Introduction to Software Testing
(*2nd edition*)

Chapter 2

Model-Driven Test Design

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Complexity of Testing Software

- No other engineering field builds products as complicated as software

- The term correctness has no meaning
  - Is a building correct?
  - Is a car correct?
  - Is a subway system correct?

- Like other engineers, we must use abstraction to manage complexity
  - This is the purpose of the model-driven test design process
  - The "model" is an abstract structure

Software Testing Foundations (2.1)

Testing can only show the presence of failures

Not their absence

Edsger W. Dijkstra

Software Testing

- Goal of testing
  - finding faults in the software
  - demonstrating that there are no faults in the software (for the test cases that has been used during testing)
- It is not possible to *prove* that there are no faults in the software using testing
- Testing should help locate errors, not just detect their presence
  - a "yes/no" answer to the question "is the program correct?" is not very helpful
- Testing should be repeatable
  - could be difficult for distributed or concurrent software
  - effect of the environment, uninitialized variables

Testing Software is Hard

- If you are testing a bridge's ability to sustain weight, and you test it with 1000 tons you can infer that it will sustain weight $\leq$ 1000 tons

- This kind of reasoning does not work for software systems
  - software systems are not linear nor continuous

- Exhaustively testing all possible input/output combinations is too expensive
  - the number of test cases increase exponentially with the number of input/output variables

Testing & Debugging

- Testing: Evaluating software by observing its execution
- Test Failure: Execution of a test that results in a software failure.
- Debugging: The process of finding a fault given a failure.
  - Fault localization
  - Repair

Not all inputs will "trigger" a fault into causing a failure

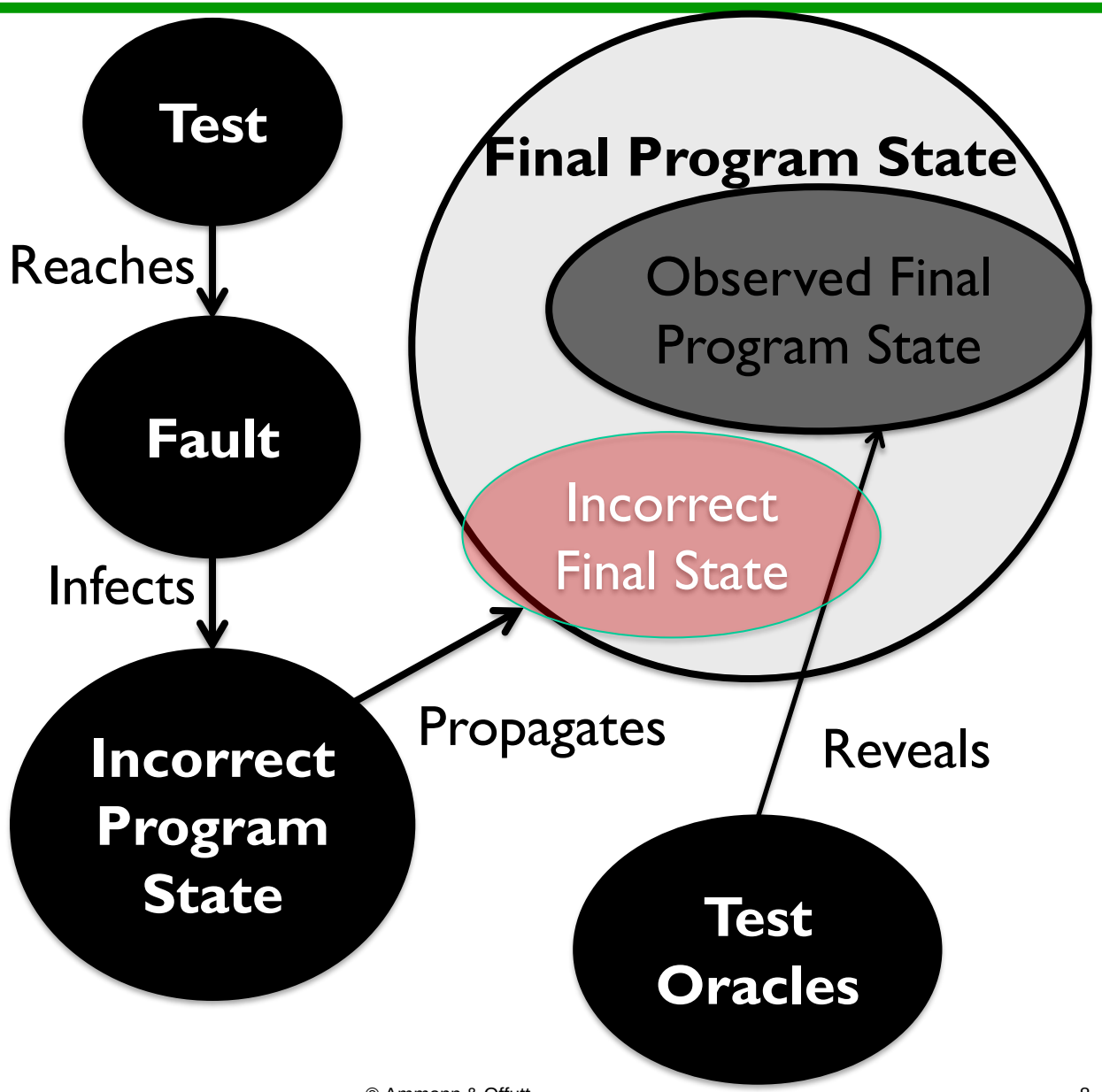
Fault & Failure Model (RIPR)

Four conditions necessary for a failure to be observed

1. **Reachability:** The location or locations in the program that contain the fault must be reached
2. **Infection:** The state of the program must be incorrect
3. **Propagation:** The infected state must cause some output or final state of the program to be incorrect
4. **Reveal:** The tester must observe part of the incorrect portion of the program state

