Model-based test generation

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Main topics of the course

- Overview (1.5)
  - Introduction, V&V techniques
- Static techniques (1.5)
  - Specification, Verifying source code
- Dynamic techniques: Testing (7)
  - Testing overview, Test design techniques
  - **Test generation**, Automation
- System-level verification (3)
  - Verifying architecture, Dependability analysis
  - Runtime verification

Learning outcomes

- Illustrate how models can be used in testing (K2)
- Explain the typical model-based test generation process (K2)
- Apply different selection criteria to finite state machines to select test cases (K3)
- Use an MBT tool to generate test cases (K3)

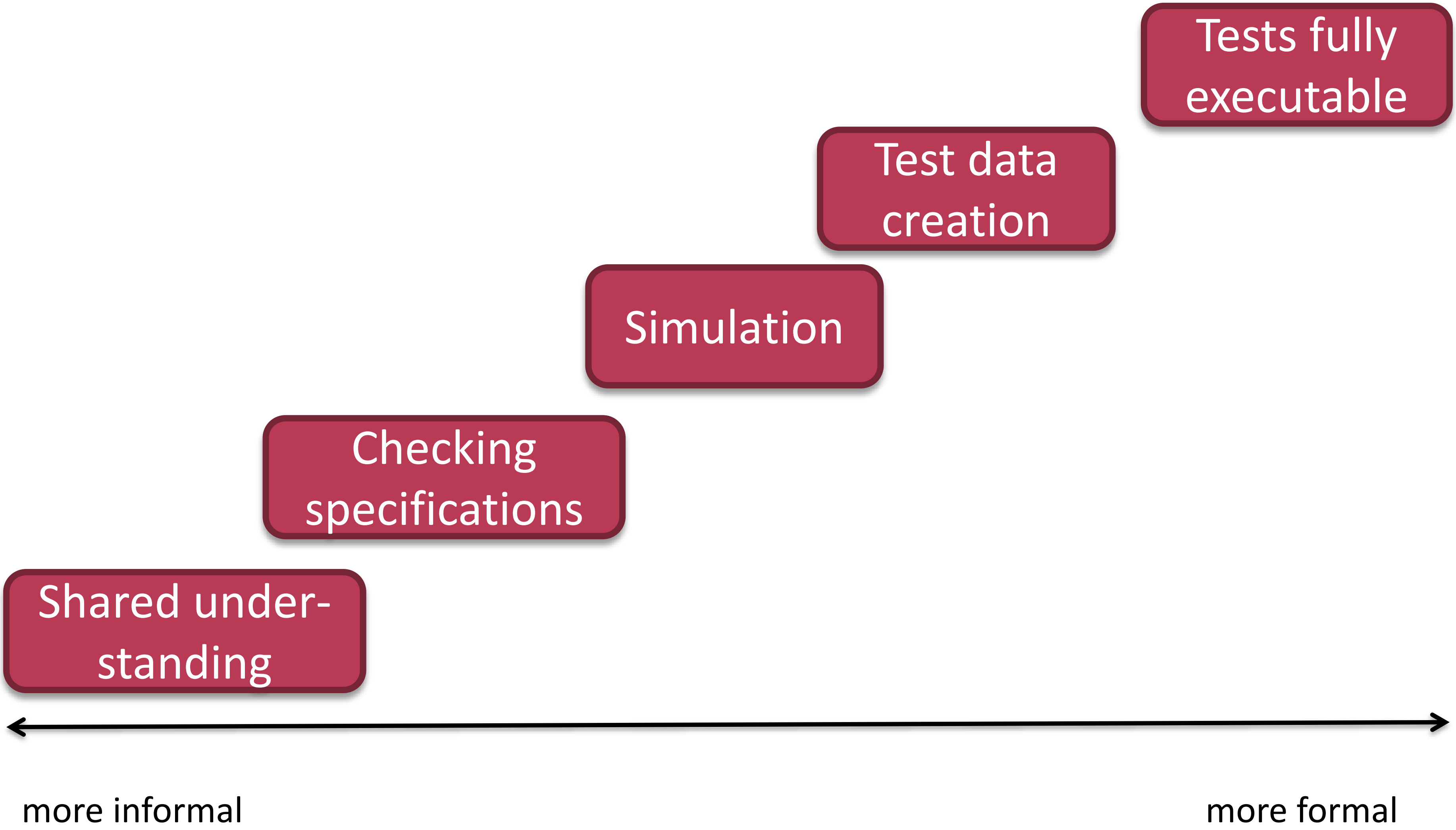
What is model-based testing?

“Testing based on or involving models” [ISTQB]

- Not just test generation
- Not just automatic execution
- Not just for model-driven engineering

Source of definition: ISTQB. “Foundation Level Certified Model-Based Tester Syllabus”, Version 2015

Landscape of MBT goals



Tests fully executable

Test data creation

Simulation

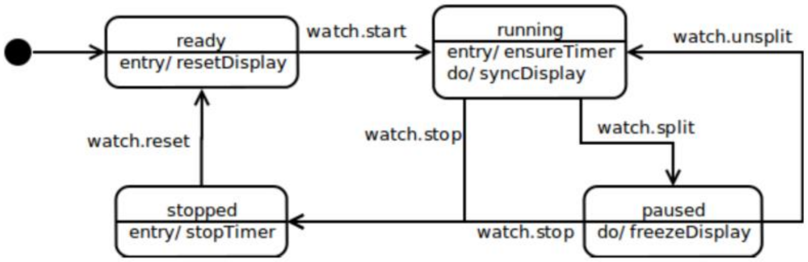
Checking specifications

Shared under-standing

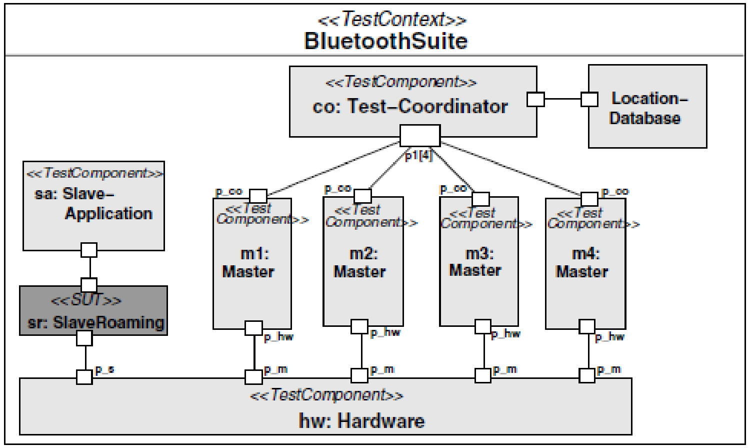
more informal

more formal

Using models in testing (examples)



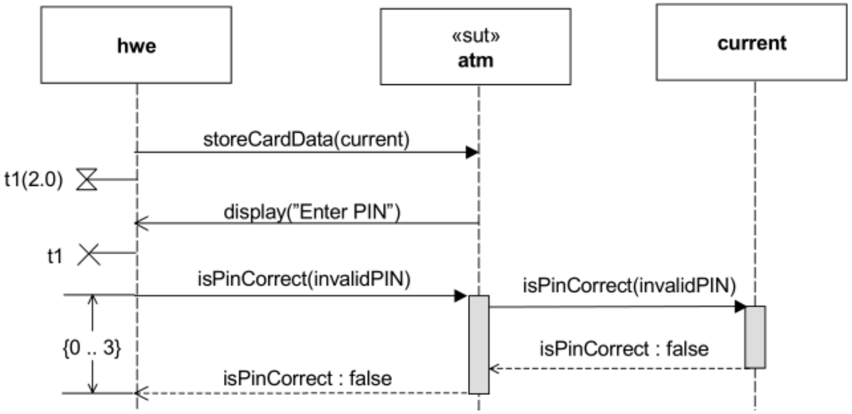
Behavior of SUT



Test configuration

```
timer t;
t.start(5.0);
alt {
 [] i.receive("coffee") {
  Count := Count+1; }
 [] t.timeout { }
}
```

Test sequences



Test sequences

Source: OMG UTP

Benefits of using models

- Close communication with stakeholders
  - Understanding of domain and requirements
- Early testing: modeling/simulation/generation
- Higher abstraction level (manage complexity)
- Automation (different artefacts)

