符合ISO 26262的汽车电子软件开发流程

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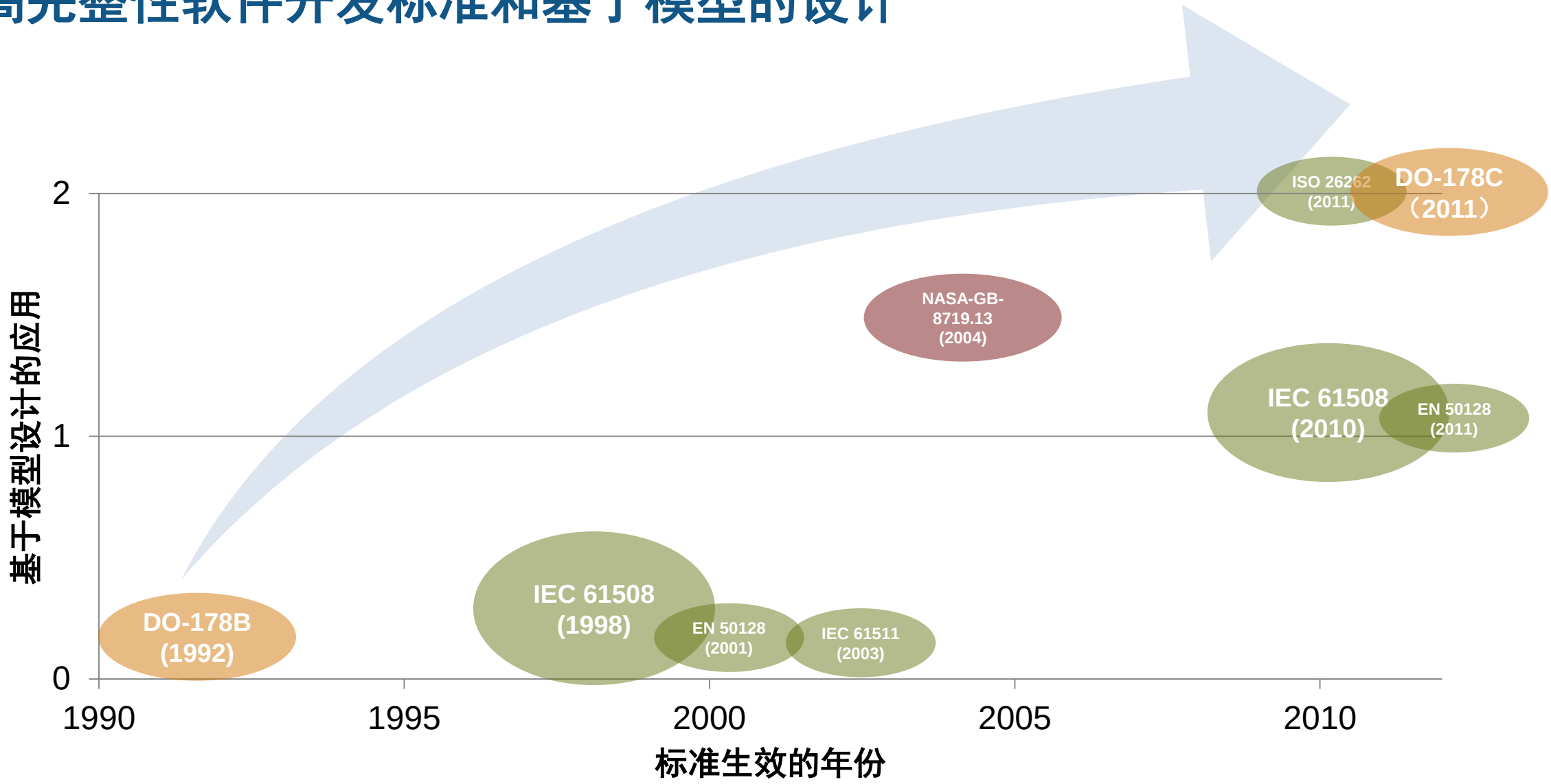
高完整性软件开发标准和基于模型的设计



