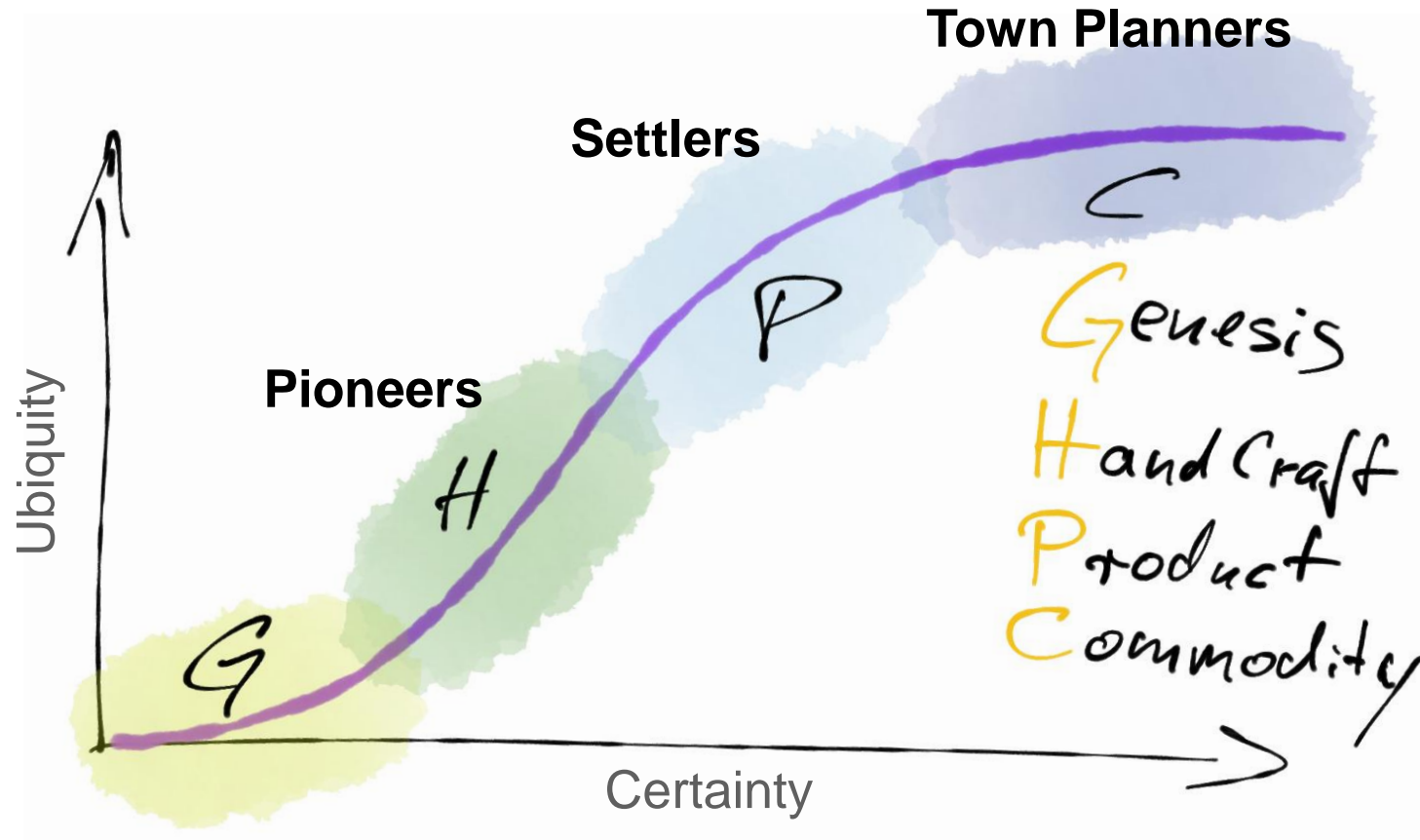
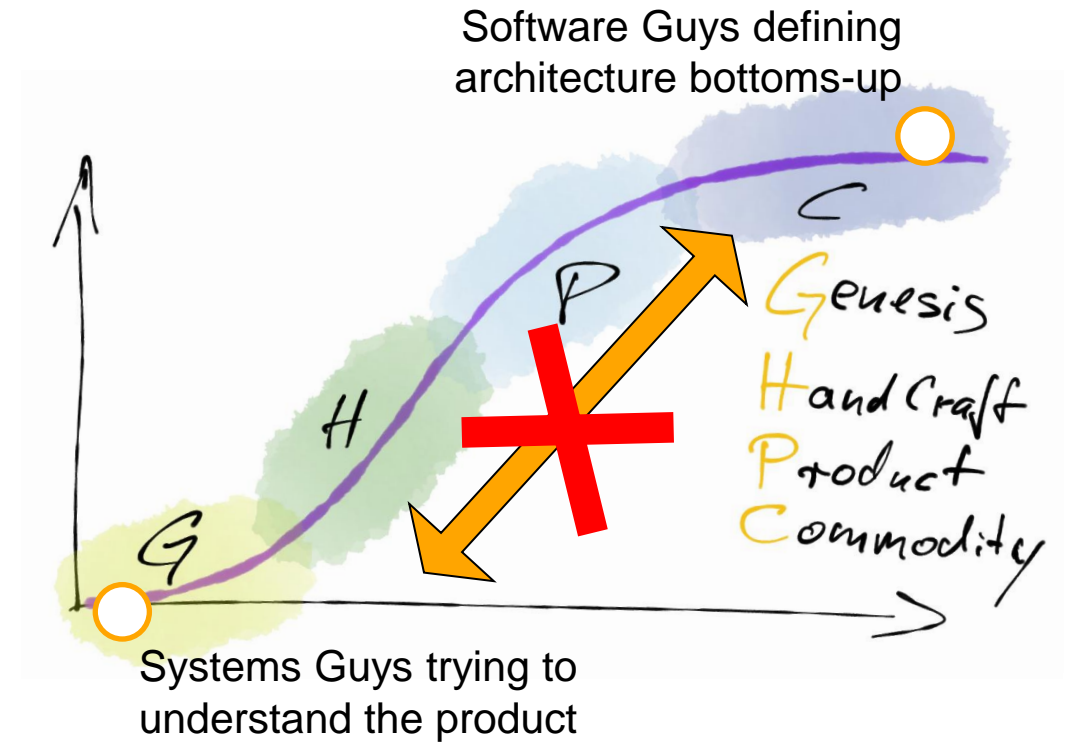


Image based on Wardley Evolution Maps by Simon Wardley 2015

20 Years of Automotive Software & Systems History

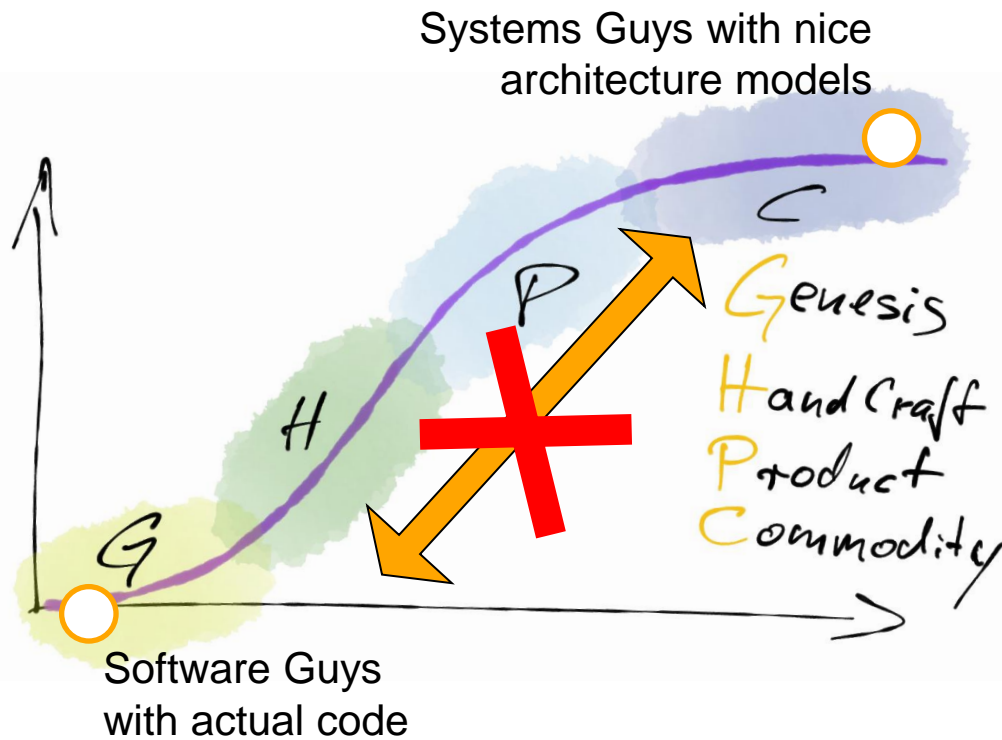
Too **little** Systems Engineering



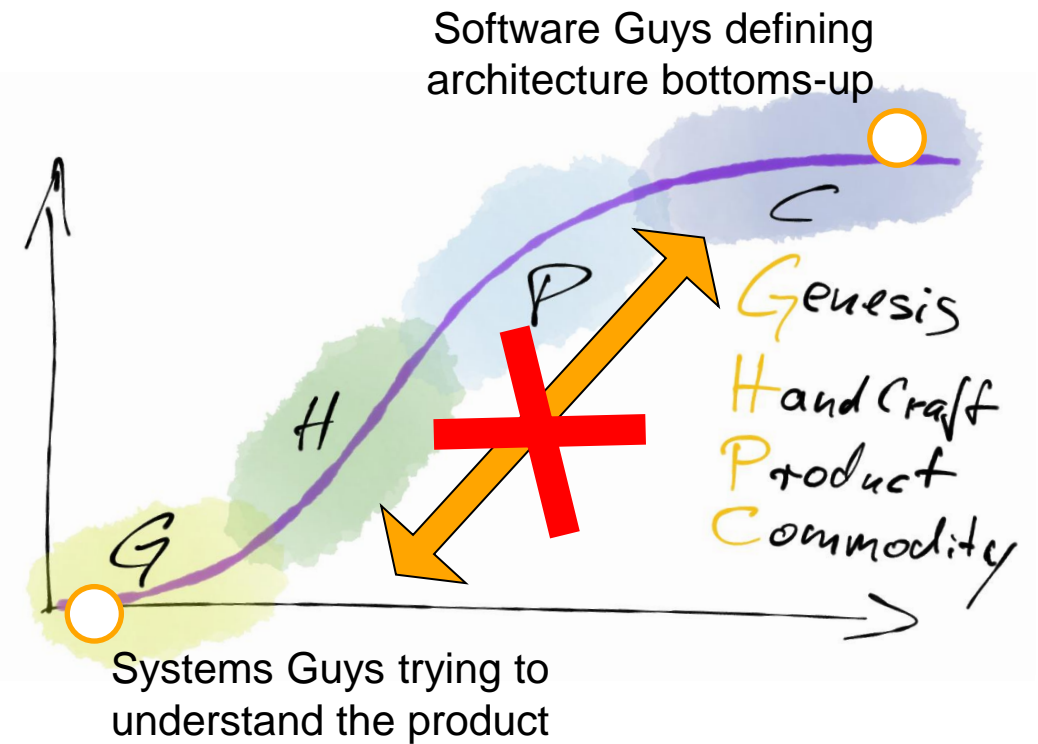
20 Years of Automotive Software & Systems History