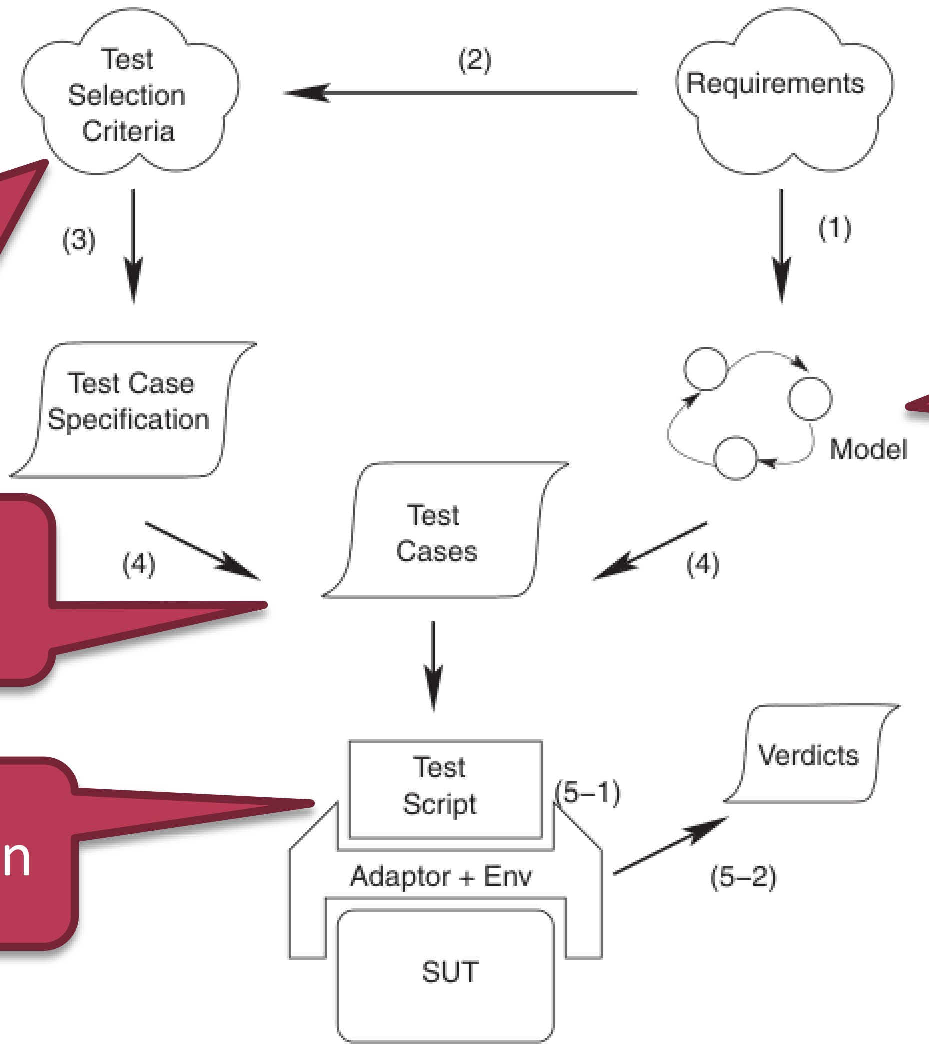
More specific meaning: Test generation

„MBT encompasses the processes and techniques for

- the automatic derivation of abstract test cases from abstract models,
- the generation of concrete tests from abstract tests,
- the manual or automated execution of the resulting concrete test cases”

Source: M. Utting, A. Pretschner, B. Legeard. „A taxonomy of model-based testing approaches”, STVR 2012; 22:297–312

Typical MBT process



State, path, requirement coverage…

Test model

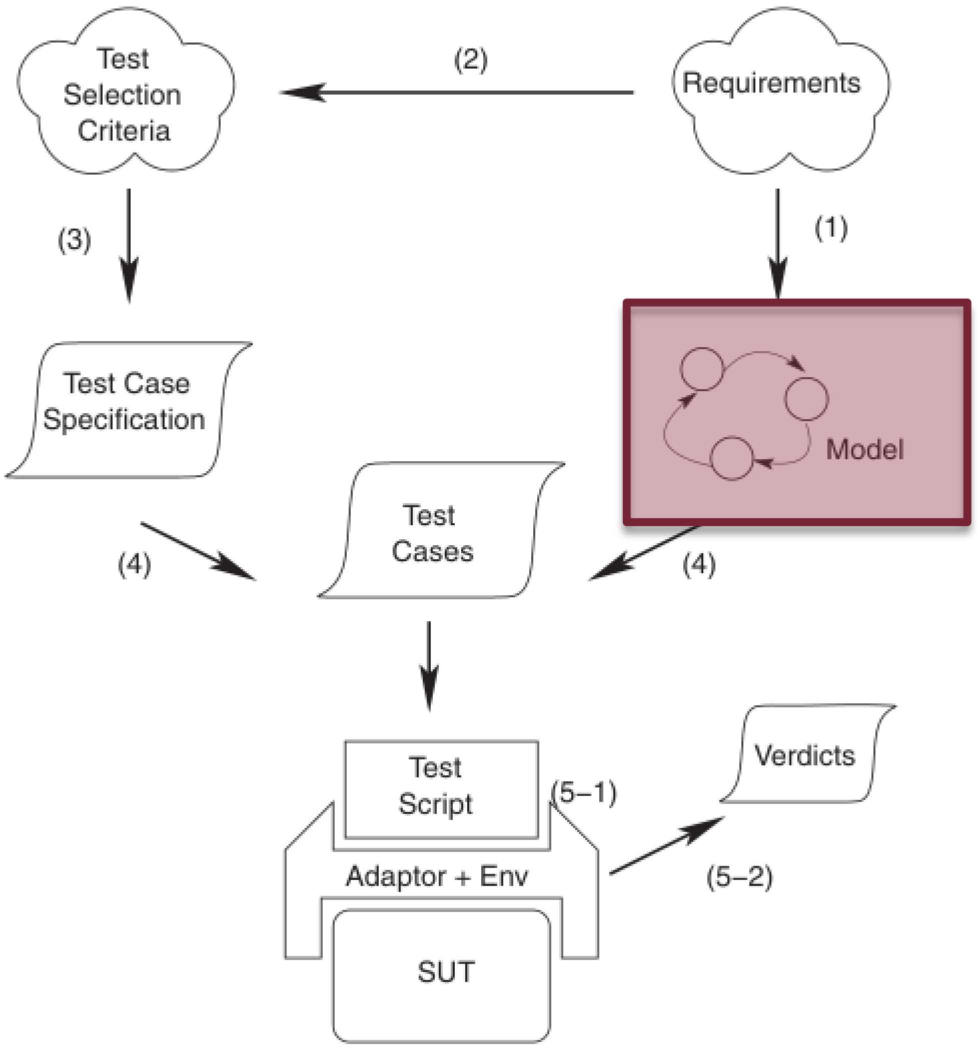
Abstract test case

Concretization

Source: M. Utting, A. Pretschner, B. Legeard. „A taxonomy of model-based testing approaches", STVR 2012; 22:297–312

MBT PROCESS

Typical MBT process



Source: M. Utting, A. Pretschner, B. Legeard. „A taxonomy of model-based testing approaches", STVR 2012; 22:297–312

Questions for modeling

- What to model?
  - What is the test object?
  - Functionality / performance factors / …
- What abstraction level to use?
  - Too many or too few details
  - Separate models for different test objectives
- What modeling language to use?
  - Structural, behavioral

Focus of the model

System

- System as intended to be
- Conformance of model-SUT

Usage

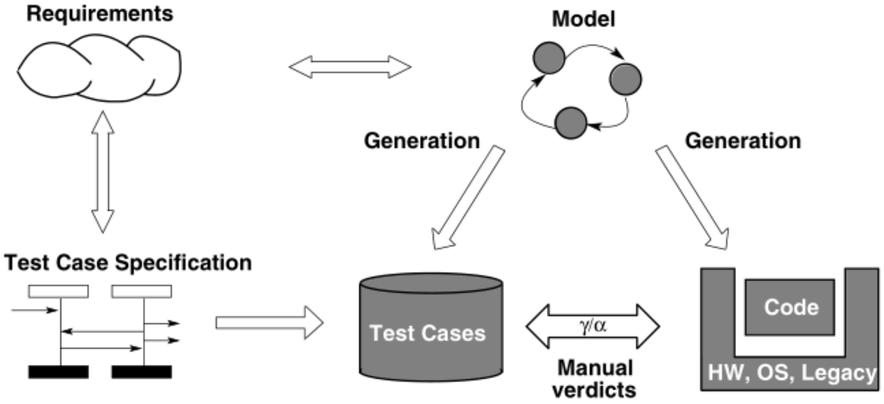
- Model environment/users
- Inputs to the system

Test

- Model one or more test case
- E.g. sequences + evaluation

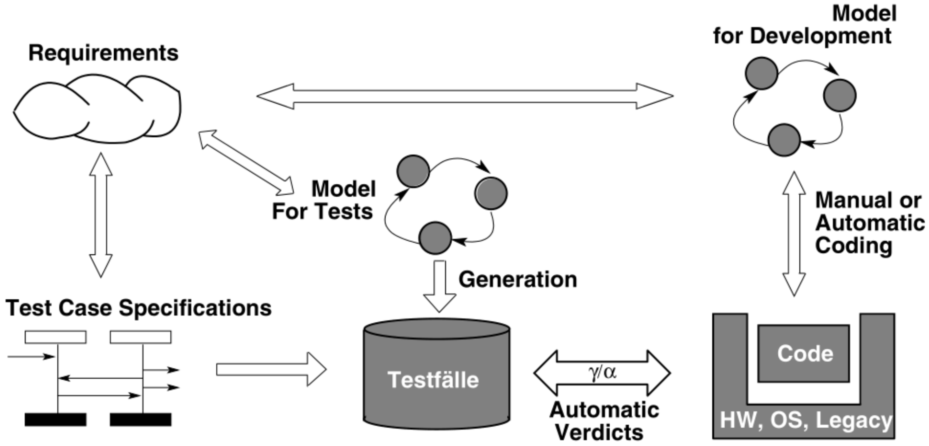
Reuse: Development and Test modeling

What if I have existing design models?



