Model-Based Testing

(DIT848 / DAT261)
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Lecture 7
Introduction to MBT

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Many slides based on material provided by Mark Utting

What have we seen

- V&V: Validation & Verification
  - The V model
  - Black box testing
  - White box testing
  - Something on coverage
- (Extended) Finite State Machines

Guest lectures?

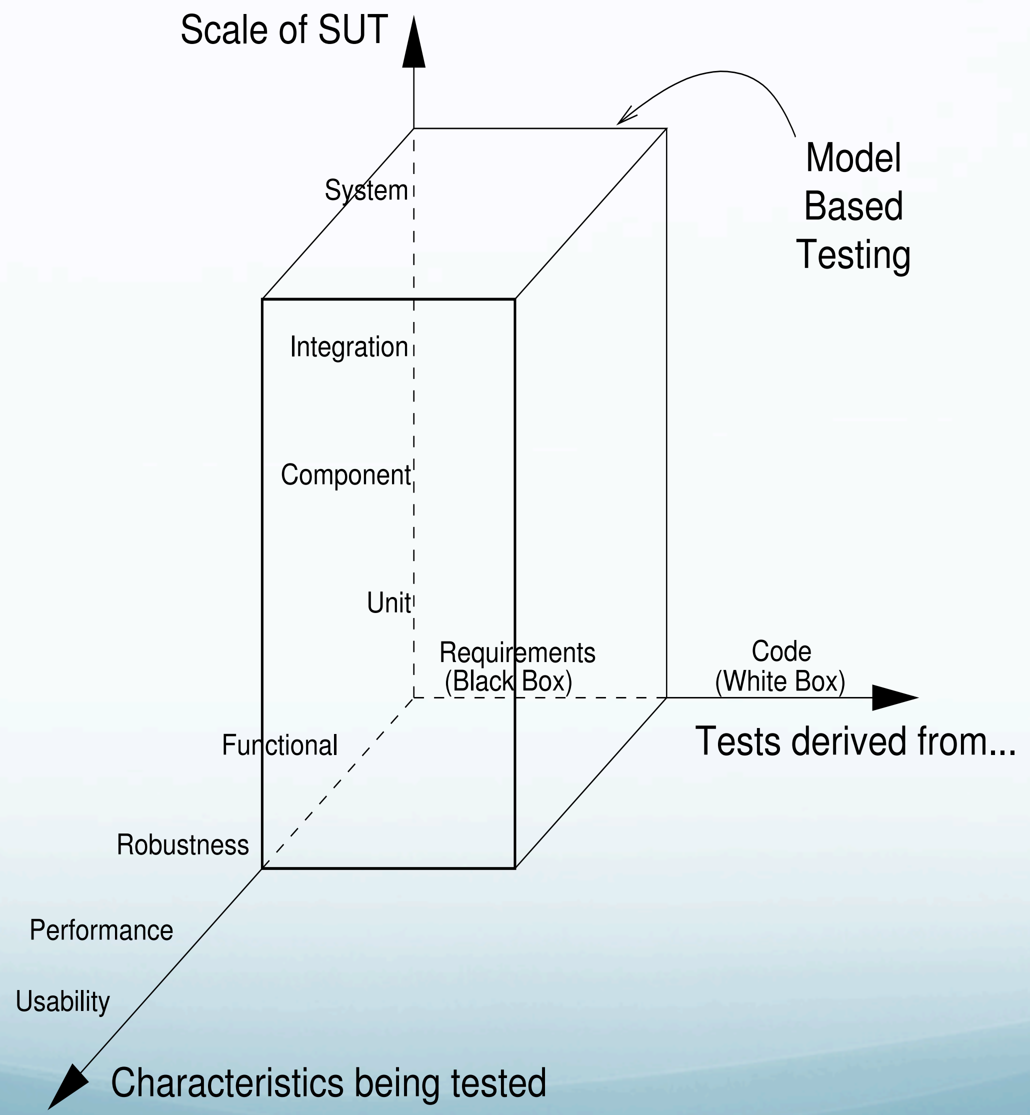
- TBD

What remains

The rest of the lectures: MBT

1. Introduction (concepts, terminology,…) – Today
2. ModelJUnit – today
3. Graph theory for MBT – Wed next week
4. Making your tests executable – Wed next week
5. How to select your tests – Wed next week

Kinds of Testing



Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

What is Model-Based Testing

Four main approaches known as MBT

1. Automatic generation of test input data from a domain model
   - Information on the domain of input values
   - Not known whether test passess or not
2. Automatic generation of test cases from an environmental model
   - Environment: expected usage of SUT, operation frequences…
   - Do not specify expected output
3. Automatic generation of test scripts from abstract tests
   - Abstract description of test cases (eg. UML seq. Diag.)
   - Transforms abstract test cases into low-level executable script
4. Automatic generation of test cases with oracles from a behavior model
   - Executable tests with expected output
   - Model must describe expected behavior of SUT

Our focus!