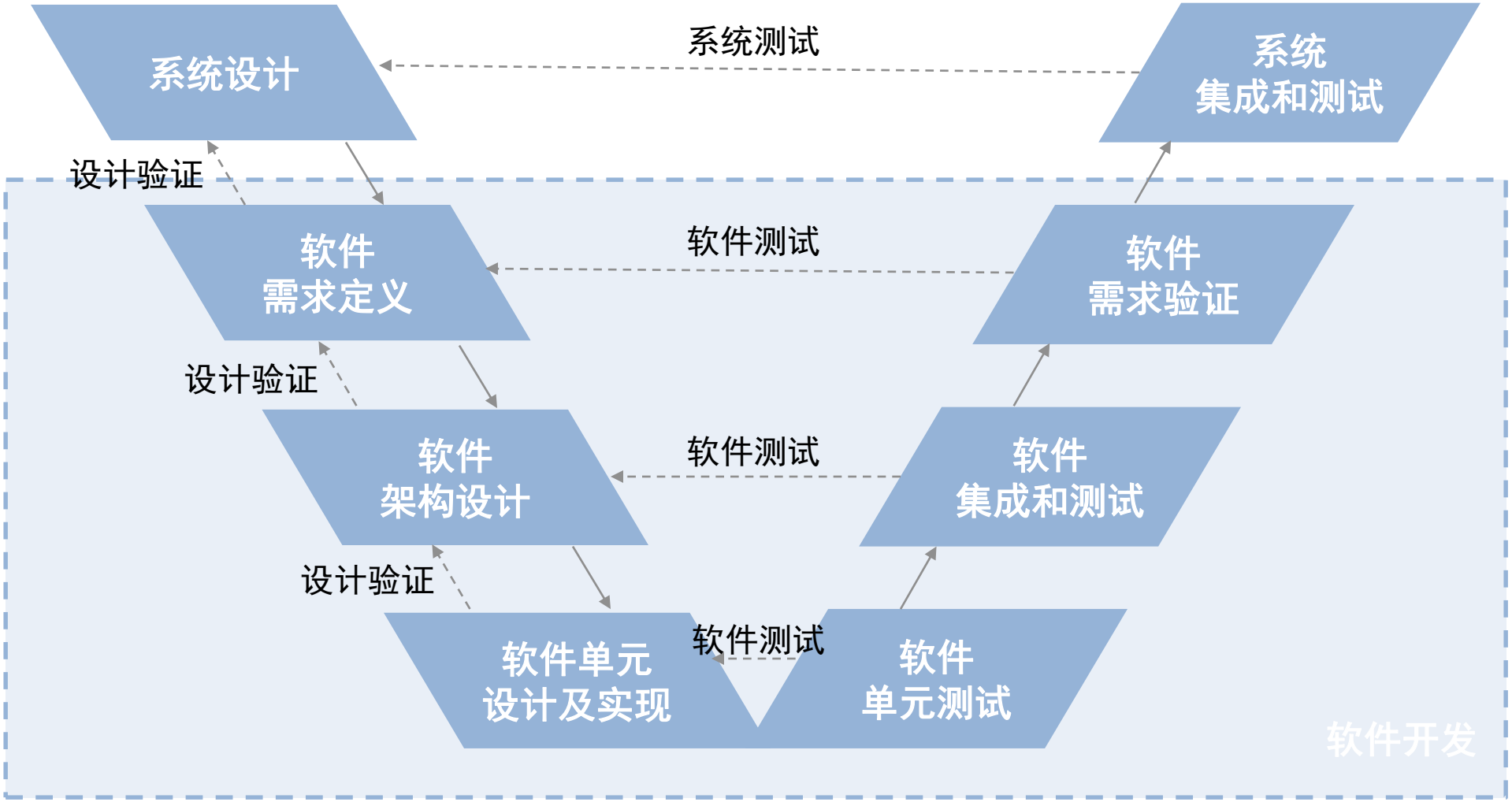
软件开发标准里出现基于模型的设计

为什么？

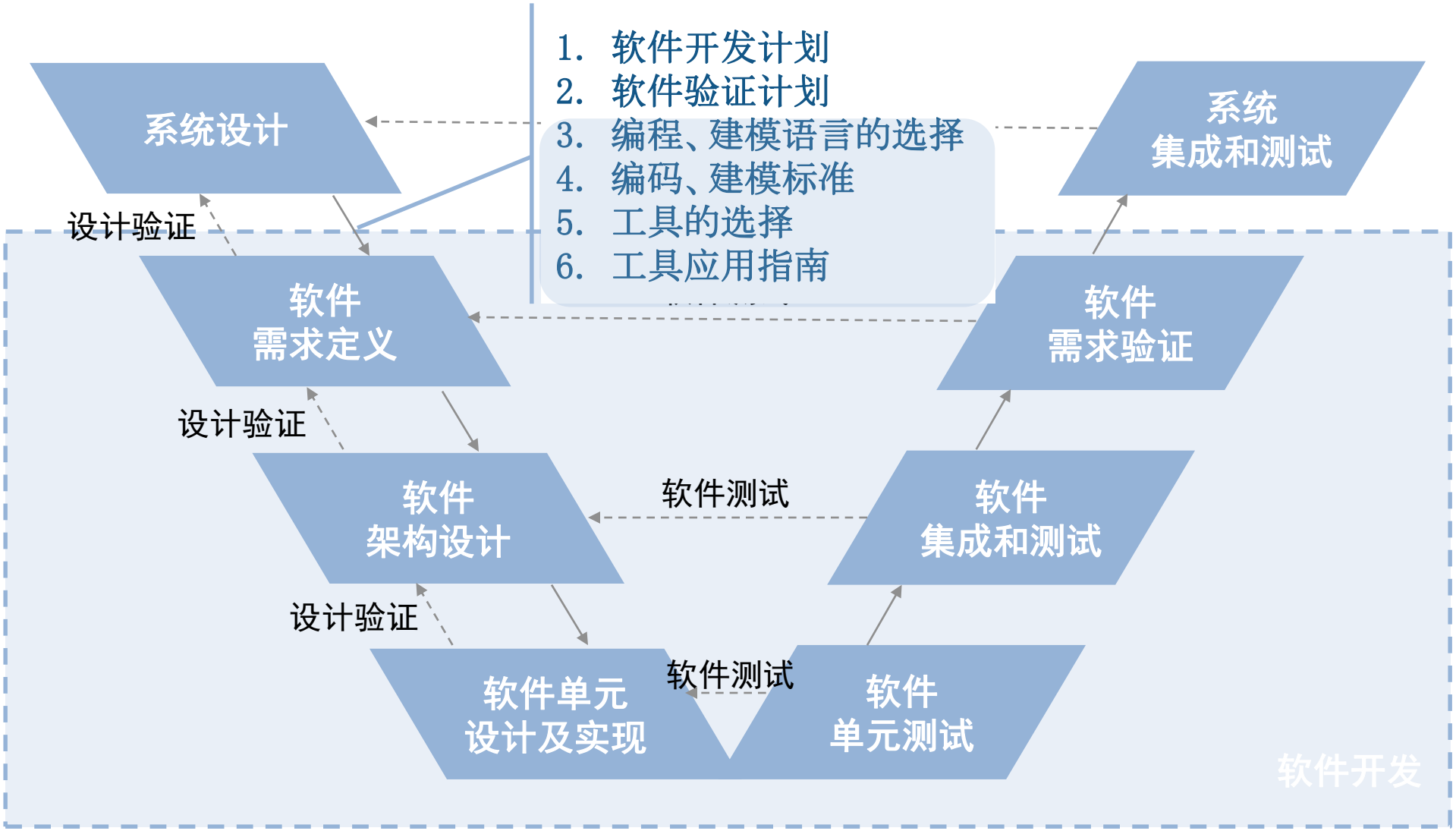
大 纲

- ISO 26262软件开发项目的启动
- 符合ISO 26262的软件开发过程

ISO 26262定义的软件开发过程



ISO 26262的软件项目启动



建模/编程语言的选择及相关标准

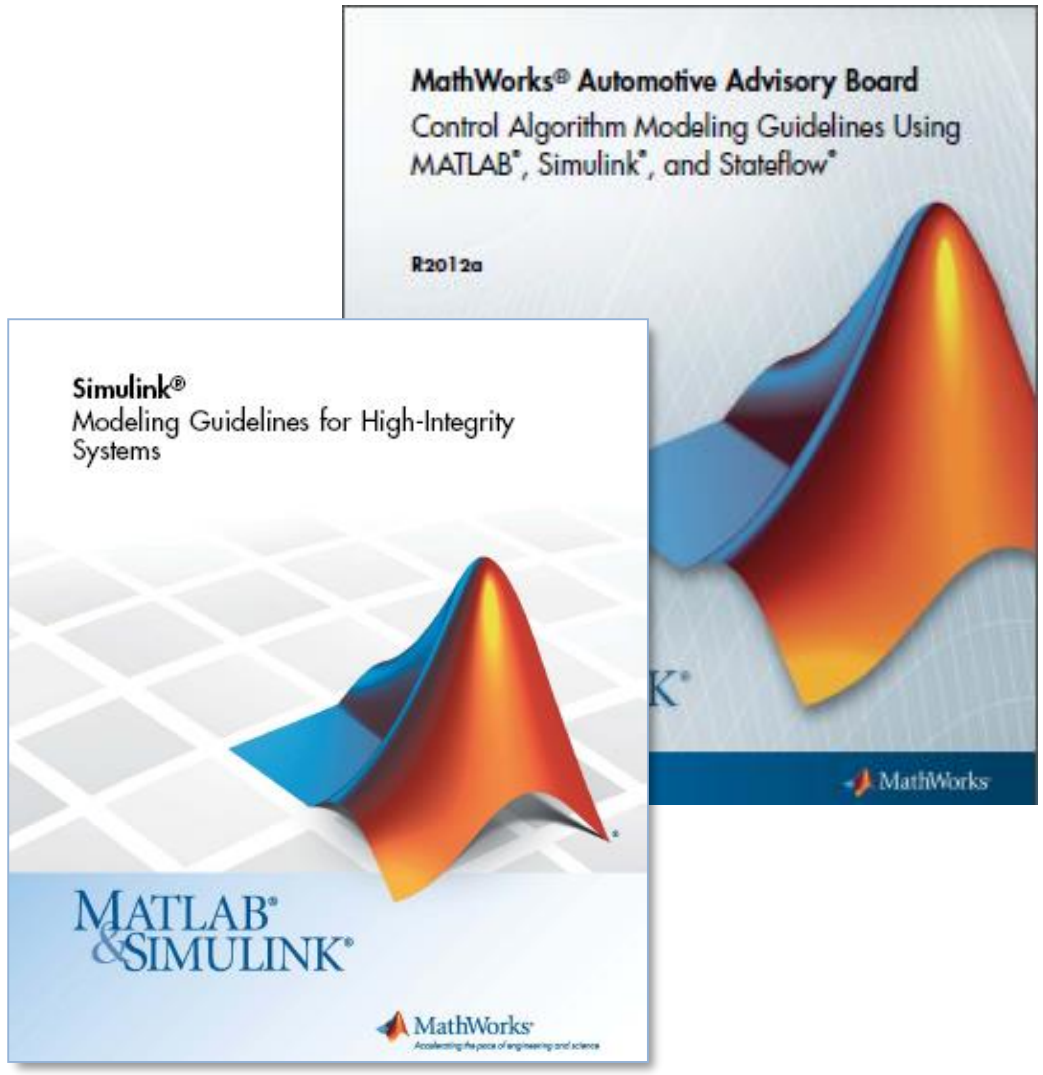
- 建模或者编程语言的选择标准
  - 明确的定义
  - 支持嵌入式实时软件和运行时错误处理
  - 支持模块化、抽象及结构化
- 语言本身不能涵盖的上述标准应通过相应的指导或开发环境涵盖
- 通常，汽车电子软件选择C语言
  - 基础软件手工编写C代码
  - 控制策略软件通过Simulink建模并自动生成代码C代码

- 建模/编码标准要涵盖的内容

Topics		ASIL			
		A	B	C	D
1a	Enforcement of low complexity	++	++	++	++
1b	Use of Language subsets	++	++	++	++
1c	Enforcement of strong typing	++	++	++	++
1d	Use of defensive implementation technique	O	+	++	++
1e	Use of established design principles	+	+	+	++
1f	Use of unambiguous graphical representation	+	++	++	++
1g	Use of style guides	+	++	++	++
1h	Use of naming conventions	++	++	++	++

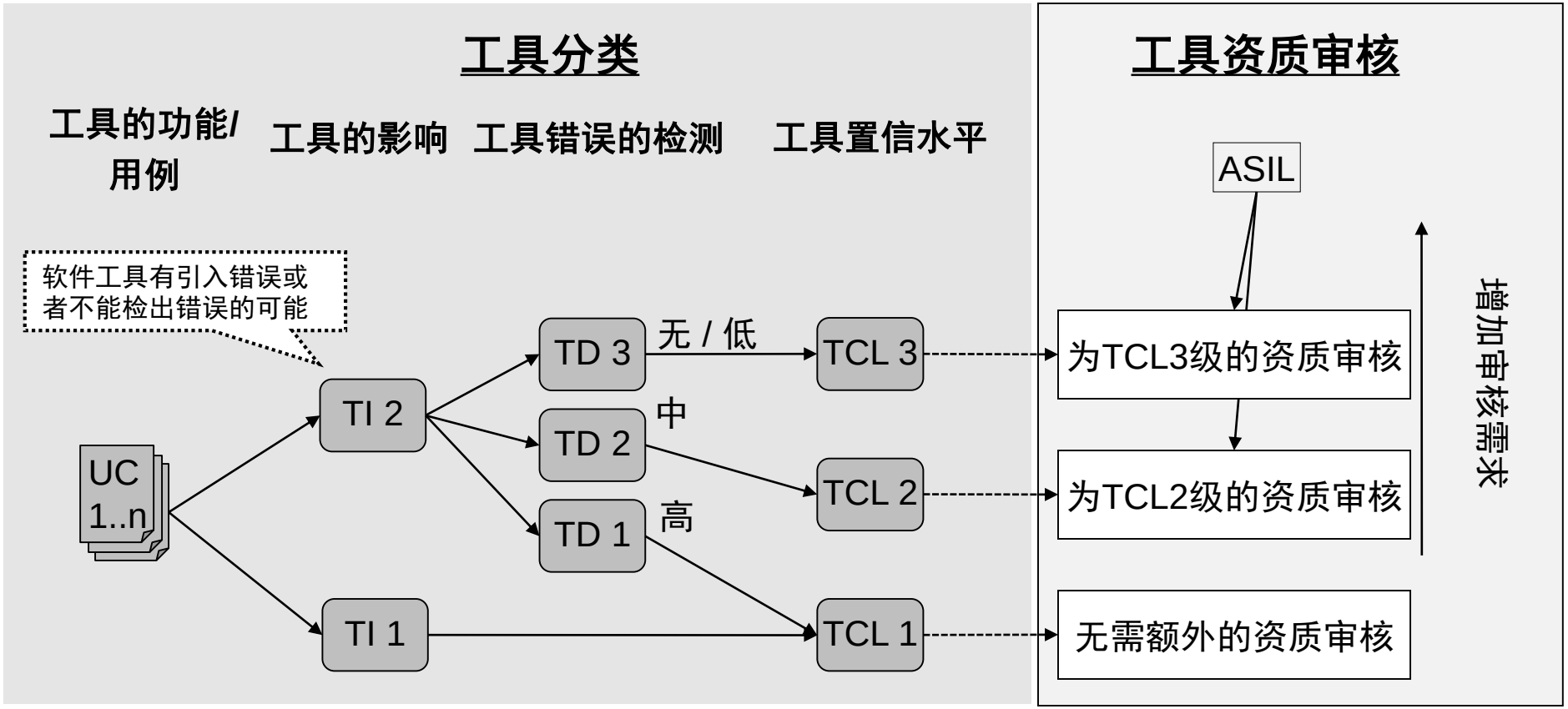
Simulink/Stateflow 建模标准

- 汽车行业建模标准（MAAB）
  - 专门为汽车行业Simulink用户制定
- 高完整性系统建模标准
  - 专门为民航、火车、汽车等高完整性系统建模制定



设计工具/验证工具的选择

- 工具的分类及资质审核



注：ISO 26262要求对工具进行资质审核

TÜV SÜD认证的工具

- **Embedded Coder™**

  功能：生产针对嵌入式优化的C和C++代码

- **Simulink® Verification and Validation™**

  功能：验证模型和模型生成的代码

- **Simulink® Design Verifier™**

  功能：定位设计错误，生成测试用例，并根据需求对设计进行验证

- **Polyspace® Client™ for C/C++**

  功能：证明源代码没有运行期错误

- **Polyspace® Server™ for C/C++**

  功能：在计算机集群执行代码验证并发布度量

СЕРТИФИКАТ ◆ CERTIFICADO ◆ CER

CERTIFICATE

No. Z10 11 12 67052 014

Holder of Certificate: The MathWorks, Inc.
3 Apple Hill Drive
Natick MA 01760-2098
USA

Factory(ies): 67052

Certification Mark:

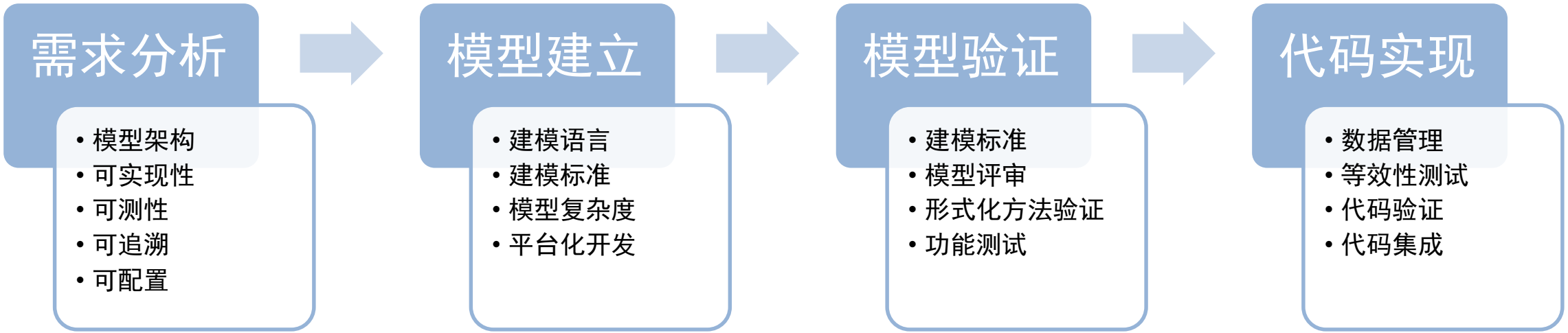
Product: Software Tool for Safety Related Development