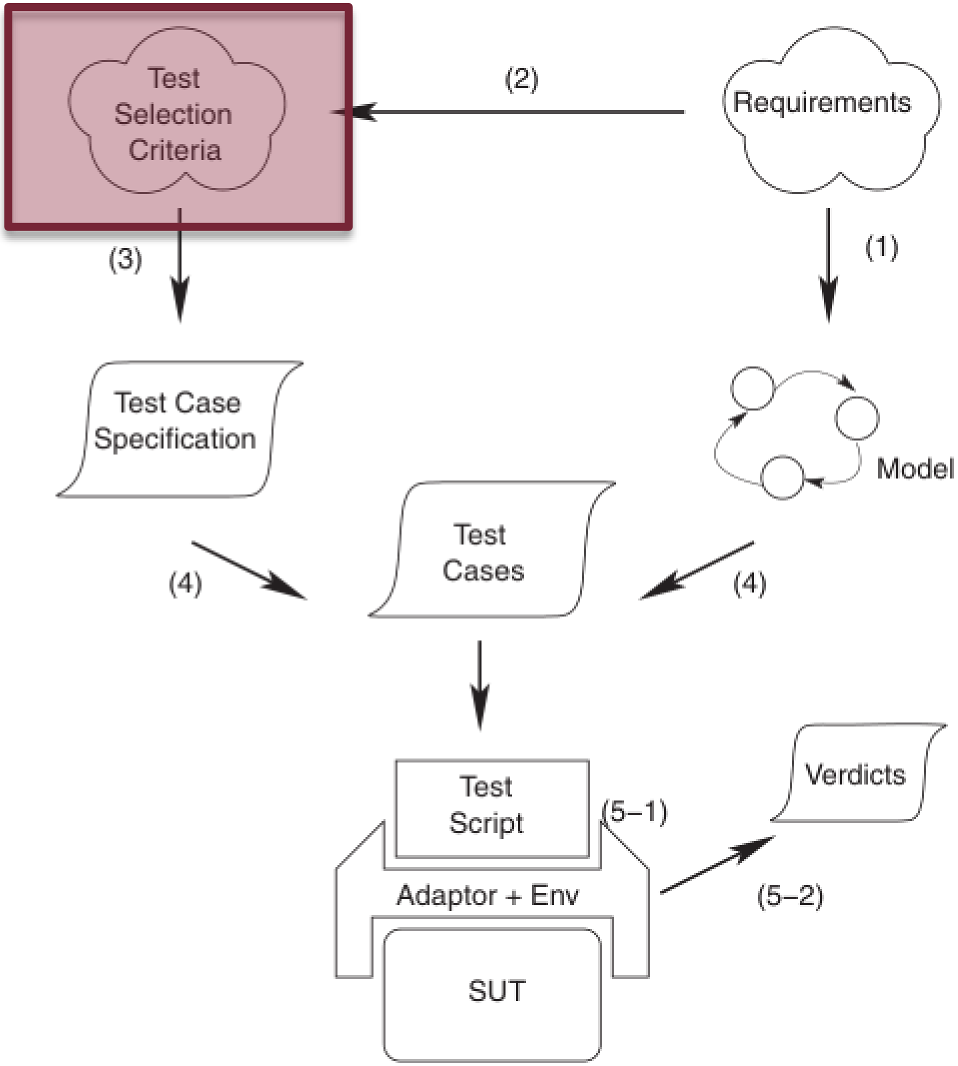
Problem: what do we test here?

Approach: separate dev. and test models



A. Pretschner, J. Philipps. „Methodological Issues in Model-Based Testing", Model-Based Testing of Reactive Systems, 2005.

Typical MBT process

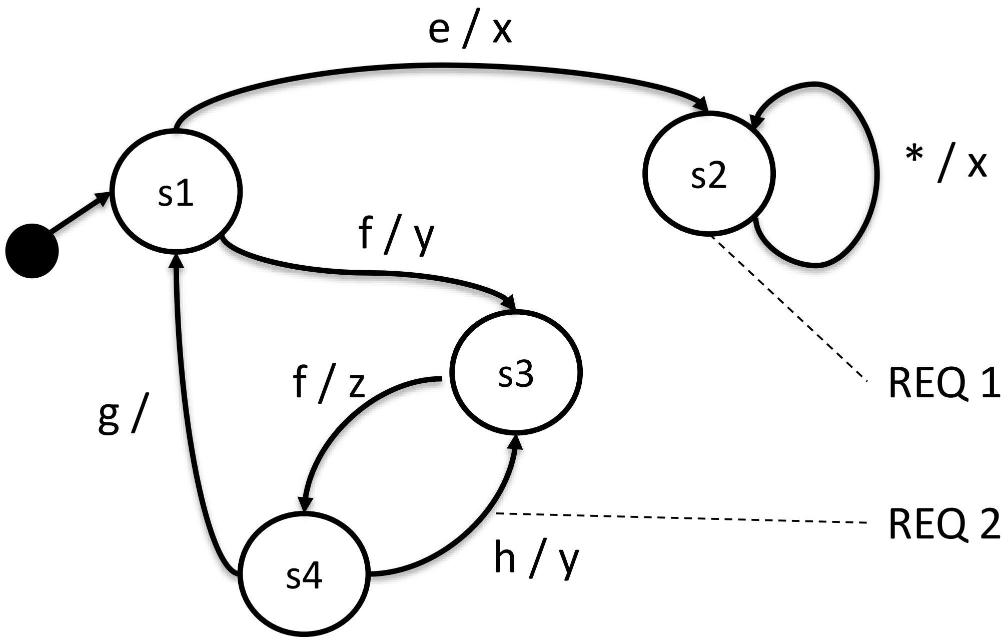


Source: M. Utting, A. Pretschner, B. Legeard. „A taxonomy of model-based testing approaches", STVR 2012; 22:297–312

Typical test selection criteria

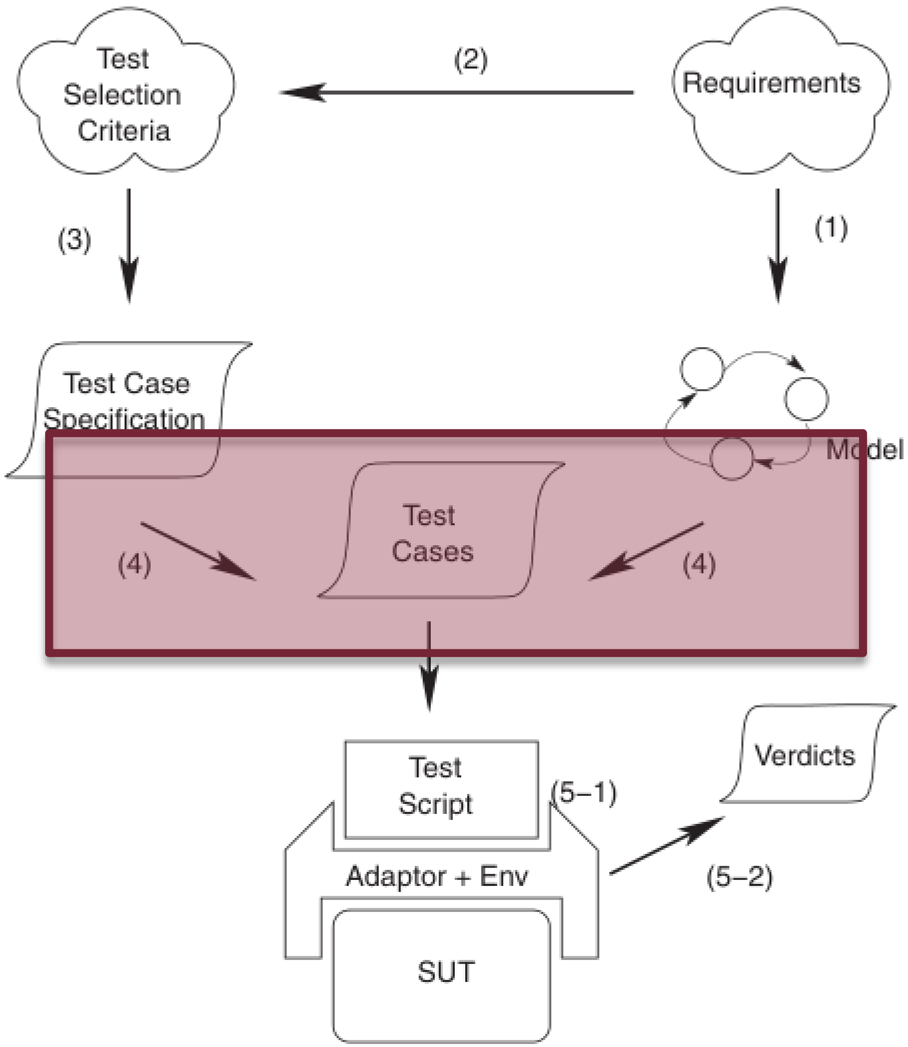
- Coverage-based
  - Requirements linked to the model
  - MBT model elements (state, transition, decision…)
  - Data-related (see spec. test design techniques)
- Random / stochastic
- Scenario- and pattern based (use case…)
- Project-driven (risk, effort, resources…)

EXERCISE Test selection for state models



- Select test cases for full
  - requirement coverage
  - state coverage
  - transition coverage