Too much Systems Engineering

Too little Systems Engineering



VS

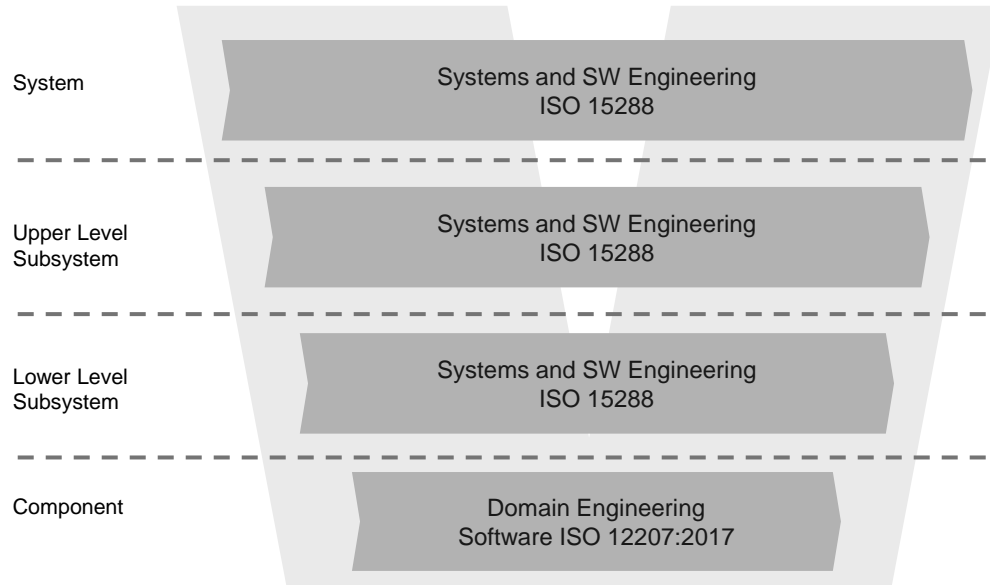


Is the gap only in our heads?

ISO15288

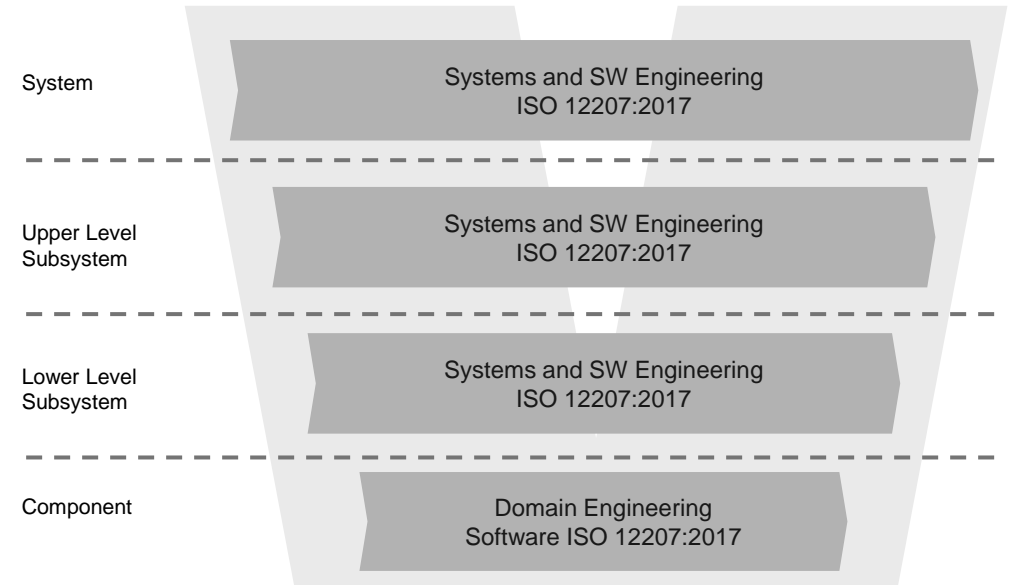
ISO12207 (2017)

Process Reference Model (PRM)

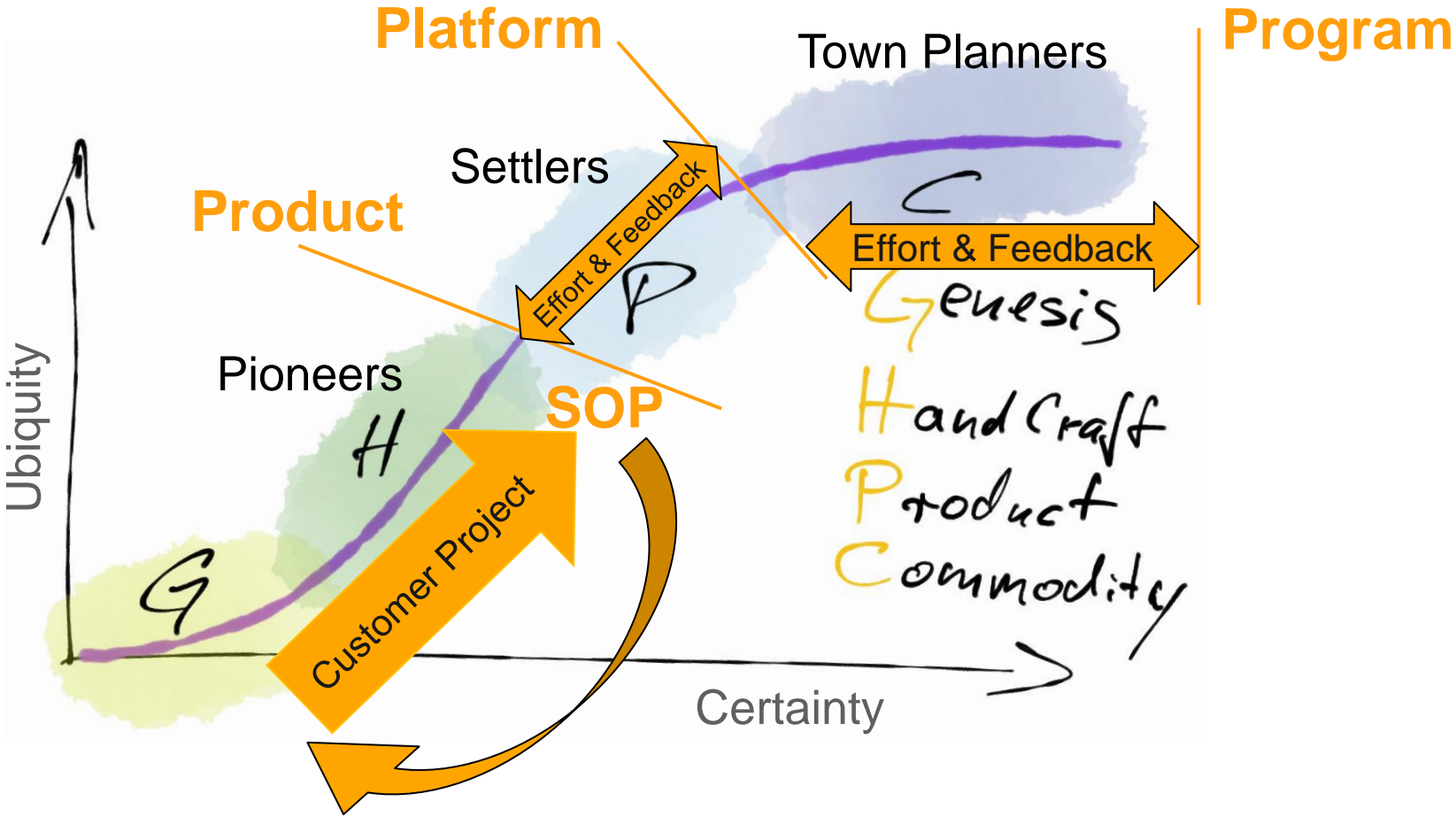


VS

Process Reference Model (PRM)



Product & Organization Maturity vs. Reuse & Synergy Effects



Where are we now? It's not just processes or technologies

Digital Transformation



Stage	NO PROCESS	WATERFALL	AGILE	CLOUD NATIVE	NEXT
Culture	Individualist	Predictive	Iterative	Collaborative	Experimental
Product Management	Arbitrary	Long-term plan	Feature driven	Data driven	AI driven
Delivery	Irregular releases	Periodic releases	Continuous Integration	Continuous Delivery	Continuous Deployment
Process	Random	Waterfall	Agile (Scrum/Kanban)	Design Thinking + Agile + Lean	Distributed, self-organised
Team	No organisation, single contributor	Siloed	DevOps	SRE	Internal supply chains
Architecture	Emerging from trial and error	Tightly coupled monolith	Client server	Microservices	Functions
Reliability	Respond to users complaints	Ad-hoc monitoring	Alerting	Full observability & self-healing	Preventive ML, AI
Provisioning	Manual	Scripted	Config. management (Puppet/Chef/Ansible)	Orchestration (Kubernetes)	Serverless
Infrastructure	Single server	Multiple servers	VMs (pets)	Containers/ hybrid cloud (cattle)	Edge computing

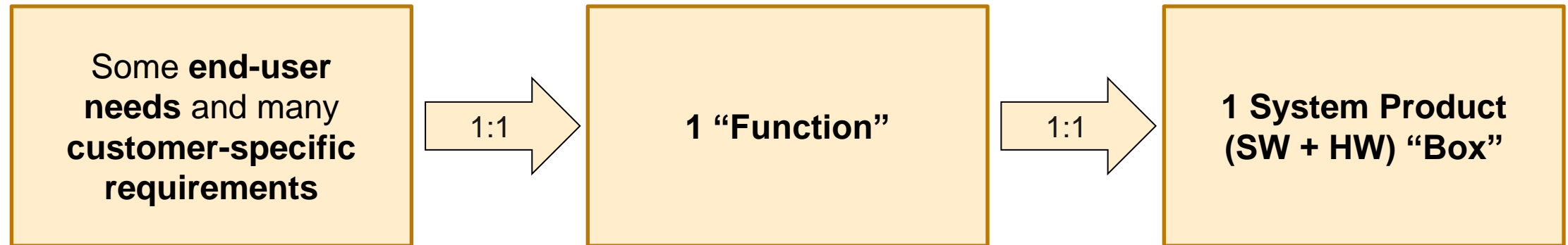


Cloud Native Technologies

From "Cloud Native Transformation" Copyright Container Solutions 2019

The evolution of the “System” – where we come from

Traditional Automotive system product



What the **customer** wants and expects

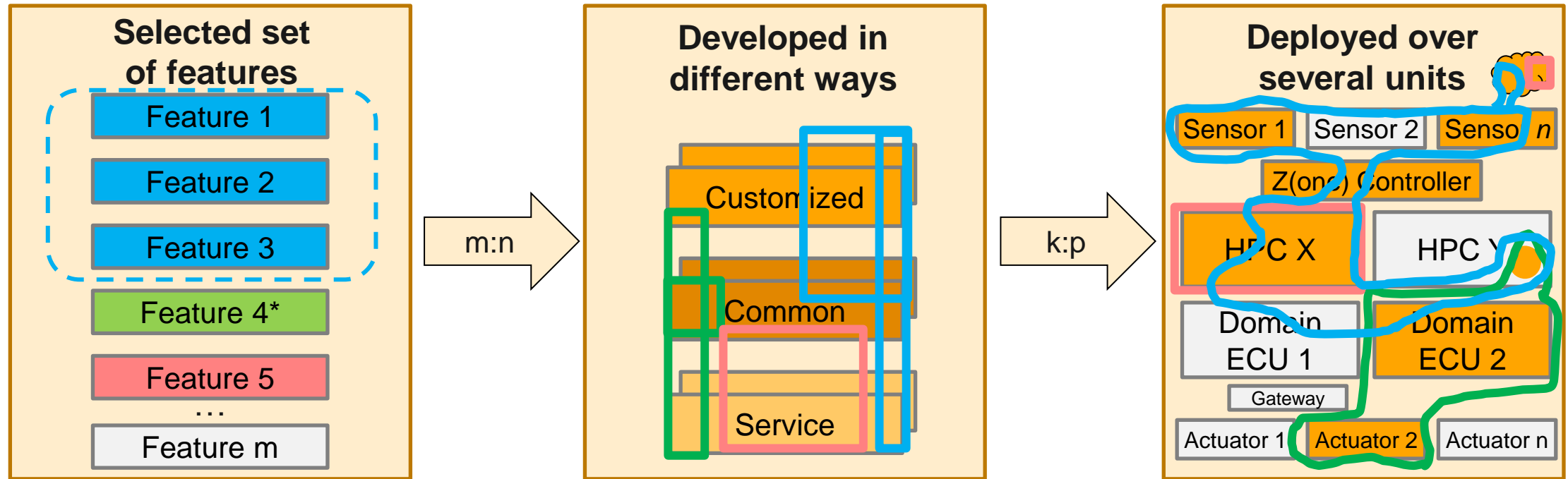
What **Continental** designs and develops

What **Continental** delivers

Local “per individual Function” optimization driven by Domain competence.