So… MBT is the automation of the design of black-box tests

MBT in context…

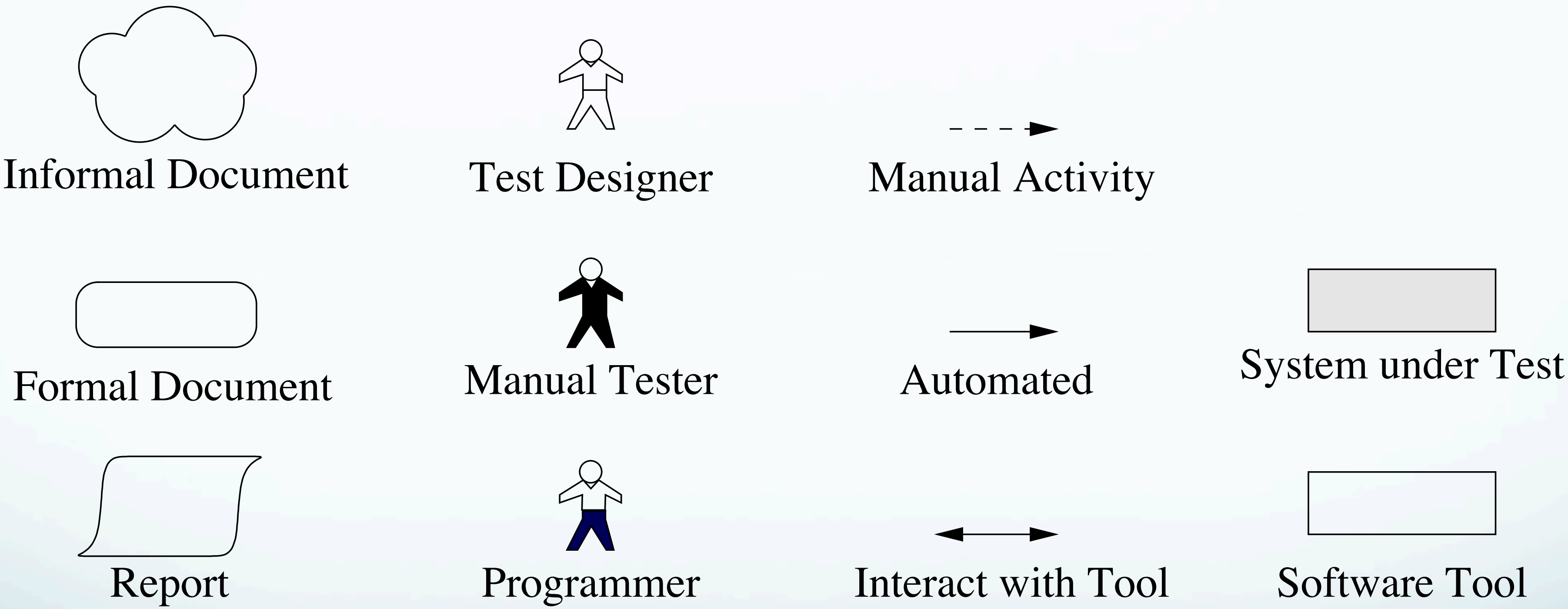
When designing **functional testing**, 3 key steps:

1. Designing the test case
2. Executing the tests and analyzing the result
3. Verifying how the tests cover the requirements

Different testing processes

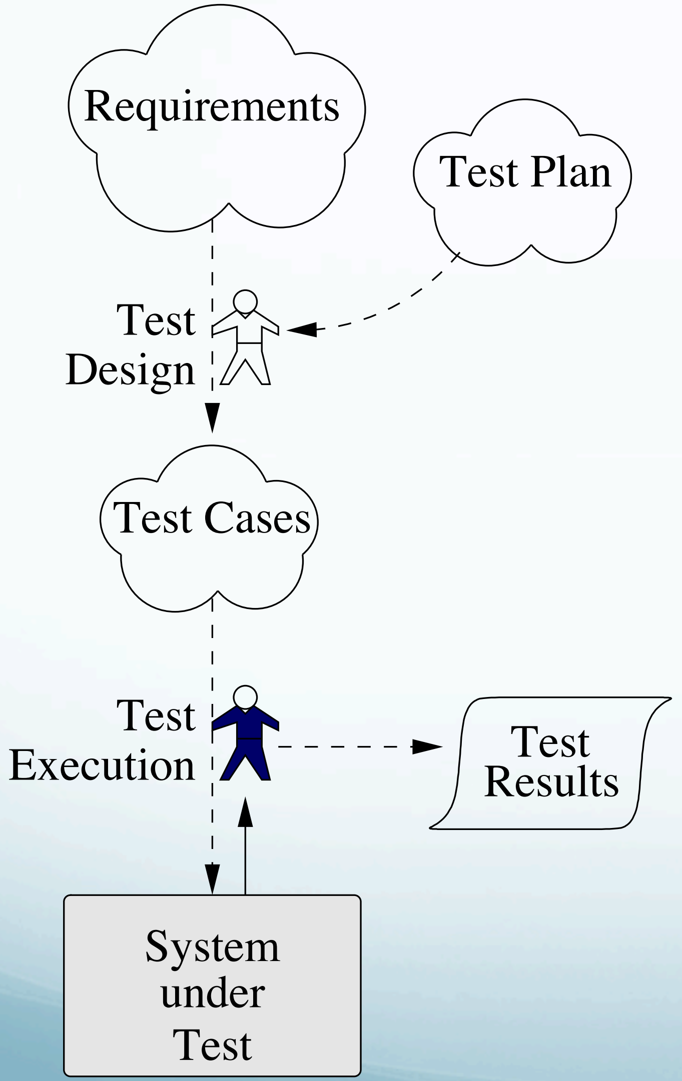
1. Manual testing process
2. Capture/replay testing process
3. Script-based testing process
4. Keyword-driven automated testing process
5. The MBT process