Typical MBT process

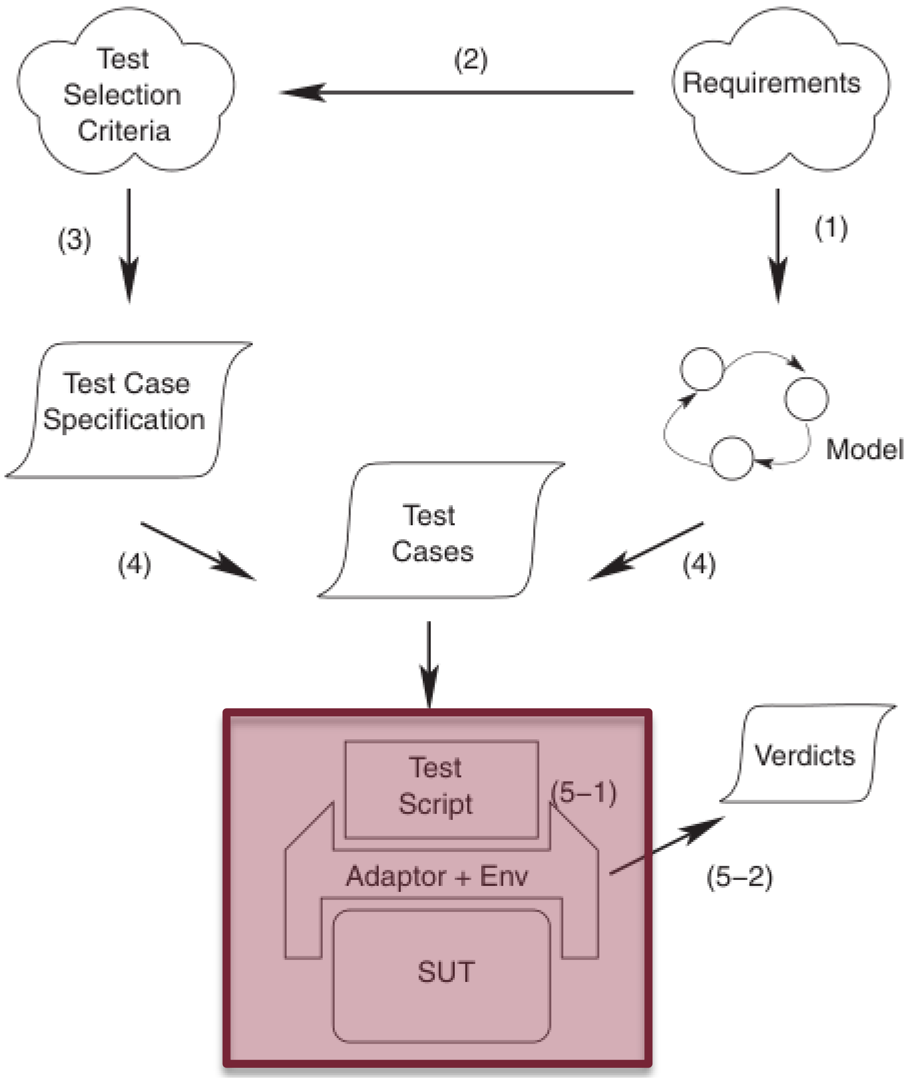


Source: M. Utting, A. Pretschner, B. Legeard. „A taxonomy of model-based testing approaches", STVR 2012; 22:297–312

Test generation methods (sample)

- Direct graph algorithms
  - Transition coverage → “New York Street Sweeper problem”
- FSM testing
  - Homing and synchronizing sequences, state identification and verification, conformance…
- LTS testing
  - Equivalence and preorder relations, ioco
- Using model checkers
- Fault-based (mutation)

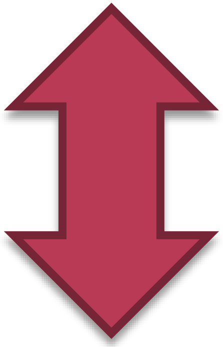
Typical MBT process



Source: M. Utting, A. Pretschner, B. Legeard. „A taxonomy of model-based testing approaches", STVR 2012; 22:297–312

Abstract and concrete test cases

- Abstract test case
  - Logical predicate instead of values (e.g. SLOW/FAST instead of 122.35)
  - High-level events and actions



Abstraction gap!

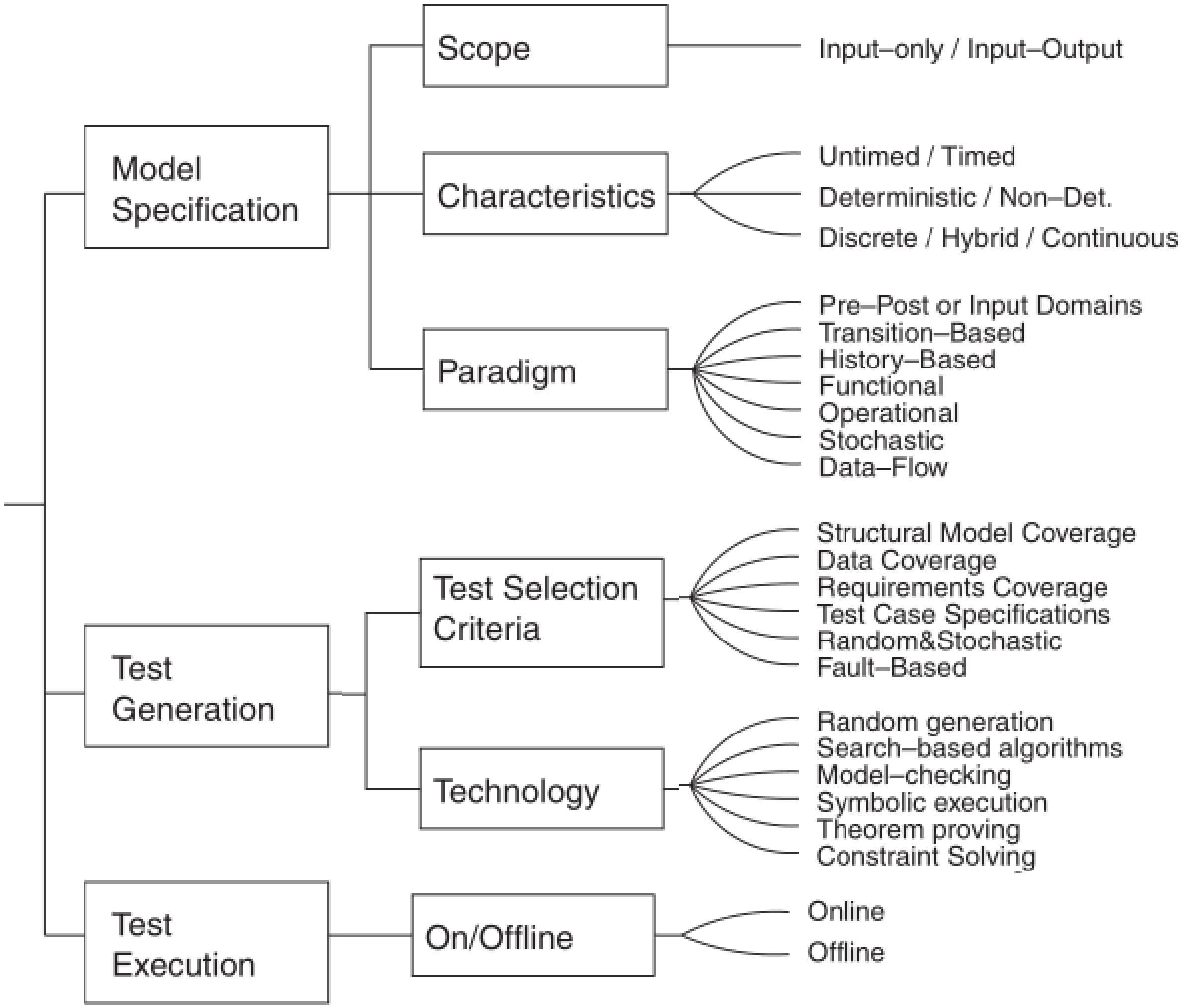
- Concrete test case
  - Concrete input data
  - Detailed test procedure (manual or automatic)

Adaptation (automatic execution)

- Adaptation layer
  - Code blocks for each model-level event and action
  - Wrapper around the SUT

