Introduction to Software Testing
Chapter 1
Introduction

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A Talk in 3 Parts

1. **Why** do we test ?
2. **What** should we do during testing ?
3. **How** do we get to this future of testing ?

We are in the middle of a revolution in how software is tested

Research is *finally* meeting practice

Here! Test This!

My first “professional” job

A stack of computer printouts—and no documentation

Cost of Testing

You're going to spend at least half of your development budget on testing, whether you want to or not

- **In the real-world, testing is the principle post-design activity**
- **Restricting early testing usually increases cost**
- **Extensive hardware-software integration requires more testing**

Part 1 : Why Test?

If you don't know why you're conducting a test, it won't be very helpful

- **Written test objectives and requirements are rare**
- **What are your planned coverage levels?**
- **How much testing is enough?**
- **Common objective – spend the budget …**

Why Test?

If you don't start planning for each test when the functional requirements are formed, you'll never know why you're conducting the test

- **1980: "The software shall be easily maintainable"**
- **Threshold reliability requirements?**
- **What fact is each test trying to verify?**
- **Requirements definition teams should include testers!**

Cost of Not Testing

Program Managers often say:
"Testing is too expensive."

- **Not testing is even more expensive**
- **Planning for testing after development is prohibitively expensive**
- **A test station for circuit boards costs half a million dollars …**
- **Software test tools cost less than $10,000 !!!**

Caveat: Impact of New Tools and Techniques

"Knowing is not enough, we must apply. Willing is not enough, **we must do**." Goethe

Part 2 : What ?

But … what should we do ?

1. **Types of test activities**
2. **Software testing terms**
3. **Changing notions of testing**
   - **test coverage criteria**
   - **criteria based on structures**

Testing in the 21st Century

- We are going through a **time of change**
- Software Defines **Behavior**
  - network routers
  - financial networks
  - telephone switching networks
  - other infrastructure

Testing ideas have matured enough to be used in practice

- **Embedded Control** Applications
  - airplanes, air traffic control
  - spaceships
  - watches
  - ovens
  - remote controllers
  - PDAs
  - memory seats
  - DVD players
  - garage door openers
  - cell phones
- **Safety** critical, **real-time** software
- **Web apps** must be highly reliable
- And of course … **security** is now all about software faults !

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 is clearly a waste of 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**
  - Fairly straightforward programming – small pieces and simple algorithms
- Requires very **little theory**
- Very **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, …)
  - 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

Other Activities

- **Test management : Sets policy, organizes team, interfaces with development, chooses criteria, decides how much automation is needed, …**
- **Test maintenance : Tests must be saved 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**
  - **Traceability throughout the process must be ensured**
  - **Documentation must be kept in the automated tests**

Approximate Number of Personnel

- A mature test organization 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

Types of Test Activities – Summary

1a.	Design	Design test values to satisfy engineering goals
	Criteria	Requires knowledge of discrete math, programming and testing
1b.	Design	Design test values from domain knowledge and intuition
	Human	Requires knowledge of domain, UI, testing
2.	Automation	Embed test values into executable scripts
		Requires knowledge of scripting
3.	Execution	Run tests on the software and record the results
		Requires very little knowledge
4.	Evaluation	Evaluate results of testing, report to developers
		Requires domain knowledge

- **These four general test activities are quite different**
- **It is a poor use of resources to use people inappropriately**