The evolution of the “System” – where we are

Current & future System Products



What the **customer** wants and expects

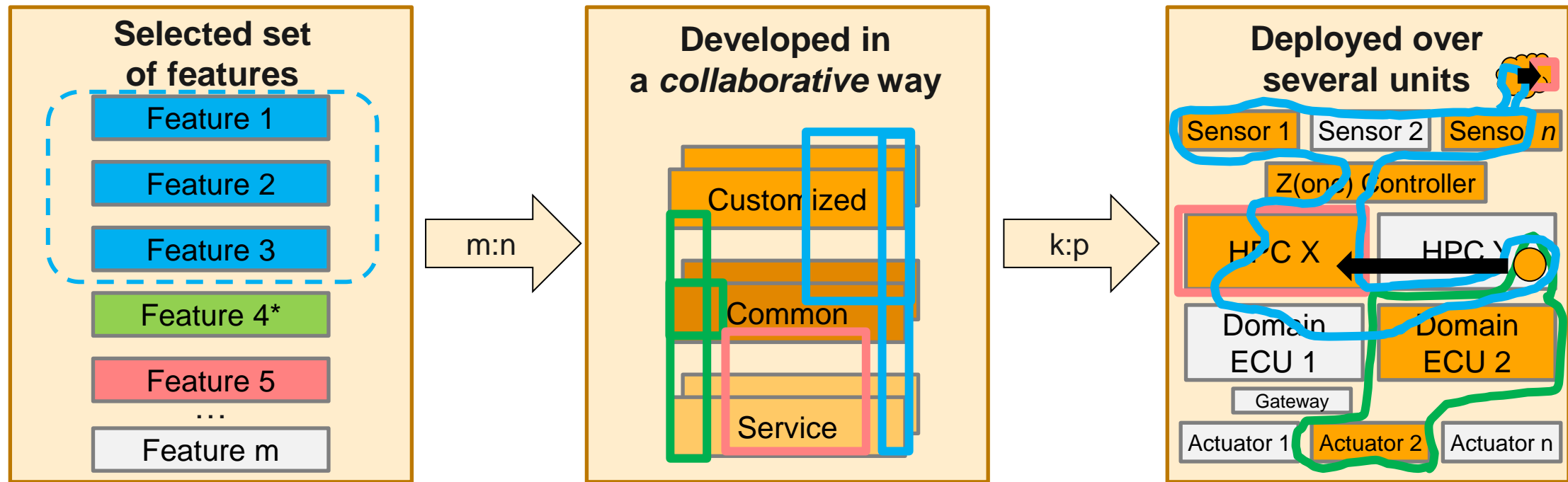
What **Continental** designs and develops

What **Continental** delivers

Many “Systems” co-exist and collaborate.

The evolution of the “System” – where we are going

Current & future System Products



What the **customer** wants and expects

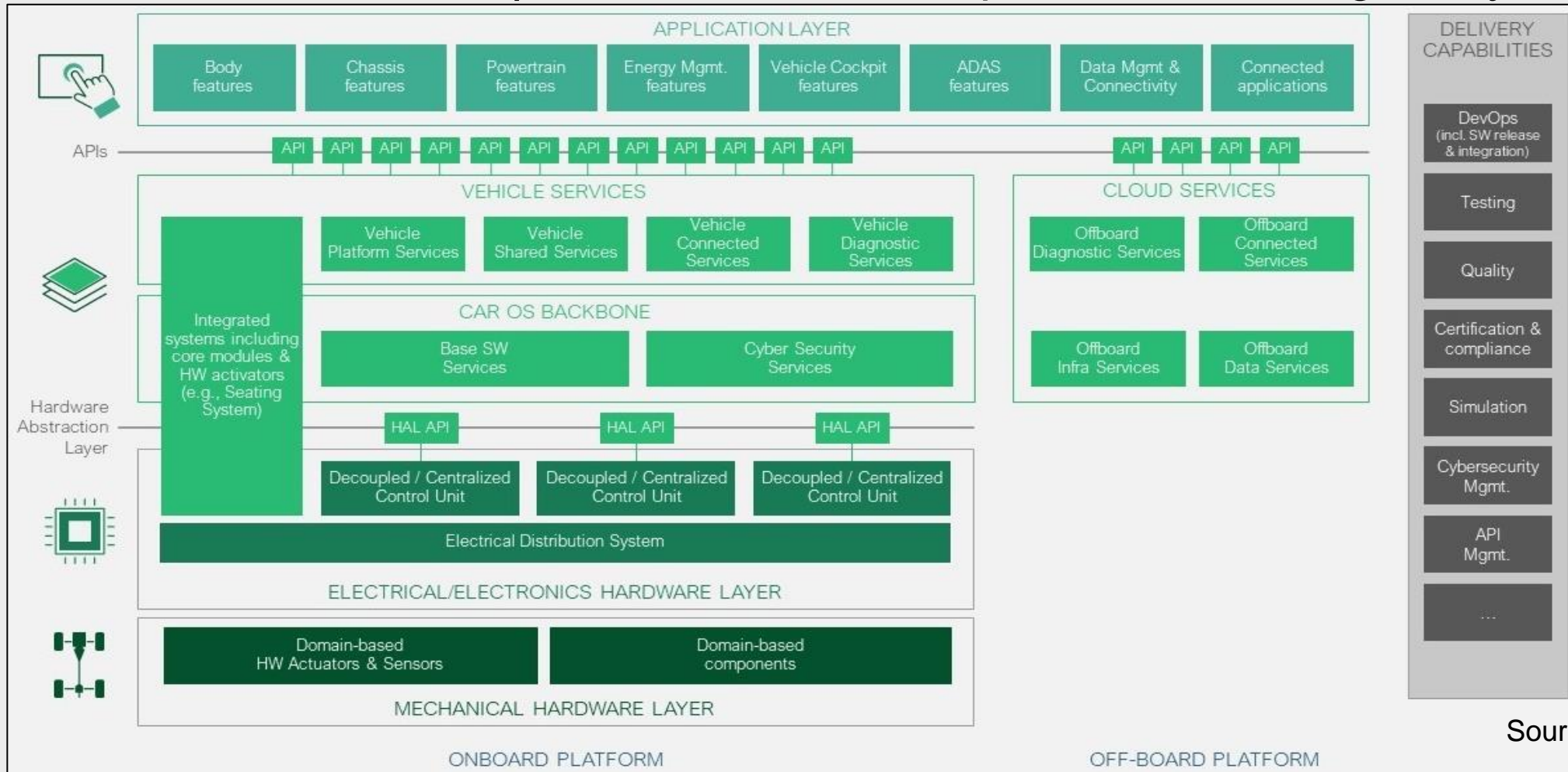
What **Continental** designs and develops

What **Continental** delivers

Global “Vehicle/Platform” optimization driven by Systems competence.

The evolution of the “System” – where we need to go

Automotive Product Landscape – Fundamental capabilities enabling many “Systems”



Source: BCG 2022

Automotive “Systems” combine capabilities to create value.

4

Continental's Software-Defined-Vehicle Offerings





One framework. Many solutions. Welcome to **CAEdge**.

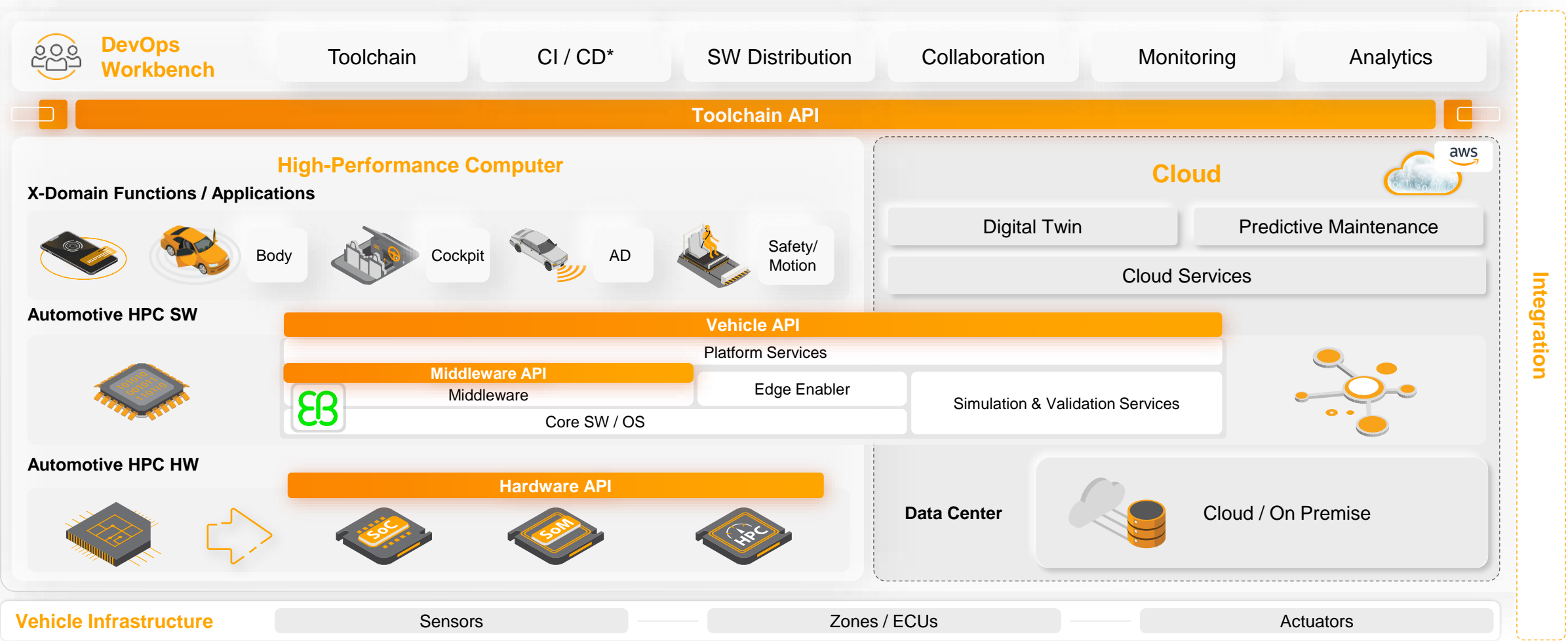
In order to integrate vast amounts of software into modern vehicle systems - also from different suppliers - Continental provides a platform the **CCP** for all of it to be developed, tested and compiled. Just like a smartphone has different applications from different developers, modern vehicles contain different softwares from

[Signup now](#)[More infos](#)