- See: Keyword-driven testing

Summary: Taxonomy of MBT approaches



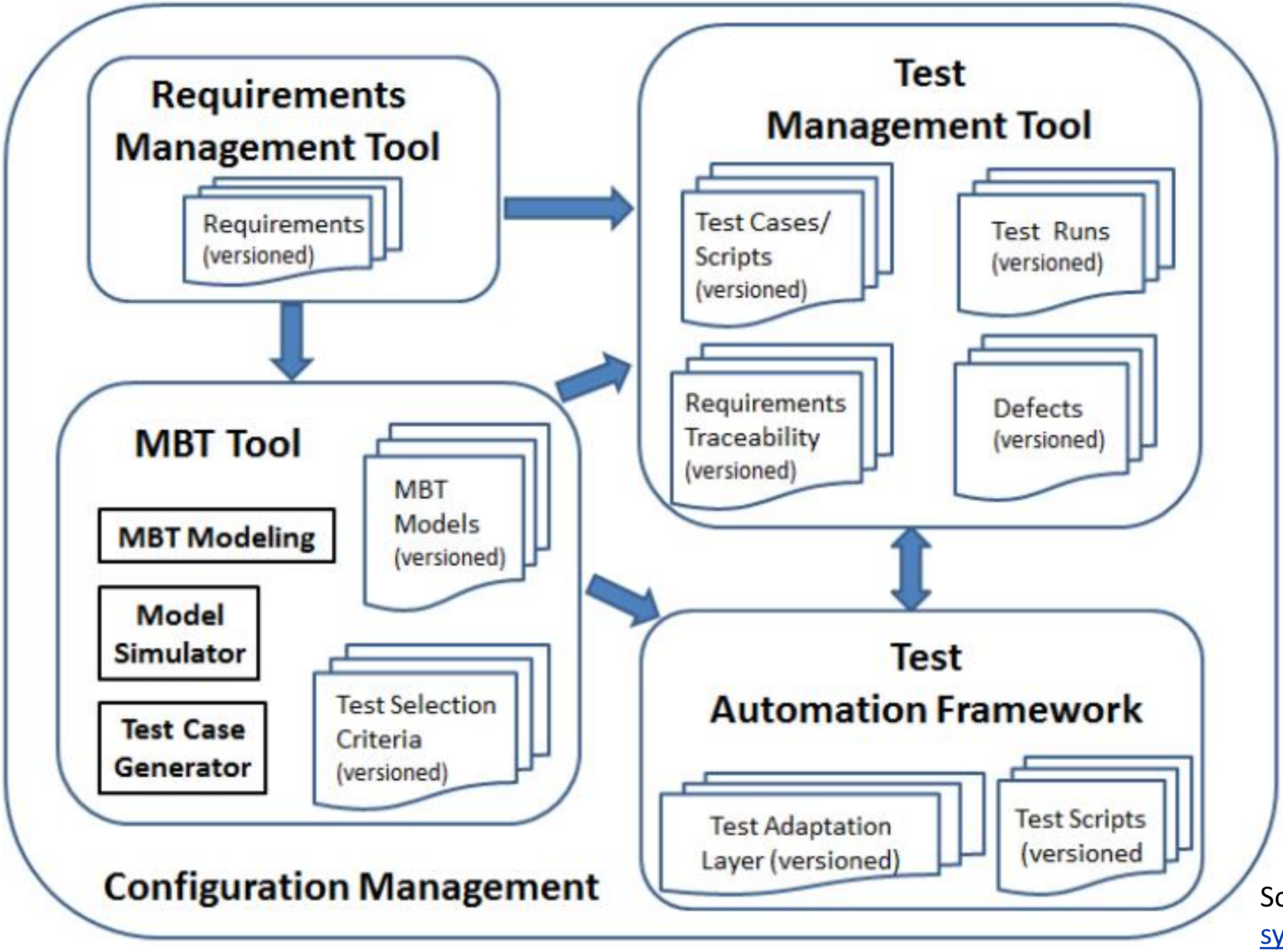
Source: M. Utting, A. Pretschner, B. Legeard. „A taxonomy of model-based testing approaches", STVR 2012; 22:297–312

TOOLS AND CASE STUDIES

Typical use cases

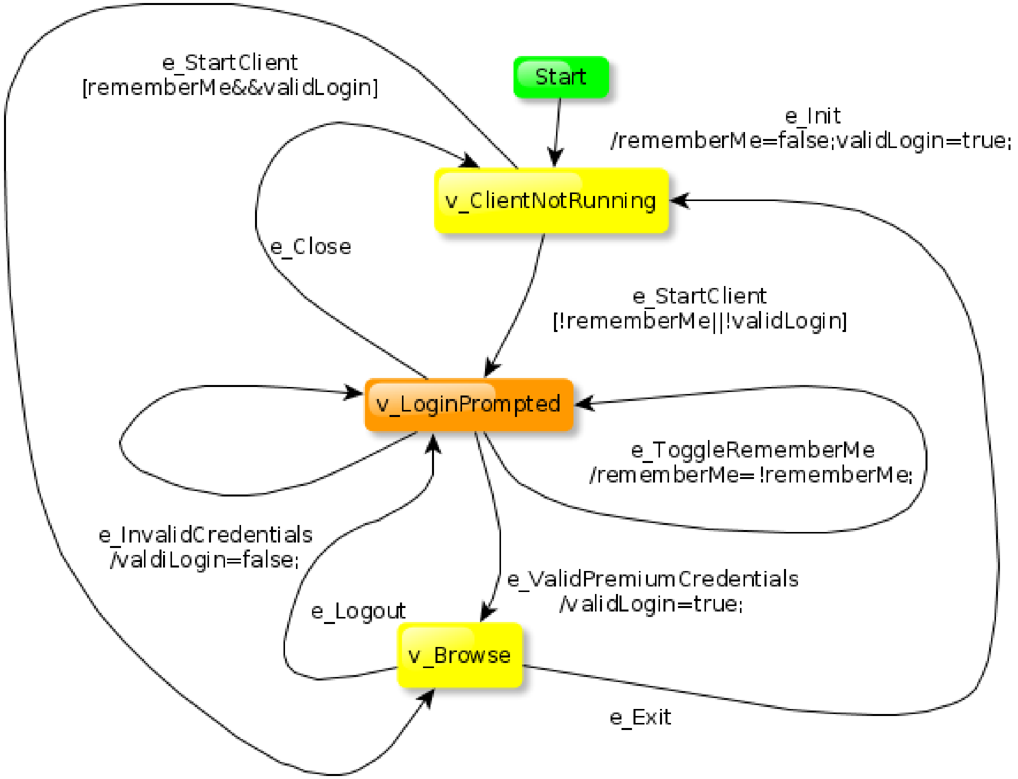
- **Fast & easy**
  - Simple modeling
  - Using open tools
- **Full fledged**
  - Complex, commercial tool
  - Full lifecycle support
- **Advanced**
  - Custom modeling languages/tools

MBT tool chain



Source: ISTQB syllabus

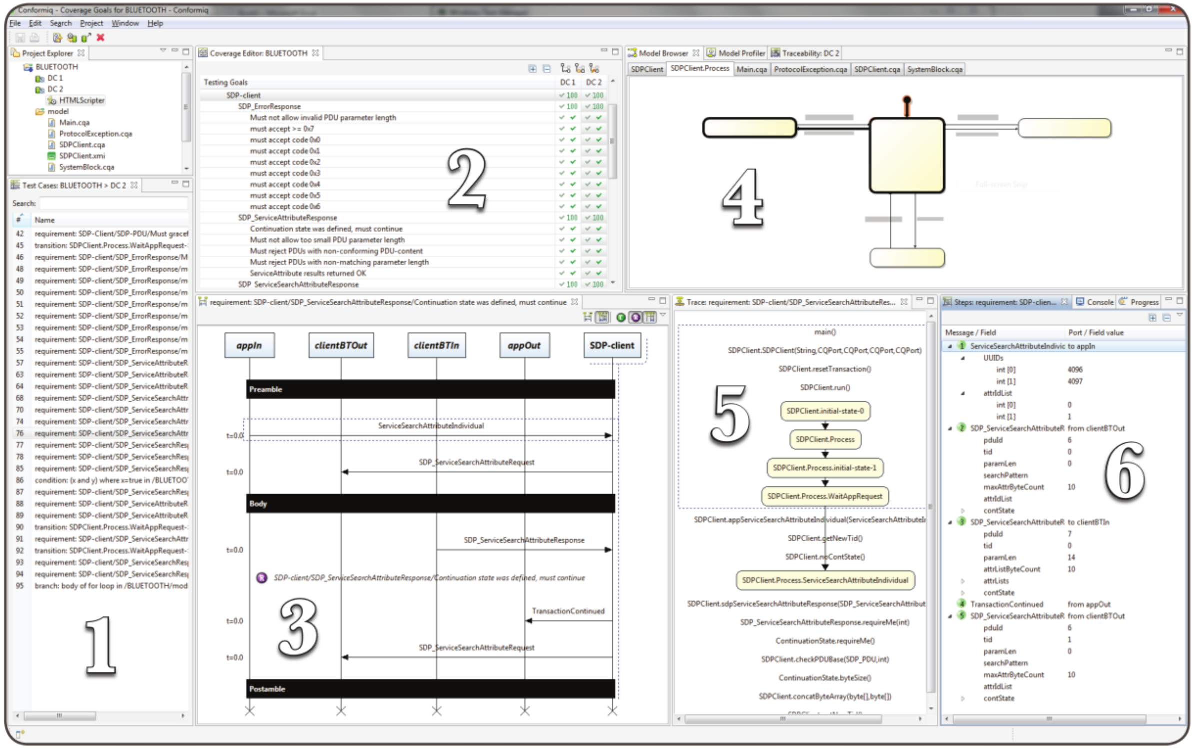
Open source tool: GraphWalker



Source: GraphWalker

- FSM model + simple guards
- Coverage: state, transition, time limit (random walk)
- Traversing the graph: random, A*, shortest path
- Generating JUnit test stubs (adapter)