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

Applying Test Activities

To use our people effectively

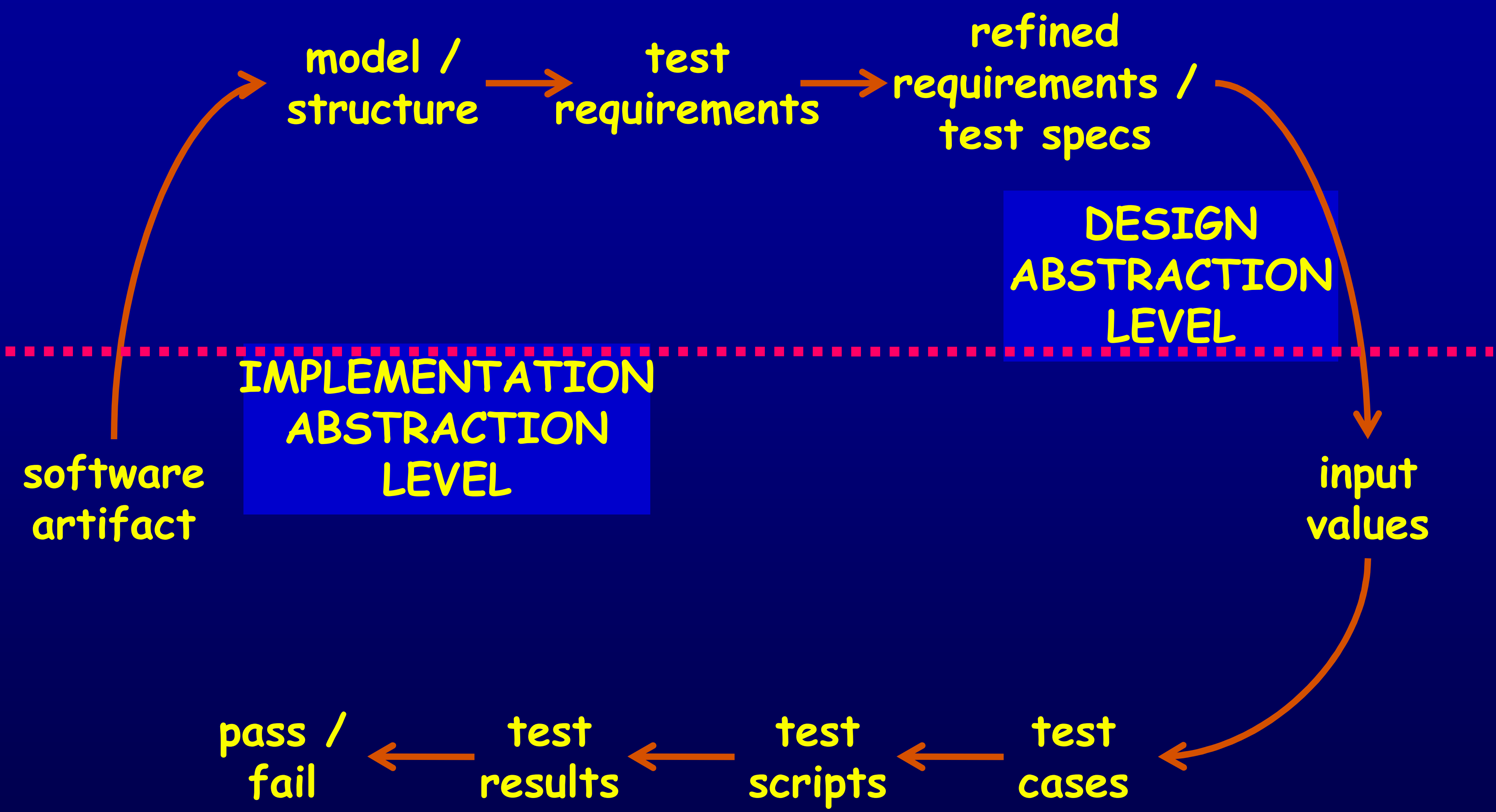
and to test efficiently

we need a process that

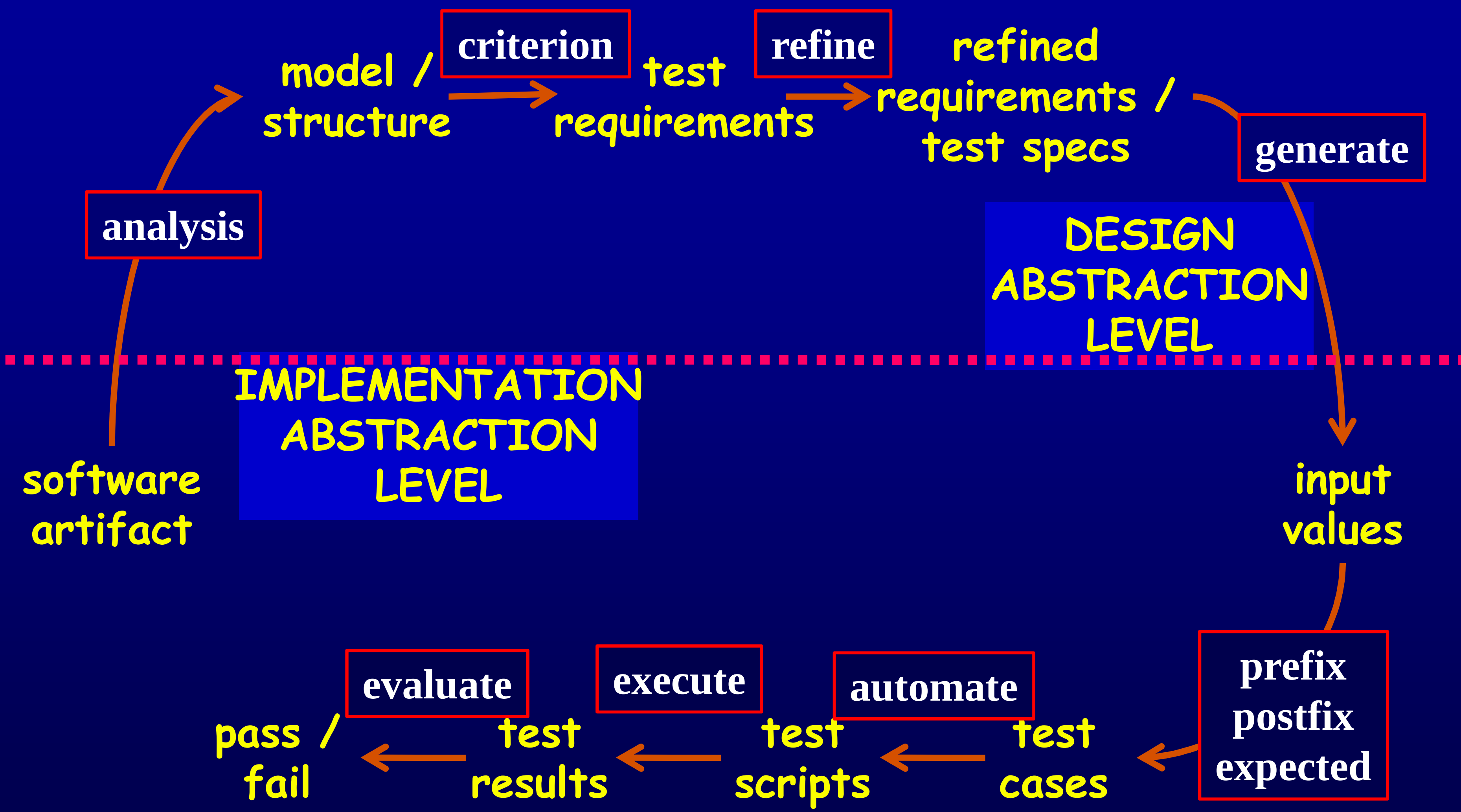
lets test designers

raise their level of abstraction

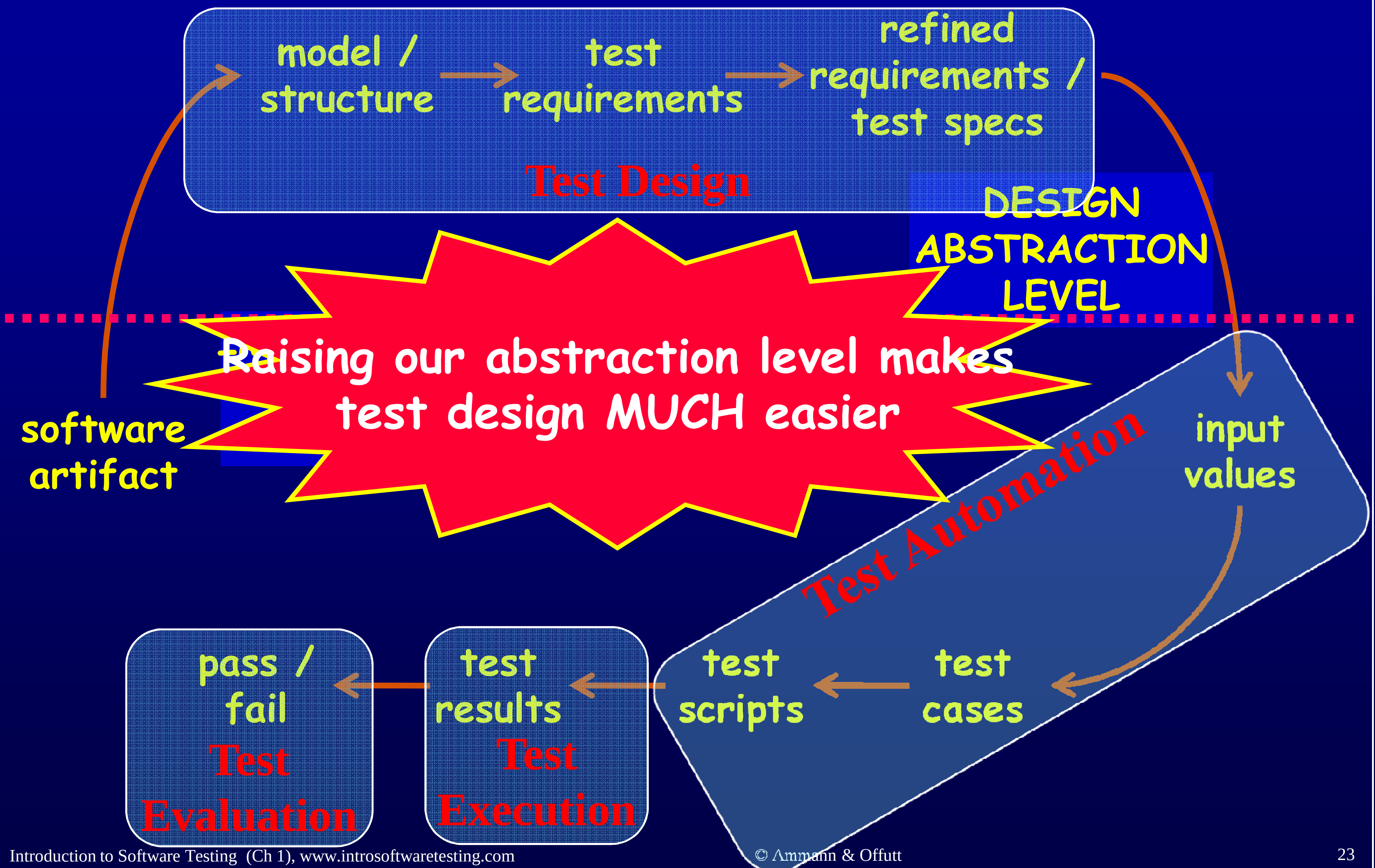
Model-Driven Test Design



Model-Driven Test Design – Steps



Model-Driven Test Design – Activities



Types of Activities in the Book

Most of this book is on test design

Other activities are well covered elsewhere

Software Testing Terms

- Like any field, software testing comes with a large number of **specialized terms** that have particular meanings in this context