Model(s): Embedded Coder™
Real-Time Workshop® Embedded Coder™

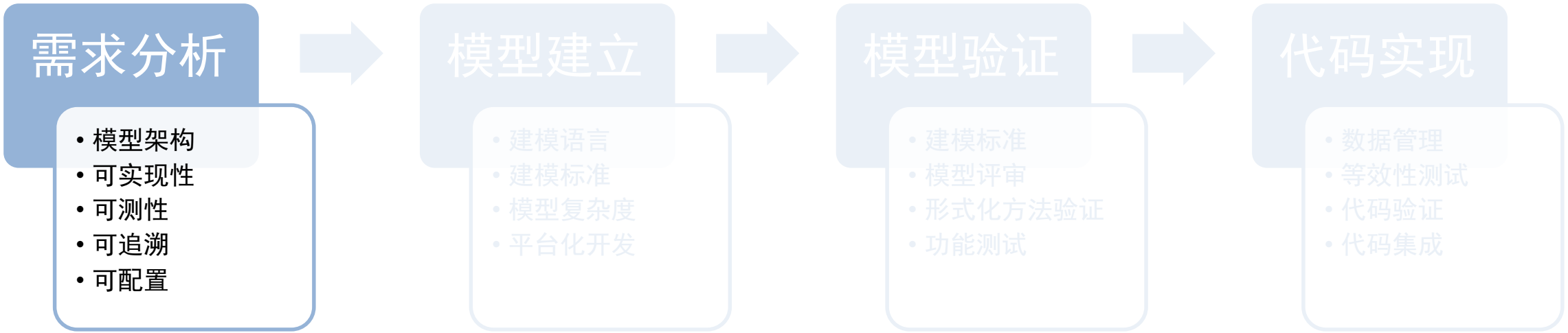
开发工具的应用指南

- 除了选择开发工具之外，还要提供开发工具的应用指南
- Embedded Coder等工具具有非常详实的用户手册

基于模型的嵌入式软件开发

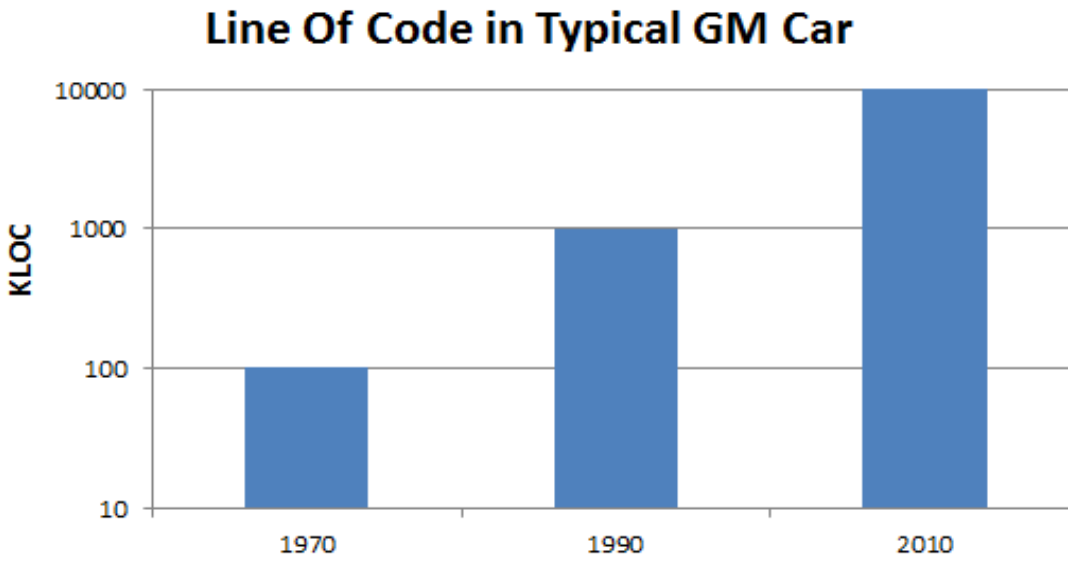


基于模型的嵌入式软件开发

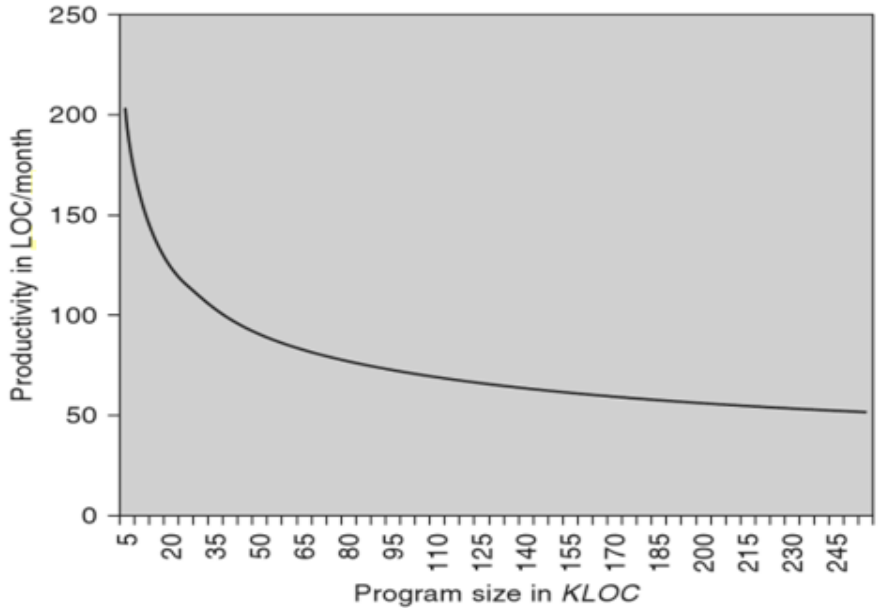


汽车电子软件的现状和复杂软件开发的困境

- GM汽车上的代码量



- 软件工程师的工作效率



- 解决复杂软件开发效率低下的途径
  - 模块化开发

模块化的原则和目标

- 模块划分的一般原则
  - 从功能上
  - 高内聚
  - 低耦合

- 模块划分的目标
  - 简化设计
  - 便于分工
  - 便于测试
  - 便于后期维护

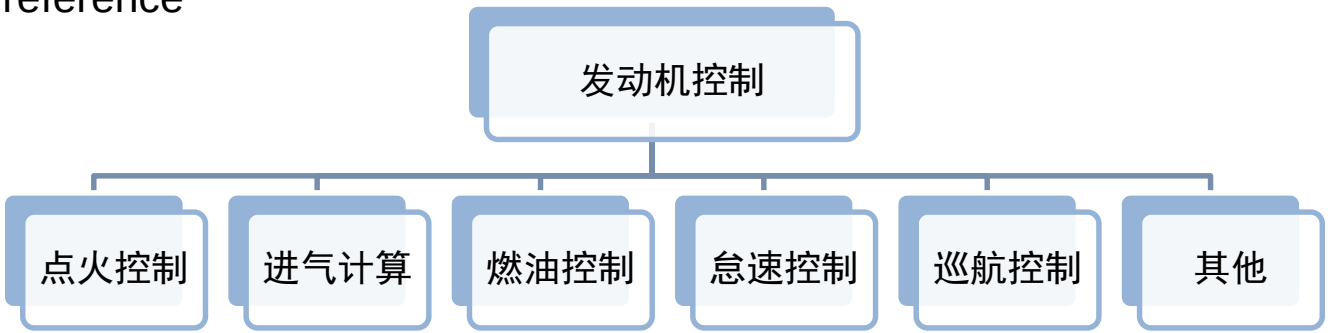
ISO 26262软件架构设计原则

- In order to avoid failures resulting from high complexity, the software architecture design shall exhibit the following properties,
  - Modularity;
  - Encapsulation; and
  - Simplicity.
- 软件架构设计原则

Methods		ASIL			
		A	B	C	D
1a	Hierarchical structure of software components	++	++	++	++
1b	Restricted size of software components	++	++	++	++
1c	Restricted size of interfaces	+	+	+	+
1d	High cohesion within each software component	+	++	++	++
1e	Restricted coupling between software components	+	++	++	++
1f	Appropriate scheduling properties	++	++	++	++
1g	Restricted use of interrupts	+	+	+	++

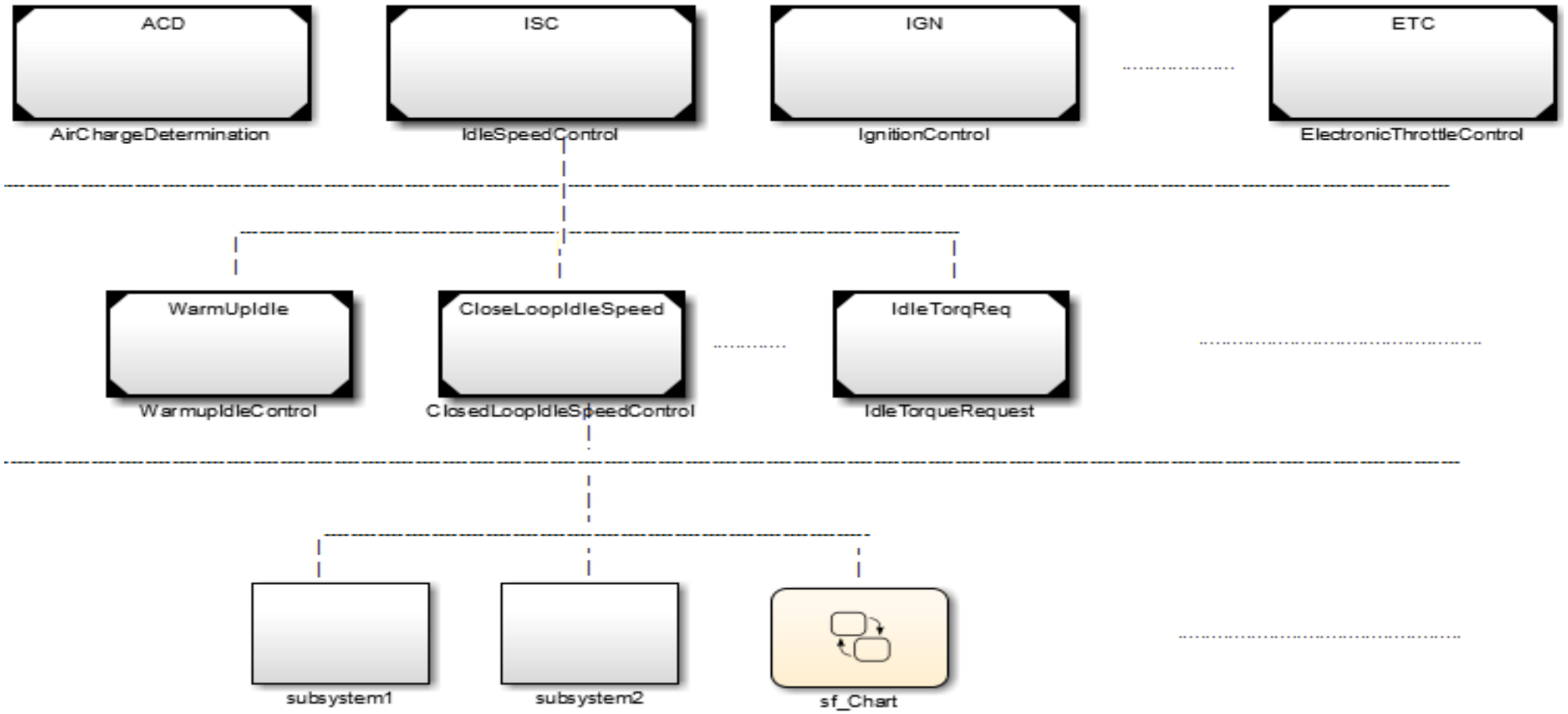
软件的层次化结构设计

- 模块如何划分
  - 从功能上划分组件
    - 以发动机为例，分为：点火、进气、油量计算、怠速、巡航等
    - 模型实现上 model reference

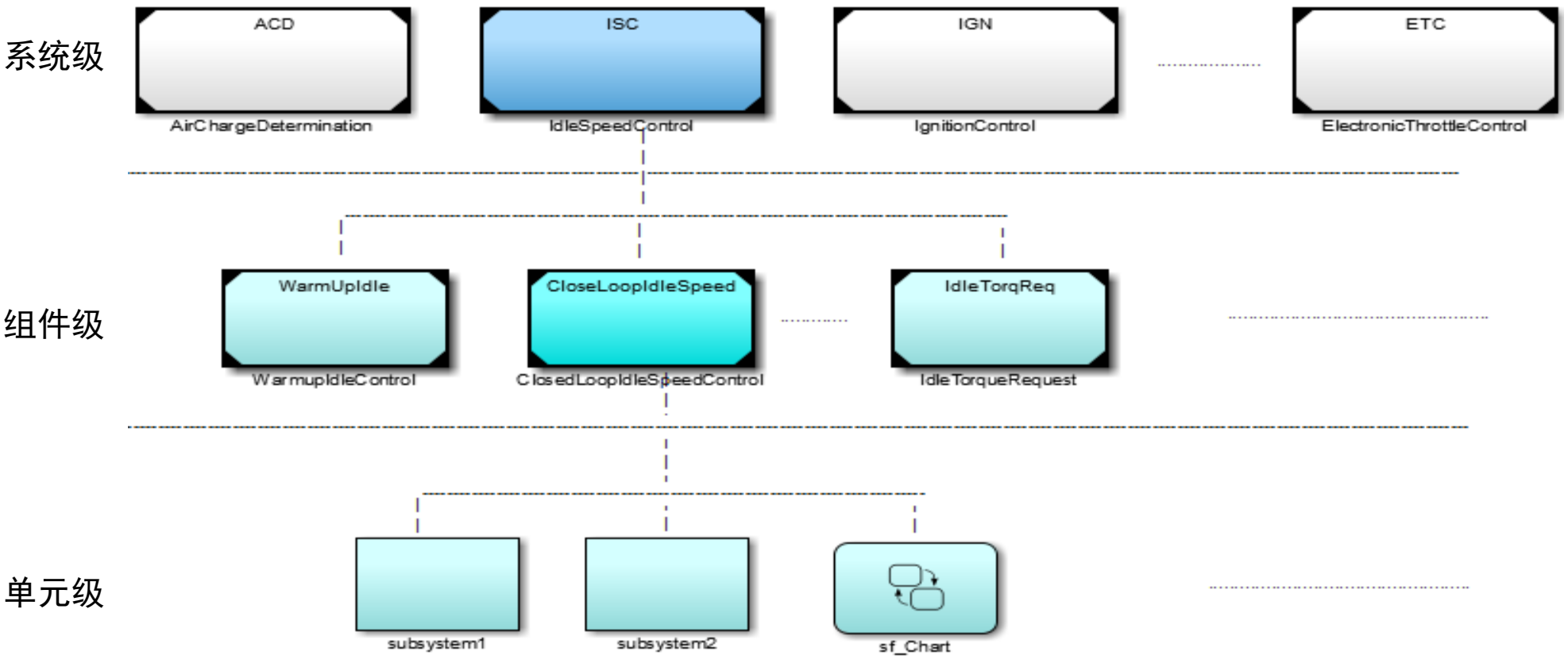


  - 对复杂组件进一步划分为单元模块
    - 以发动机的怠速控制为例，分为暖机怠速、闭环速度控制、扭矩请求等单元
    - 模型实现上 model reference