RIPR Model

- Reachability
- Infection
- Propagation
- Revealability

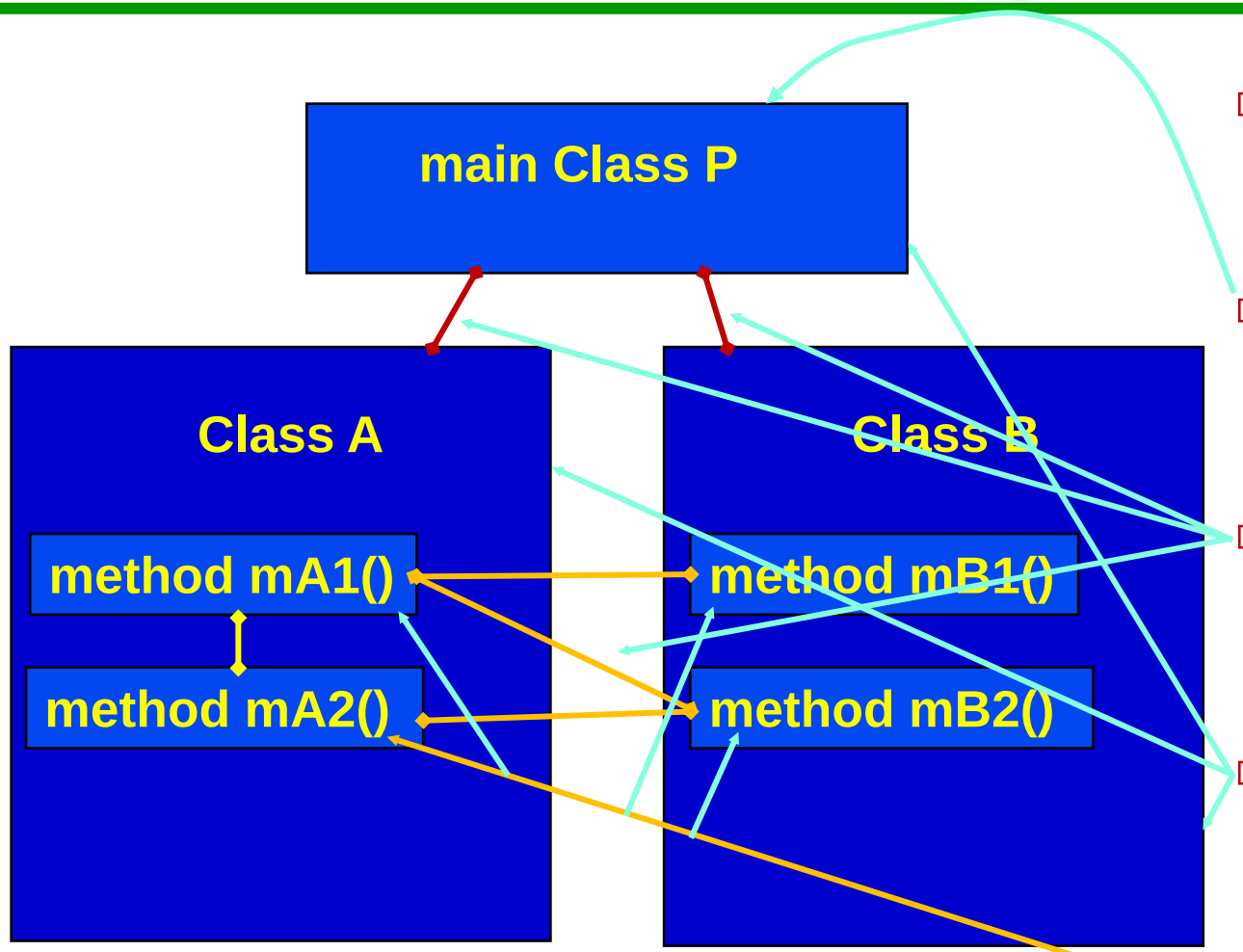


Software Testing Activities (2.2)

- **Test Engineer:** An IT professional who is in charge of one or more technical test activities
  - Designing test inputs
  - Producing test values
  - Running test scripts
  - Analyzing results
  - Reporting results to developers and managers

- **Test Manager:** In charge of one or more test engineers
  - Sets test policies and processes
  - Interacts with other managers on the project
  - Otherwise supports the engineers

Traditional Testing Levels (2.3)

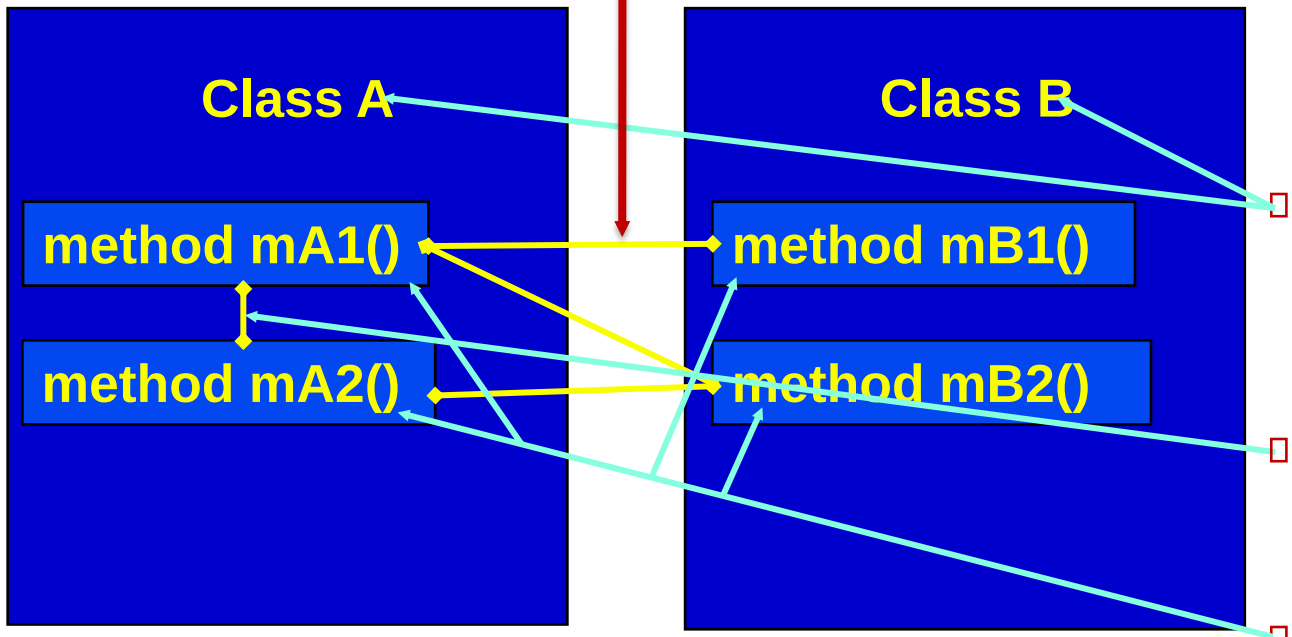


- **Acceptance testing:** Is the software acceptable to the user?
- **System testing:** Test the overall functionality of the system
- **Integration testing:** Test how modules interact with each other
- **Module testing (developer testing):** Test each class, file, module, component
- **Unit testing (developer testing):** Test each unit (method) individually

This view obscures underlying similarities

Object-Oriented Testing Levels

- **Inter-class testing:** Test multiple classes together



- **Intra-class testing:** Test an entire class as sequences of calls
- **Inter-method testing:** Test pairs of methods in the same class
- **Intra-method testing:** Test each method individually

System Testing, Acceptance Testing

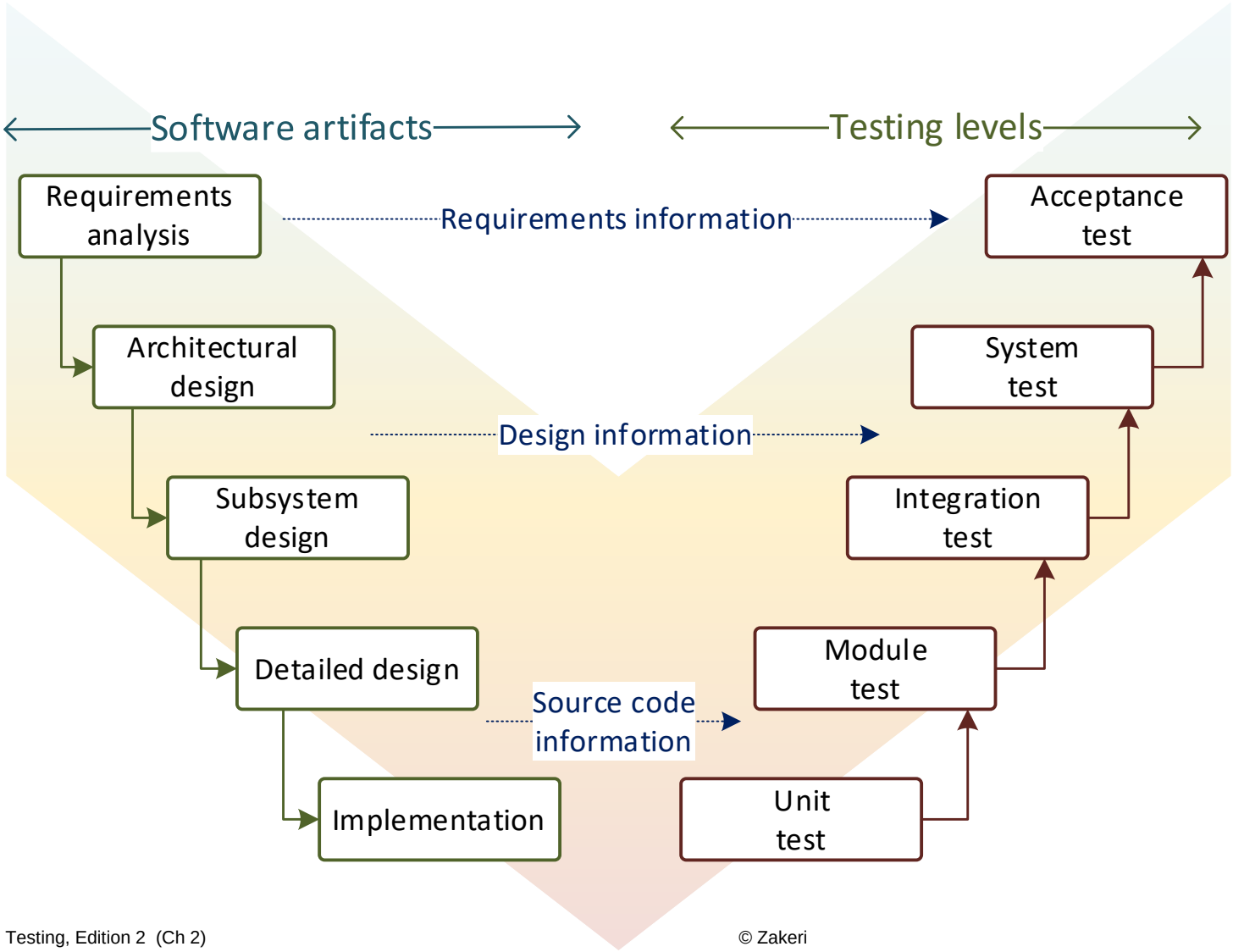
- **Alpha testing** is performed within the development organization
- **Beta testing** is performed by a select group of friendly customers
- **Stress testing**
  - push system to extreme situations and see if it fails
  - large number of data, high input rate, low input rate, etc.