Industrial MBT tool – Conformiq

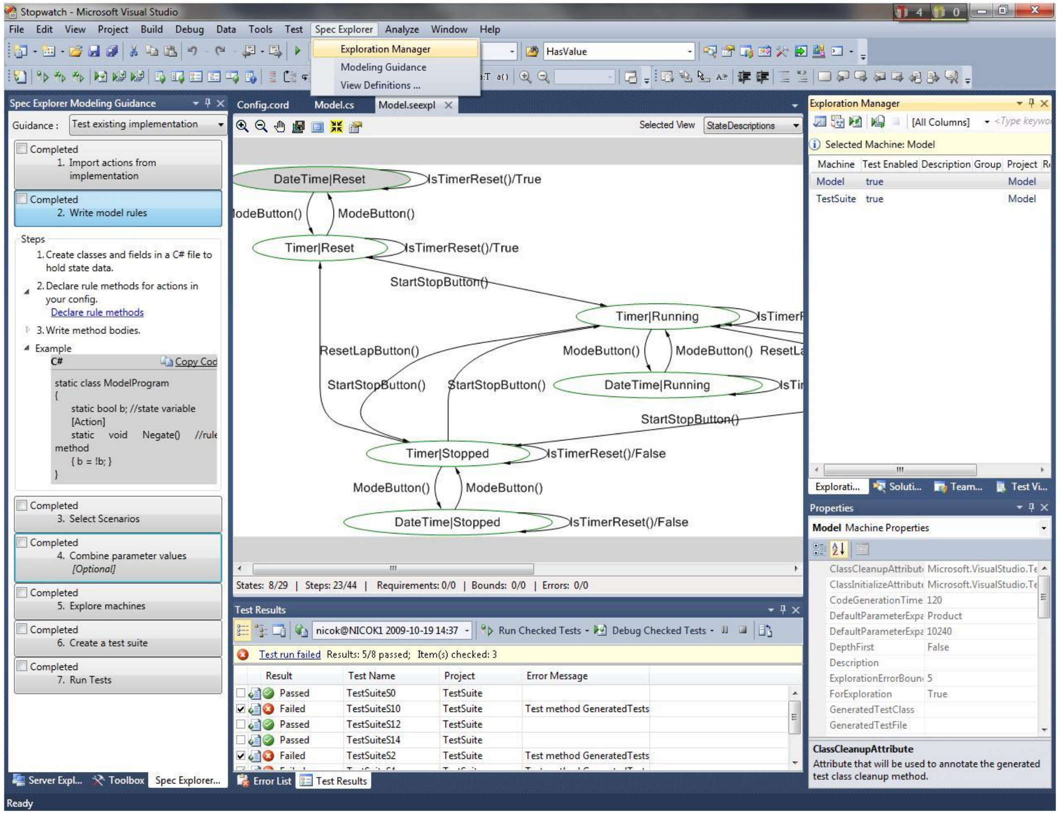


Conformiq Designer IDE for automatic test case generation

Source: Conformiq. „Testing Bluetooth Protocol Stacks with Computer-Generated Tests”. Technology brief. 2010

- State machine models + Java action code
- Coverage: requirement, state, transition…
- Integration with numerous other tools

Industrial MBT tool – SpecExplorer



Spec Explorer Modeling Guidance

Guidance : Test existing implementation

□ Completed
1. Import actions from implementation

□ Completed
2. Write model rules

Steps
1. Create classes and fields in a C# file to hold state data.
2. Declare rule methods for actions in your config.
Declare rule methods
3. Write method bodies.

Example

C# Copy Cod

```
static class ModelProgram
{
     static bool b; //state variable
     [Action]
     static     void     Negate()     //rule
method
     { b = !b; }
}
```

□ Completed
3. Select Scenarios

□ Completed
4. Combine parameter values *[Optional]*

□ Completed
5. Explore machines

□ Completed
6. Create a test suite

□ Completed
7. Run Tests

States: 8/29 | Steps: 23/44 | Requirements: 0/0 | Bounds: 0/0 | Errors: 0/0

Test Results

nicok@NICOK1 2009-10-19 14:37 · Run Checked Tests · Debug Checked Tests

Test run failed Results: 5/8 passed; Item(s) checked: 3

	Result	Test Name	Project	Error Message
□	Passed	TestSuiteS0	TestSuite	
☑	Failed	TestSuiteS10	TestSuite	Test method GeneratedTests
□	Passed	TestSuiteS12	TestSuite	
□	Passed	TestSuiteS14	TestSuite	
☑	Failed	TestSuiteS2	TestSuite	Test method GeneratedTests

Exploration Manager

[All Columns] <Type keywo

Selected Machine: Model

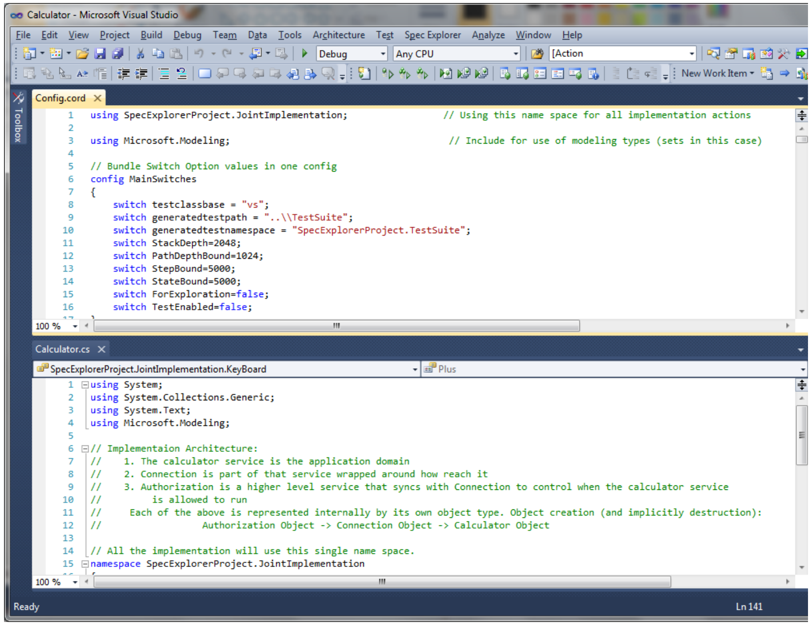
Machine	Test Enabled	Description	Group	Project
Model	true			Model
TestSuite	true			Model

Properties

Model Machine Properties

ClassCleanupAttribut	Microsoft.VisualStudio.Te
ClassInitializeAttribute	Microsoft.VisualStudio.Te
CodeGenerationTime	120
DefaultParameterExpa	Product
DefaultParameterExpa	10240
DepthFirst	False
Description	
ExplorationErrorBoun	5
ForExploration	True
GeneratedTestClass	
GeneratedTestFile	

ClassCleanupAttribute
Attribute that will be used to annotate the generated test class cleanup method.



Calculator - Microsoft Visual Studio
File Edit View Project Build Debug Team Data Tools Architecture Test Spec Explorer Analyze Window Help
Debug
Any CPU
[Action
New Work Item
Toolbox
Config.cord
Calculator.cs
SpecExplorerProject.JointImplementation.KeyBoard
Plus
100 %
Ready
Ln 141

```
using SpecExplorerProject.JointImplementation;              // Using this name space for all implementation actions

using Microsoft.Modeling;                                    // Include for use of modeling types (sets in this case)

// Bundle Switch Option values in one config
config MainSwitches
{
    switch testclassbase = "vs";
    switch generatedtestpath = "..\\TestSuite";
    switch generatedtestnamespace = "SpecExplorerProject.TestSuite";
    switch StackDepth=2048;
    switch PathDepthBound=1024;
    switch StepBound=5000;
    switch StateBound=5000;
    switch ForExploration=false;
    switch TestEnabled=false;
```

```
using System;
using System.Collections.Generic;
using System.Text;
using Microsoft.Modeling;

// Implementaion Architecture:
//    1. The calculator service is the application domain
//    2. Connection is part of that service wrapped around how reach it
//    3. Authorization is a higher level service that syncs with Connection to control when the calculator service
//          is allowed to run
//     Each of the above is represented internally by its own object type. Object creation (and implicitly destruction):
//                Authorization Object -> Connection Object -> Calculator Object

// All the implementation will use this single name space.
namespace SpecExplorerProject.JointImplementation
```

Source: https://visualstudiogallery.msdn.microsoft.com/271d0904-f178-4ce9-956b-d9bfa4902745

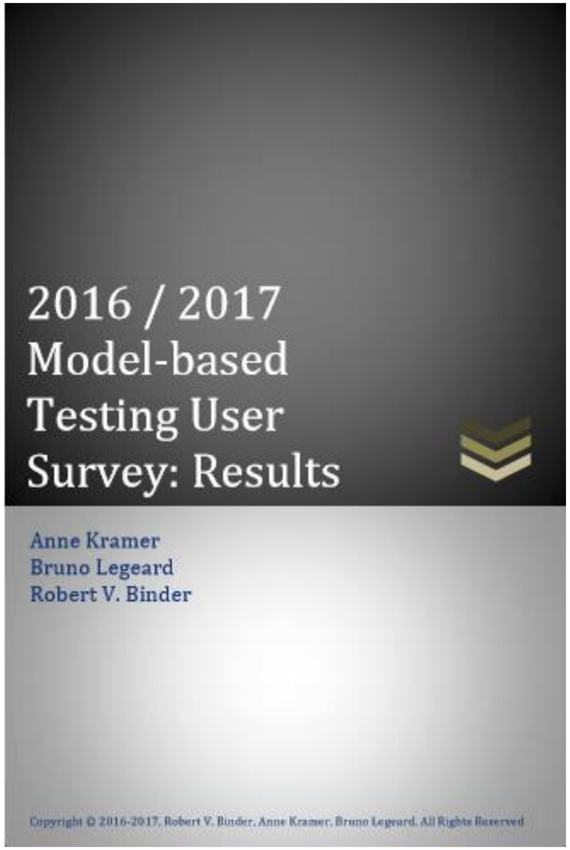
- C# model program + adapter code
- Slicing: scenarios, action patterns