模块化设计和验证——模块划分举例

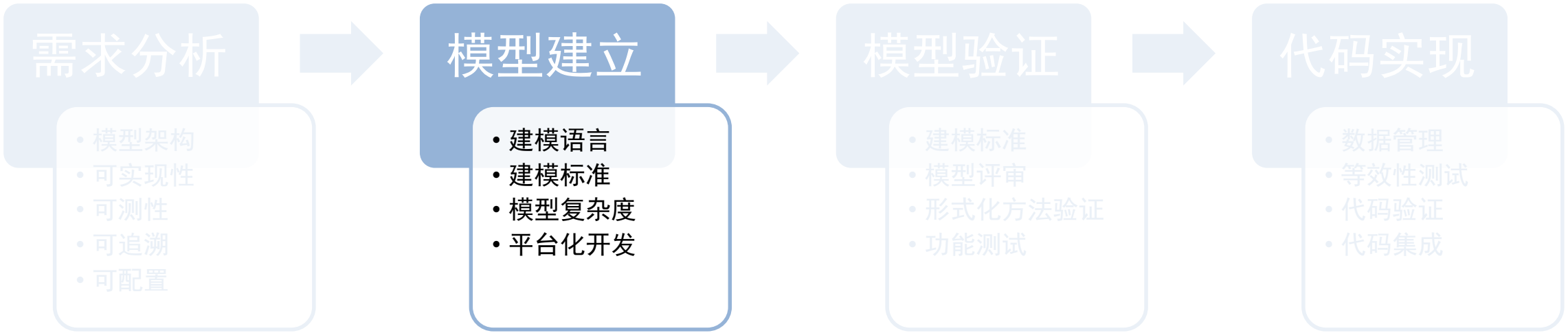


模块化设计和验证——模块划分举例



单元模块的设计不建议使用Model Reference.

基于模型的嵌入式软件开发



Simulink建模语言

- 使用建模语言的子集
- Simulink和Stateflow之间的选择
  - 如果算法是复杂的逻辑运算，使用Stateflow；
  - 如果算法主要是数据运算，使用Simulink；
- Stateflow的flow chart和state chart之间的选择
  - 如果算法本质上是计算工作状态或者离散状态，使用state chart；
  - 如果算法本质上是if-then-else结构，使用flow chart或者真值表；

ISO 26262软件单元的设计原则

- 软件单元的设计和实现原则

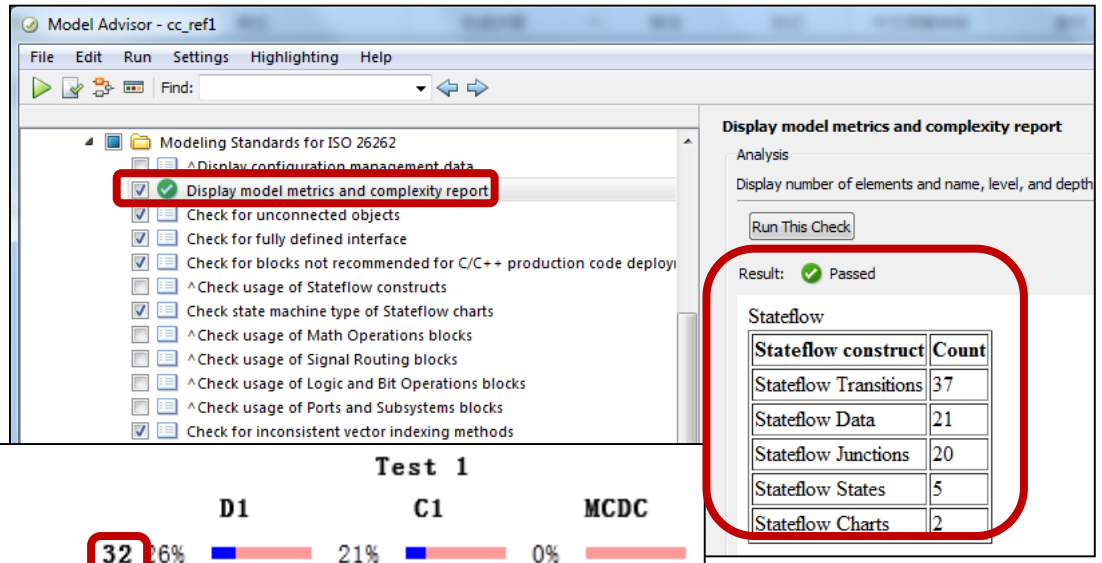
Methods		ASIL			
		A	B	C	D
1a	One entry and one exit point in subprograms and functions	++	++	++	++
1b	No dynamic objects or variables, or else online test during their creation	+	++	++	++
1c	Initialization of variables	++	++	++	++
1d	No multiple use of variable names	+	++	++	++
1e	Avoid global variables or else justify their usage	+	+	++	++
…	……				
1h	No hidden data flow or control flow	+	++	++	++
1j	No recursions	+	+	++	++

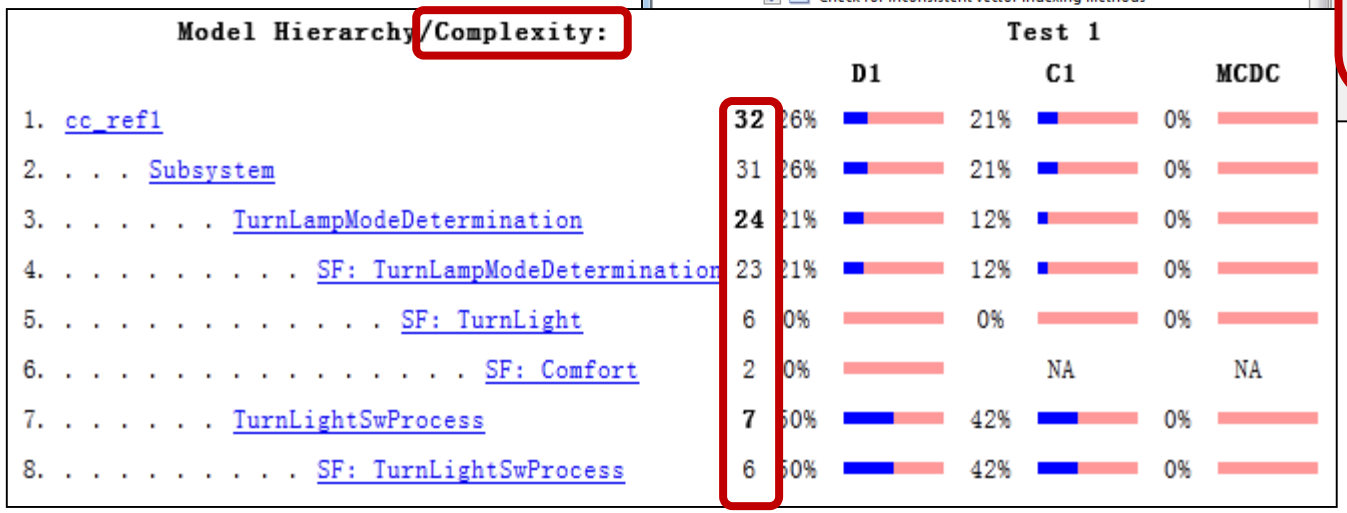
- Example: Parallel states should not appear at the top level of a state-chart.

-- Misra Modeling Guideline

模型复杂度监测

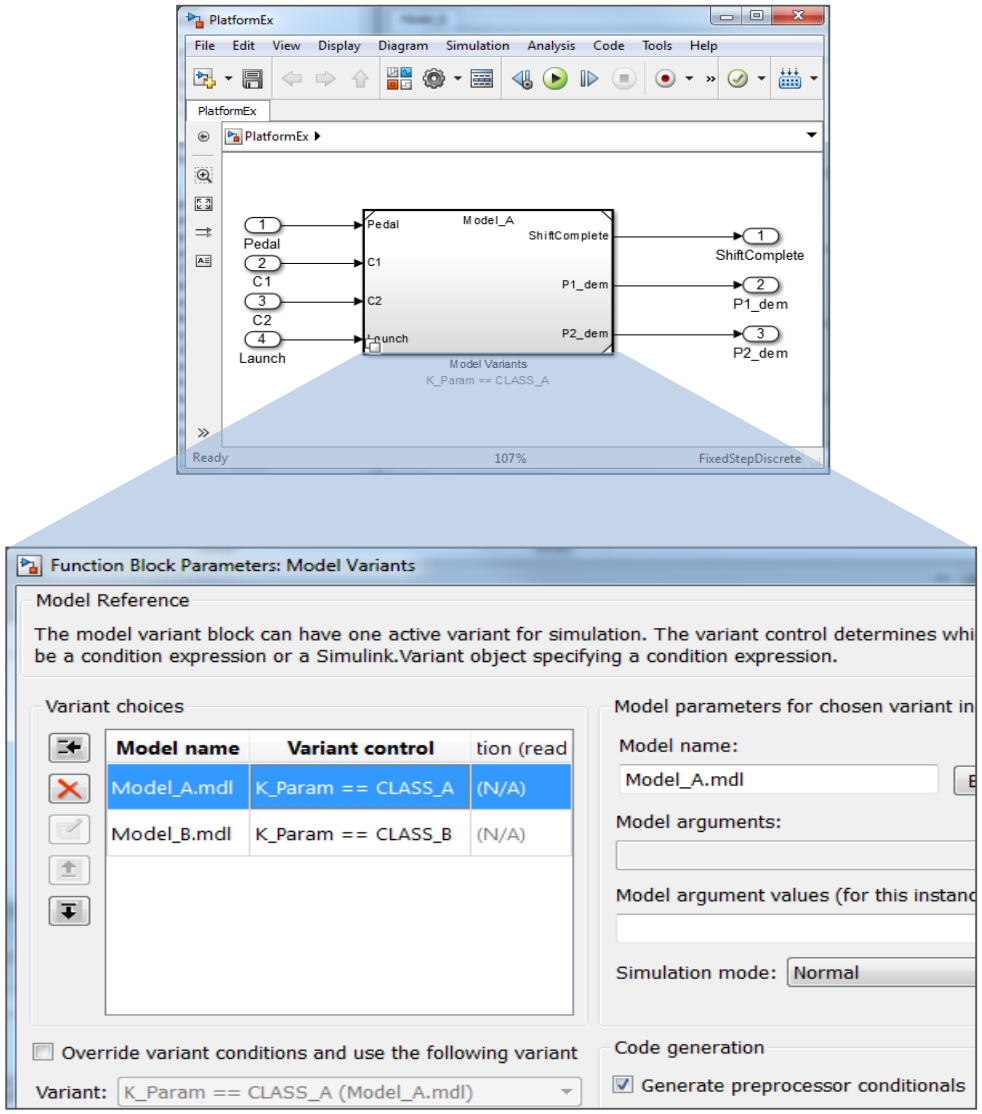
- 对单元模块进行复杂度监测
  - Model advisor
  - 圈复杂度