Gartner Report:
Continental in
top 6 companies in
“Software Defined
Vehicle” space

SDV enabler: Continental Automotive Edge Framework

HPC ecosystem that goes beyond the component







* μP = Micro-Processor, SoC = System on Chip, SoM = System on Module, CI/CD: Continuous Integration / Continuous Deployment

Continental Automotive Edge Framework for SDVs

Bottom line and benefits

Continental Automotive Edge (CAEdge) **FRAMEWORK**

With CAEdge you can:

-  **Validate** your architecture before you build physical vehicles
-  **Run** a new function within 1 day in any physical car at anytime
-  **Drive** 1 Mio km in simulation at your desk in 1 day
-  **Share** the same target hardware for all developers worldwide instantly

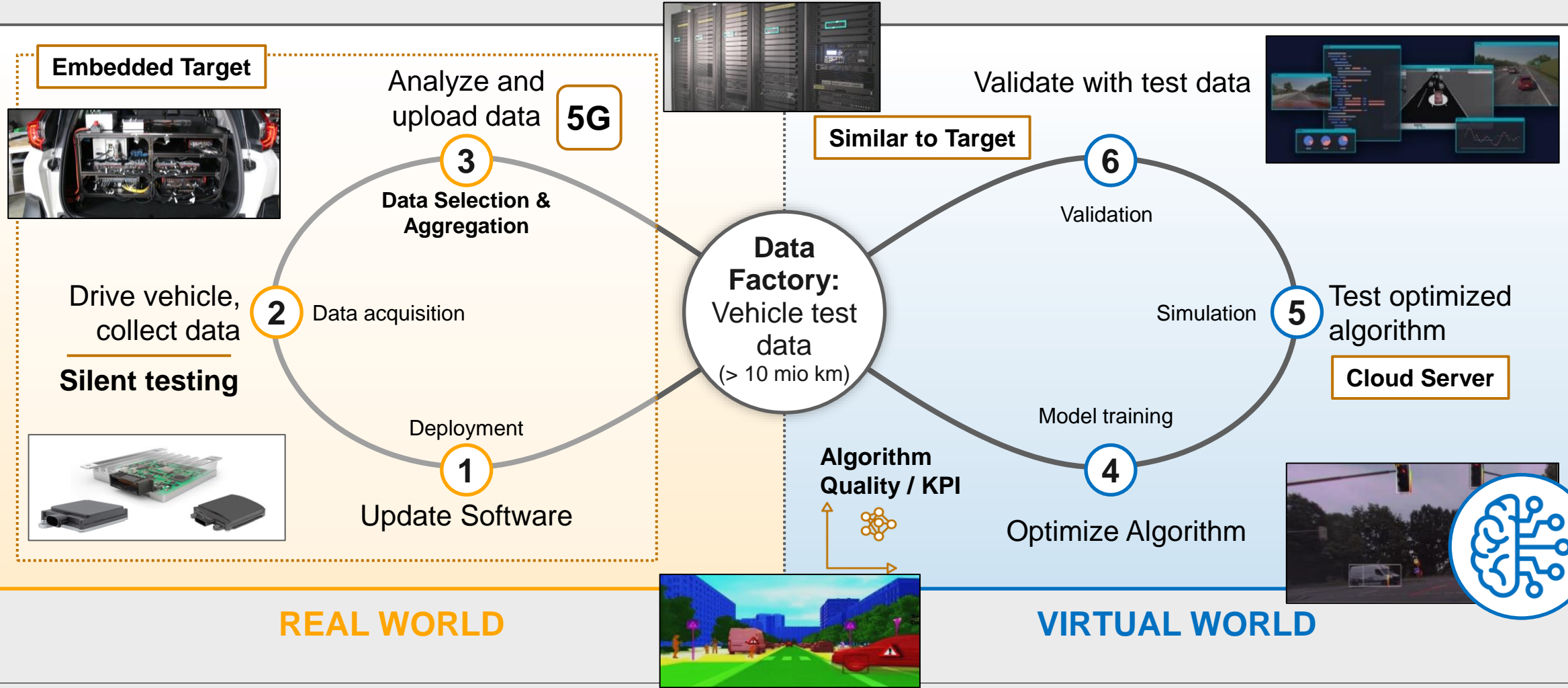
Simplify and accelerate
Development of
Vehicle software

... all while sitting at your desk!



IoT Ecosystem Architecture Transformation

Evolution Towards Data Driven Ecosystem



Software Defined Vehicle

OEM benefits



Functions can evolve and improve over lifetime and **functions** can be **added through software**



Sell new functions to end customers and enables new business models (function, service, data)



Use the **same functions over vehicle car lines and brands**



Edge computing is well-established and highly capable **cloud technologies** are (re-)used in automotive



Enables **Data driven engineering** (with big data loop)



Software Defined Vehicle

Customer benefits



Customization: Drivers can **personalize** their driving experience by configuring vehicle settings, performance characteristics, infotainment preferences, and others through **software updates**.



Software Updates: SDVs receive regular over-the-air (OTA) software updates that can improve performance, introduce **new features**, and enhance cybersecurity.



Improved Efficiency: SDVs can optimize energy usage and power distribution through software control, resulting in **extended range** in electric vehicles, or better fuel economy in ICEs.



Remote Diagnostics: Reducing the need for in-person service appointments and **minimizing downtime**. This can lead to increased vehicle reliability and convenience for drivers.



Improved Resale Value: Vehicles with up-to-date software and advanced features tend to retain their **value better** in the used car market



Overall, software-defined vehicles offer drivers greater control, safety, convenience, and the potential for ongoing improvements through software updates

Initiatives, Standards and Associations

Standards are mandatory to manage complexity

AUTOSAR

Develop and establish standardized SW framework and open E/E system architecture

Our Goal:

- › Influence further development of Autosar to optimize the benefit of all industry partners

SOAFEE

Cloud-native architecture enhanced for mixed-criticality automotive applications; building on technologies which define standard boot and security requirements for Arm architecture

Our Goal:

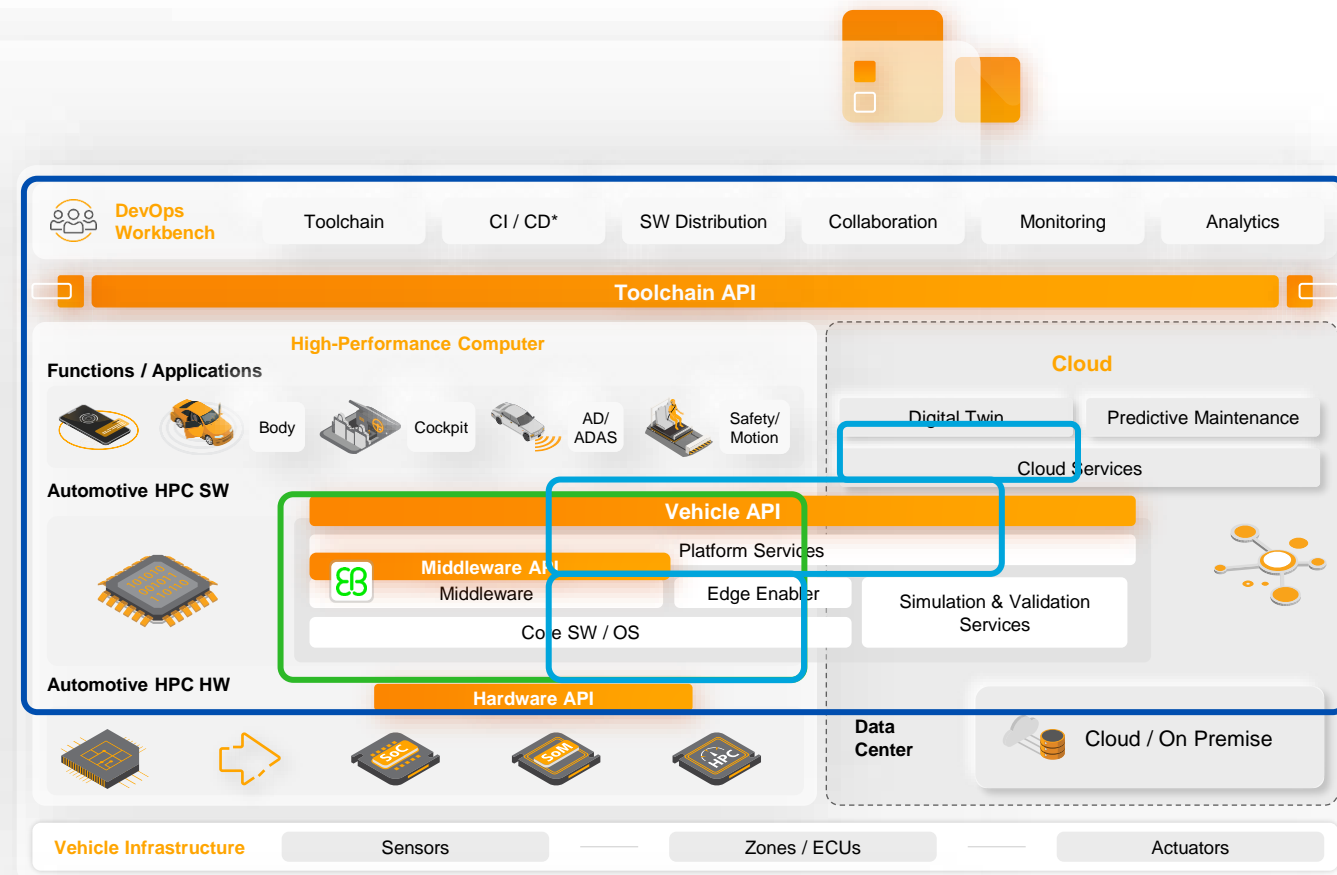
- › Apply cloud-native concepts to achieve parity of SW between cloud and vehicle.

Eclipse SDV

Open technology platform for the SW defined vehicle of the future; using open source and open specifications

Our Goal:

- › x-industry compatibility for key interfaces (Toolchain, Vehicle API, Middleware) across the full scope of the SDV
- › Continental has contributed eCAL™ (enhanced Communication Abstraction Layer)



