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Model-Based Development : MBD Concepts Module

MAAM Subtitle

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# Introduction

### Model-Based Development (MBD) is

* the practice of leveraging simulation to understand the behavior of a to-be-constructed or existing physical system. “Focuses on creating mathematical models to represent system behavior”.
* shift from traditional coding to model-driven approaches for software and system development “auto-generating code from the model”.
* widely used in the automotive industry to improve quality, reduce errors, and shorten time-to-market. also it is used in aeromechanics and robotics industries.



### Concepts and Definitions:

* A **model** is a Software representation of any components of the physical system.
* A **system** is a set of interconnected or interdependent components that work together to achieve a common purpose or goal.

### Advantages of MBD:

* + Efficiency and Time Savings
    - MBD automates code generation 30% Faster than Traditional coding , saving time and resources, and reducing development costs.
    - Easy to deal with complexity.
  + Quality and Error Prevention
    - MBD ensures high-quality, error-free software through formal verification, validation, and bug detection in model simulation Reduce Errors and Risks.
  + Reuse, Standardization, and Flexibility
    - MBD allowing model and component reuse, ensuring consistent development practices.
  + Traceability and Cost Savings
    - MBD provides traceability from requirements to code, reducing the cost of software bugs and improving reliability through effective testing and defect identification.

### Why we need to shift to a MBD?

* Market Competition and Feature Race:
  + OEMs strive to introduce new automotive features for competitive advantage, creating a race to be the first with unique and complex algorithms, leading to increased cost and time-to-market.
* Software Engineering Challenge:
  + Shortening development cycles and reducing testing time is a key challenge for software engineers, necessitating a paradigm shift from code-based to model-driven development (MBD).
* MBD Emphasizes Function Over Code:
  + MBD focuses on function over code in automotive software development, enabling early error detection in product design and development, unlike conventional coding that often finds errors in late and costly testing phases.
* Efficiency Gains with MBD:
  + The adoption of MBD addresses the inefficiencies in development, allowing for quicker feature implementation, reduced testing time, and ultimately overcoming the challenges posed by the race to introduce new automotive features.

### Automotive Use Cases:

* + Applications include ADAS, BMS, HVAC systems, engine control, and electric powertrains.

### Automotive Market

|  |  |
| --- | --- |
| OEMs  (Original Equipment Manufacturers) | are companies that produce parts and components specifically for use in new vehicles. They play a critical role in the automotive industry, as the parts they create are designed to meet the exact specifications and requirements of specific vehicle makes and models. |
| Tier 1 suppliers | are companies that provide complete systems or major components directly to OEMs. These components are often "plug-and-play" and integrate seamlessly into the vehicle's assembly line. |
| Tier 2 suppliers | are typically smaller companies that manufacture specific components and parts used by Tier 1 suppliers to create their systems or modules. |

### Software Architecture

AutOSAr (Automotive Open System Architecture) is an open and standardized software architecture for automotive electronic control units (ECUs). It is designed to facilitate the development of complex automotive software systems, improve scalability, and enhance interoperability among different automotive manufacturers and suppliers.



### MBD through V-Model

* MBD aligns with the V-shaped Software Development Lifecycle (SDLC)
  + Requirement Gathering and Analysis
  + Model Development and Auto-Code Generation
    - particularly beneficial in the development phase, reducing the need for costly prototypes.
  + Iterative Testing and Bug Resolution
  + Early Hardware and Embedded Software Insight

Successful MBD trials can extend models to other project areas, and simulations inform hardware design parameters.



### Guidelines and Standards:

Follows AUTOSAR and MAAB “MATLAB Automotive Advisory Board” guidelines for consistency and interoperability.

* MathWorks works closely with “Japan- Europe” subgroups. MathWorks hosts and maintains the guidelines but does not create the guidelines.

#### Modeling Tools:

* **MATLAB** a Powerful calculation tool which provide many Toolboxes.
* **Simulink** for graphical modeling and code generation.
* **Simscape** for acausal modeling.
* **Stateflow** for sequential behavior control.
* **Embedded Coder** for generating efficient C/C++ code.
* **Mathematical Model** Control, Plant Model, PID Controllers
* **Product Knowledge**

#### Modeling Approaches:

There are many approaches for different system complexities.

* **White Box**
  + Develop models by writing and solving mathematical equations representing system behavior.
  + Requires domain knowledge and a deep understanding of the system.
* **Multi-physics modeling**
  + Builds models by assembling pre-built components with predefined behavior models from libraries.
  + Covers various physics domains such as mechanical, electrical, hydraulic, and thermal systems.
  + Allows the integration of 3D geometry to capture non-linearities and dynamic behaviors.
* **Black Box**
  + Creates models purely from observed experimental data, without relying on physical equations.
  + Known as "system identification." suggesting models for complex identifications
* **Gray Box**
  + Combines aspects of both white box (theory-driven) and black box (data-driven) modeling.
  + Estimates unknown parameters by comparing the model's response to real system behavior.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Aspect | White Box | Multi-Physics | Gray Box | Black Box |
| Knowledge Level | Full system knowledge | Partial, predefined components | Partial system knowledge | No system knowledge |
| Development Time | High | Medium | Medium | Low |
| Accuracy | High (if parameters known) | High (with robust libraries) | Medium-High | Moderate |
| Automation | Low | Medium-High | Medium-High | High |
| Use Case | Physics-based insights | Cross-domain system modeling | Partial understanding | Pure data-driven tasks |

#### In-Loop Testing:

Each stage of in-loop testing serves to progressively validate a system, ensuring accuracy, performance, and reliability at every step.

* Model-In-Loop (**MIL**)
  + Focuses on testing the control algorithms in a simulation environment (e.g., MATLAB/Simulink).
  + To validate the logic and functionality of the model before implementation.
* Software-In-Loop (**SIL**)
  + Tests the compiled code (often generated from the model) in a simulated environment to verify the implementation matches the model's behavior.
  + To ensure the software behaves as intended once the control algorithm is implemented.
* Processor-In-Loop (**PIL**)
  + Executes the control software on the actual processor or microcontroller to test how the code performs in a real-world processing environment.
  + To validate the performance of the software on the target hardware.
* Hardware-In-Loop (**HIL**)
  + Integrates the target hardware (including processors and I/O systems) into a simulated environment that mimics the real-world system.
  + To verify the complete system's behavior in near-real-world conditions.
* Back-to-Back Testing **MIL-SIL**
  + Compares the outputs of the MIL and SIL tests to ensure the implemented software behaves identically to the original model.
  + To identify discrepancies between the high-level model and the compiled code.



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