Regression testing

- You should preserve all the test cases for a program
- During the maintenance phase, when a change is made to the program, the test cases that have been saved are used to do **regression testing**
  - figuring out if a change made to the program introduced any faults
- Regression testing is crucial during maintenance
  - It is a good idea to automate regression testing so that all test cases are run after each modification to the software
- When you find a bug in your program you should write a test case that exhibits the bug
  - Then using regression testing you can make sure that the old bugs do not reappear

V Model

- Testing levels and software artifacts



Test Plan

- Testing is a complicated task
  - it is a good idea to have a test plan

- A test plan should specify
  - Unit tests
  - Integration plan
  - System tests
  - Regression tests

Exhaustive Testing is Hard

```
int max(int x, int y)
{
  if (x > y)
    return x;
  else
    return x;
}
```

- Number of possible test cases (assuming 32 bit integers)
  - $2^{32} \times 2^{32} = 2^{64}$
- Do bigger test sets help?
  - Test set

    {(x=3,y=2), (x=2,y=3)}

    will detect the error
  - Test set

    {(x=3,y=2),(x=4,y=3),(x=5,y=1)}

    will not detect the error although it has more test cases
- It is not the number of test cases
- But, if $T_1 \supseteq T_2$, then T_1 will detect every fault detected by T_2

Exhaustive Testing

- Assume that the input for the `max` procedure was an integer array of size *n*
  - Number of test cases: $2^{32 \times n}$
- Assume that the size of the input array is not bounded
  - Number of test cases: ∞
- The point is, naive exhaustive testing is pretty hopeless

Coverage Criteria (2.4)

- Even small programs have too many inputs to fully test them all
  - *private static double computeAverage (int A, int B, int C)*
  - On a **32-bit machine**, each variable has over 4 billion possible values
  - Over 80 octillion possible tests!!
  - Input space might as well be infinite
- Testers search a huge input space
  - Trying to find the fewest inputs that will find the most problems
- Coverage criteria give structured, practical ways to search the input space
  - Search the input space thoroughly
  - Not much overlap in the tests

Advantages of Coverage Criteria

- Maximize the "bang for the buck"
- Provide traceability from software artifacts to tests
  - Source, requirements, design models, …
- Make regression testing easier
- Gives testers a "*stopping rule*" … when testing is finished
- Can be well supported with powerful tools

Test Requirements and Criteria

- Test Criterion: A collection of rules and a process that define test requirements
  - Cover every statement
  - Cover every functional requirement
- Test Requirements: Specific things that must be satisfied or covered during testing
  - Each statement might be a test requirement
  - Each functional requirement might be a test requirement

Testing researchers have defined dozens of criteria, but they are all really just a few criteria on four types of structures …

1. Input domains
2. Graphs
3. Logic expressions
4. Syntax descriptions

Old View: Colored Boxes

- Black-box testing: Derive tests from external descriptions of the software, including specifications, requirements, and design
- White-box testing: Derive tests from the source code internals of the software, specifically including branches, individual conditions, and statements
- Model-based testing: Derive tests from a model of the software (such as a UML diagram)

MDTD makes these distinctions less important.

The more general question is:

from what abstraction level do we derive tests?

Types of Testing

- Functional (**Black box**) vs. Structural (**White box**) testing
  - **Functional testing:** Generating test cases based on the functionality of the software
  - **Structural testing:** Generating test cases based on the structure of the program
  - **Black box** testing and white box testing are synonyms for functional and structural testing, respectively.
    - In black box testing the internal structure of the program is hidden from the testing process
    - In white box testing internal structure of the program is taken into account
- Module vs. Integration testing
  - Module testing: Testing the modules of a program in isolation
  - Integration testing: Testing an integrated set of modules

Functional Testing, Black-Box Testing

- Functional testing:
  - identify the functions which software is expected to perform
  - create test data which will check whether these functions are performed by the software
  - no consideration is given how the program performs these functions, program is treated as a black-box: **black-box testing**
  - need an **oracle**: oracle states precisely what the outcome of a program execution will be for a particular test case. This may not always be possible, oracle may give a range of plausible values
- A systematic approach to functional testing: **requirements based testing**
  - driving test cases automatically from a formal specification of the functional requirements

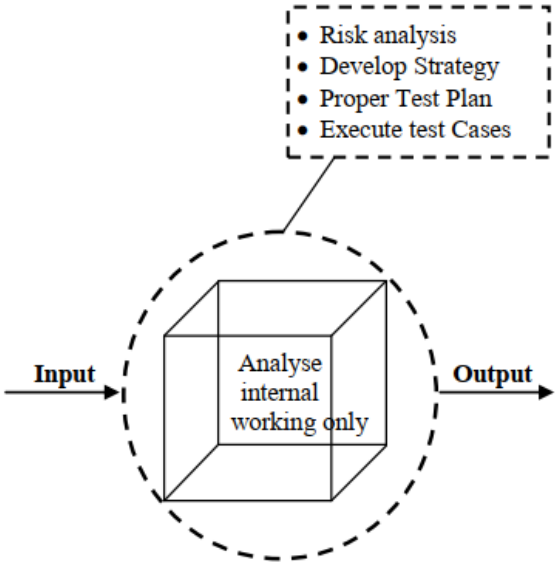
Structural Testing, White-Box Testing

- Structural Testing
  - The test data is derived from the structure of the software
  - **White-box testing**: the internal structure of the software is taken into account to derive the test cases

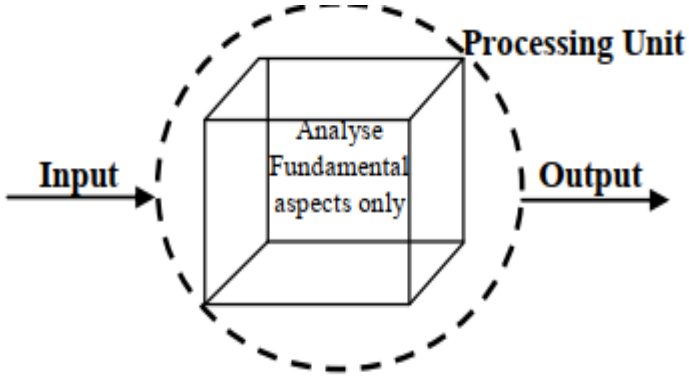
- One of the basic questions in testing:
  - When should we stop adding new test cases to our test set?
  - **Coverage metrics** (**test adequacy criteria**) are used to address this question.

