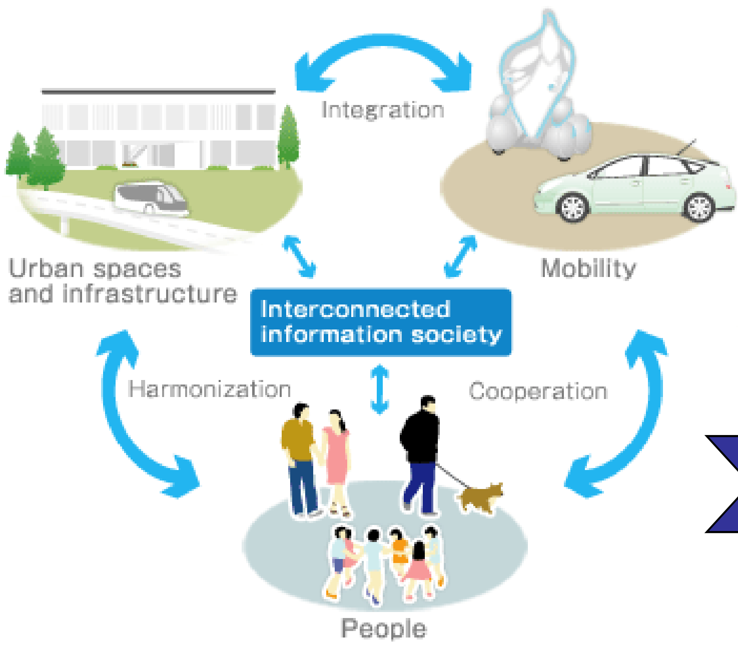
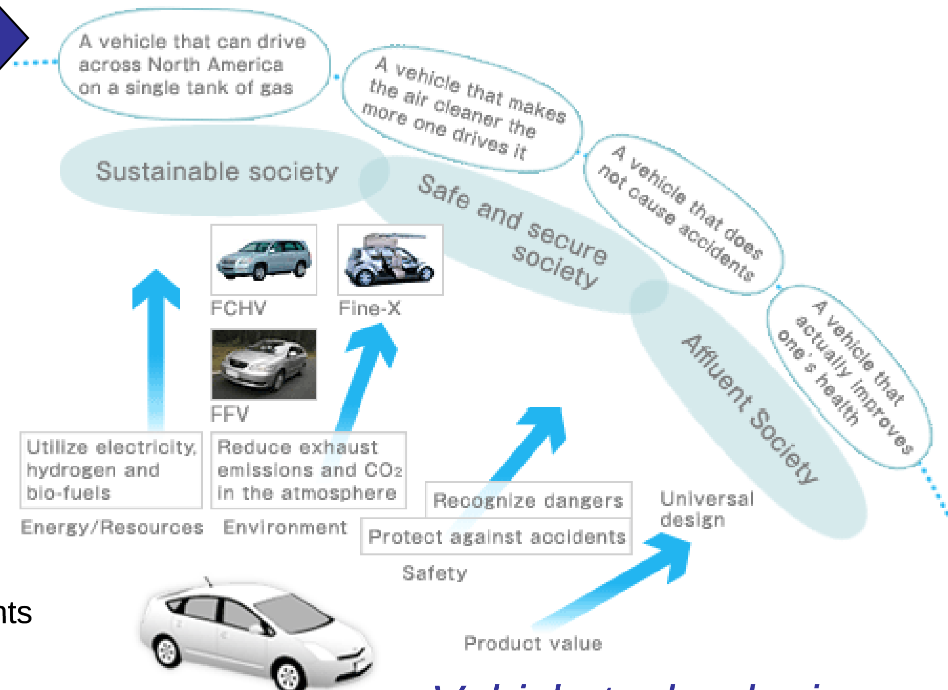
Toyota’s Direction



Infrastructure integration

Our sustainable mobility strategy includes products, partnerships, the urban environment and energy solutions.*