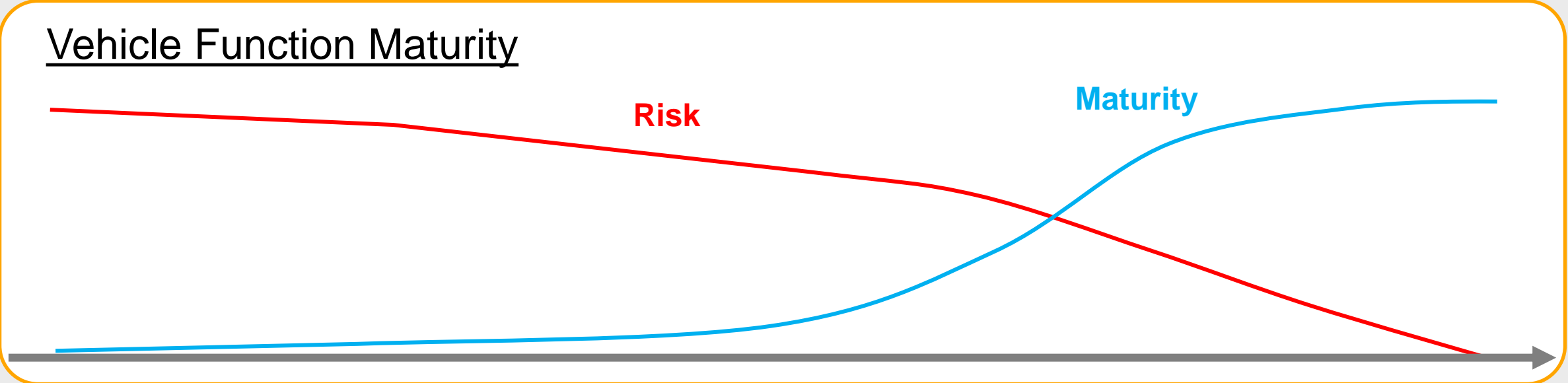
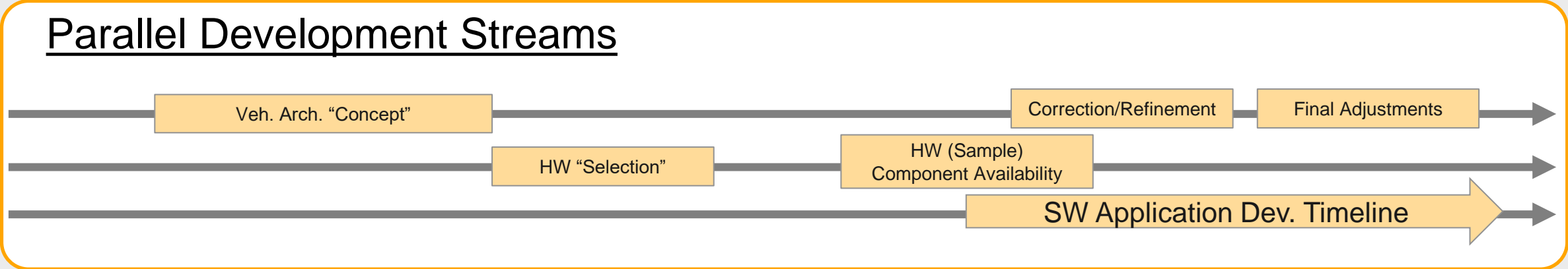
5

About the modeling



Maturity Shift-Left with CAEdge for the SDV

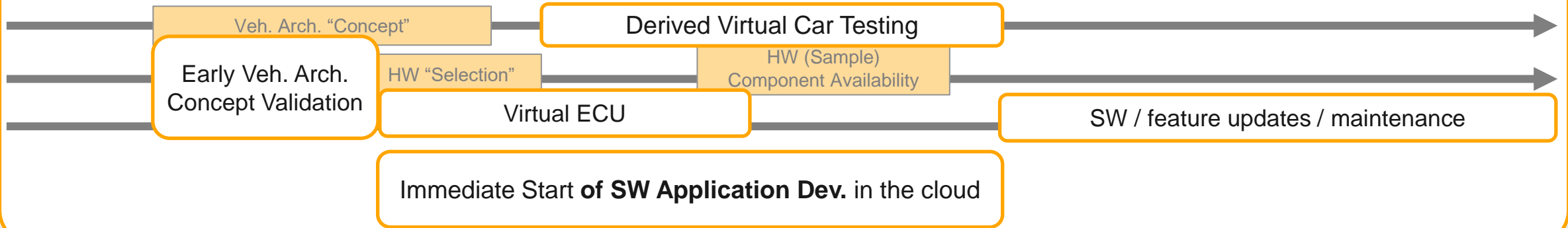
Traditional Development Approach



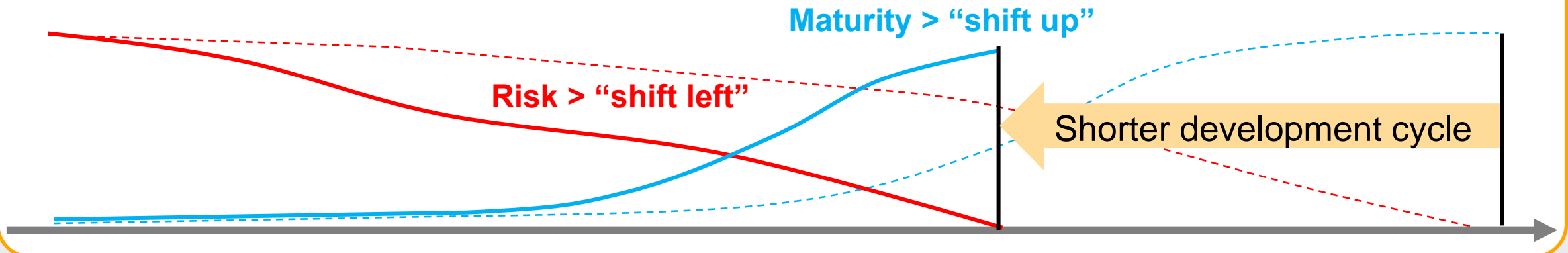
Maturity Shift-Left with CAEdge for the SDV