White box, Black box, Gray box

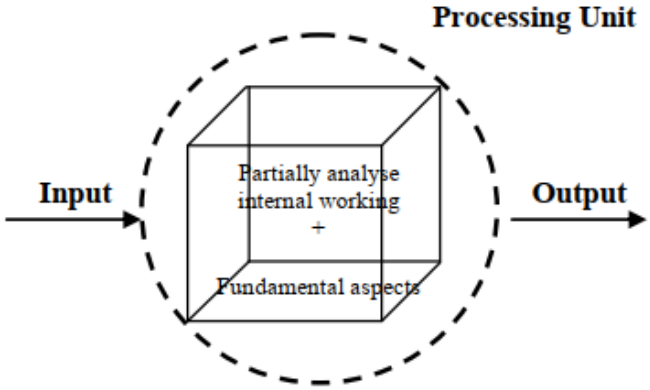
- Representations of **testing color-boxes**



white-box



black-box



grey-box

Khan, M. E., & Khan, F. (2012). **A comparative study of white box , black box and grey box testing techniques**. *International Journal of Advanced Computer Science and Applications*, *3*(6), 12–15. https://doi.org/10.1017/CBO9781107415324.004

Comparison

- Comparison between three forms of testing techniques

S. No.	Black Box Testing	Grey Box Testing	White Box Testing
1.	Analyses fundamental aspects only i.e. no proved edge of internal working	Partial knowledge of internal working	Full knowledge of internal working
2.	Granularity is low	Granularity is medium	Granularity is high
3.	Performed by end users and also by tester and developers (user acceptance testing)	Performed by end users and also by tester and developers (user acceptance testing)	It is performed by developers and testers
4.	Testing is based on external exceptions – internal behaviour of the program is ignored	Test design is based on high level database diagrams, data flow diagrams, internal states, knowledge of algorithm and architecture	Internal are fully known
5.	It is least exhaustive and time consuming	It is somewhere in between	Potentially most exhaustive and time consuming
6.	It can test only by trial and error method	Data domains and internal boundaries can be tested and over flow, if known	Test better: data domains and internal boundaries
7.	Not suited for algorithm testing	Not suited for algorithm testing	It is suited for algorithm testing (suited for all)

Model-Driven Test Design (2.5)

- *Test Design* is the process of designing input values that will effectively test software

- Test design is one of several activities for testing software
  - Most mathematical
  - Most technically challenging

Types of Test Activities

- Testing can be broken up into four general types of activities
  1. **Test Design** → **1.a) Criteria-based** / **1.b) Human-based**
  2. **Test Automation**
  3. **Test Execution**
  4. **Test Evaluation**
- Each type of activity requires different skills, background knowledge, education and training
- No reasonable software development organization uses the same people for requirements, design, implementation, integration and configuration control.

Why do test organizations still use the same people for all four test activities??

This clearly wastes resources

1. Test Design—(a) Criteria-Based

Design test values to satisfy coverage criteria or other engineering goal

- This is the most technical job in software testing
- Requires knowledge of :
  - Discrete math
  - Programming
  - Testing
- Requires much of a traditional CS degree
- This is intellectually stimulating, rewarding, and challenging
- Test design is analogous to software architecture on the development side
- Using people who are not qualified to design tests is a sure way to get ineffective tests

1. Test Design—(b) Human-Based

Design test values based on domain knowledge of the program and human knowledge of testing

- This is much harder than it may seem to developers
- Criteria-based approaches can be blind to special situations
- Requires knowledge of :
  - Domain, testing, and user interfaces
- Requires almost no traditional CS
  - A background in the domain of the software is essential
  - An empirical background is very helpful (biology, psychology, …)
  - A logic background is very helpful (law, philosophy, math, …)
- This is intellectually stimulating, rewarding, and challenging
  - But not to typical CS majors – they want to solve problems and build things

2. Test Automation

Embed test values into executable scripts

- This is slightly less technical
- Requires knowledge of programming
- Requires very little theory
- Often requires solutions to difficult problems related to observability and controllability
- Can be boring for test designers
- Programming is out of reach for many domain experts
- Who is responsible for determining and embedding the expected outputs ?
  - Test designers may not always know the expected outputs
  - Test evaluators need to get involved early to help with this

3. Test Execution

Run tests on the software and record the results

- This is easy – and trivial if the tests are well automated
- Requires basic computer skills
  - Interns
  - Employees with no technical background
- Asking qualified test designers to execute tests is a sure way to convince them to look for a development job
- If, for example, GUI tests are not well automated, this requires a lot of manual labor
- Test executors have to be very careful and meticulous with bookkeeping

4. Test Evaluation

Evaluate results of testing, report to developers

- This is much harder than it may seem
- Requires knowledge of :
  - Domain
  - Testing
  - User interfaces and psychology
- Usually requires almost no traditional CS
  - A background in the domain of the software is essential
  - An empirical background is very helpful (biology, psychology, …)
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Other Activities

- **Test management:** Sets policy, organizes team, interfaces with development, chooses criteria, decides how much automation is needed, …
- **Test maintenance:** Save tests for reuse as software evolves
  - Requires cooperation of test designers and automators
  - Deciding when to trim the test suite is partly policy and partly technical – and in general, very hard!
  - Tests should be put in configuration control
- **Test documentation:** All parties participate
  - Each test must document "why" – criterion and test requirement satisfied or a rationale for human-designed tests
  - Ensure traceability throughout the process
  - Keep documentation in the automated tests

Organizing the Team

- A mature test organization needs only one test designer to work with several test automators, executors and evaluators
- Improved automation will reduce the number of test executors
  - Theoretically to zero … but not in practice
- Putting the wrong people on the wrong tasks leads to inefficiency, low job satisfaction and low job performance
  - A qualified test designer will be bored with other tasks and look for a job in development
  - A qualified test evaluator will not understand the benefits of test criteria
- Test evaluators have the domain knowledge, so they must be free to add tests that "blind" engineering processes will not think of
- The four test activities are quite different

Many test teams use the same people for ALL FOUR activities !!