- Some of the following terms are **standardized**, some are used **consistently** throughout the literature and the industry, but some **vary** by author, topic, or test organization

- The definitions here are intended to be the **most commonly** used

Important Terms
Validation & Verification (*IEEE*)

- **Validation : The process of evaluating software at the end of software development to ensure compliance with intended usage**

- **Verification : The process of determining whether the products of a given phase of the software development process fulfill the requirements established during the previous phase**

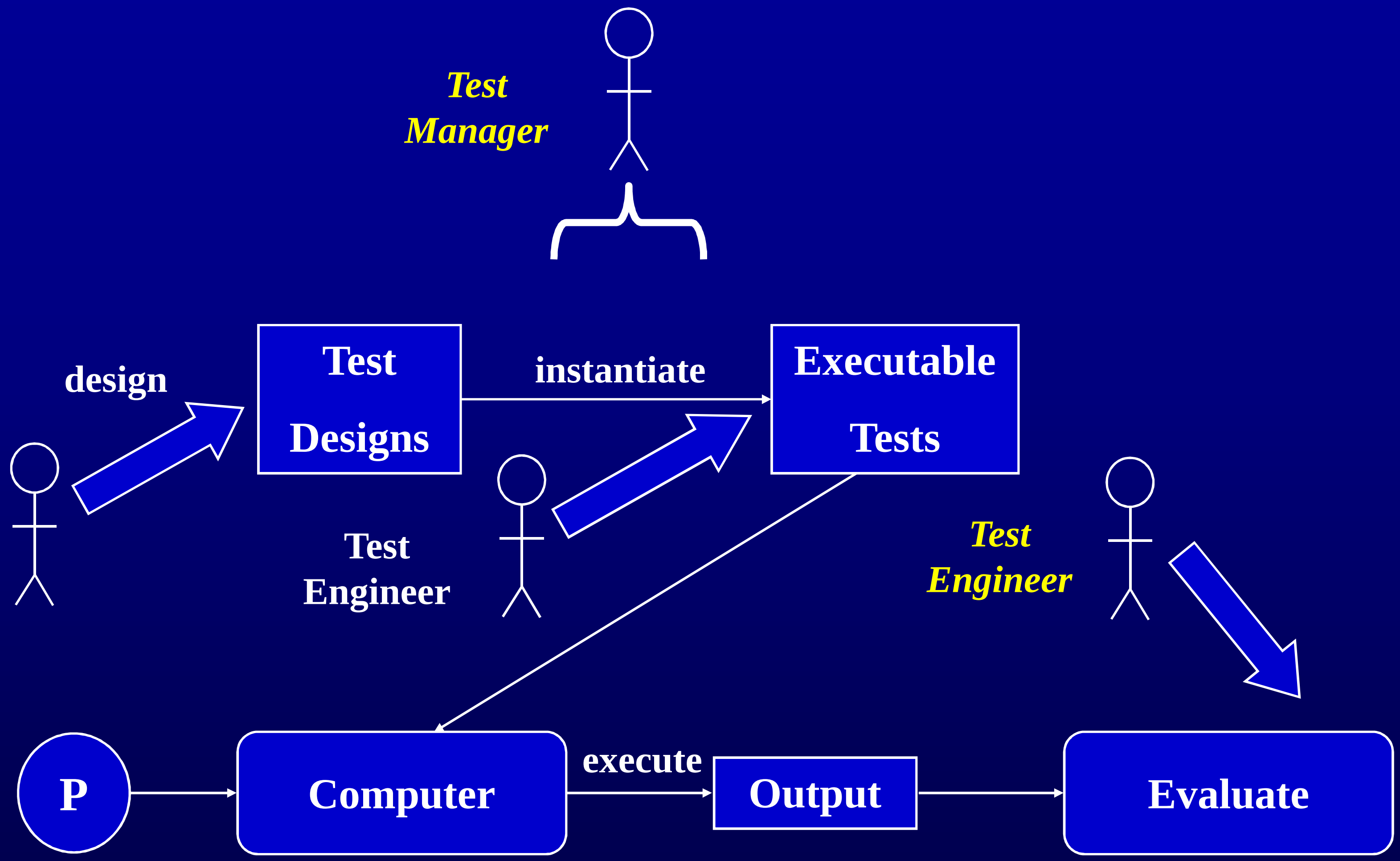
IV&V stands for "*independent verification and validation*"