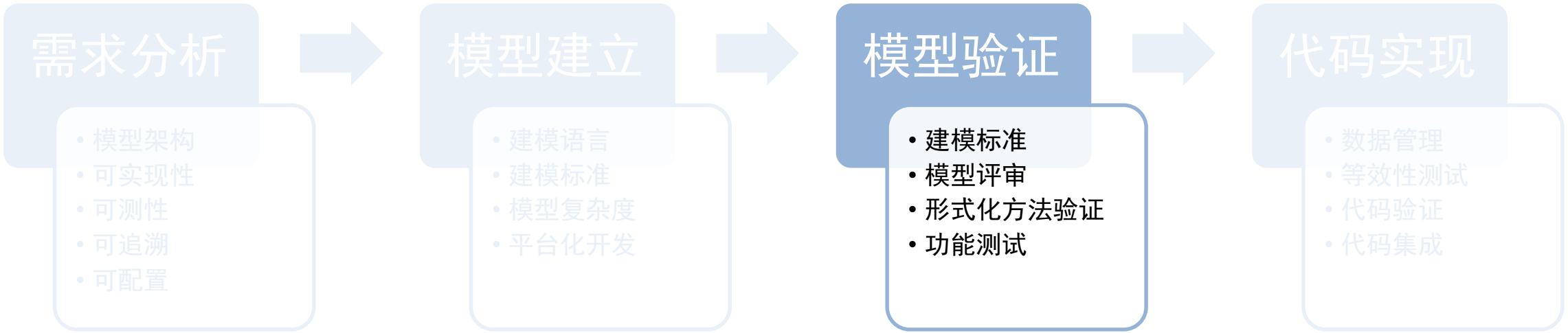


Simulink模型的平台化开发

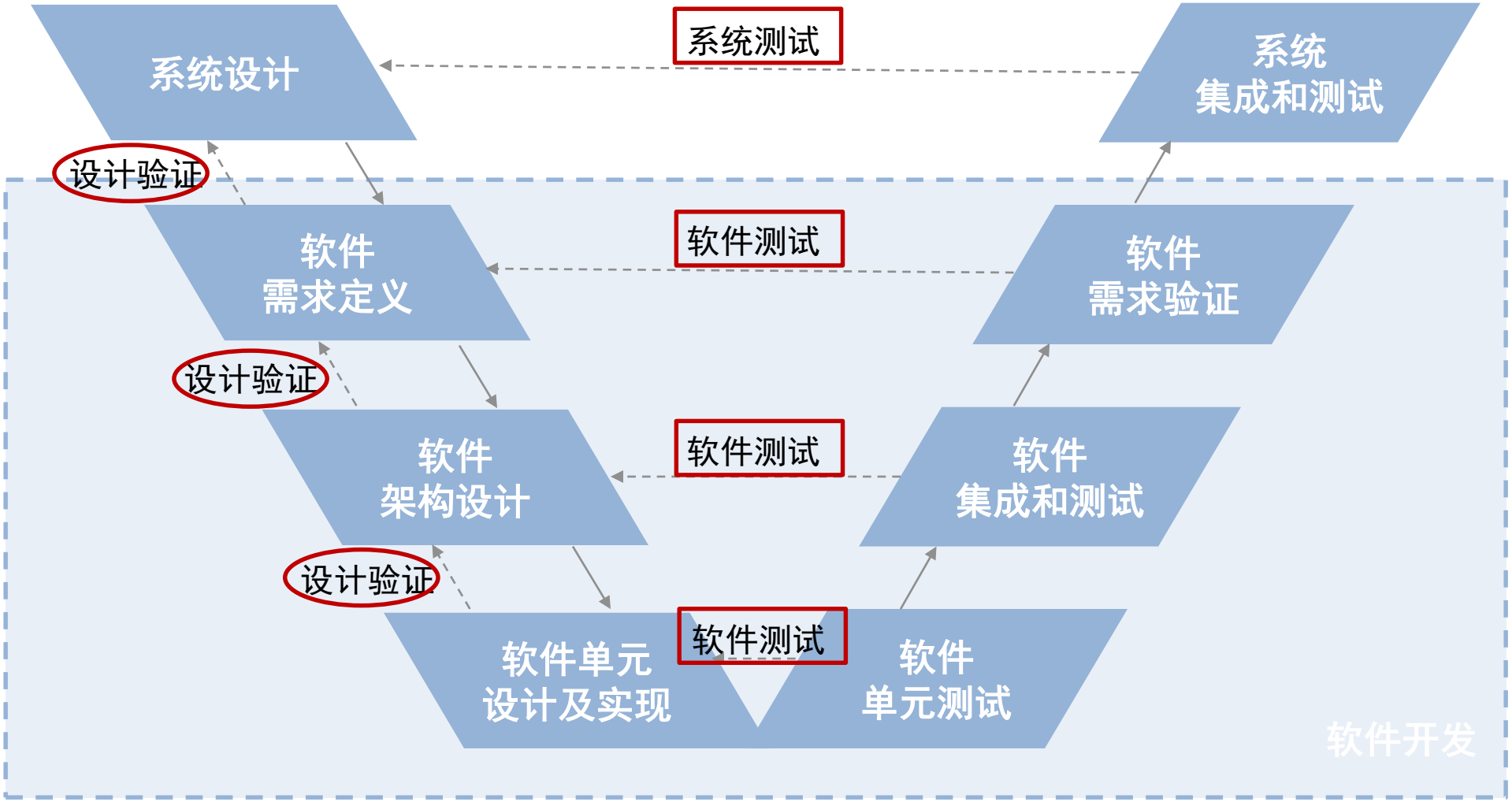
- Model Variants
  - 通过配置不同的参数选择不同的被引用模型
  - 比如，K_Param == CLASS_A，选择Model_A.mdl；K_Param == CLASS_B，选择Model_B.mdl
  - 支持生成条件编译的代码
- System Variants