Applying Test Activities

To use our people effectively

and to test efficiently

we need a process that

lets test designers

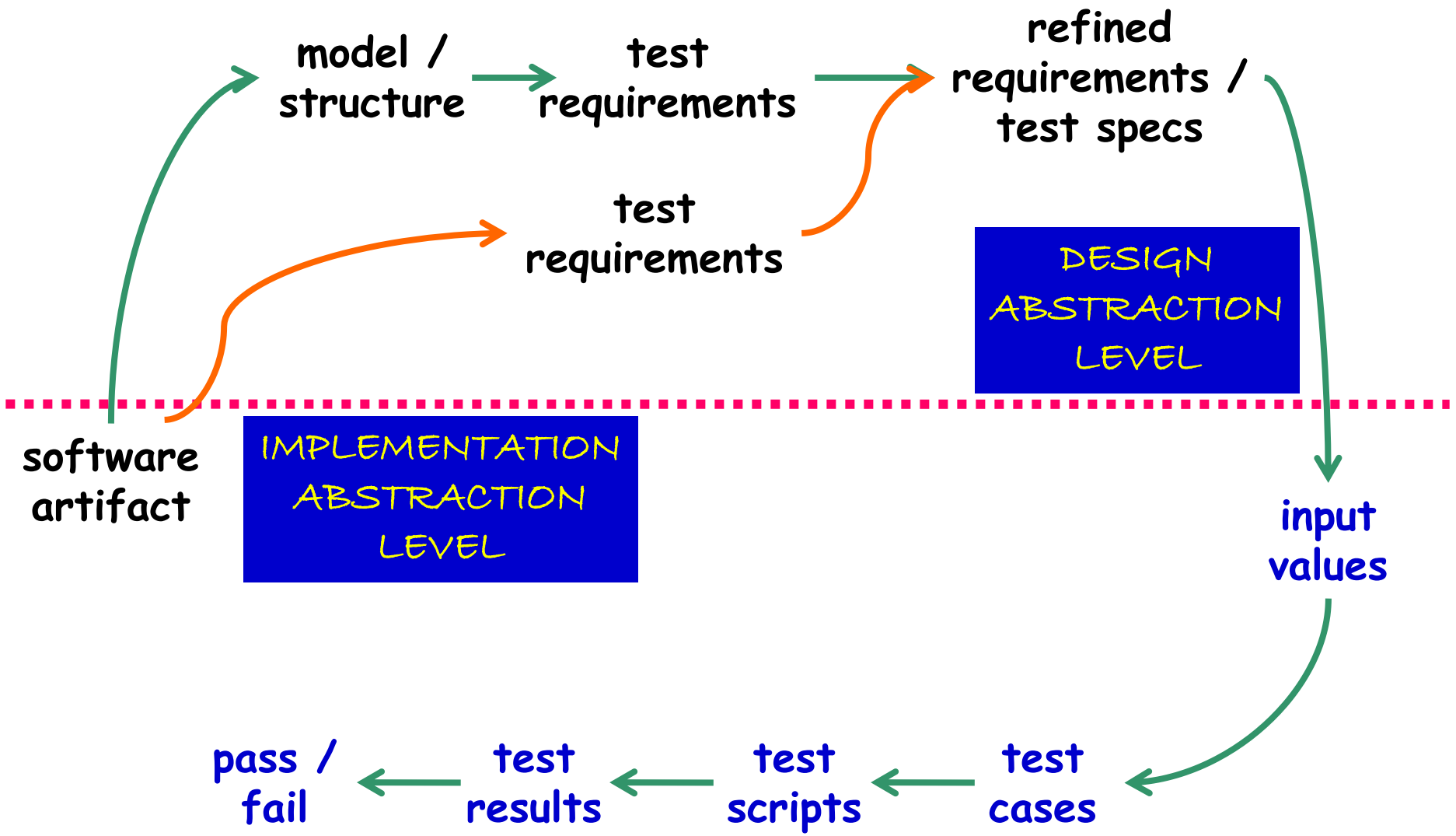
raise their level of abstraction

Using MDTD in Practice

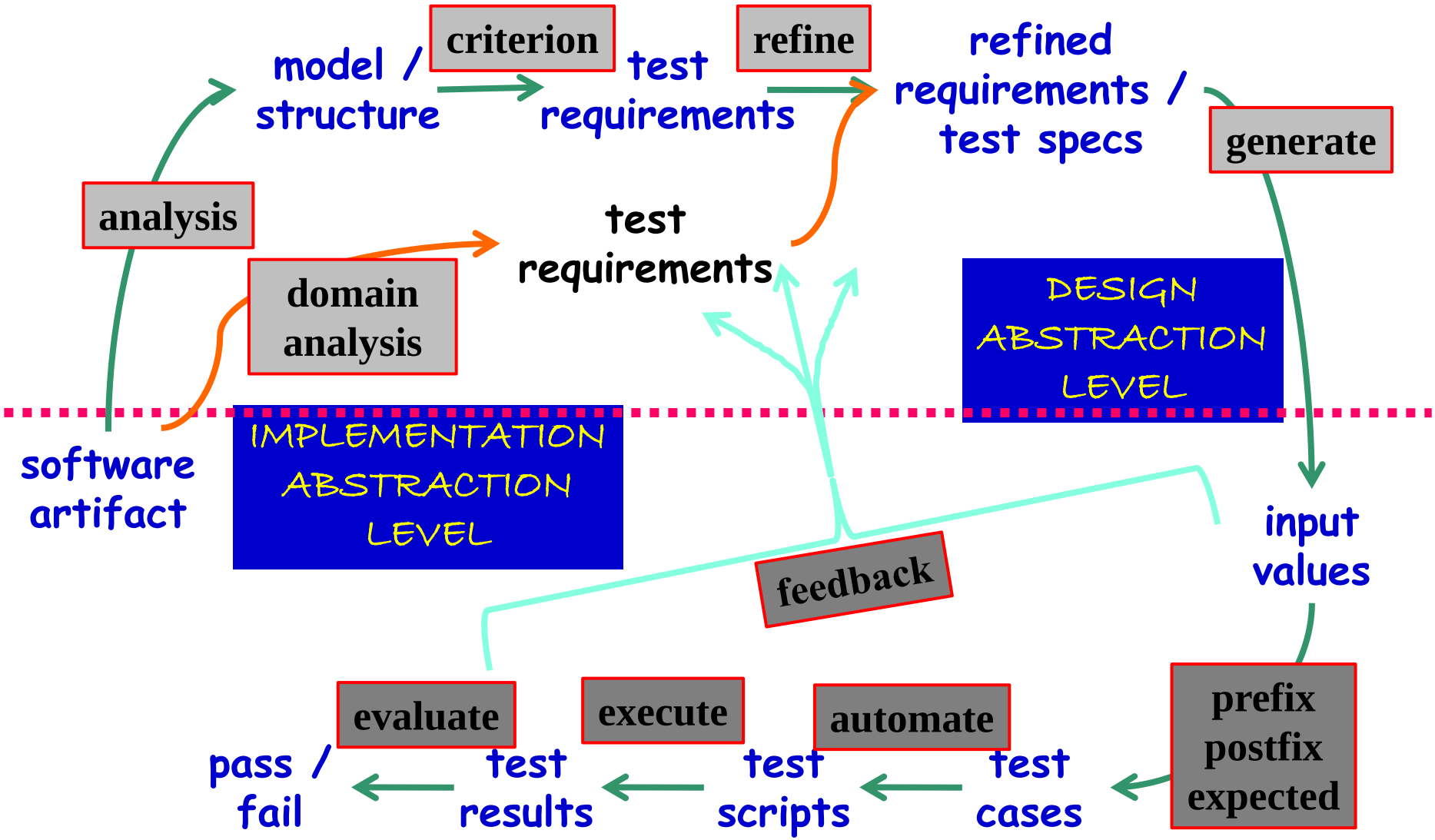
- This approach lets one test designer do the math
- Then traditional testers and programmers can do their parts
  - Find values
  - Automate the tests
  - Run the tests
  - Evaluate the tests
- Just like in traditional engineering … an engineer constructs models with calculus, then gives direction to carpenters, electricians, technicians, …