Vehicle technologies

*Toyota 2010 North American Environmental Report Highlights

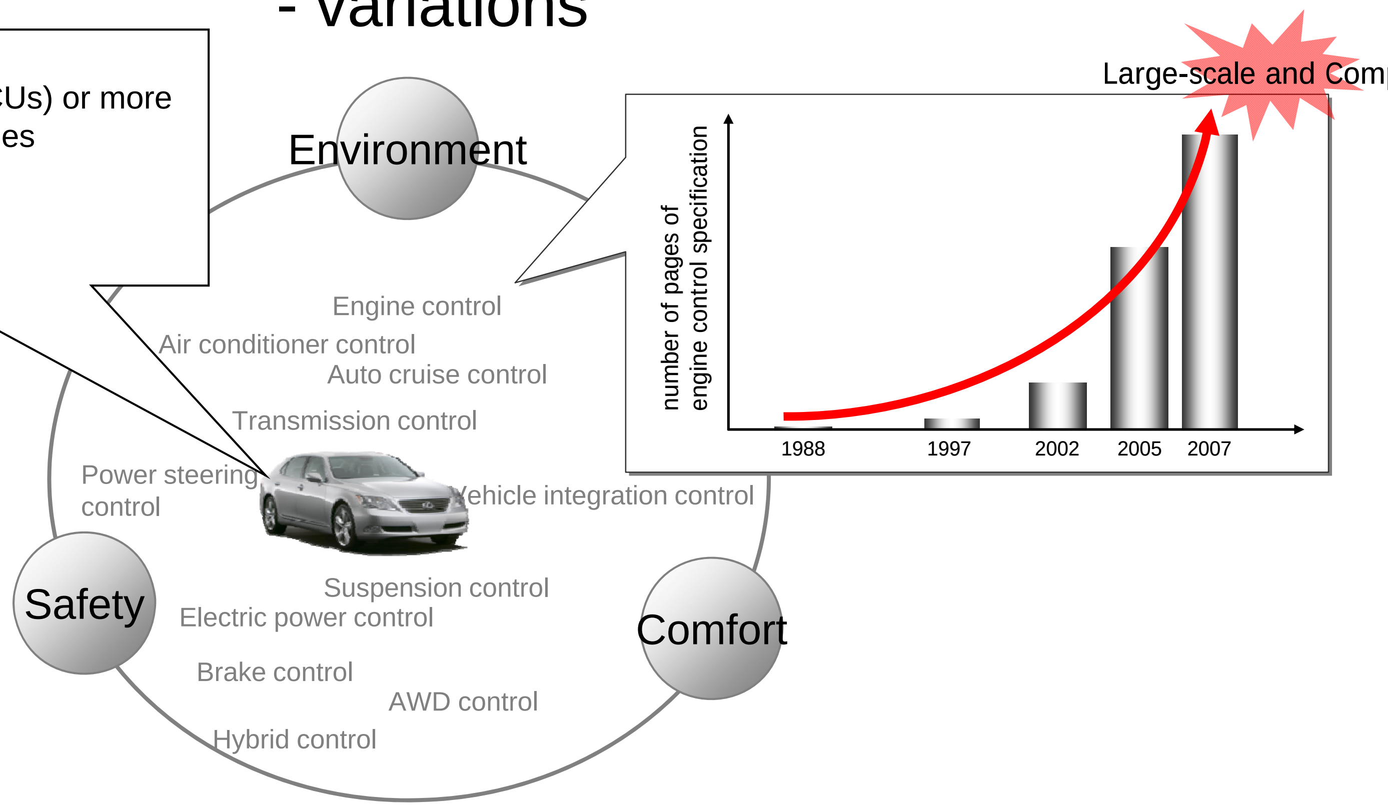
Presentation Flow

1. Development Challenges
2. Focus on Verification and Validation
3. Open Challenge: Engineering Processes for Verification and Validation of Cyber-Physical Systems

Product Direction: Today's Complexity
- system scale
- variations

LEXUS LS460 …
- 100 Electronic Control Units (ECUs) or more
- Program size of seven million lines