Preliminaries: notation…



Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

1. Manual Testing



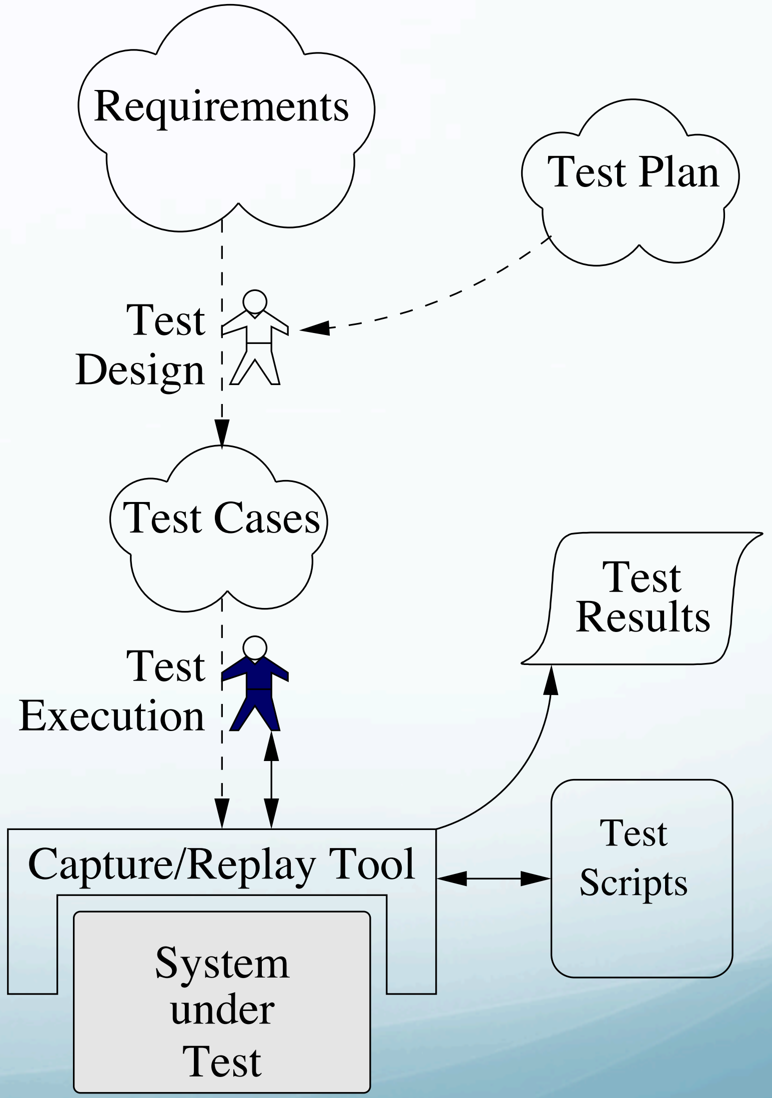
+ easy & cheap to start
+ flexible testing
- expensive every execution
- no auto regression testing
- ad-hoc coverage
- no coverage measurement

Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

2. Capture-Replay Testing

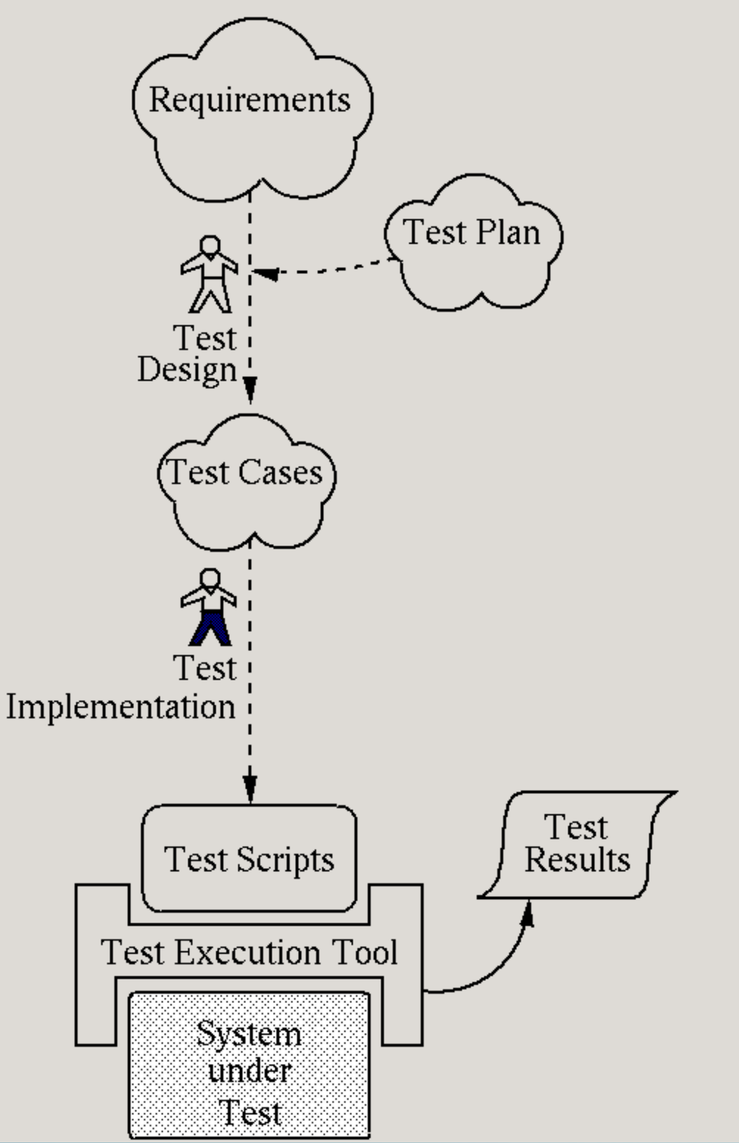
+ flexible testing
- expensive first execution
+ auto regression testing
- fragile tests break easily
- ad-hoc coverage
- no coverage measurement
- low-level recorded tests