Tools (cont’d)

- **CertifyIt (Smartesting)**
  - UML + OCL models
- **MoMuT::UML (academic)**
  - UML state machines, mutation testing
- **4Test-Plus (4test.io)**
  - Gherkin-like syntax for partitions/constraints

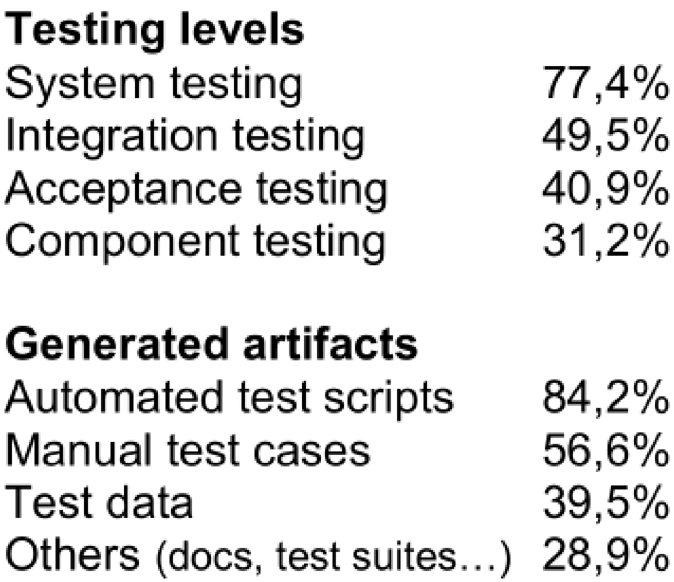
List of tools: http://mit.bme.hu/~micskeiz/pages/modelbased_testing.html

MBT User Survey



2016 / 2017
Model-based
Testing User
Survey: Results

Anne Kramer
Bruno Legeard
Robert V. Binder



Testing levels	
System testing	77,4%
Integration testing	49,5%
Acceptance testing	40,9%
Component testing	31,2%

Generated artifacts	
Automated test scripts	84,2%
Manual test cases	56,6%
Test data	39,5%
Others (docs, test suites…)	28,9%

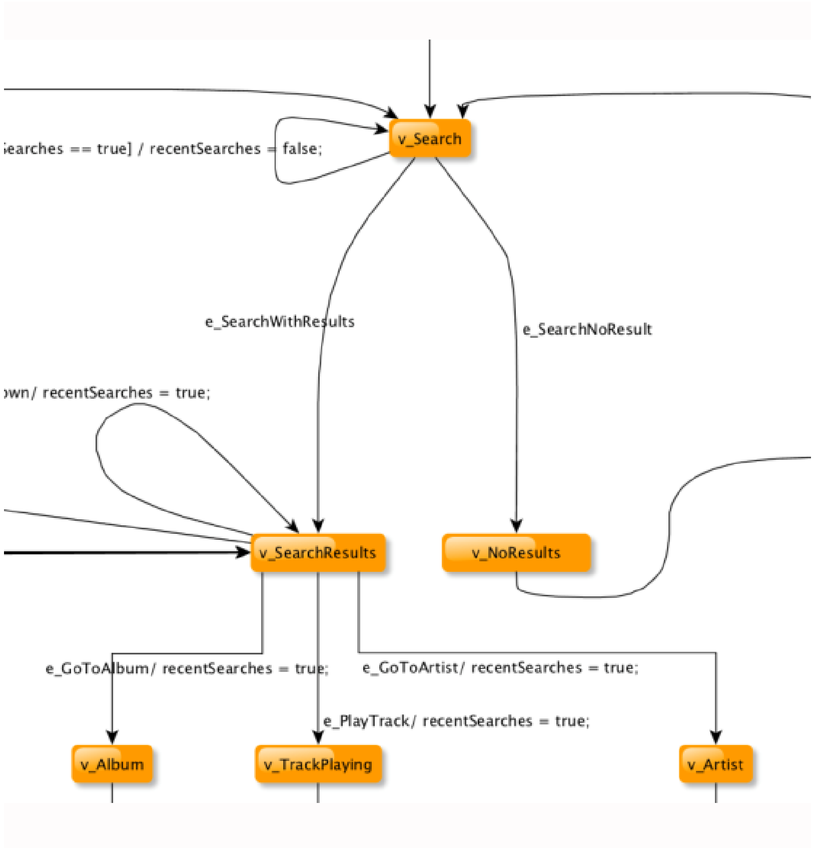
- “approx. 80h needed to become proficient”
- MBT is effective
- Lots of other details!

~100 participants
32 questions

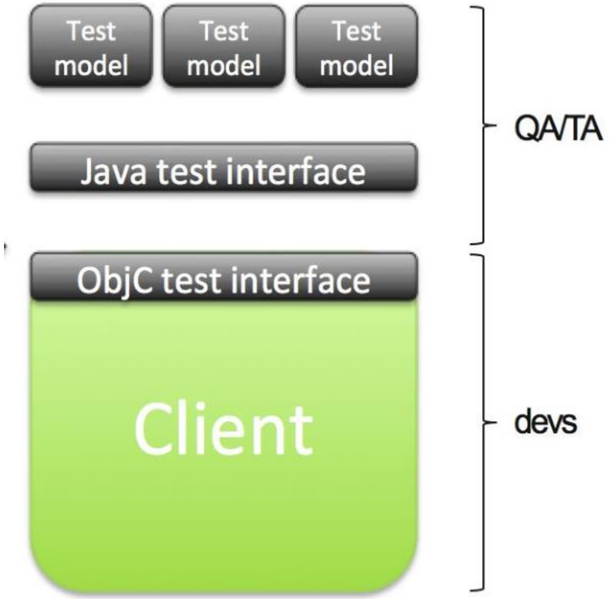
Source: http://www.cftl.fr/wp-content/uploads/2017/02/2016-MBT-User-Survey-Results.pdf

Case study: Spotify

Modell + GraphWalker


v_Search
earches == true] / recentSearches = false;
e_SearchWithResults
e_SearchNoResult
own/ recentSearches = true;
v_SearchResults
v_NoResults
e_GoToAlbum/ recentSearches = true;
e_GoToArtist/ recentSearches = true;
e_PlayTrack/ recentSearches = true;
v_Album
v_TrackPlaying
v_Artist

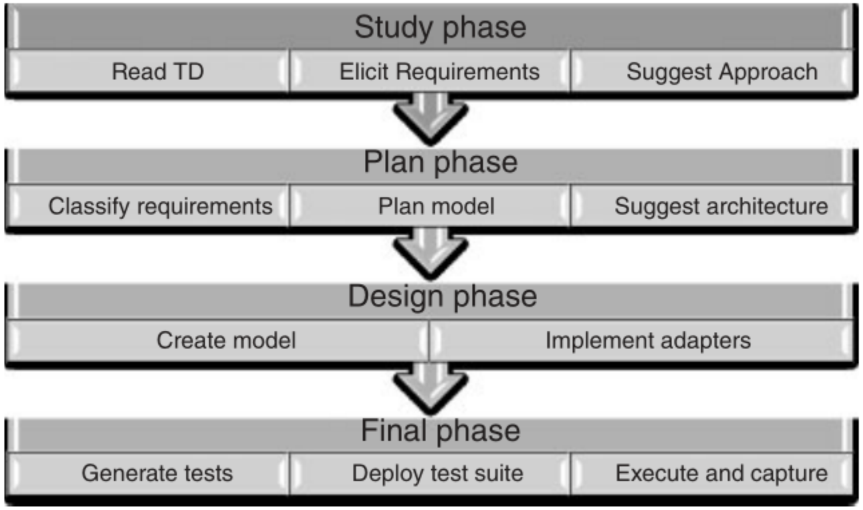
MBT + test automation



Test automation and Model-Based Testing in agile dev cycle @ Spotify, UCAAT 2013

Case study: MS protocol documentation

- 250+ protocol, 25.000+ pages documentation
- 250+ man year, 350+ engineer
- Tool: SpecExplorer