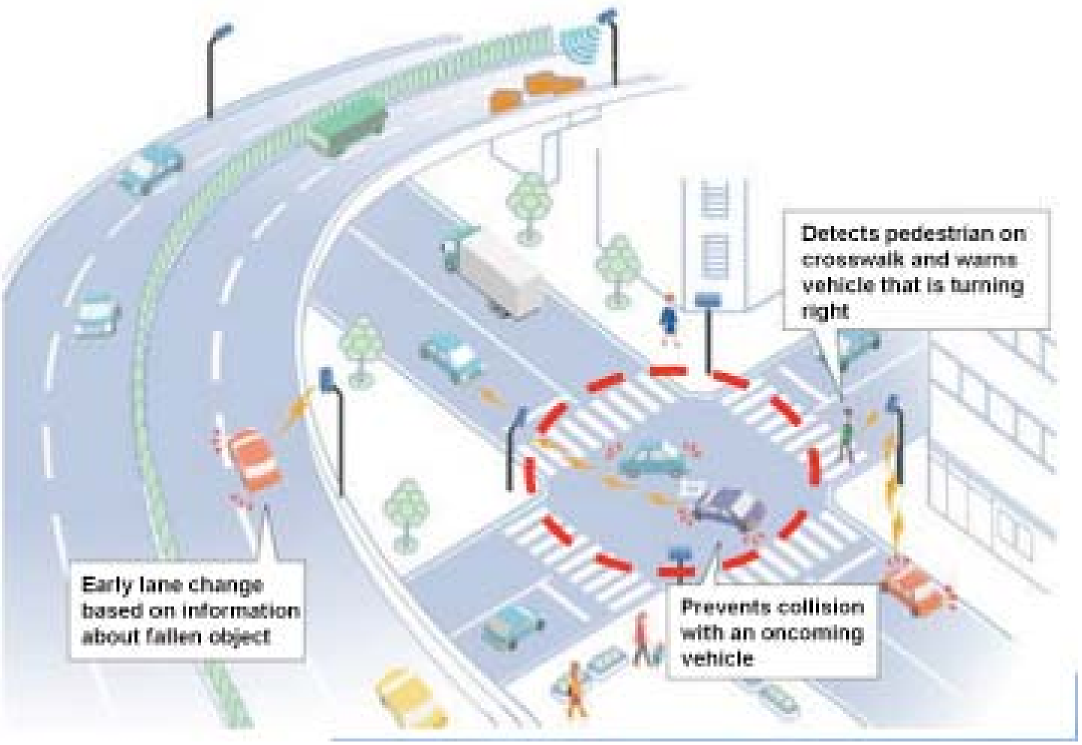
Nikkei business (September, 2006)