Leveraging data, models and cloud-enabled virtualization

Coupled Development Streams

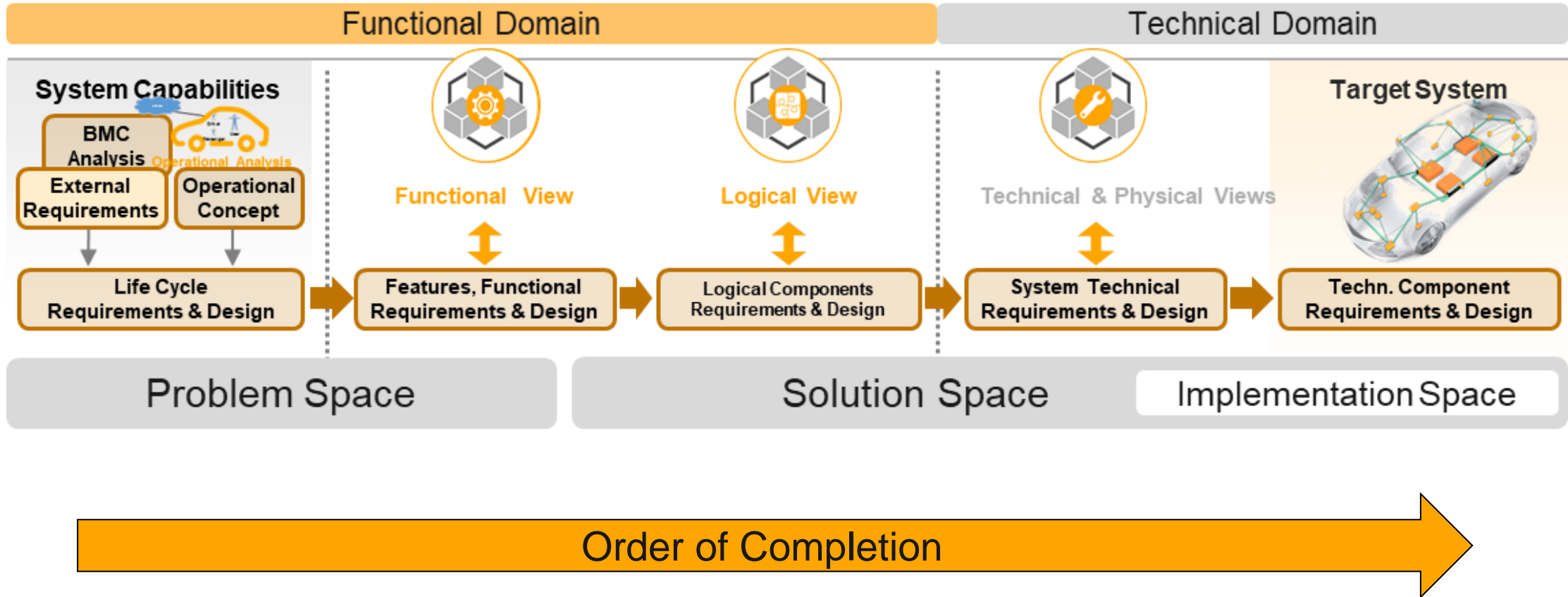


Vehicle Function Maturity



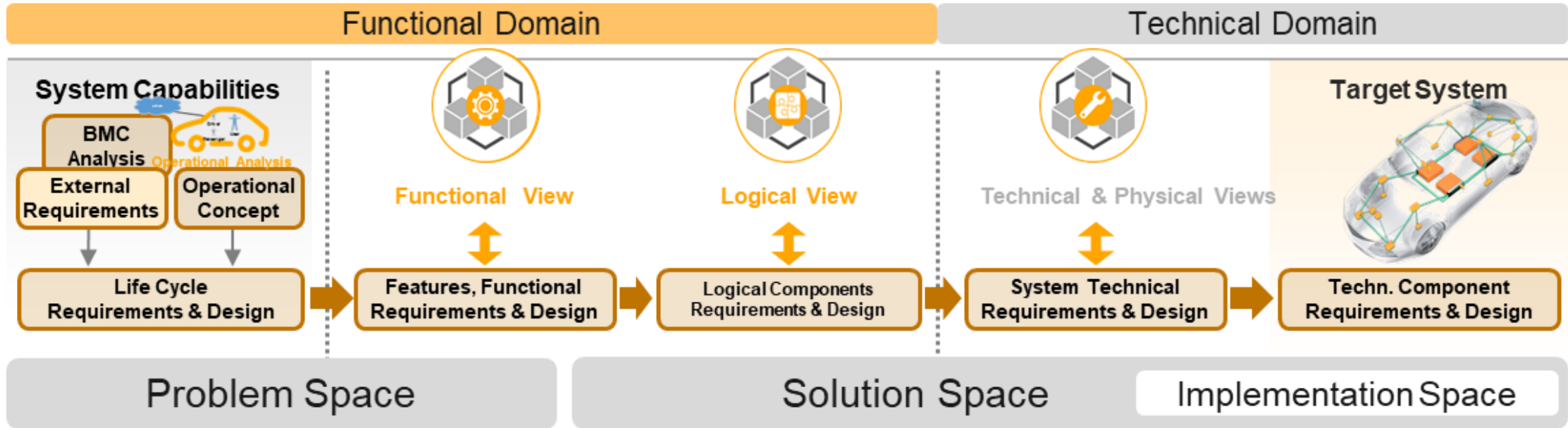
Systems Engineering at Continental

Systems Design Flow overview – Separation of Concerns via System Views



Systems Engineering at Continental

Systems Design Flow overview – Separation of Concerns



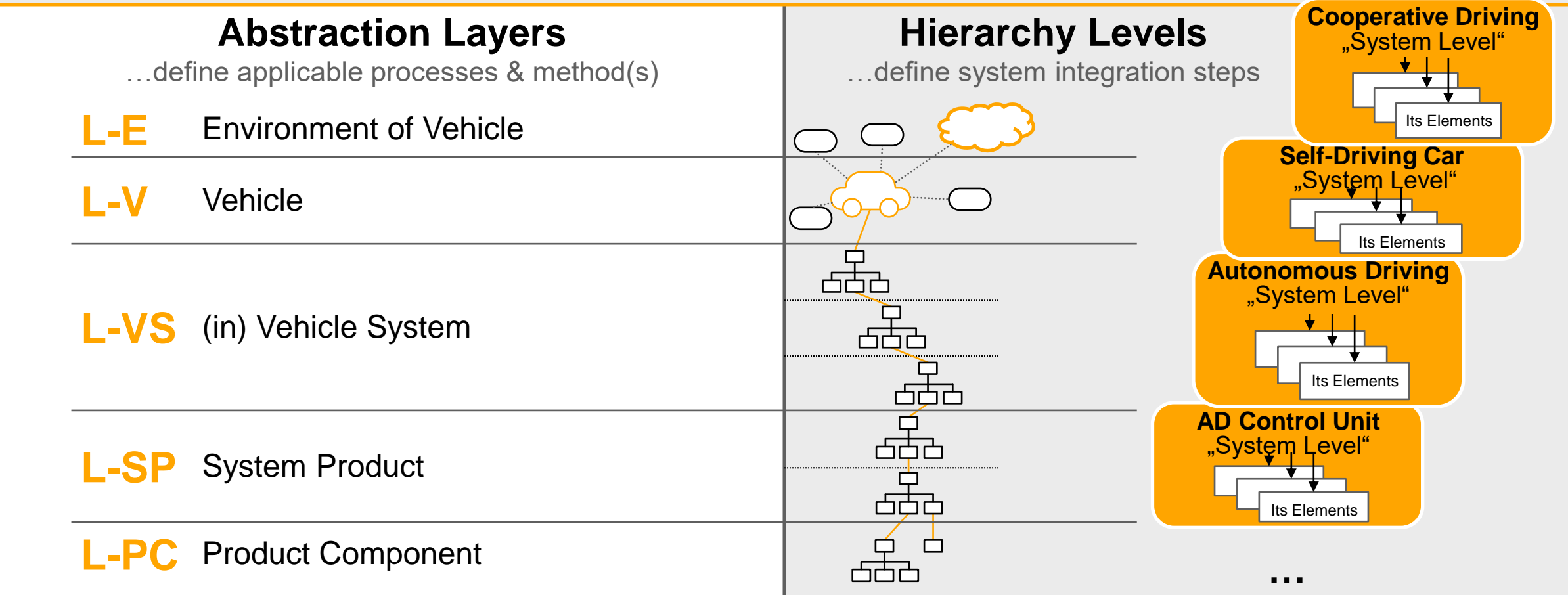
What the **customer** wants & expects

What **Continental** designs & develops

What **Continental** delivers

Systems Engineering at Continental

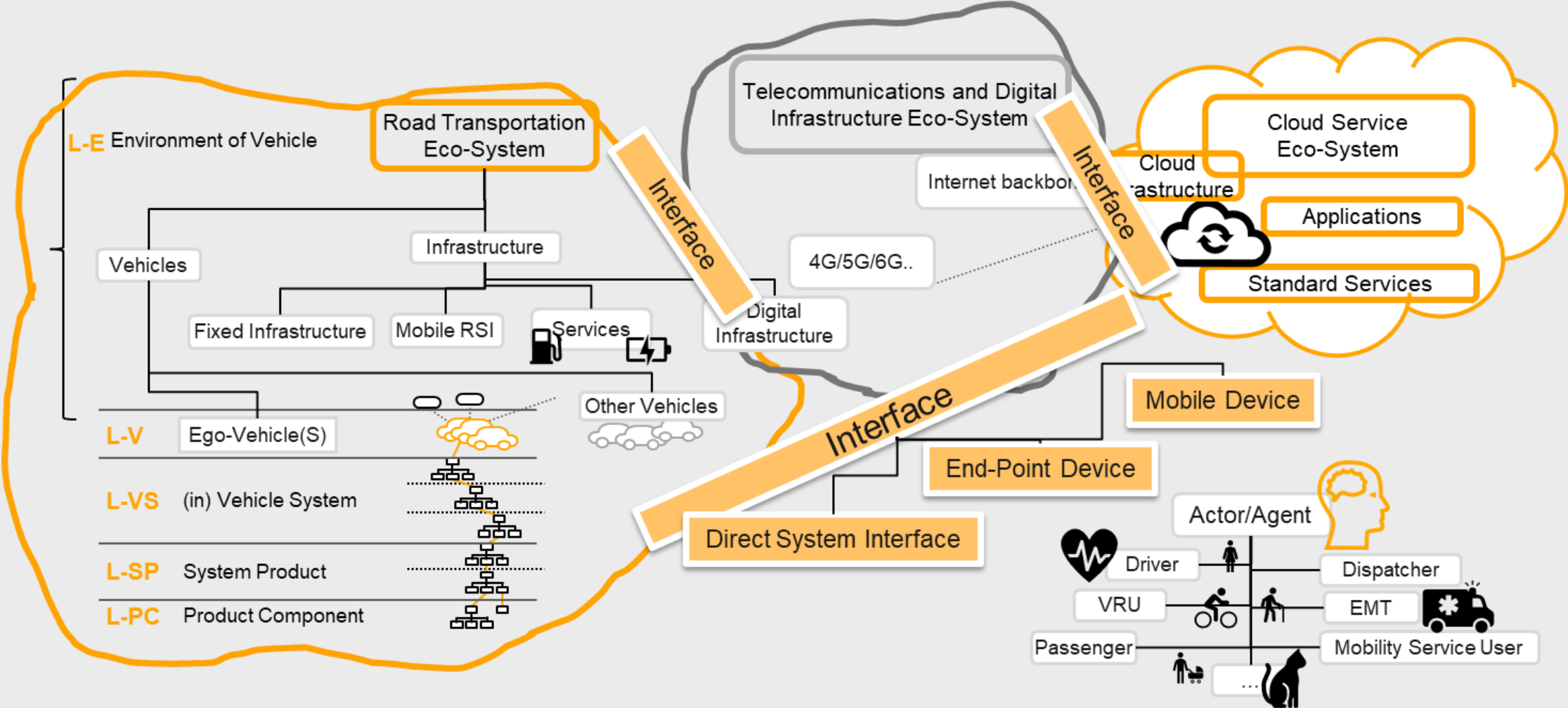
System Abstraction and Hierarchy Levels – Divide & Conquer



Products (and their requested Capabilities) exist at multiple hierarchy levels

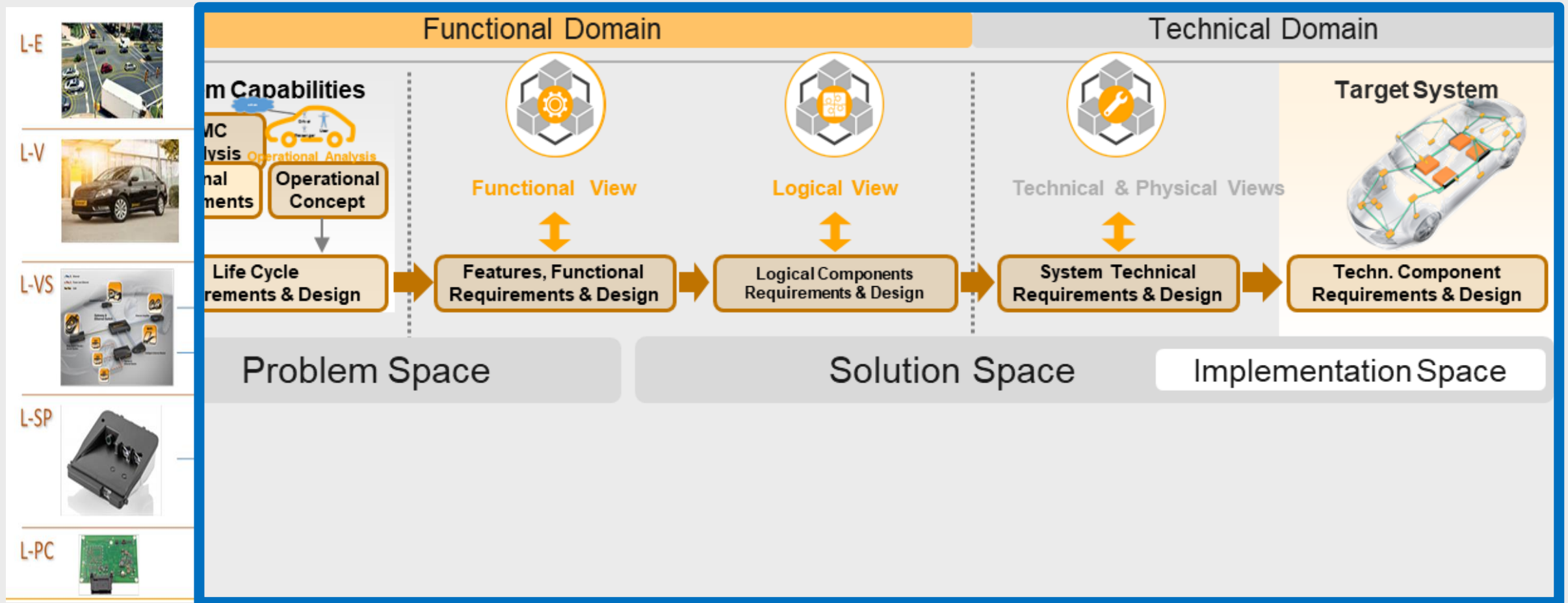
Systems Engineering at Continental

Extending the taxonomy to structure new mobility solutions



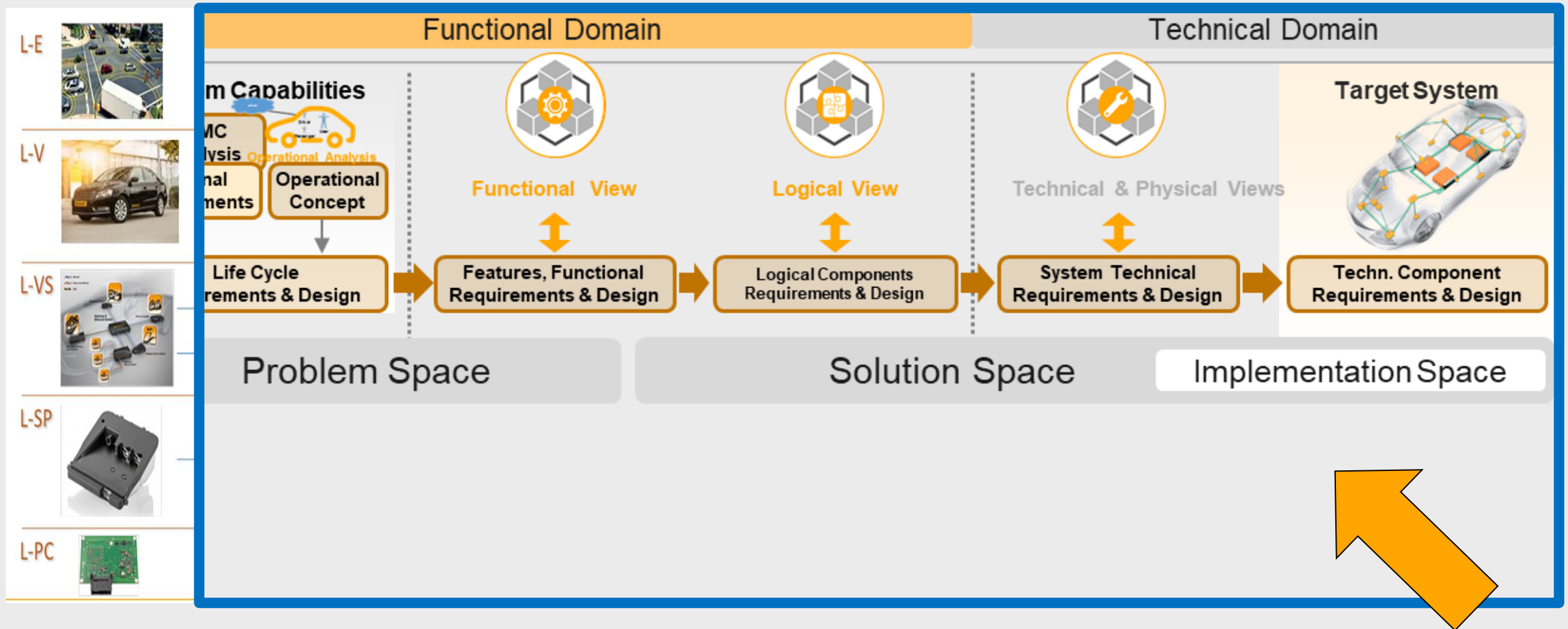
Scaling Systems Modelling vs. Increased parity simulations