NOTE: Mostly used to automate testing of graphical user interface (GUI)



Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

3. Script-Based Testing



+/- test impl. = programming

+ automatic execution

+ auto regression testing

- fragile tests break easily?

  (depends on abstraction)

- ad-hoc coverage

- no coverage measurement

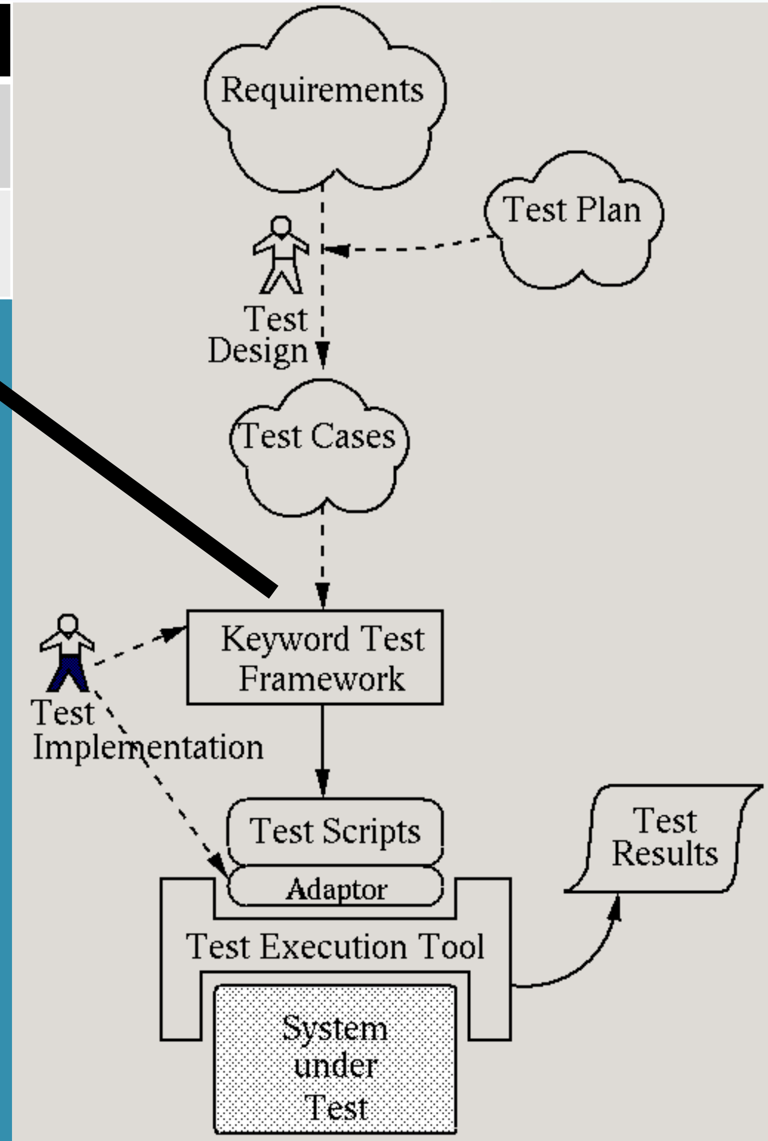
Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

4. Keyword-Driven Testing

Keyword	Name	Address	Course
Enter Student	Alain Turingo	London, UK	Computability
Enter Student	Claudio Shannoni	Michigan, USA	Digital Design

Similar to:

- **data-driven**
- **table-driven**
- **action-word driven**



Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

4. Keyword-Driven Testing

+ abstract tests

+ automatic execution

+ auto regression testing

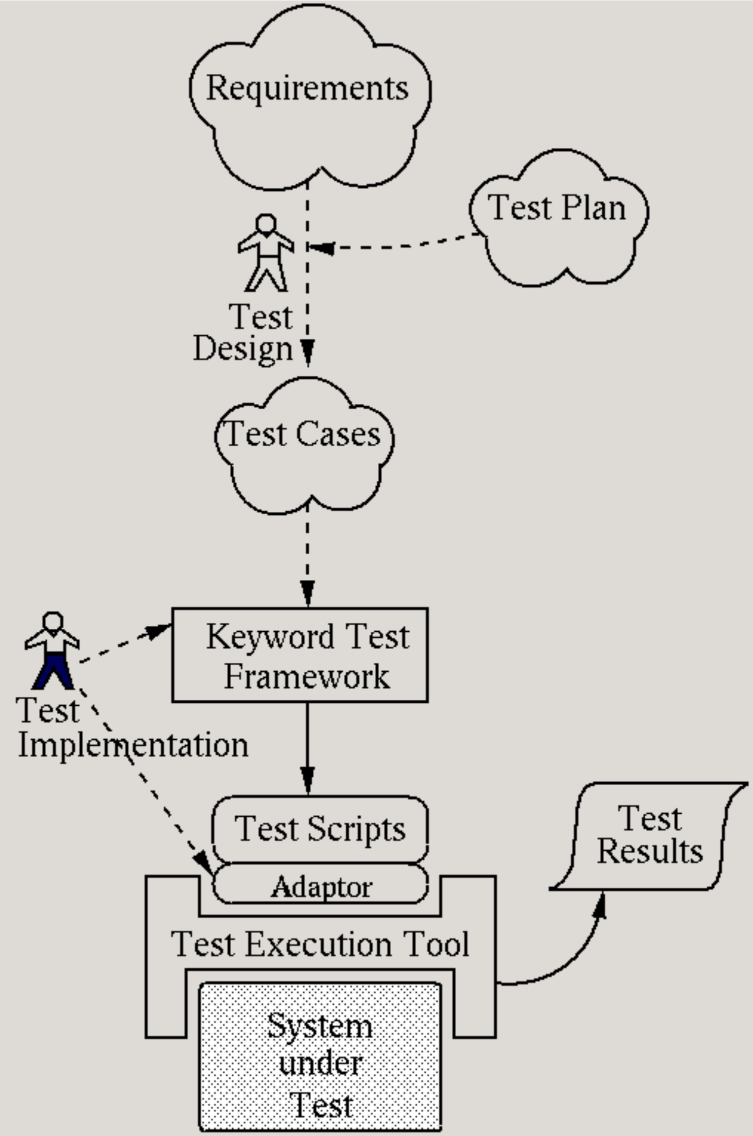
- robust tests

- ad-hoc coverage

- no coverage measurement

- manual design of test data and oracle

Note: The "adaptor" allows translate sequence of keywords and data into executable tests

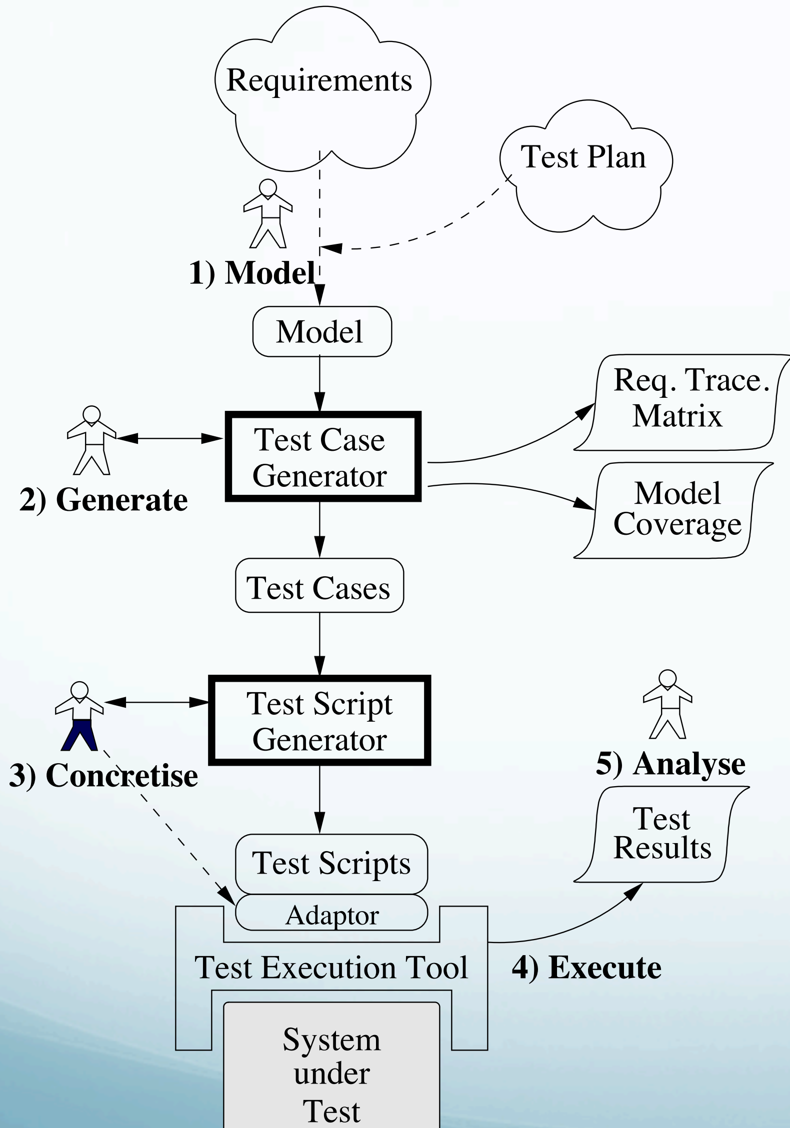


Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

5. Model-Based Testing

1. Model the SUT and/or its environment
   - Write some abstract model / annotate with relationship between tests and requirements
2. Generate abstract tests from the model
   - Chose some test selection criteria to generate tests from the model. Coverage and results refer to the model!
3. Concretize the abstract tests to make them executable
   - Use a transformation tool to get concrete tests (on the SUT) from the abstract tests from the model
4. Execute the tests on the SUT and assign verdicts
5. Analyze the test results (and take corrective action)
   - A fault in the test case might be due to a fault in the adaptor code or in the model

5. Model-Based Testing



+ abstract tests

+ automatic execution

+ auto regression testing

+ auto design of tests

+ systematic coverage

+ measure coverage of model and requirements

- modeling overhead

Important: usually first **abstract tests** -> needs to get **concrete** tests: **adaptor**!

Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

Building Models…

Reusing or building from scratch?

Reusing existing development model

- 100% reuse; not always possible:
  1. Develop. model usually contains too much detail
  2. Usually doesn't describe the SUT dynamic behavior
- Not abstract enough yet precise enough for test generation

Reuse something

- Some x% of reuse (0<x<100)
- Eg. reuse high-level class diagram and some use cases; add behavioral details

Developing model from scratch

- 0% reuse
- Maximize independence
- A lot of effort

Whatever approach: relate your model to the informal requirements as close as possible!

Benefits of MBT

1. SUT fault detection
   - Increase the possibility of finding errors
2. Reduces testing cost and time
   - Less time and effort spent on writing tests and analyzing results
   - Could generate shortest test sequences
3. Improves test quality
   - Possible to measure the ”quality” by considering coverage (of model)
4. Detects requirements defects
   - Modeling phase exposes requirements issues
5. Traceability
   - Between requirements and the model
   - Between informal requirements and generated test cases
6. Requirements evolution
   - Update test suite to reflect new requirements: update model and do it automatically

Limitations of MBT

Inherent to MBT:

1. Cannot guarantee to find all differences between the model and the implementation
2. Need of skilled model designers: abstract and design models
3. Mostly (only?) for functional testing
4. Some tests not easily automated:
   eg. installation process

After you adopt MBT:

1. Outdated requirements
   - Might build the wrong model
2. Inappropriate use of MBT
   - Parts difficult to model; may get the wrong model
3. Time to analyze failed tests
   - It may give complex test sequences
4. Useless metrics
   - *Number-of-tests* metrics not useful (huge number!) – other metrics needed

How to model your system?

1. Decide on a good level of abstraction
   - What to include and what not to
2. Think about the data it manages, operations it performs, subsystems, communication…
   - Maybe start from a UML class diagram?
   - Be sure you simplify your class diagram (simpler for testing than for design!)
3. Decide notation
4. Write the model
5. Ensure your model is accurate
   - Validate the model (it specifies the behavior you want)
   - Verify it (correctly typed and consistent)
6. Use your model to generate your tests

Notations for modeling

Seven possible ”paradigms”

1. Pre/post (state-based)

Snapshot of internal state of the system + operations

- B, Z, UML OCL, VDM, …

2. Transition-based

- FSMs, statecharts, LTS, I/O automata, …

3. History-based

Allowable traces if behavior over time

- MSC, sequence diagrams, …

4. Functional

Collection of mathematical functions

- FOL, HOL, …

5. Operational

Collection of executable parallel processes

- CSP, CCS, Petri nets, PI-calculus, …

6. Statistical

Probabilistic model of the event and input values

- Markov chains, …

7. Data-flow

- Lustre, Block diagrams in Simulink, …

Choosing a notation

For **MBT**, transition-based and pre/post notations are the most used

- Guidelines: Is the system data-oriented or control-oriented?

Data-oriented systems have state variables, rich types (sets, relations, sequences,…).

Operations to access and manipulate data

Data-oriented systems are most easily specified using pre/post notations

- Eg. **B**, having powerful libaries of data structures

In control-oriented systems the set of available operations depends on the state

Control-oriented systems are most easily specified using transition-based notations

- Eg. **FSMs**

- **Note 1**: Possible to use transition-based notations for data-oriented systems: handle data structures too (eg. **EFSMs**)

Note 2: In MBT the model should be **formal**!

Our focus in this course: transition-based notations!

Drinking Vending Machine (DVM)
Case Study

Utting & Legeard book: sec 3.2, pp.66!

Requirements:

Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

DVM case study

Use case

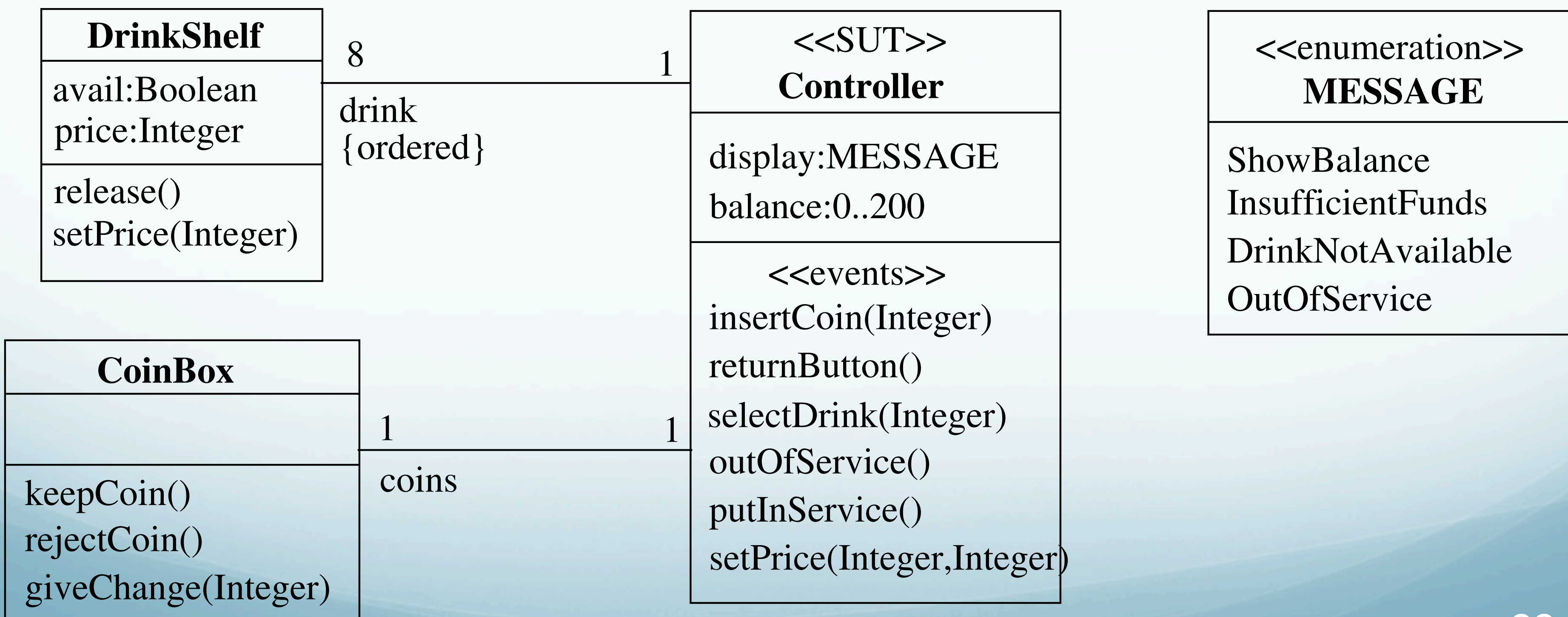
Utting & Legeard book:
Use Case 3.1, pp.67!

Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

DVM case study
High-level design

We need a high-level architecture of the DVM: how the controller interacts with other components

UML class diagram:



Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

DVM case study
What's next?

- Informal description, use cases, high-level design, etc. give us an idea of what a DVM controller does
- But… it doesn't specify all the input conditions, alternatives, exception cases, we want to **test**
- **Not precise enough for test generation**

We need to write a model "for testing"!

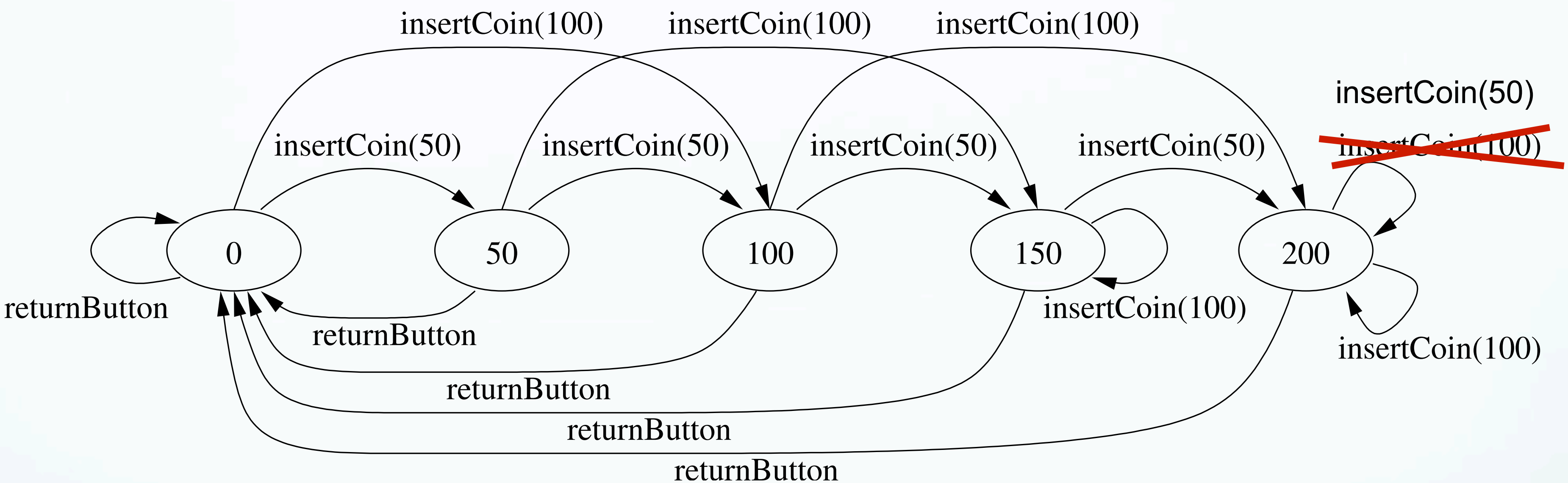
DVM – Transition-based model
Group exercise

- Come up with a **finite state machine (FSM)** that models the Controller component of the DVM
  - Start with a machine for the money operation *insertCoin* and *returnButton*
  - Assume you only have coins of 50 and 100

Groups 2-5 persons: 7-10 min

DVM - FSM model

Partial solution to FSM for the DVM money operation (*insertCoin, returnButton*)