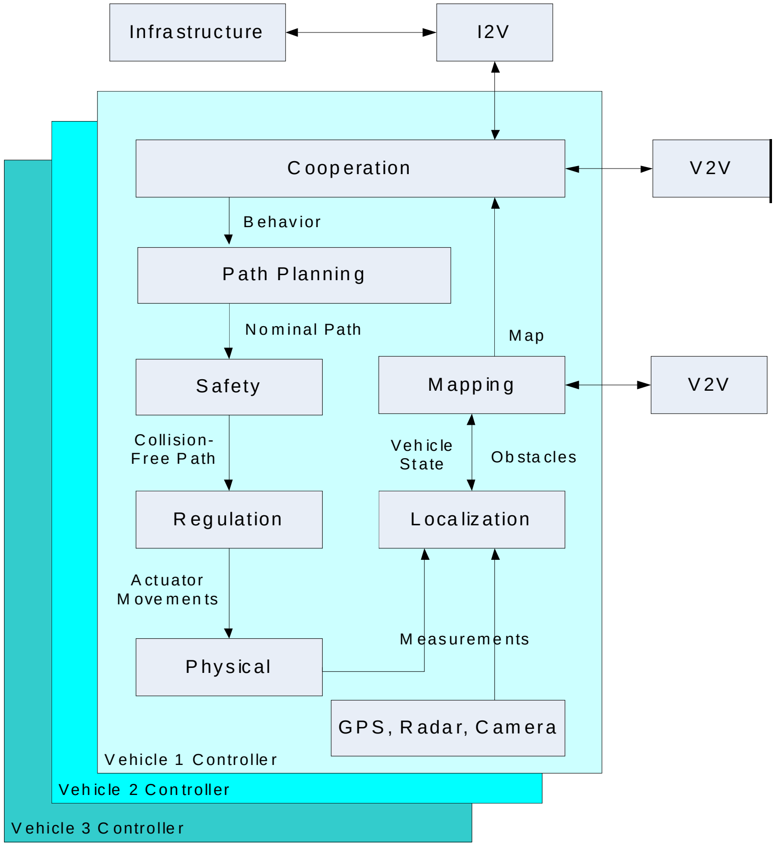


In-vehicle control systems

Control, integration, and complexity are accelerating in order to improve vehicle performance and provide new features.

Product Direction: Tomorrow's Complexity: Cyber-Physical Systems
- Vehicle to Infrastructure and Vehicle to Vehicle
- Collision Avoidance and Cooperative Driving





CPS: distributed computation nodes operating in a control hierarchy that interact with the vehicle's physical processes in real-time to provide critical function.

Today’s Situation: Control Development Process Overview

Insufficient requirement analysis and test design

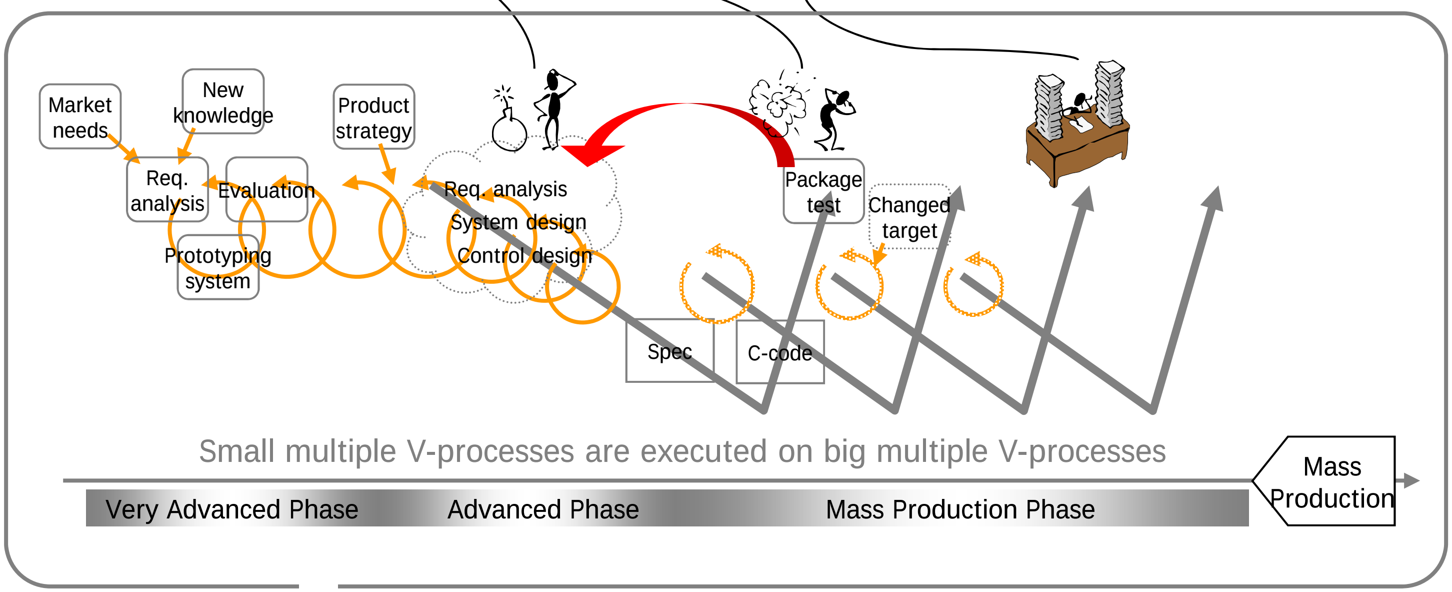
➔High possibility of re-design and re-evaluation