Test Engineer & Test Managers

- **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 helps the engineers do their work

Test Engineer Activities



Static and Dynamic Testing

- **Static Testing : Testing without executing the program**
  - This include software inspections and some forms of analyses
  - Very effective at finding certain kinds of problems – especially "potential" faults, that is, problems that could lead to faults when the program is modified

- **Dynamic Testing : Testing by executing the program with real inputs**

Software Faults, Errors & Failures

- **Software Fault : A static defect in the software**
- **Software Error : An incorrect internal state that is the manifestation of some fault**
- **Software Failure : External, incorrect behavior with respect to the requirements or other description of the expected behavior**

Faults in software are design mistakes and will always exist

Testing & Debugging

- **Testing : Finding inputs that cause the software to fail**
- **Debugging : The process of finding a fault given a failure**

Fault & Failure Model

Three 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 propagate to cause some output of the program to be incorrect**

Test Case

- **Test Case Values : The values that directly satisfy one test requirement**
- **Expected Results : The result that will be produced when executing the test if the program satisfies it intended behavior**

Observability and Controllability

- **Software Observability : How easy it is to observe the behavior of a program in terms of its outputs, effects on the environment and other hardware and software components**
  - Software that affects hardware devices, databases, or remote files have low observability

- **Software Controllability : How easy it is to provide a program with the needed inputs, in terms of values, operations, and behaviors**
  - Easy to control software with inputs from keyboards
  - Inputs from hardware sensors or distributed software is harder
  - Data abstraction reduces controllability and observability

Inputs to Affect Controllability and Observability

- **Prefix Values : Any inputs necessary to put the software into the appropriate state to receive the test case values**

- **Postfix Values : Any inputs that need to be sent to the software after the test case values**

- **Two types of postfix values**
  1. **Verification Values : Values necessary to see the results of the test case values**
  2. **Exit Commands : Values needed to terminate the program or otherwise return it to a stable state**

- **Executable Test Script : A test case that is prepared in a form to be executed automatically on the test software and produce a report**

Top-Down and Bottom-Up Testing

- **Top-Down Testing : Test the main procedure, then go down through procedures it calls, and so on**

- **Bottom-Up Testing : Test the leaves in the tree (procedures that make no calls), and move up to the root.**
  - **Each procedure is not tested until all of its children have been tested**

White-box and Black-box Testing

- **Black-box testing : Deriving tests from external descriptions of the software, including specifications, requirements, and design**

- **White-box testing : Deriving tests from the source code internals of the software, specifically including branches, individual conditions, and statements**

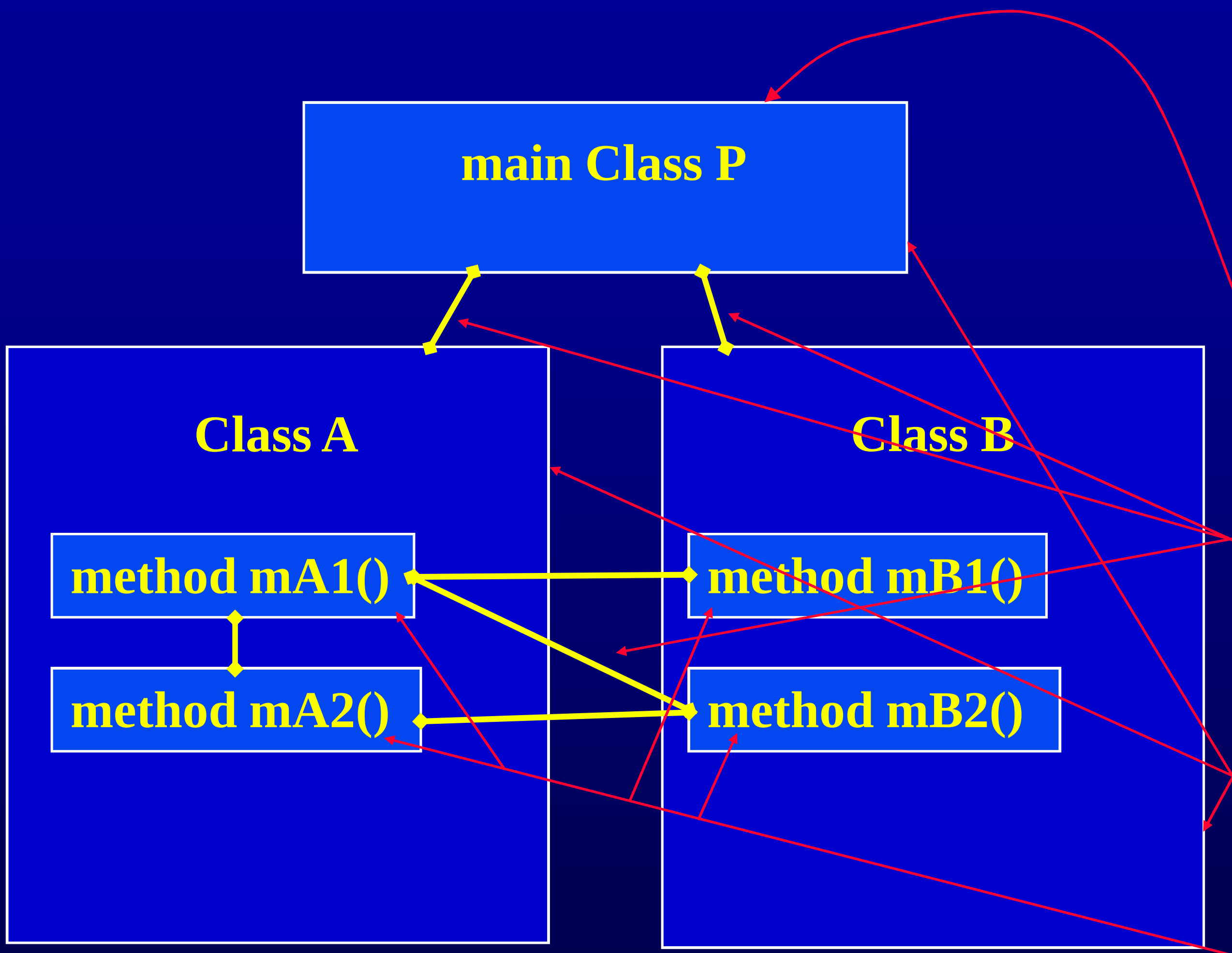
This view is really out of date.