Study phase

Read TD | Elicit Requirements | Suggest Approach

Plan phase

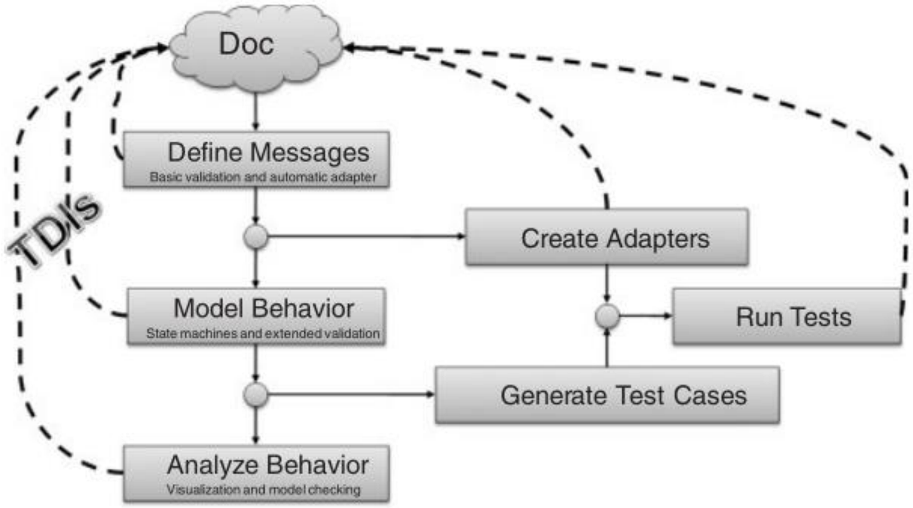
Classify requirements | Plan model | Suggest architecture

Design phase

Create model | Implement adapters

Final phase

Generate tests | Deploy test suite | Execute and capture



Doc

TDIS

Define Messages

Basic validation and automatic adapter

Create Adapters

Model Behavior

State machines and extended validation

Run Tests

Generate Test Cases

Analyze Behavior

Visualization and model checking

Details: http://queue.acm.org/detail.cfm?id=1996412

Source: W. Grieskamp et al. „Model-based quality assurance of protocol documentation: tools and methodology," STVR, 21:55-71, 2011

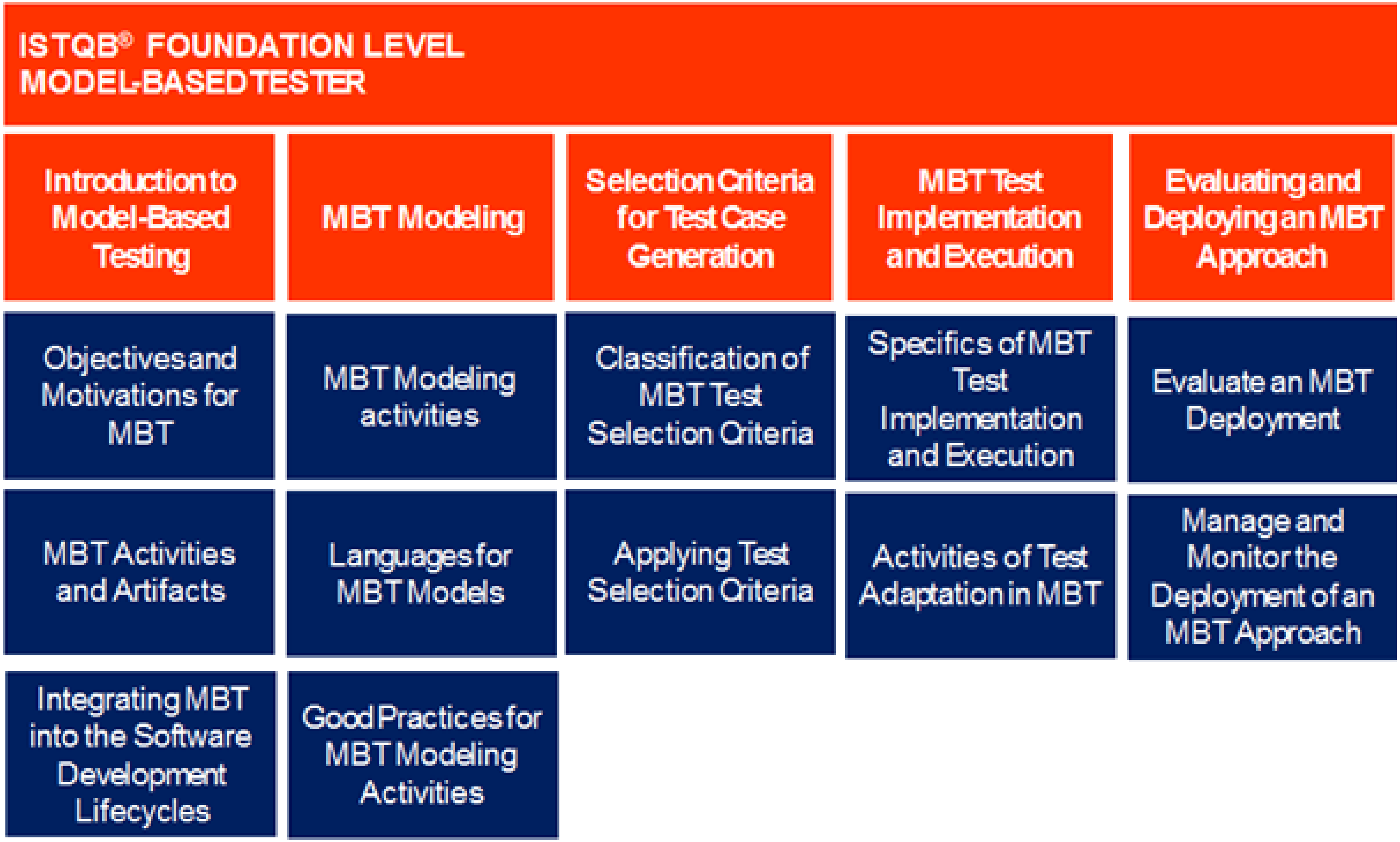
“Cheat sheet” for introducing MBT

From Robert V. Binder (http://robertvbinder.com/)

Recommended	Not recommended
Complex SUT behavior	Simple functionality
Abstractable requirements	Subjective evaluation
Testable interfaces	Monolithic GUI
Must to regression testing	Low-value, deprecated GUI
Sophisticated test engineers	Little or no established testing
	Non-technical QA team

See also: „Model-Based Testing: Why, What, How,” http://www.slideshare.net/robertvbinder/model-basedtestingignite

ISTQB CTFL-MBT training + exam

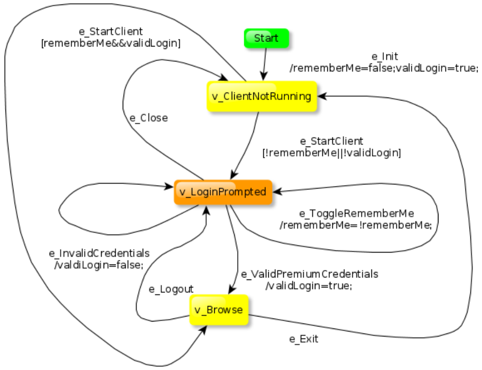


ISTQB® FOUNDATION LEVEL
MODEL-BASED TESTER

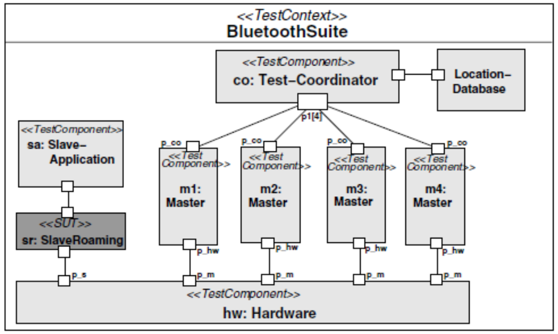
Introduction to Model-Based Testing	MBT Modeling	Selection Criteria for Test Case Generation	MBT Test Implementation and Execution	Evaluating and Deploying an MBT Approach
Objectives and Motivations for MBT	MBT Modeling activities	Classification of MBT Test Selection Criteria	Specifics of MBT Test Implementation and Execution	Evaluate an MBT Deployment
MBT Activities and Artifacts	Languages for MBT Models	Applying Test Selection Criteria	Activities of Test Adaptation in MBT	Manage and Monitor the Deployment of an MBT Approach
Integrating MBT into the Software Development Lifecycles	Good Practices for MBT Modeling Activities			

Source: ISTQB

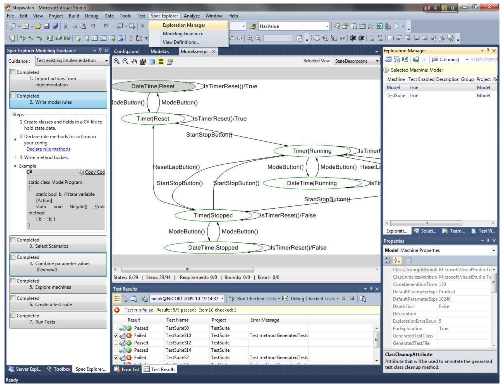
Summary



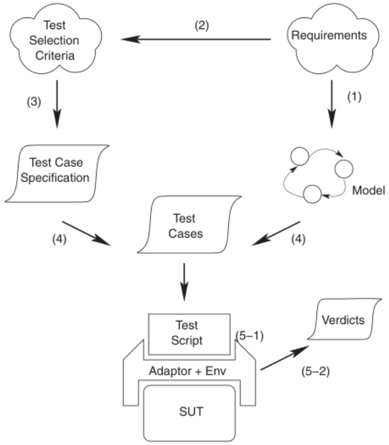
Many models, test goals and tools



MBT = using models in testing



Scaling from brainstorming to fully automatic test case generation


Test Selection Criteria
(2)
Requirements
(3)
(1)
Test Case Specification
Model
(4)
Test Cases
(4)
Test Script
(5–1)
Verdicts
Adaptor + Env
(5–2)
SUT