基于模型的嵌入式软件开发

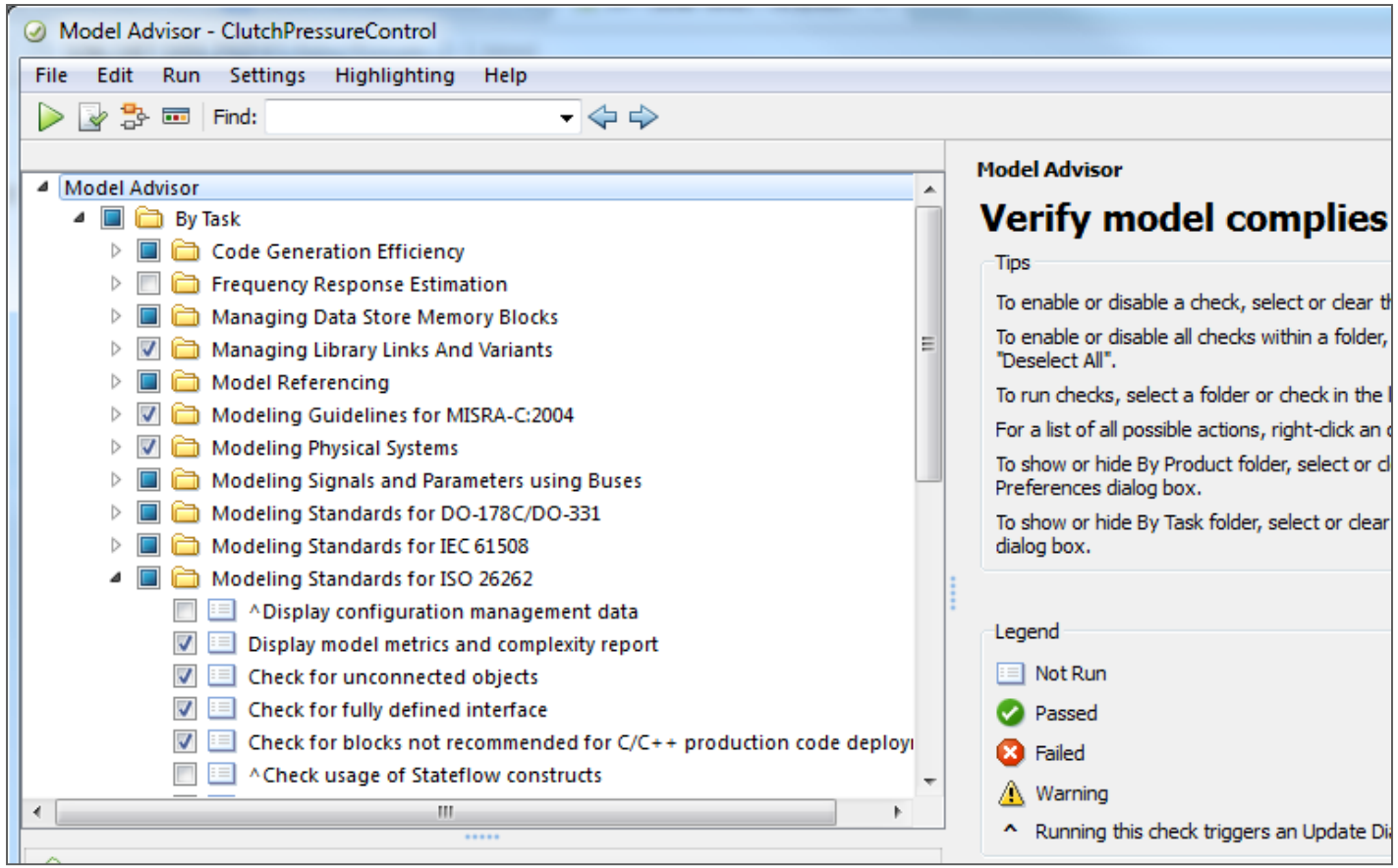


ISO 26262定义的软件开发过程



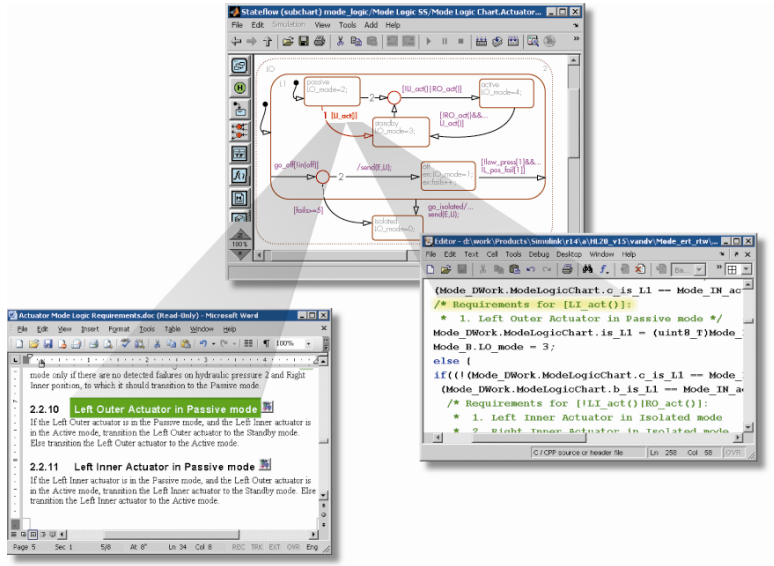
MAAB及相关规范的检查

- Model Advisor实现建模规范检查
- 定制检查集
- 定制检查项



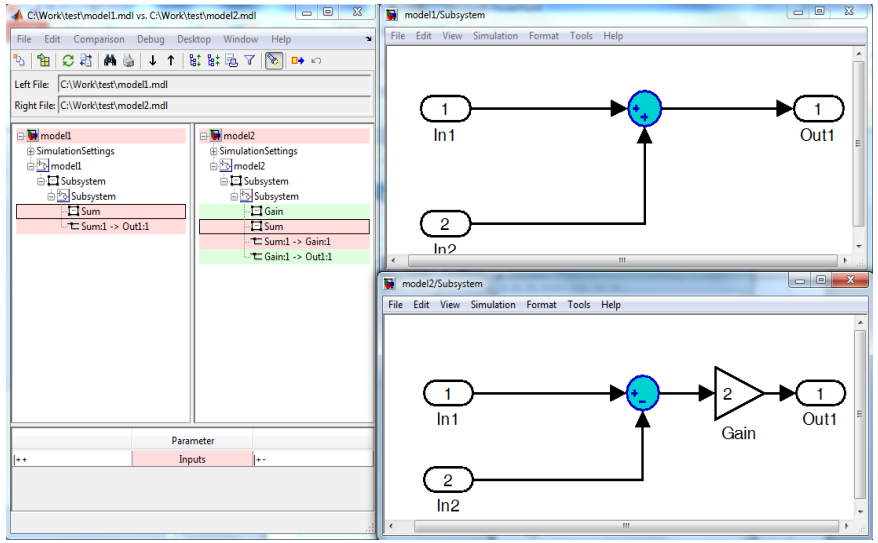
模型评审

- 模型和需求的双向追溯
  - 模型→需求
  - 需求→模型



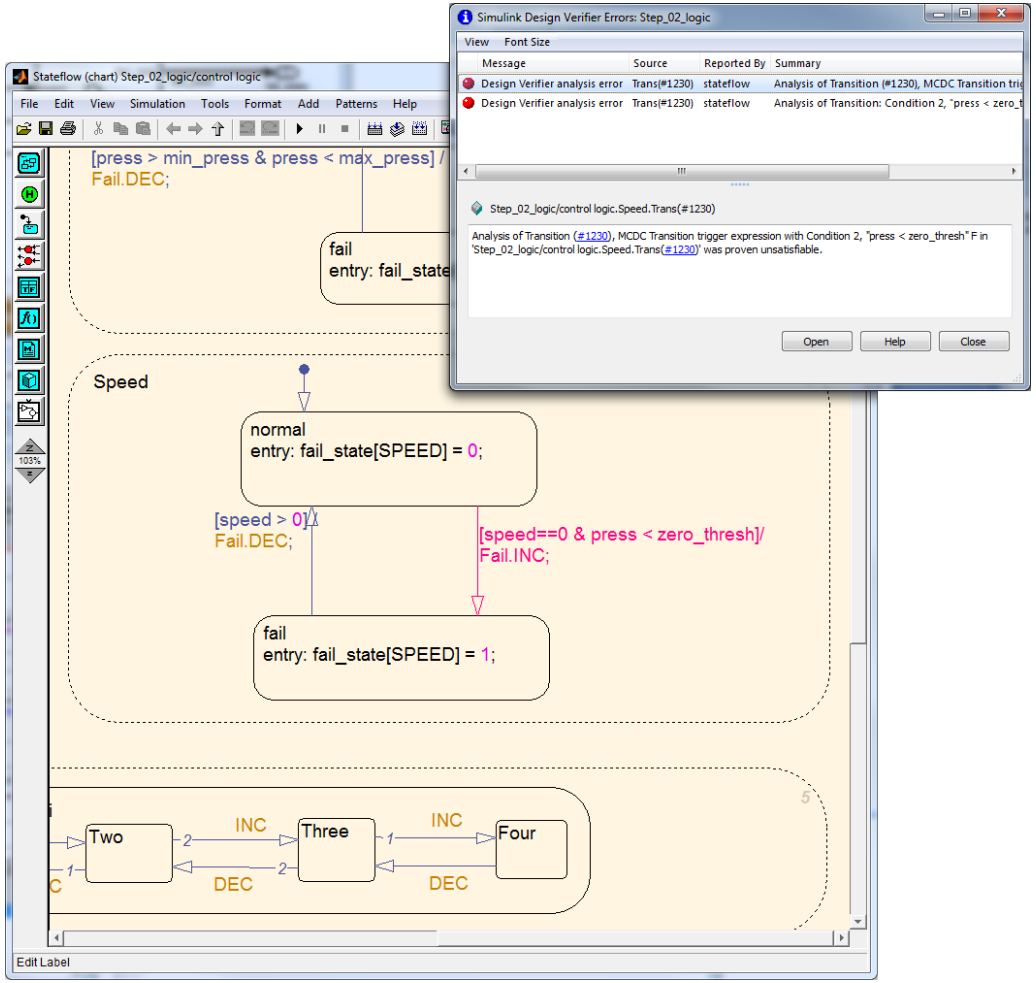
- Simulink Report Generator生成报告
  - 为非Simulink用户生成报告

- Simulink Report Generator实现
  不同版本模型比较



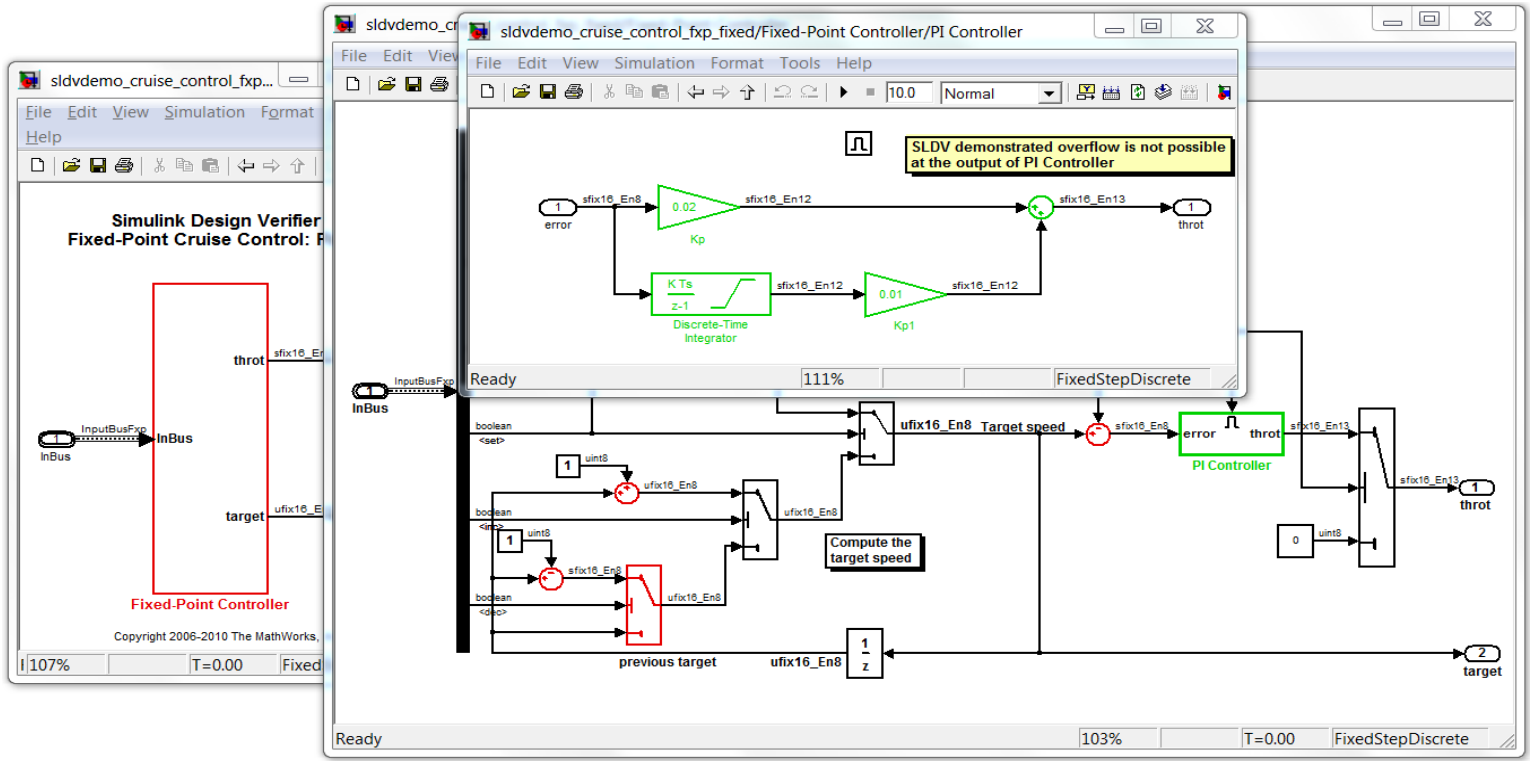
使用Simulink Design Verifier检查逻辑错误

- 设定生成测试用例目标为MC/DC 100%覆盖
- 生成测试用例
- 逻辑错误导致无法生成100%覆盖的测试用例，并提示错误逻辑

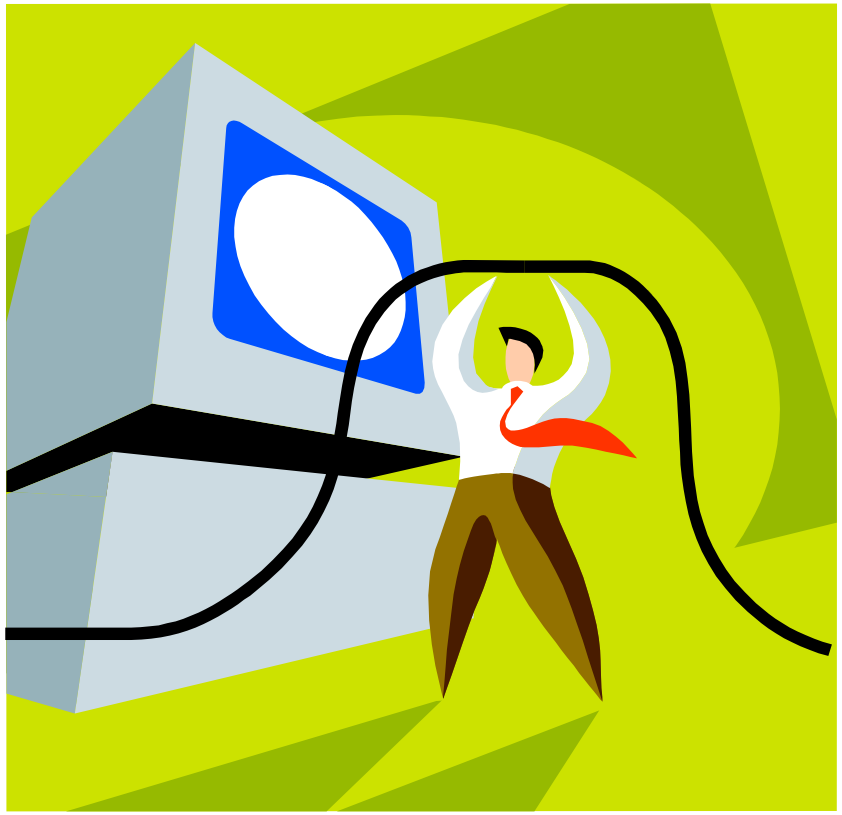


使用Simulink Design Verifier检查数据错误

- 通过算术运算分析定位错误
  - 数据溢出
  - 被零除
- 证明没有错误的运算

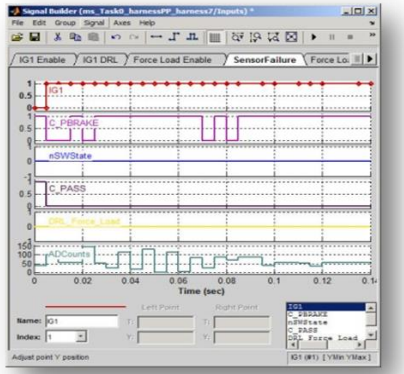


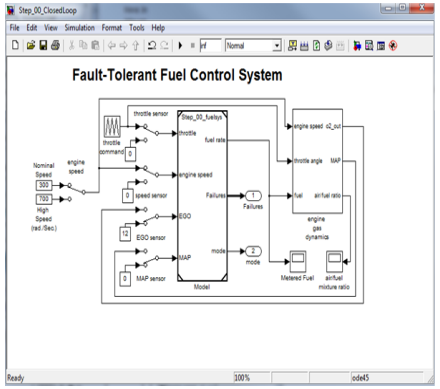
演示Simulink Design Verifier检查错误

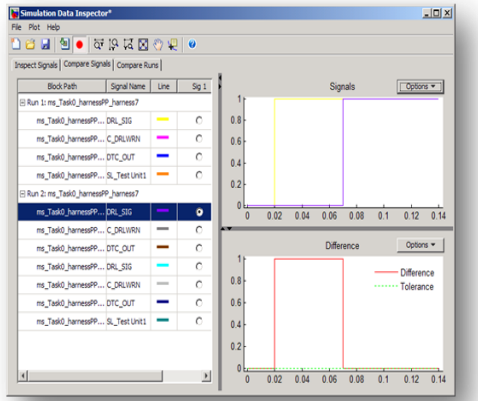


单元模块的功能测试

- 仿真测试







- 覆盖率分析

Model Hierarchy/Complexity:	Test 1					
		D1		C1		MCDC
1. cc_ref1	**32**	26%	21%		0%	
2. . . . Subsystem	31	26%	21%		0%	
3. . . . . TurnLampModeDetermination	**24**	21%	12%		0%	
4. . . . . SF: TurnLampModeDetermination	23	21%	12%		0%	
5. . . . . SF: TurnLight	6	0%	0%		0%	
6. . . . . SF: Comfort	2	0%	NA		NA	
7. . . . . TurnLightSwProcess	**7**	50%	42%		0%	
8. . . . . SF: TurnLightSwProcess	6	50%	42%		0%	