The more general question is: *from what level of abstraction to we derive tests*?

Changing Notions of Testing

- Old view of testing is of testing at specific software development **phases**
  - Unit, module, integration, system …
- New view is in terms of **structures** and **criteria**
  - Graphs, logical expressions, syntax, input space

Old : Testing at Different Levels



- **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: Test each class, file, module or component**
- **Unit testing: Test each unit (method) individually**

Old : Find a Graph and Cover It

- **Tailored to:**
  - **a particular software artifact**
    - **code, design, specifications**
  - **a particular phase of the lifecycle**
    - **requirements, specification, design, implementation**
- **This viewpoint obscures underlying similarities**
- **Graphs do not characterize all testing techniques well**
- **Four abstract models suffice …**

New : Test Coverage Criteria

A tester's job is simple : Define a model of the software, then find ways to cover it

- **Test Requirements : Specific things that must be satisfied or covered during testing**

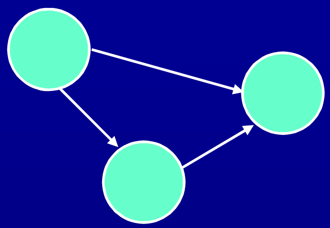
- **Test Criterion : A collection of rules and a process that define test requirements**

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

New : Criteria Based on Structures

Structures : Four ways to model software

1. **Graphs**



2. **Logical Expressions**

(not X or not Y) and A and B

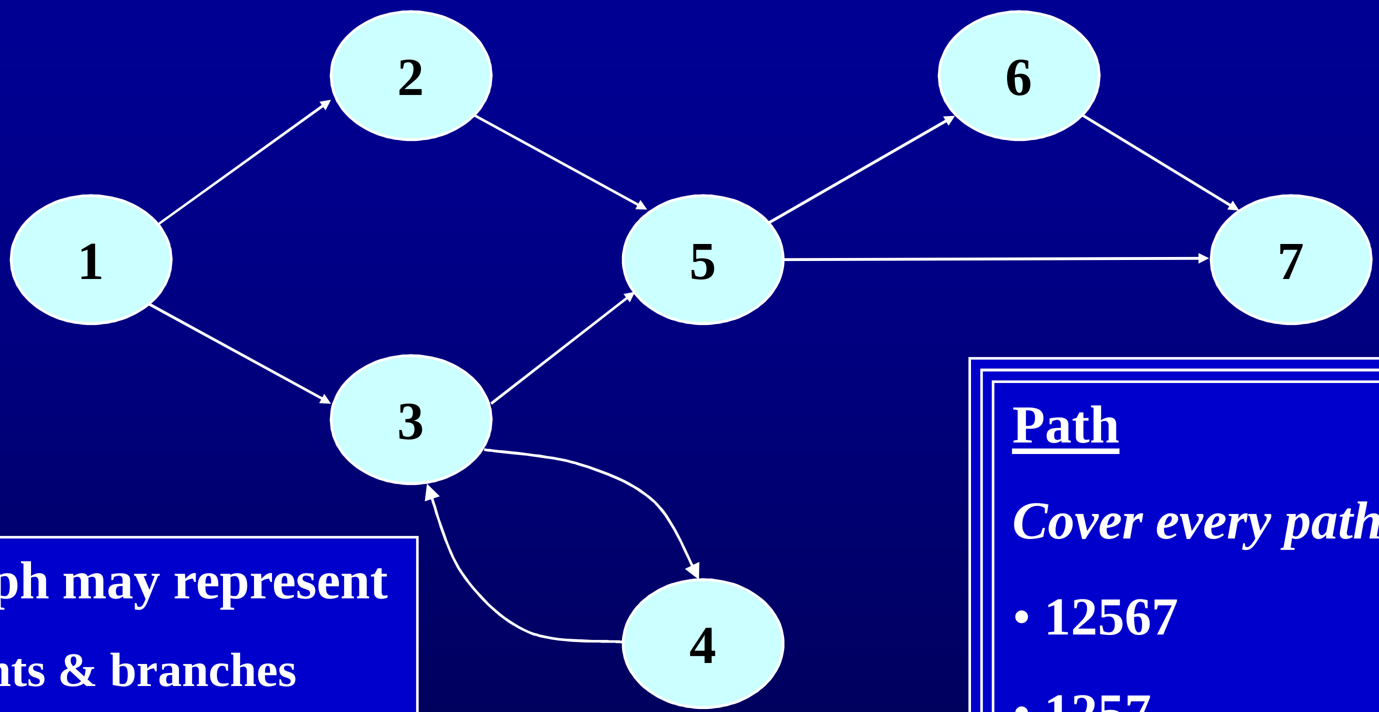
3. **Input Domain Characterization**

A: {0, 1, >1}
B: {600, 700, 800}
C: {swe, cs, isa, infs}

4. **Syntactic Structures**

```
if (x > y)
    z = x - y;
else
   z = 2 * x;
```

1. Graph Coverage – Structural



This graph may represent

- **statements & branches**
- **methods & calls**
- **components & signals**
- **states and transitions**