Focus on right hand side of V-process

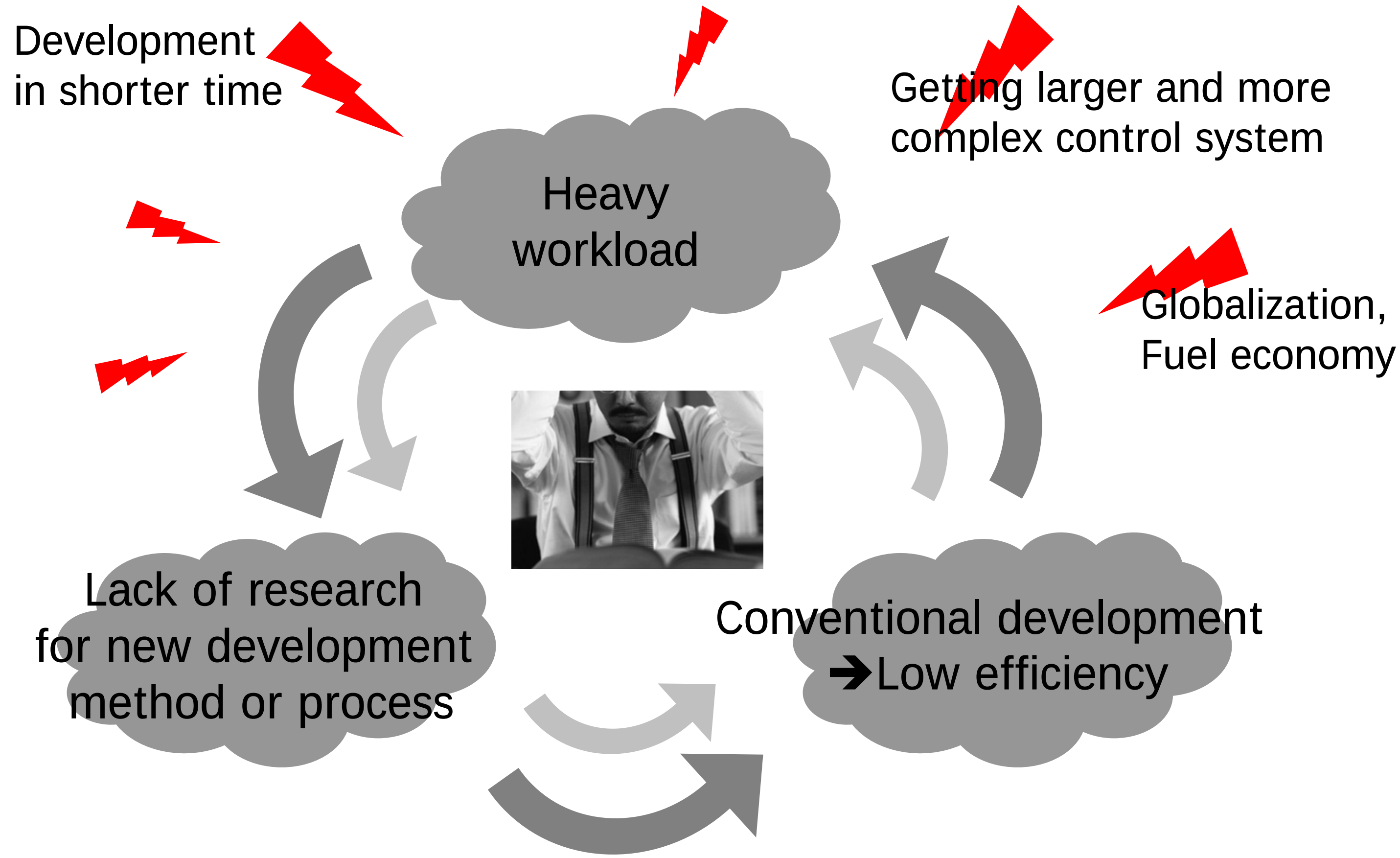
➔Inefficient V&V due to exhaustive experiment with the actual product