Balancing ROI with growing availability of Digital Twins



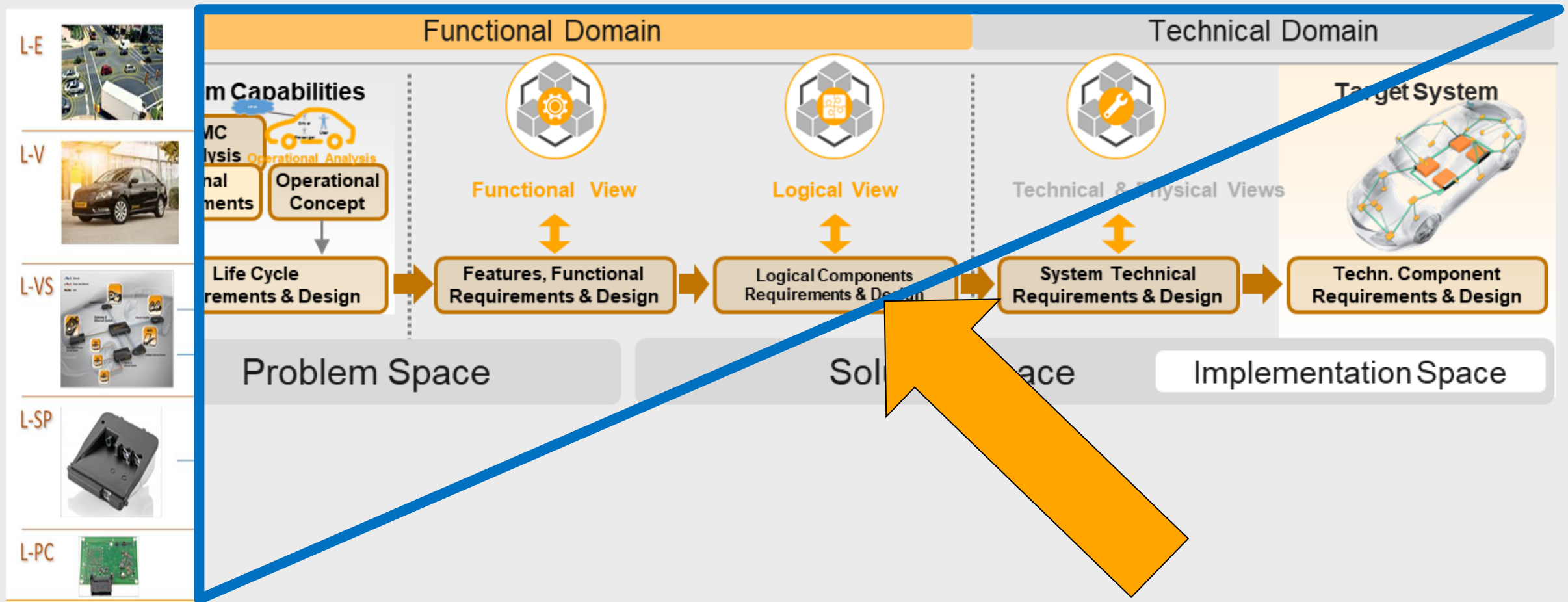
Scaling Systems Modelling vs. Increased parity simulations

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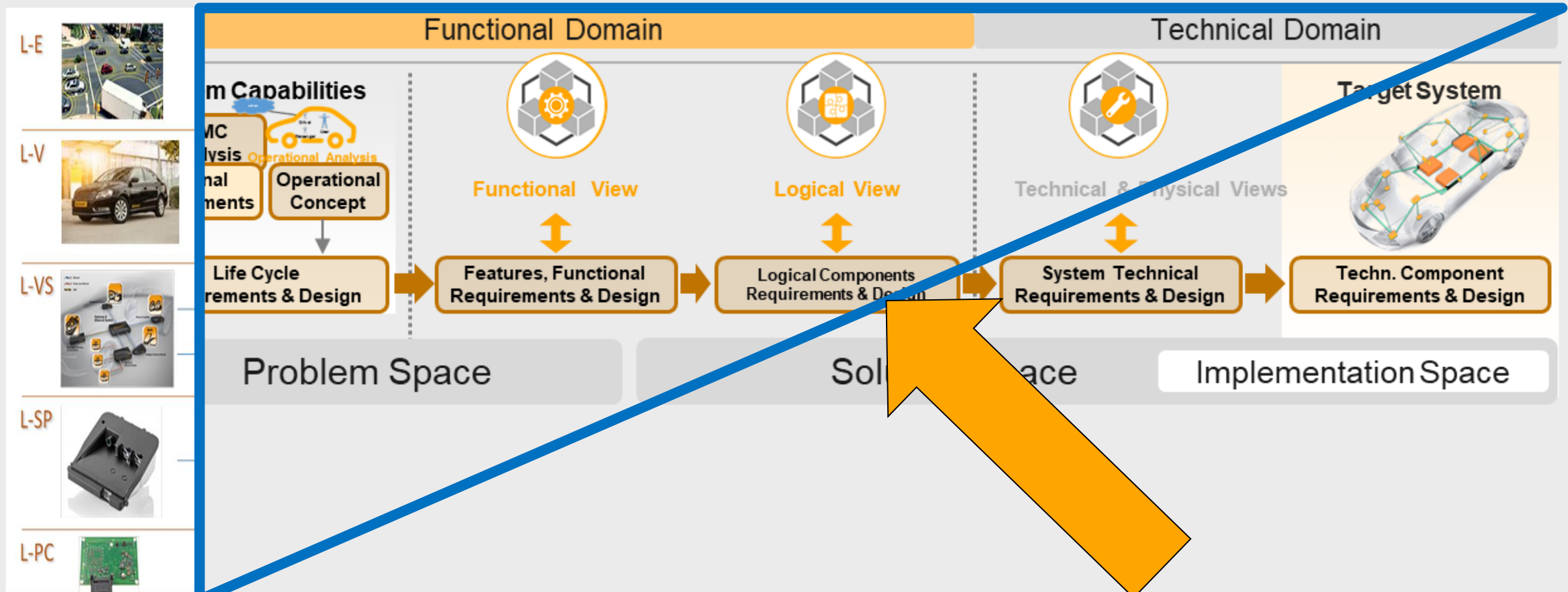
Scaling Systems Modelling vs. Increased parity simulations

Balancing ROI with growing availability of Digital Twins



Scaling Systems Modelling vs. Increased parity simulations

Balancing ROI with growing availability of Digital Twins



How much Systems Modelling do we need for the Software-Defined Vehicle?

Scaling Systems Modelling vs. Increased parity simulations

Balancing ROI with growing availability of Digital Twins

L-E



L-V



L-VS



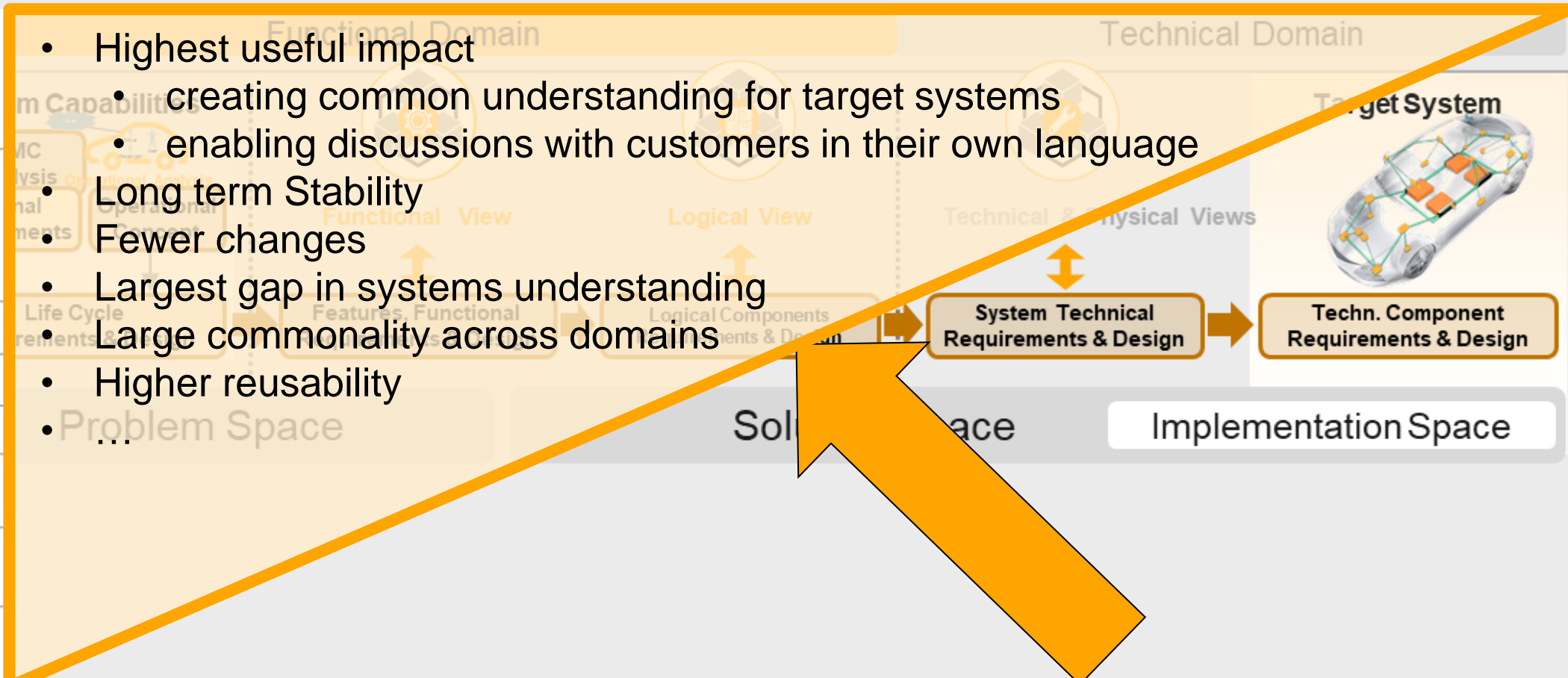
L-SP



L-PC



- Highest useful impact
 - creating common understanding for target systems
 - enabling discussions with customers in their own language
- Long term Stability
- Fewer changes
- Largest gap in systems understanding
- Large commonality across domains
- Higher reusability
- Problem Space

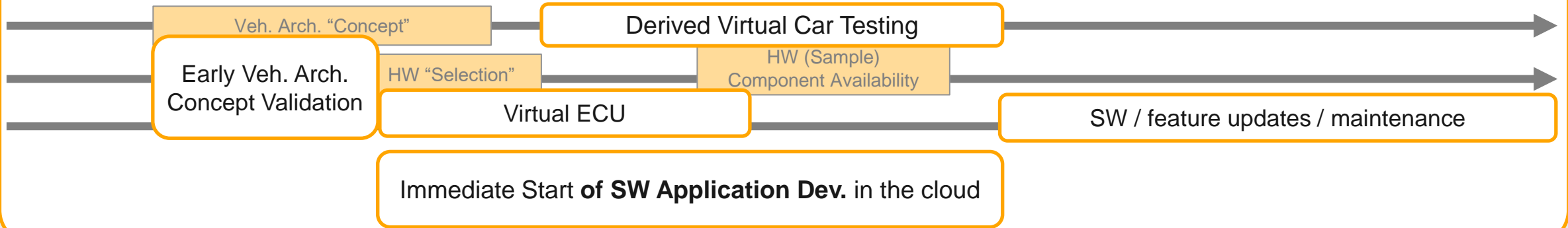


How much Systems Modelling do we need for the Software-Defined Vehicle?