模型测试的覆盖率要求

- 对单元软件测试的结构覆盖率要求
  - 覆盖率达到分支覆盖率100%
  - MC/DC要求

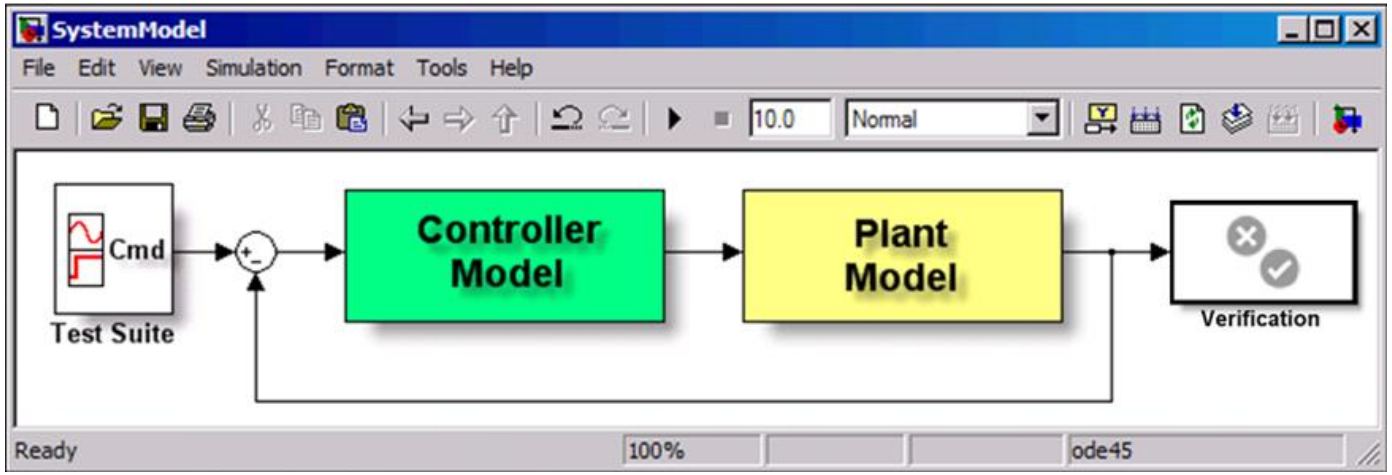
Methods		ASIL			
		A	B	C	D
1a	Statement coverage	++	++	+	+
1b	Branch coverage	+	++	++	++
1c	MC/DC (Modified Conditional/Decision Coverage)	+	+	+	++

- 对软件架构测试的覆盖率要求

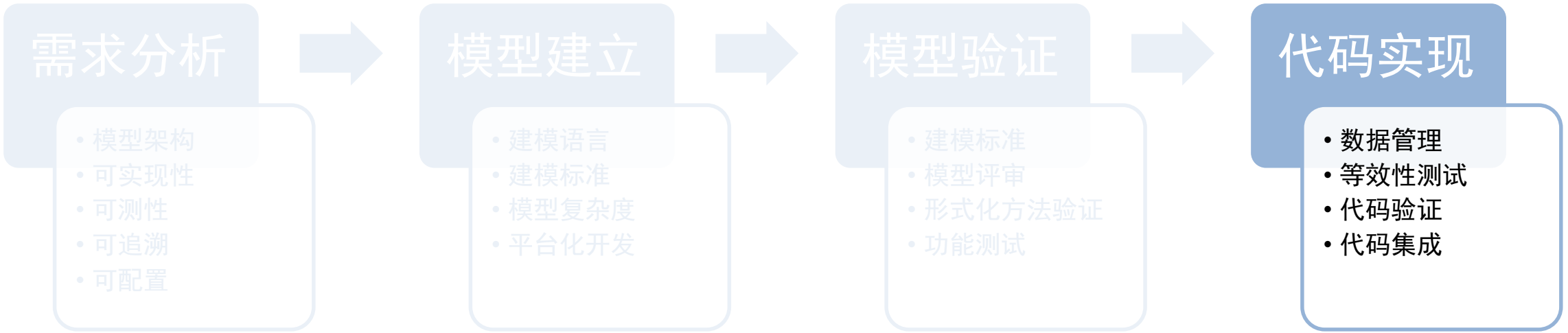
Methods		ASIL			
		A	B	C	D
1a	Function coverage	+	+	++	++
1b	Call coverage	+	+	++	++