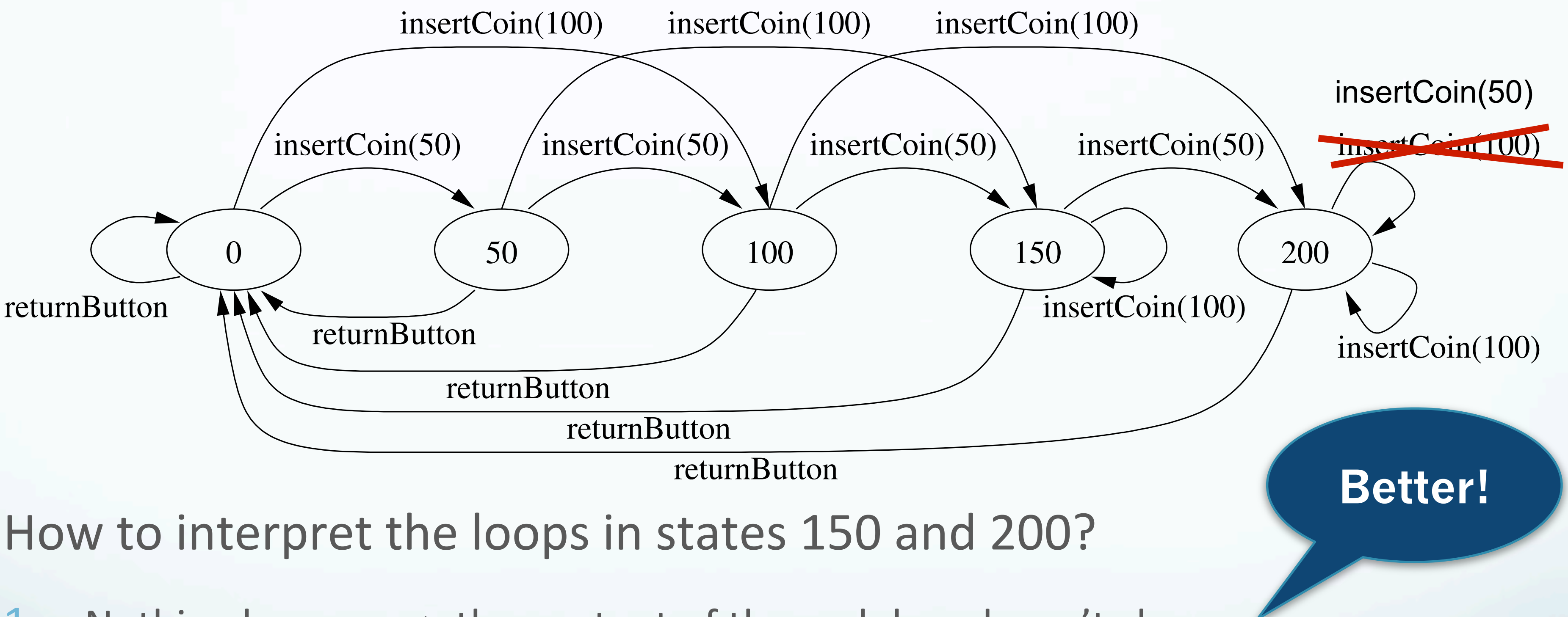
- You will need to come with **more complex transition-based notations** (UML state machine diagrams, EFSMs, etc.) for a full solution useful for **test generation**

Btw, anything wrong with the proposed solution?

- 2 transitions insertCoin(100) from state "200"
  - Correction: insertCoin(100) + insertCoin(50)

Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

DVM - FSM model
Some comments…



How to interpret the loops in states 150 and 200?

1. Nothing happens -> the content of the cash box doesn't change
2. Wrong in state 150 -> add a transition with insertCoin(100) from 150 to 200 and interpret state 200 as "containing at least 200"

- In both cases: **Underspecified what happens with the coins (change needs to be given) -> fix when full model**

Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

Pre/Post models in B… in 1 slide

- The B abstract machine notation: formal modeling notation for specifying software
  - High-level libraries of data structures
  - Code-like notation for post-conditions
- Development starts from an abstract model
  - High-level functional view
- Write a series of increasingly detailed designs: refinement
- **B** supports tools for **automatic** generation of proof obligations to prove correct refinement
- **MBT using B**: checks the model against the implementation, but via testing (does not guarantee to find all errors)!

DVM – B model

Utting & Legeard book: listing 3.1, pp.80!

Partial: models *money* only

Invariant: doesn’t change in the program

||: Multiple assignments

reject: output variable
insertCoin: name operation
coin: input variable

What follows only holds provided the **precondition** holds

Source: M. Utting and B. Legeard, *Practical Model-Based Testing*

MBT - How to do in practice?

- Next lecture on how to write an EFSM in Java
  - ModelJUnit
- In practice: future lectures
  - Extracting and selecting your tests from (E)FSM

MBT – Summary

- MBT is the automation of black-box test design
  - Test cases can be automatically generated from the model using MBT tools
- The model must be precise and concise
- Tests extracted are abstract; they must be transformed into executable tests
- Not practical to (completely) reuse a development model for MBT
- Transition-based notations: better for control-oriented systems
- Pre/post notations: preferable for data-oriented systems
- Possible to write partial models and refine
  - A very abstract model: few high-level tests covering few aspects of the system
  - A more detail model: tests covering more
- EFSM: useful for both control and data-oriented systems

The quality and number of tests that you get from MBT depend on the quality and precision of your model

References

- M. Utting and B. Legeard, *Practical Model-Based Testing*. Elsevier - Morgan Kaufmann Publishers, 2007
  - Chapters 1-3

NOTE: Look at the references to the book in the slides as many pictures have been removed for copyright reasons!