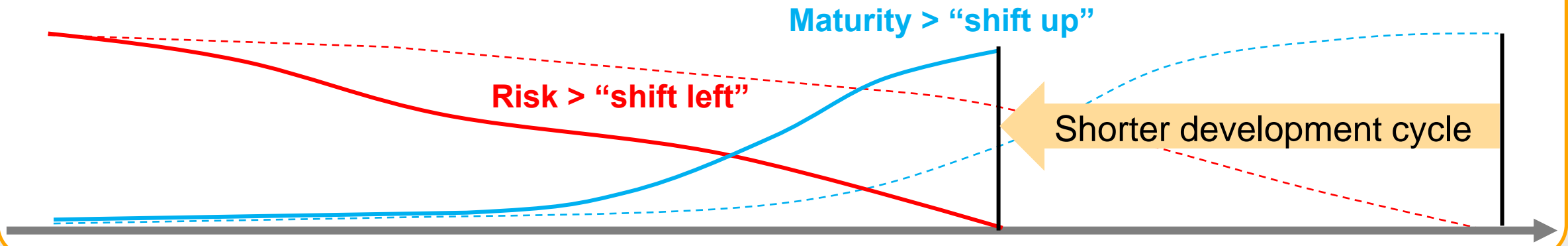
Maturity Shift-Left with CAEdge for the SDV

Leveraging data, models and cloud-enabled virtualization

Coupled Development Streams

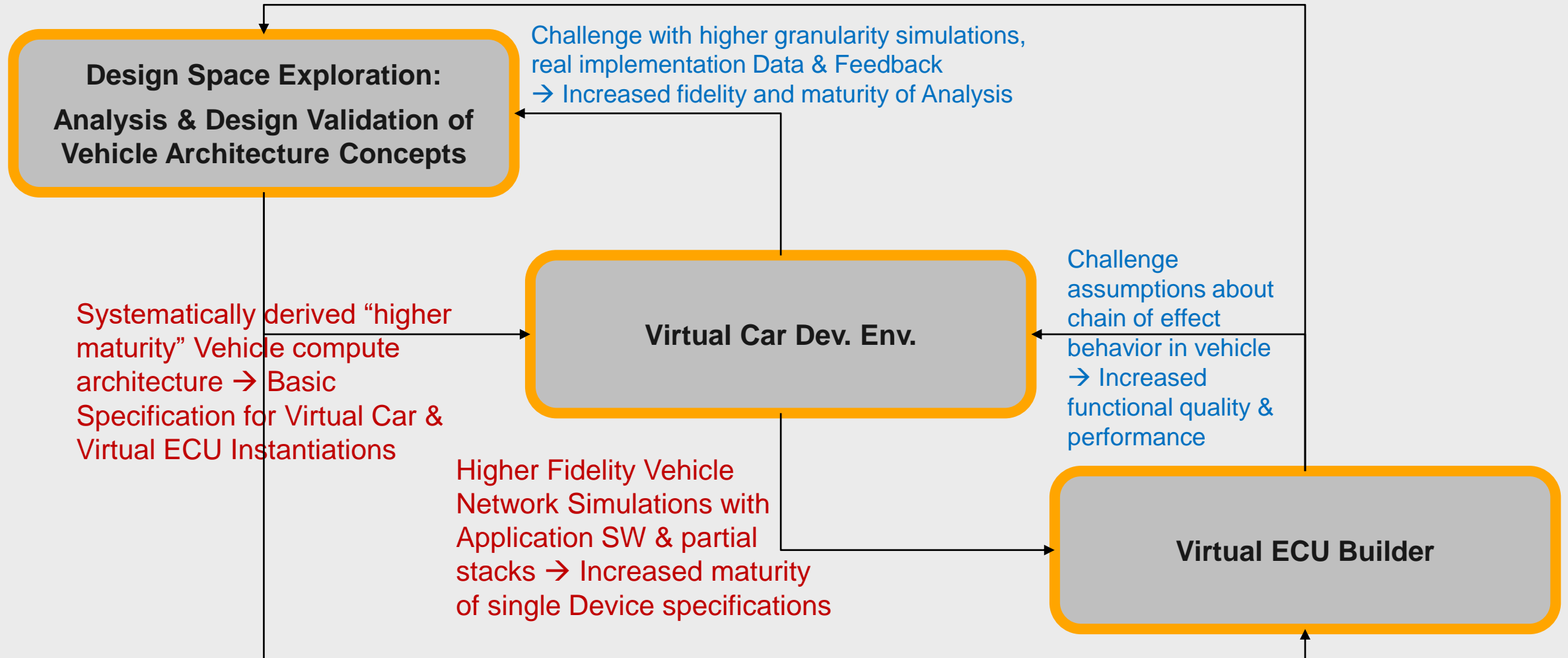


Vehicle Function Maturity



System Reference Solutions Pipeline

Frontloading maturity with Models/Simulation-enabled Shift-Left

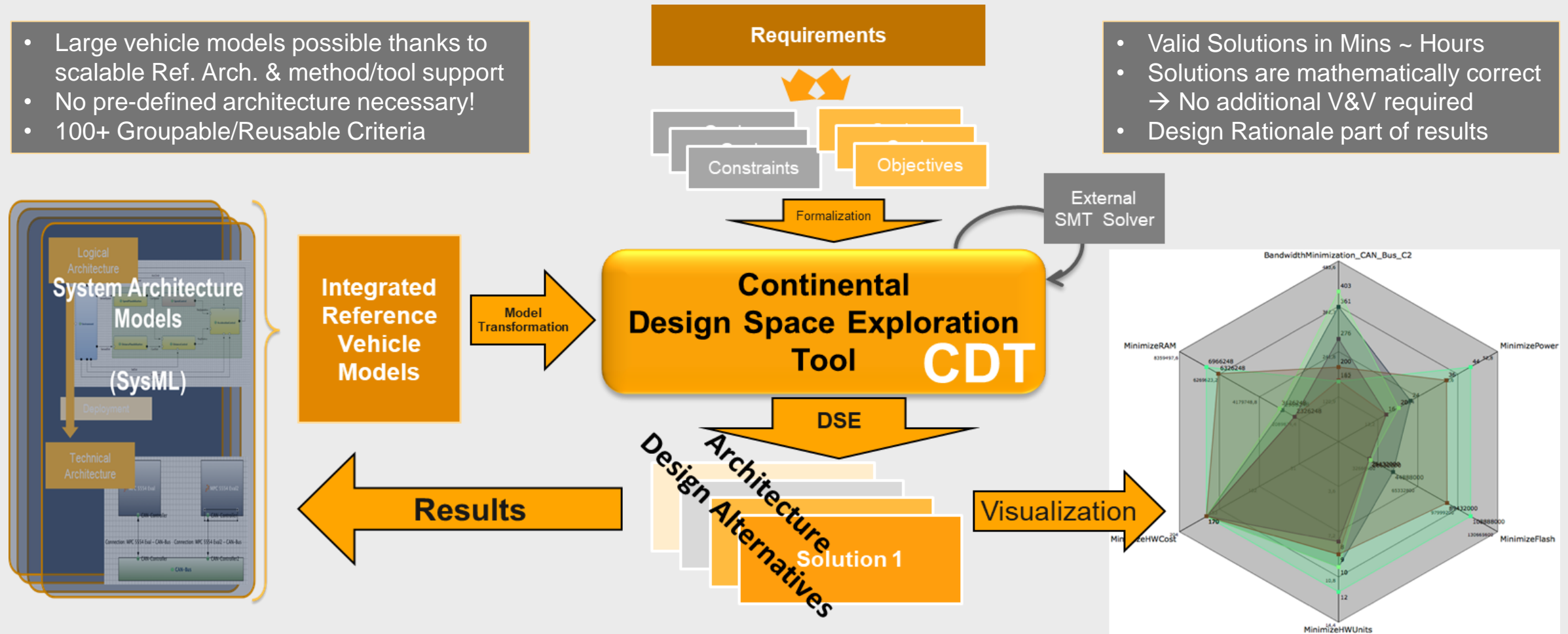


Automated Architecture Evaluation, Analysis & Synthesis

Correct-by-Design Multi-criteria Design Space Exploration

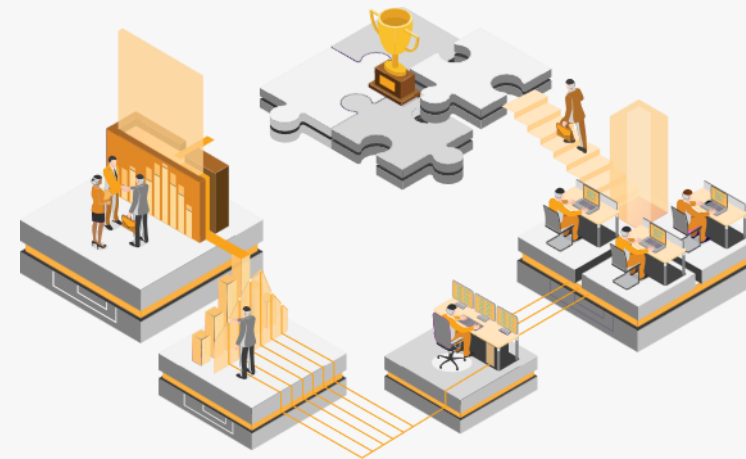
- Large vehicle models possible thanks to scalable Ref. Arch. & method/tool support
- No pre-defined architecture necessary!
- 100+ Groupable/Reusable Criteria

- Valid Solutions in Mins ~ Hours
- Solutions are mathematically correct → No additional V&V required
- Design Rationale part of results



6

Looking to the future..



Some take-aways..

Mindset & Organizational Change

- › A Town planner who never visits the construction site can't do his job properly
- › A Pioneer must accept some basic rules. Emergence is NOT synonymous with Anarchy.

Why am I Modeling? And when am I done?

- › What questions exactly should my Model answer? And for whom?

Balancing Architecture Models vs. Emergence

- › Interface-/API-First! Improved communication between Pioneers and Town Planners
- › Defining guidelines for Macro Architecture (rules and guidelines) vs. Micro Architecture (freedom of implementation design)
- › Follow standards and provide highly efficient tooling (integrated development, testing, validation, documentation and governance)

Create working feedback loop from Pioneer to Town Planner

- › Use MBSE to capture System understanding and perform early Systems Architecture analysis and design validation
- › Leveraging Cloud-hosted “SW in the Digital Twin Simulation Loop” to close gap and increase early systems design assumptions validation maturity with real implementation information

What comes next..

API first for Systems (Interface-first)

- › Semantically relevant yet decoupled interfaces

Ontological Modeling

- › How to collaborate non-restrictively across domain eco-systems (of systems)

Large scale x-domain Digital Twins

- › Extreme Importance of ModelOps → Increasingly complex systems in operation
- › No Framework-for-everything → Model Federation & Interoperability!
- › Exploring / guaranteeing dynamic configurations
- › Reduce uncertainty and (re)certification efforts

Minimum Viable Architectures

- › Balancing Architecture Models vs. Emergence
- › In conjunction with Low-/No-Code & Gen AI

In case you're interested..

Publications related to our DSE approach

- › 2017: Eder, Zverlov, Voss, Khalil, and Ipatiov. *Bringing DSE to life: exploring the design space of an industrial automotive use case*. 20th IEEE/ACM MODELS Conference.
- › 2018: Eder, Bayha, Voss, Ipatiov, and Khalil. *From deployment to platform exploration: automatic synthesis of distributed automotive hardware architectures*. 21st IEEE/ACM MODELS Conference.
- › 2020: Eder, Bayha, Voss, Ipatiov, and Khalil. *Expanding deployment to platform exploration: automatic synthesis of distributed automotive hardware architectures*. *SOSYM. Journal of Software and Systems Modeling*.

Thank you!

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