Huge number of tests and more difficult evaluation

➔Approaching the limits of human power

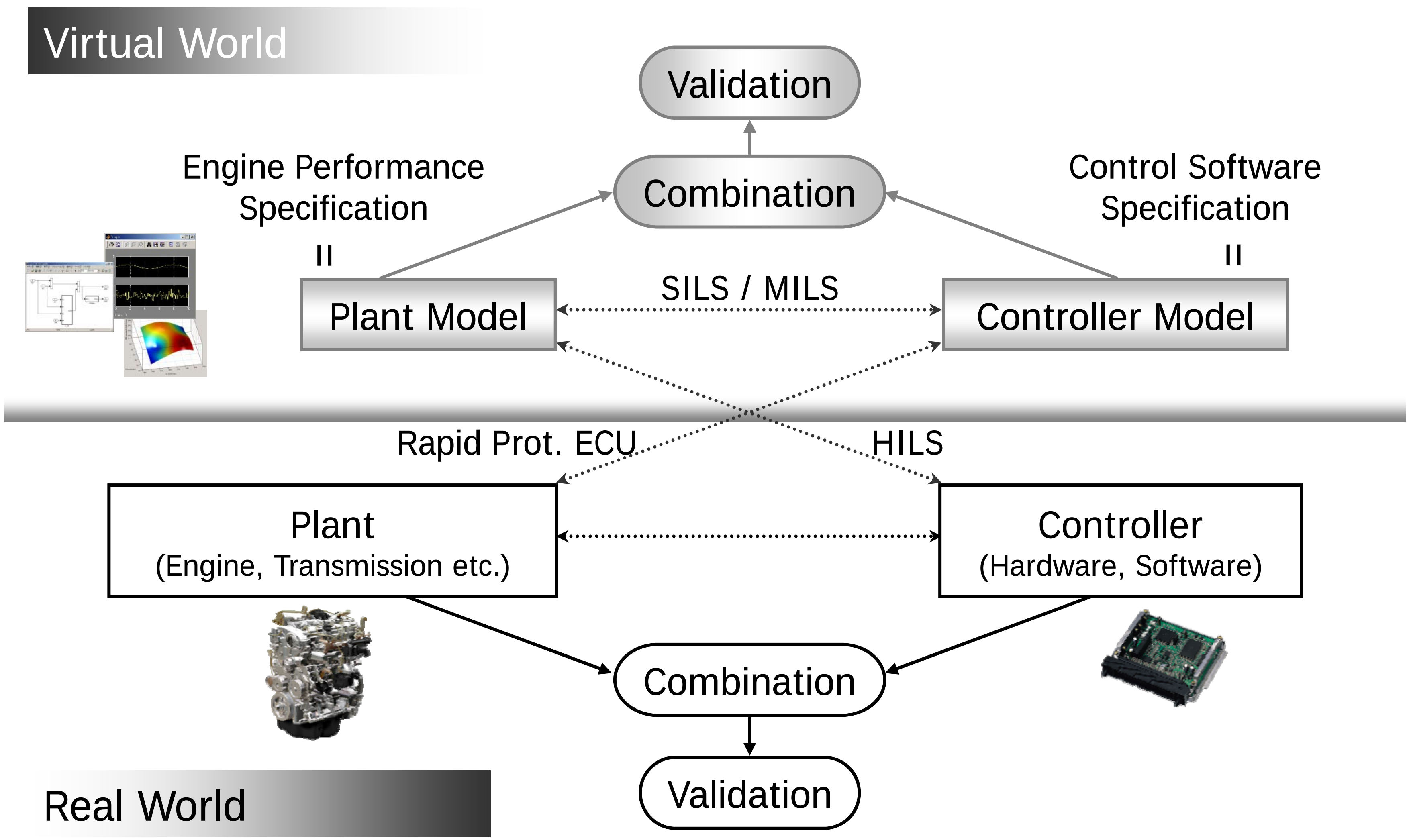


Consequence of Development Complexity



A shift in paradigm is needed to overcome the above “Demon Cycle”
Toyota has been pushing ahead with MBD as an essential solution.