Test designers become technical experts

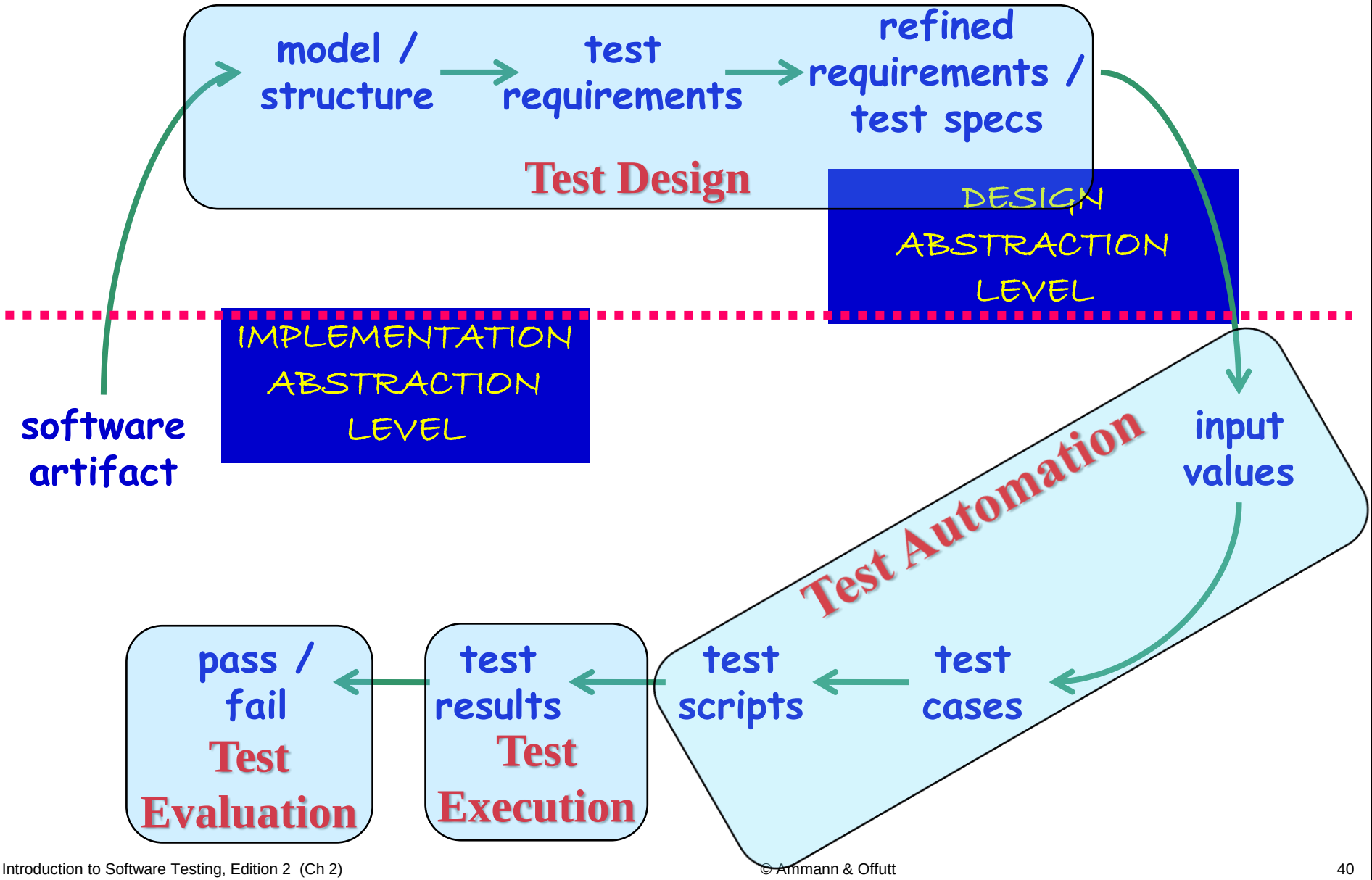
Model-Driven Test Design



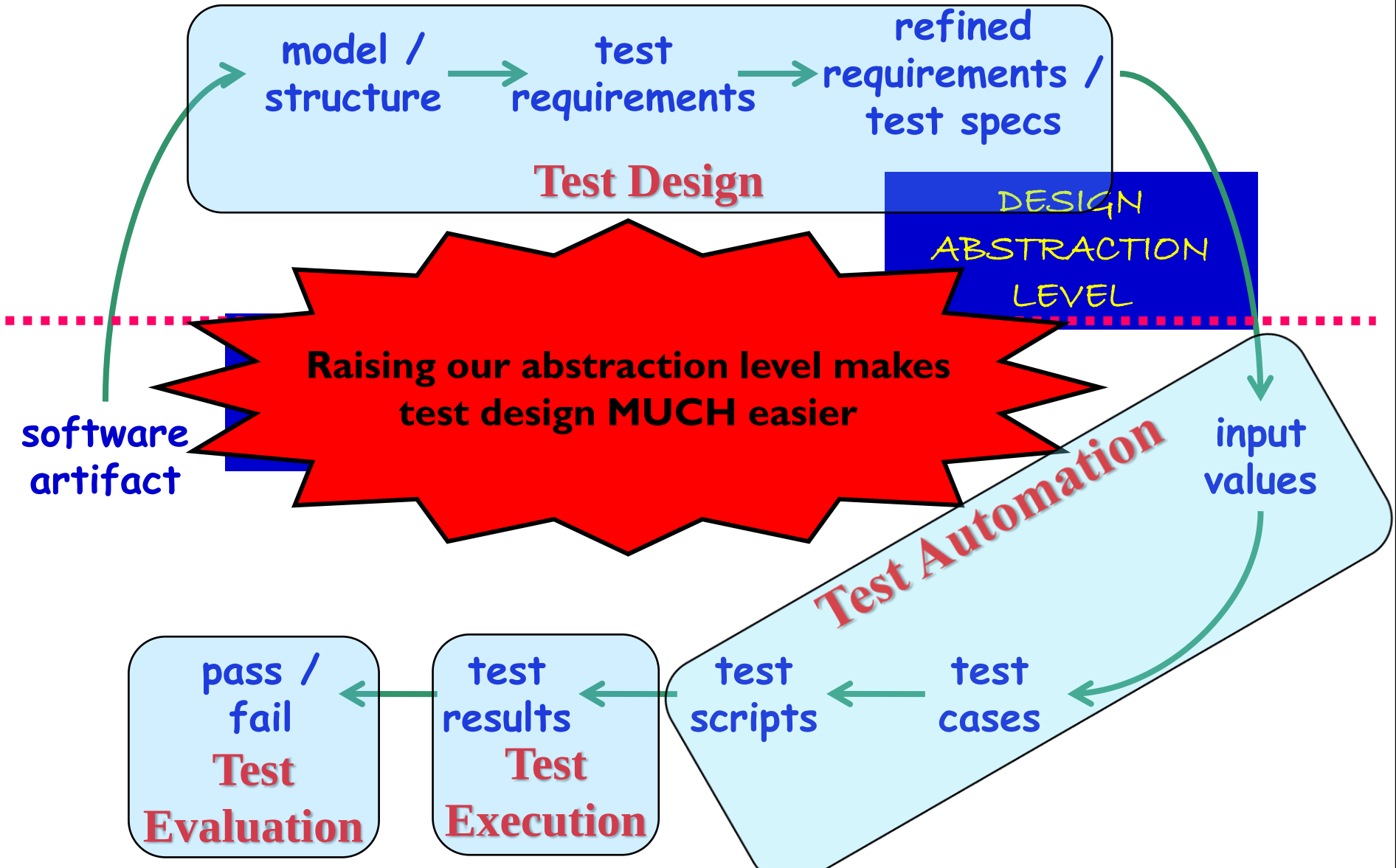
Model-Driven Test Design – Steps



Model-Driven Test Design–Activities



Model-Driven Test Design–Activities

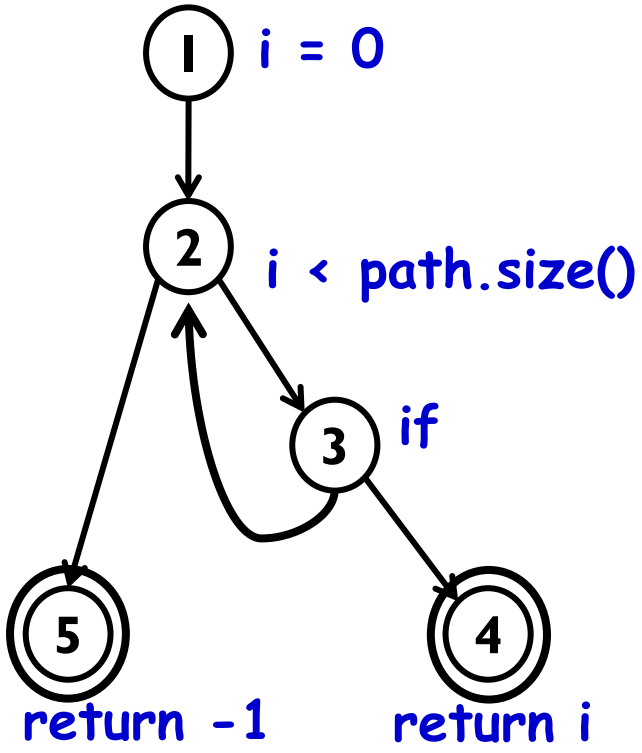


Small Illustrative Example

Software Artifact : Java Method

```
/**
    * Return index of node n at the
    * first position it appears,
    * -1 if it is not present
*/
public int indexOf (Node n)
{
    for (int i=0; i < path.size(); i++)
        if (path.get(i).equals(n))
            return i;
    return -1;
}
```