模型的集成测试

- 模型的组件级集成测试
- 模型的系统级测试
  - 模型在环测试
  - 快速原型
- 不同组件之间的接口测试
- 不同组件功能上是否冲突

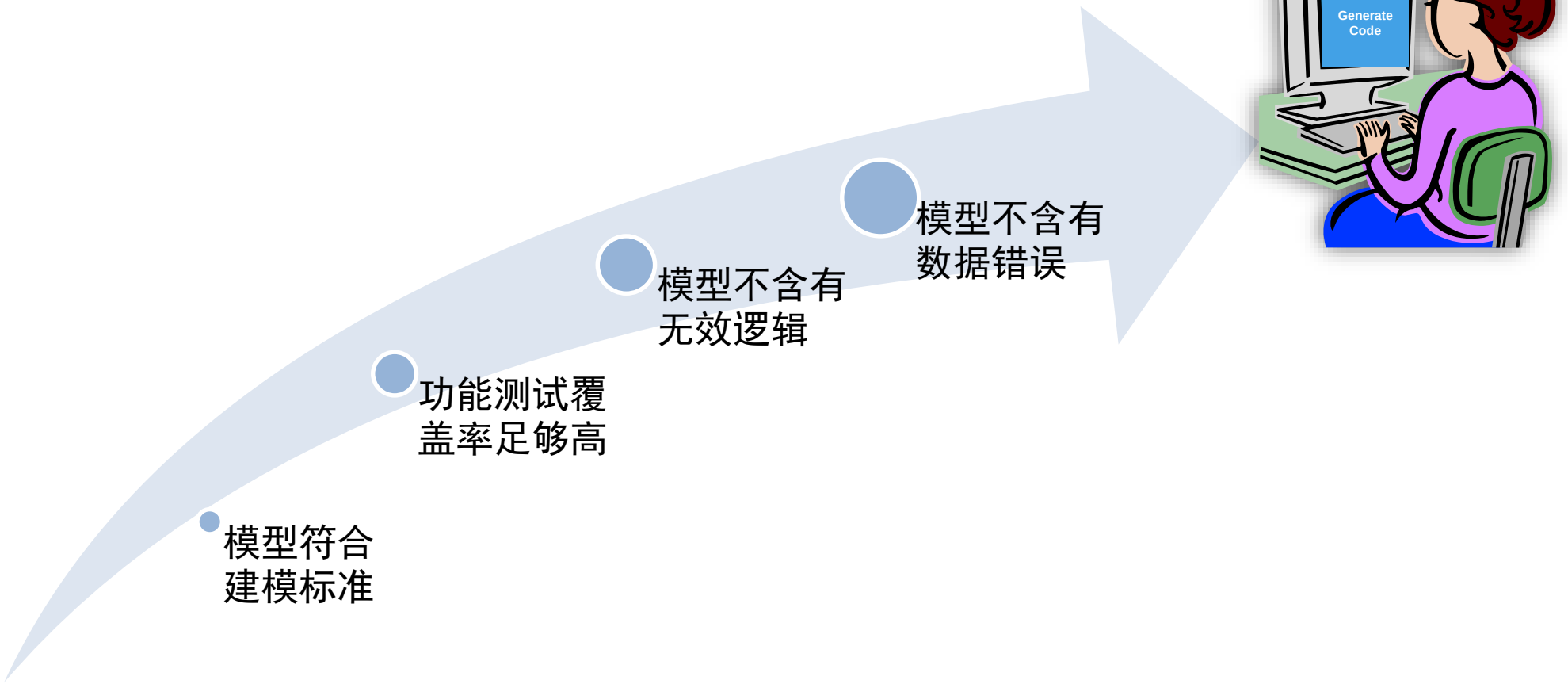


基于模型的嵌入式软件开发



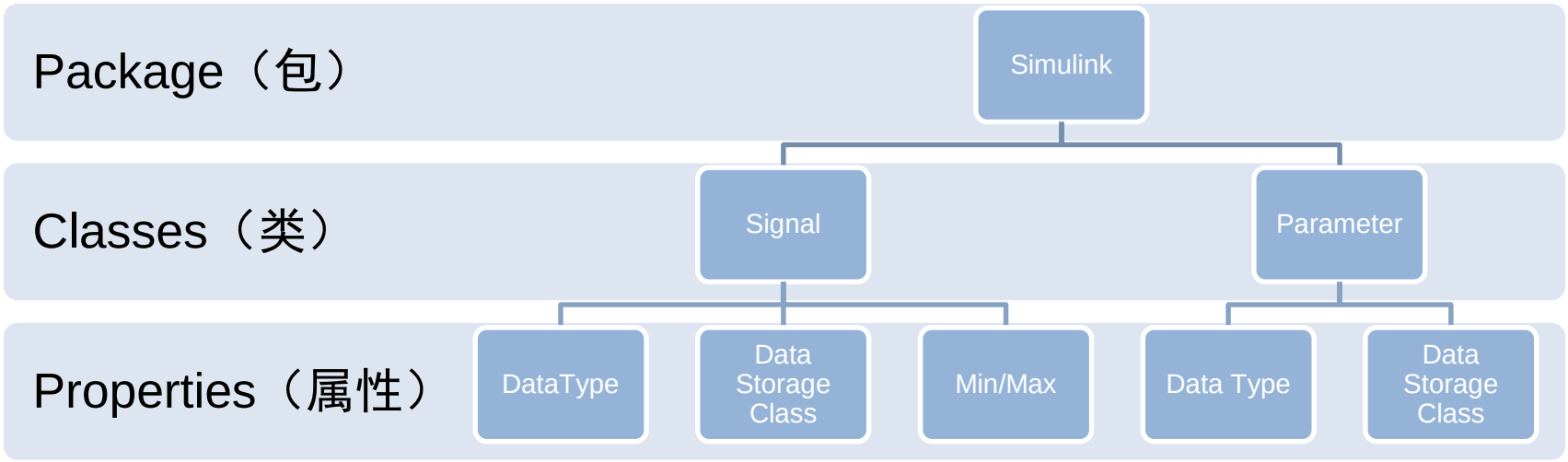
代码生成的前提条件

- 模型经过充分验证



数据对象和数据字典

- 使用数据对象定义数据属性

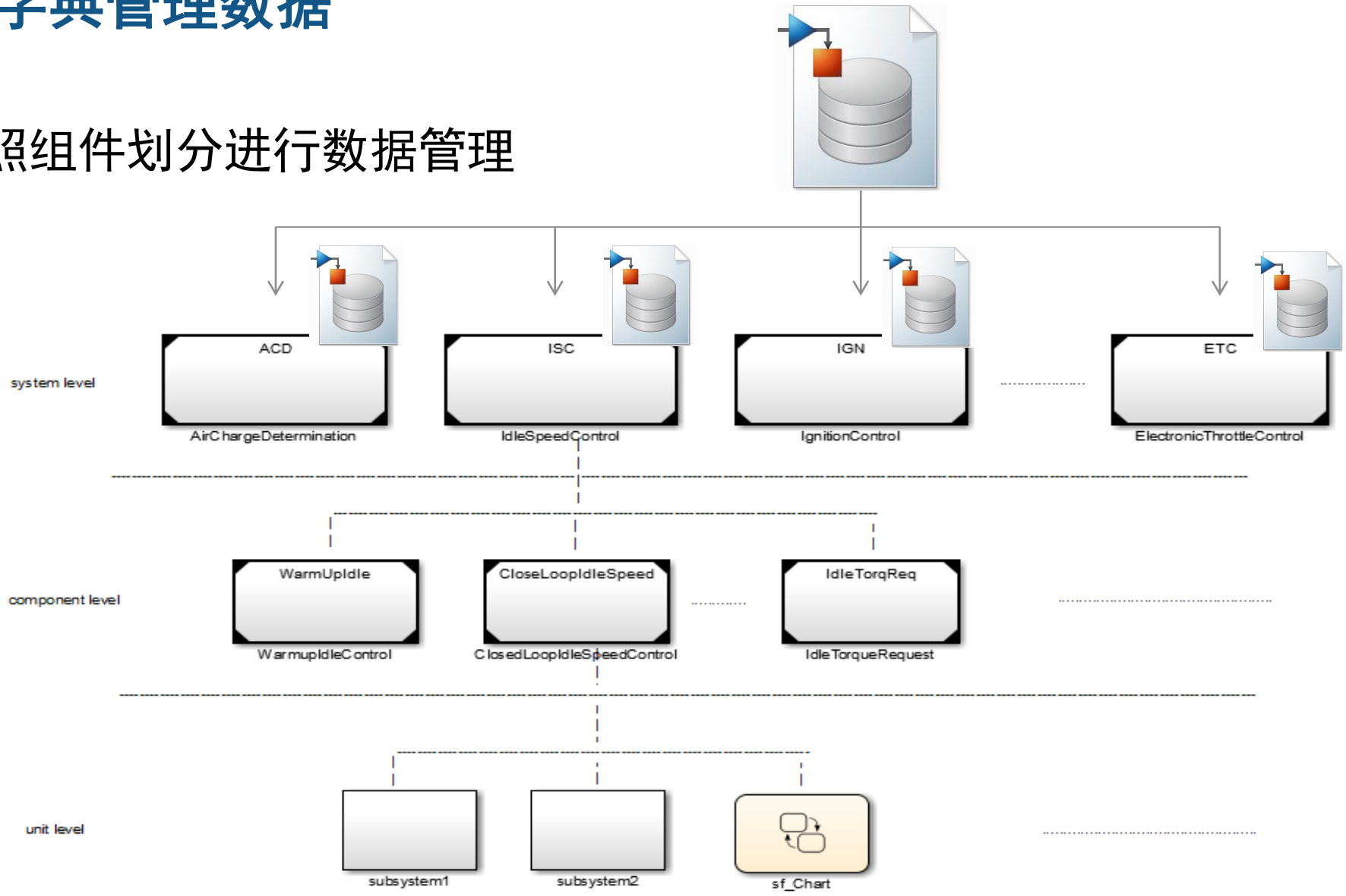


- 使用数据字典管理数据对象

```
modelName = 'f14';
dictionaryName = 'myNewDictionary.sldd‘;
dictionaryObj =Simulink.data.dictionary.create(dictionaryName);
set_param(modelName,'DataDictionary',dictionaryName);
```

数据字典管理数据

- 按照组件划分进行数据管理



代码生成工具配置

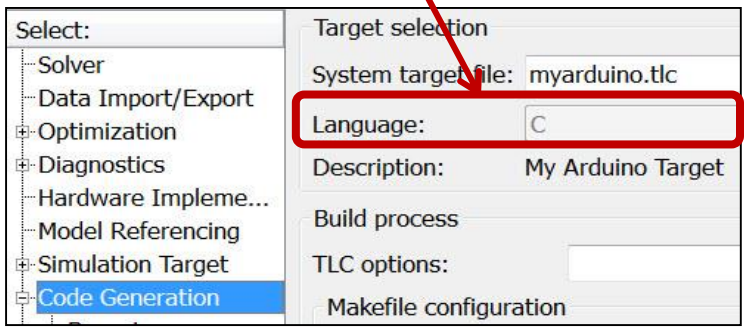
- 软件工具除确定id和版本号之外，还需要确定配置

```
%-----------------------------------------%
% Configure code generation settings %
%-----------------------------------------%

rtwgensettings.DerivedFrom = 'ert.tlc';
rtwgensettings.BuildDirSuffix = '_myarduino';
rtwgensettings.Version = '1';
rtwgensettings.SelectCallback = 'myarduino_select_callback_handler(hDlg, hSrc)';

END_RTW_OPTIONS
%/
```

1. 通过系统目标文件设定回调函数

2. 在代码生成设置的回调函数里固化设置

```
% Set the target language to C and disable modification
slConfigUISetVal(hDlg, hSrc, 'TargetLang', 'C');
slConfigUISetEnabled(hDlg, hSrc, 'TargetLang', 0);

% Set the TargetLibSuffix
slConfigUISetVal(hDlg, hSrc, 'TargetLibSuffix', '.a');
```



等效性测试

- SIL测试/PIL测试都是等效性测试
  - 验证生成的代码和用于代码生成的模型具有相同的行为属性
  - PIL除等效性验证之外，还可以用来测量运行时间
- 等效性测试的测试用例
  - 功能测试的测试用例
  - Simulink Design Verifier自动生成

> NOTE 4 For model-based development, software unit testing can be carried out at the model level followed by back-to-back comparison tests between the model and the object code. The back-to-back comparison tests are used to ensure that the behaviour of the models with regard to the test objectives is equivalent to the automatically-generated code.

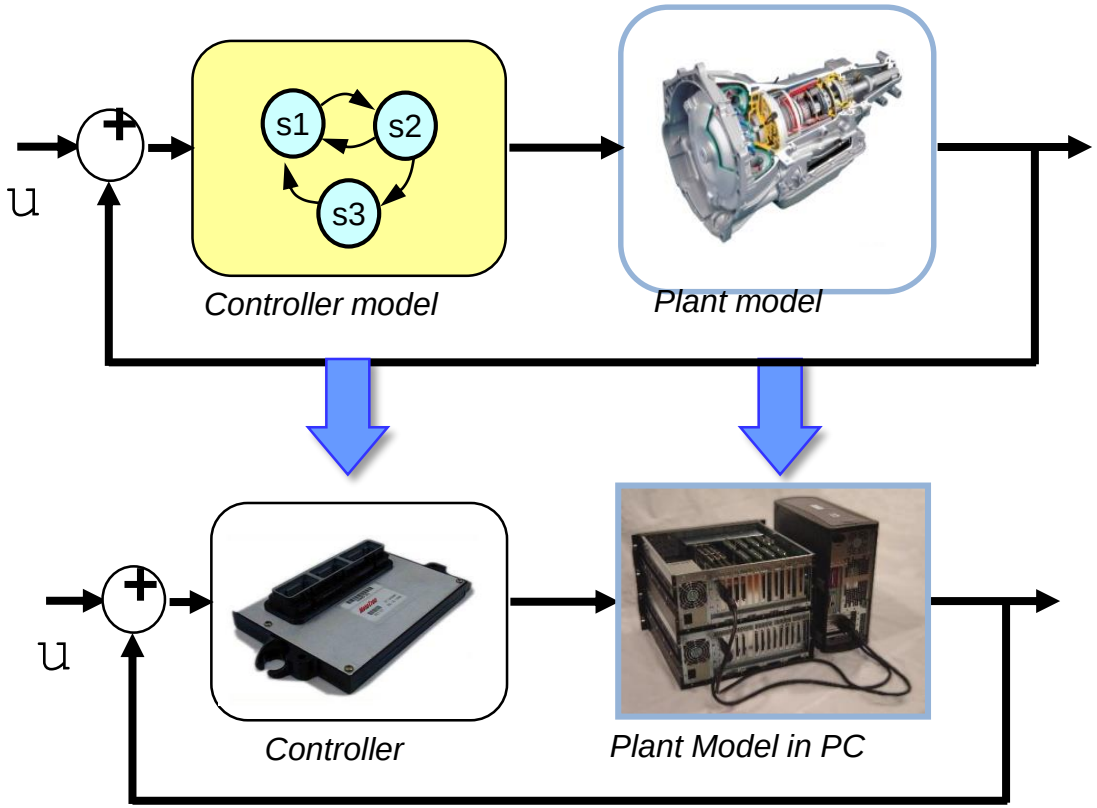
- 模型覆盖率和代码覆盖率的比较

9.4.3 The software unit testing methods listed in Table 10 shall be applied to demonstrate that the software units achieve:

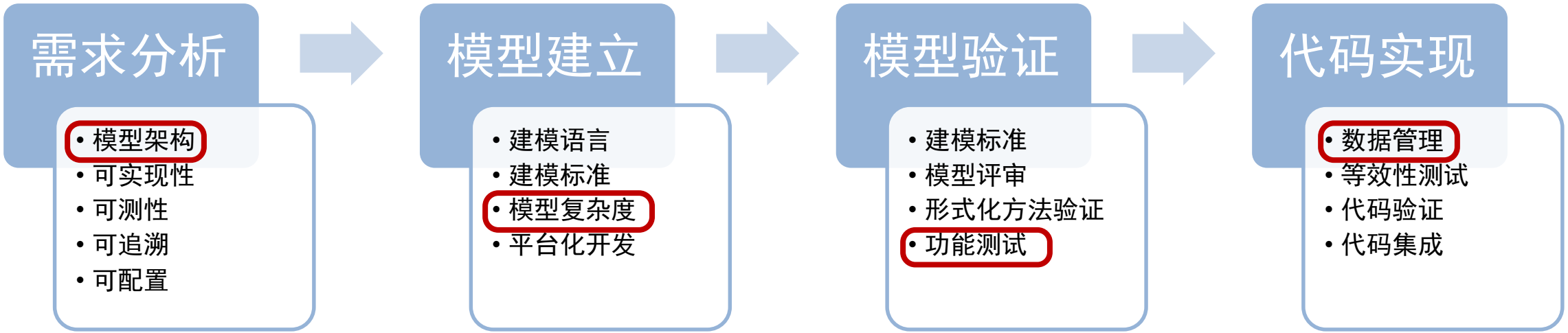
d) confidence in the absence of unintended functionality;

代码的集成和集成测试

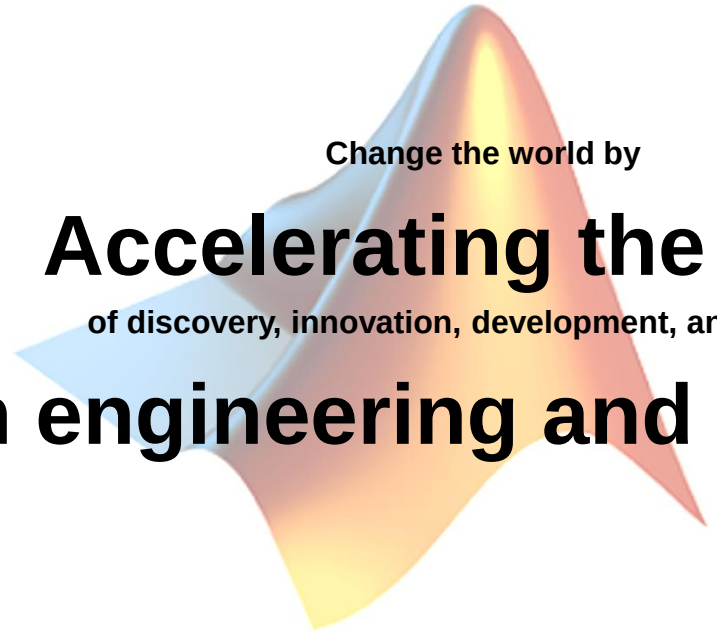
- 代码集成的两种方式
  - 单元模型的代码生成，代码级别做集成
  - 模型级别集成，然后生成代码
- 软硬件的系统级集成
  - 硬件在环测试
  - 台架测试
  - 实车测试



基于模型的嵌入式软件开发



MathWorks



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