Model-Based Development: Basic Tooling



MBD Focus areas

1. Process and Information Management
2. Plant Modeling
3. Model-based control design
4. Calibration
5. Verification and Validation

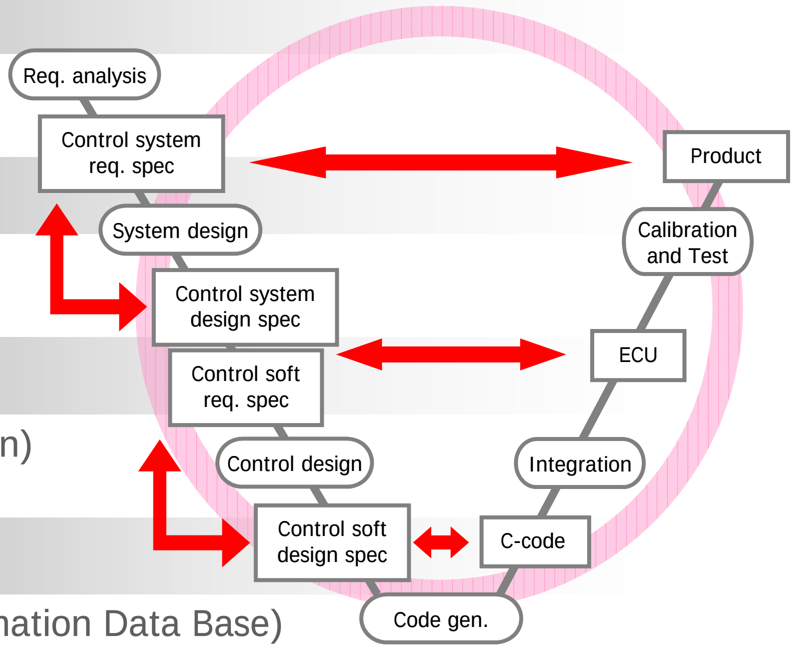
Verification and Validation
- Strategy -

1. V&V process
(ex. Hierarchical verification, Requirements specification)

2. Verification with advanced techniques
(ex. Automated test generation, Formal methods)

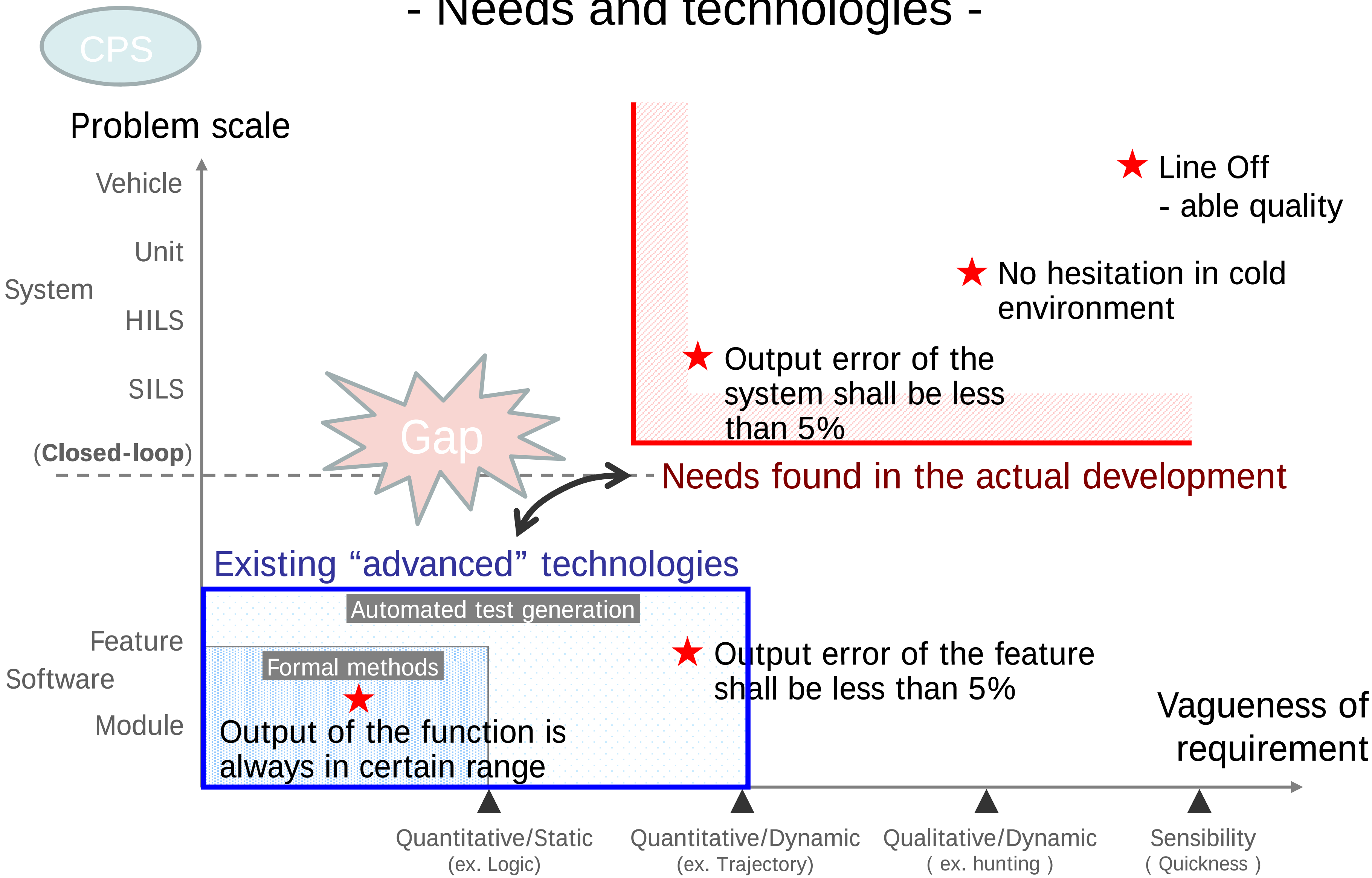
3. Efficient Validation including experiment
(ex. Software structural analysis, Defect cause exploration)