Control Flow Graph

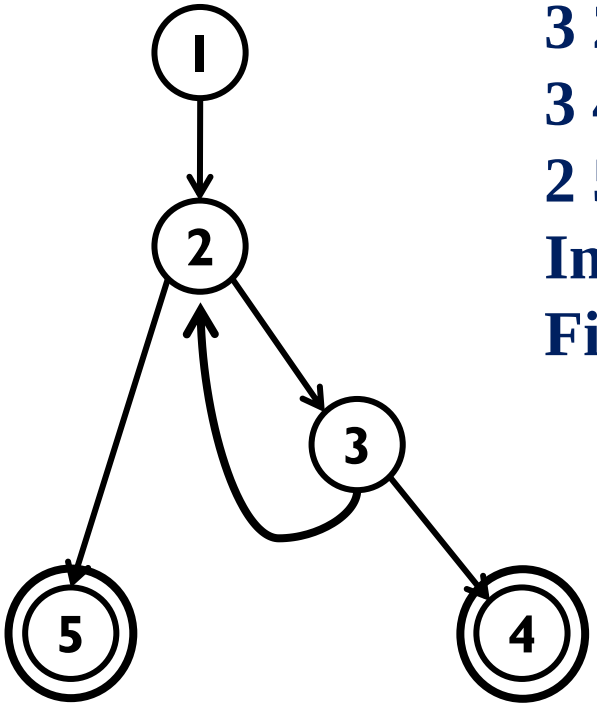


Small Illustrative Example (Cont.)

Support tool for graph coverage

http://www.cs.gmu.edu/~offutt/softwaretest/

Graph
Abstract version



Edges
1 2
2 3
3 2
3 4
2 5
Initial Node: 1
Final Nodes: 4, 5

6 requirements for Edge-Pair Coverage
1. [1, 2, 3]
2. [1, 2, 5]
3. [2, 3, 4]
4. [2, 3, 2]
5. [3, 2, 3]
6. [3, 2, 5]

Test Paths
[1, 2, 5]
[1, 2, 3, 2, 5]
[1, 2, 3, 2, 3, 4]

Find values ...