4. V&V environment
(ex. Integrated V&V environment, Test-reuse, Test Automation Data Base)



Renew development process by applying advanced V&V technologies to improve:
- ➔ Quality - no defects allowed in product
- ➔ Efficiency - minimized development cost

Verification and Validation
- Needs and technologies -



Verification of Cyber-physical systems (e.g. collision avoidance)

- The systems are **vastly heterogeneous** in nature. What mathematical or modeling representations should be used to admit validation and verification?
- The systems are **complex**. What is the maximum complexity that can be validated and verified? How do we quantify complexity?
- Given detailed design models of the system components (these are the most readily available in today's processes) how does the engineer ***properly*** **abstract** the models to satisfy the complexity constraint?
- The system functionality is **hierarchically structured**. Are there validation and verification techniques that accommodate (and possibly exploit) this structure?
- The systems are **comprised of outside elements** (e.g. infrastructure, unknown vehicles) that cannot be brought in-house for analysis or testing. How do we parameterize the outside element's performance envelope for validation and verification?
- The systems rely on **lossy wireless communication**. How do we characterize the worst-case scenarios so that we can validate and verify the dynamic behavior of the system?
- This system configuration is **multi-agent and dynamic**. How do we validate and verify given the untold number of agent scenarios?
- The systems are subject to **malicious interaction**. How do we validate and verify the system's countermeasures?
- The vehicle performance envelopes are subject to several **uncertain parameters** such as weight, road coefficient, road grade, tire wear. Are there validation and verification techniques able to accommodate these uncertainties?

Open Challenge: Engineering Processes for Verification and Validation of Cyber-Physical Systems

a) We propose a community challenge to:
   a) describe what it means to validate and verify cyber-physical systems in concrete terms,
   b) develop engineering processes that practicing engineers can use to conduct the validation and verification, and
   c) track progress by publishing metrics on the scale and complexity of systems than can be validated and verified using the processes.

b) Collision avoidance systems could be used as a representative application test-bed:
   a) much of the work is already government sponsored, and
   b) the benefits are societal.

Perhaps we need to generate a Moore's Law for Validation and Verification of Cyber-Physical Systems ?

Thank you