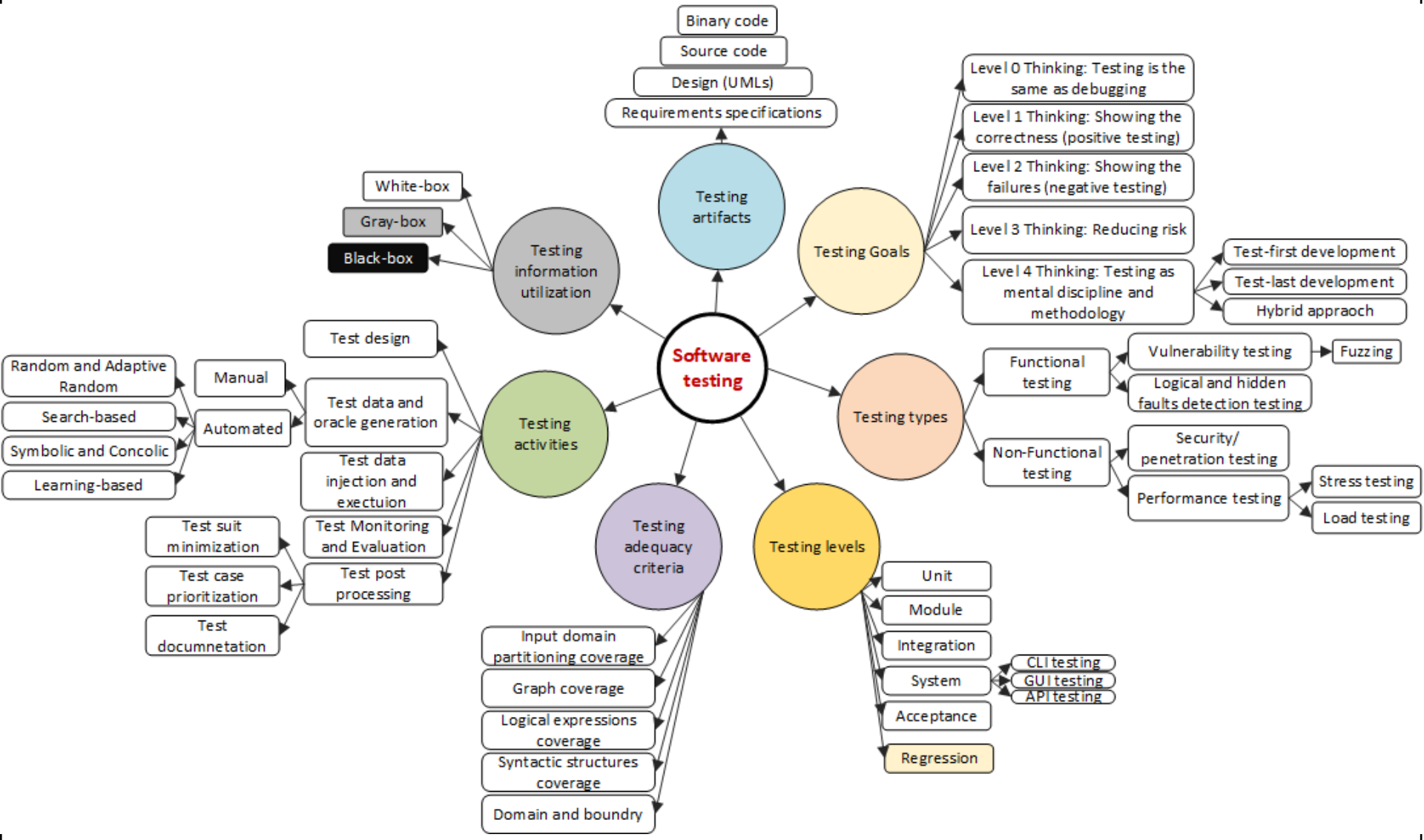
Types of Activities in the Course

Most of this course is about test design

Other activities are well covered elsewhere

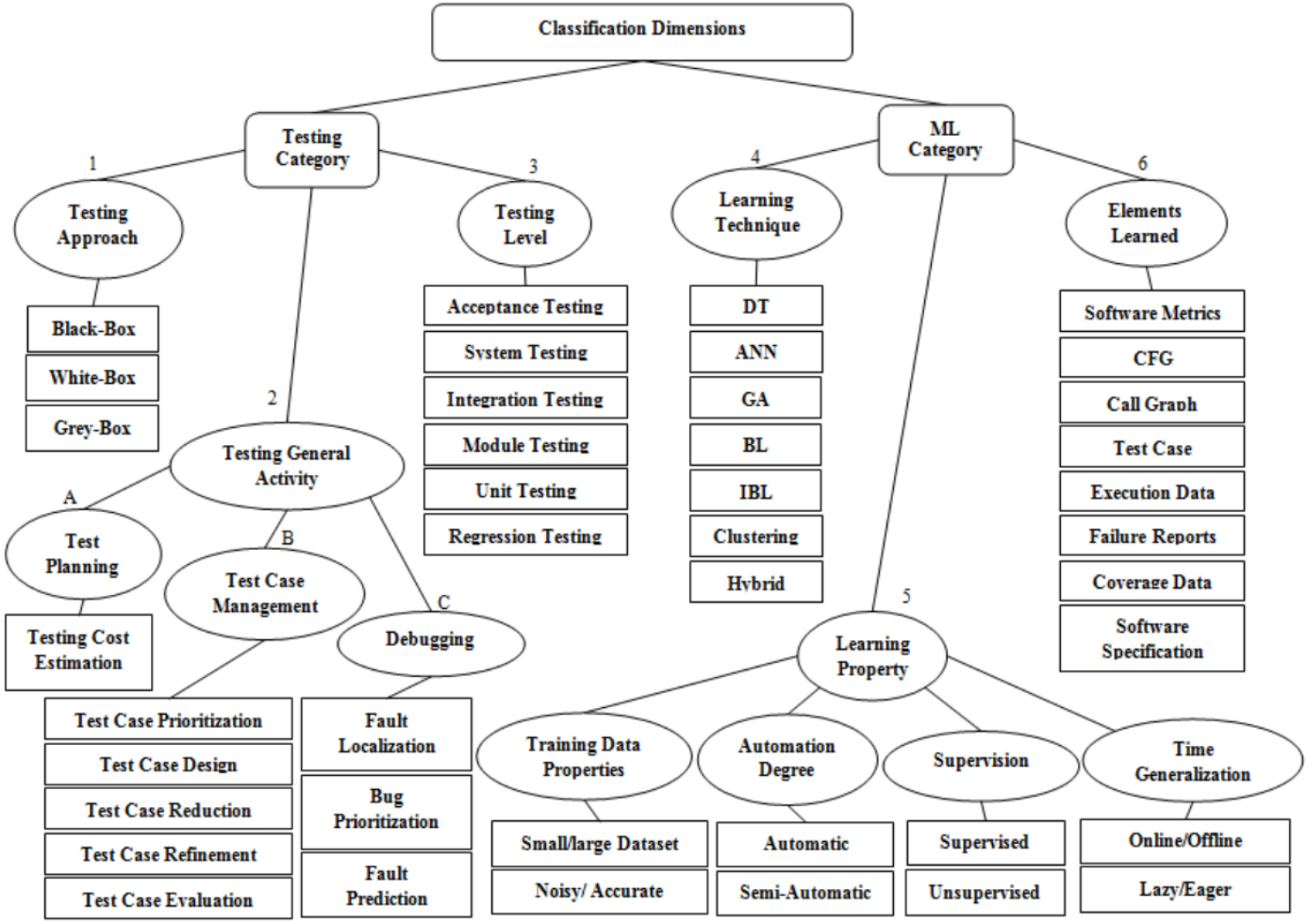
Software Testing Taxonomy and Classification

- My proposed classification for software testing (version 1.0)



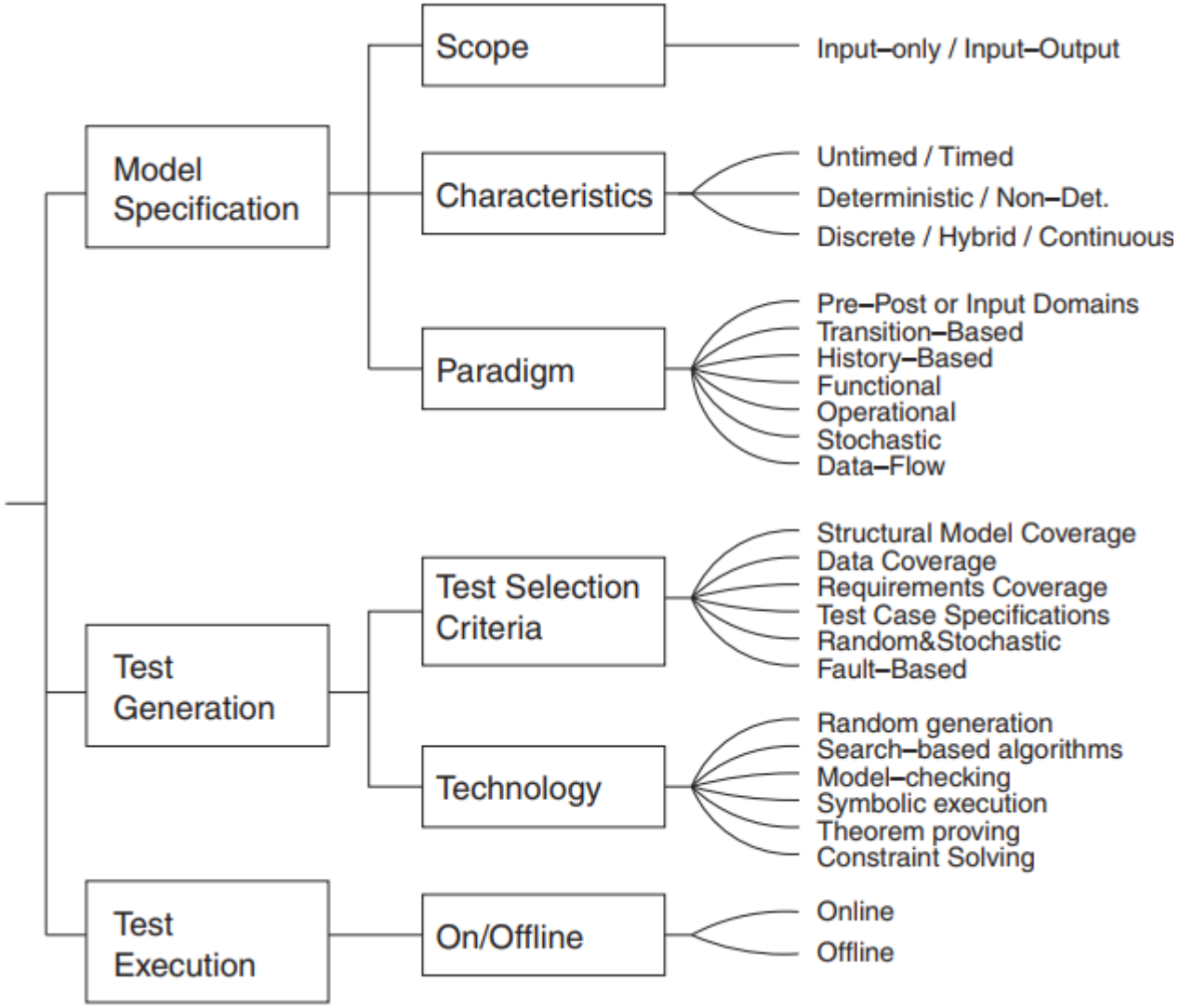
Classification summary

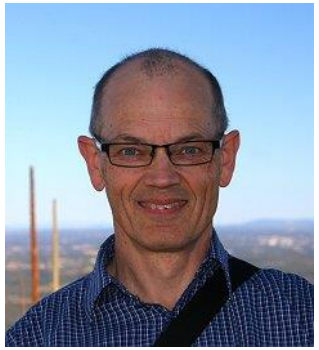
- Noorian, M. a, Bagheri, E. a B., & Du, W. a. (2011). **Machine learning-based software testing: towards a classification framework**. SEKE 2011 - Proceedings of the 23rd International Conference on Software Engineering and Knowledge Engineering, 225–229.



A taxonomy of model-based testing

- Utting, M., Pretschner, A. and Legeard, B. (2012), **A taxonomy of model-based testing approaches.** Softw. Test. Verif. Reliab., 22: 297-312. https://doi.org/10.1002/stvr.456





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