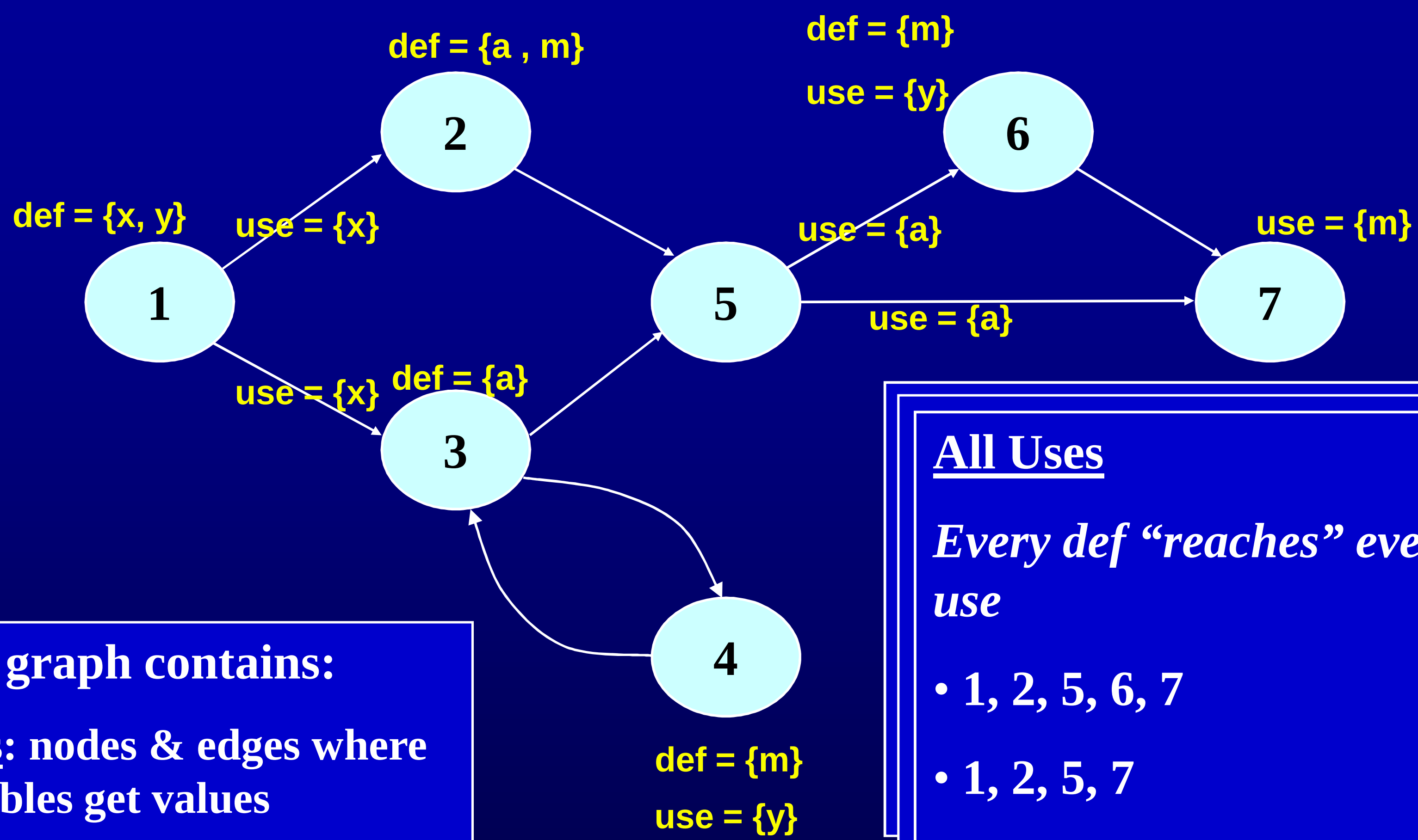
•
•
•

Path

Cover every path

- **12567**
- **1257**
- **13567**
- **1357**
- **1343567**
- **134357 …**

1. Graph Coverage – Data Flow



This graph contains:

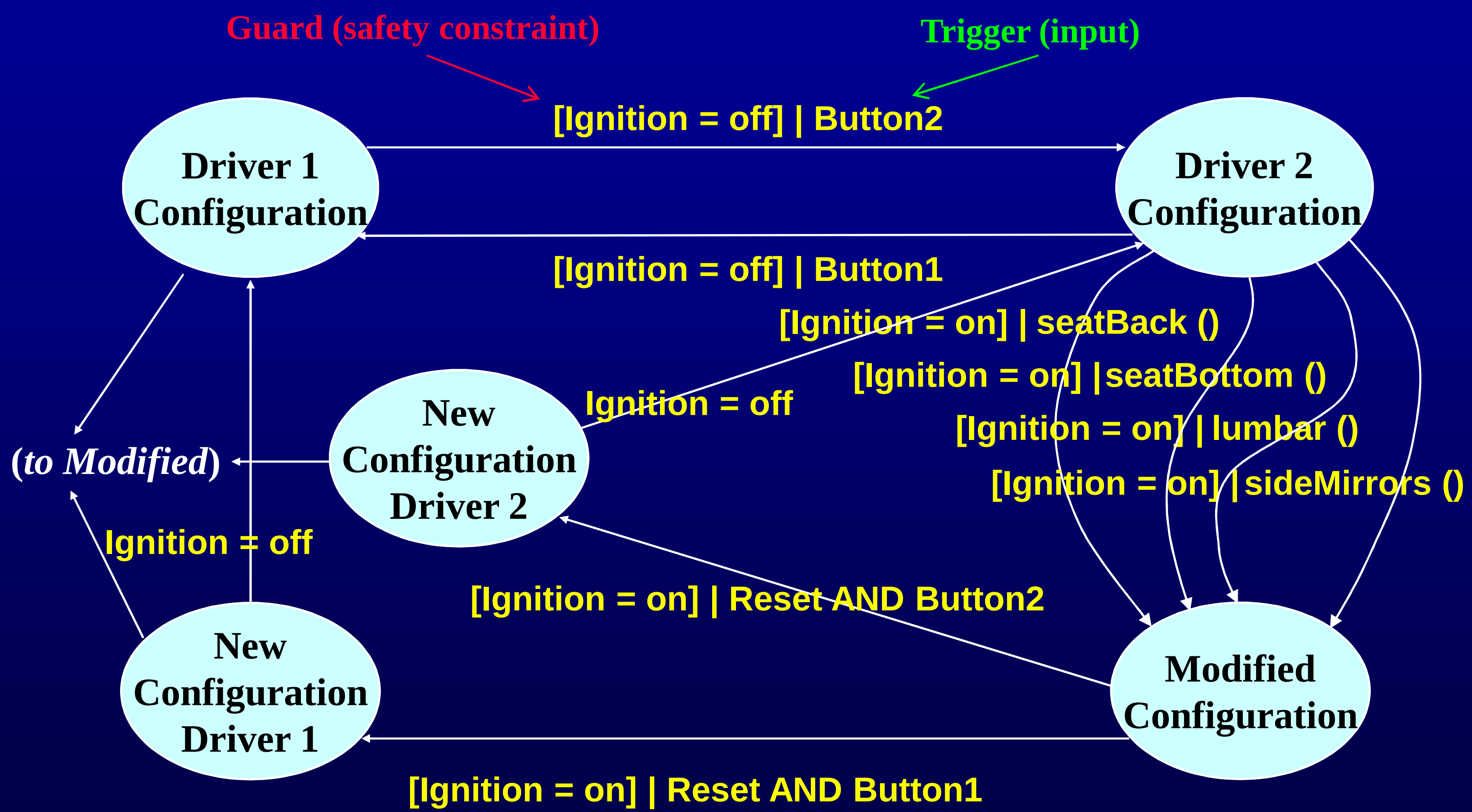
- **<u>defs</u>: nodes & edges where variables get values**
- **<u>uses</u>: nodes & edges where values are accessed**

<u>All Uses</u>

Every def "reaches" every use

- **1, 2, 5, 6, 7**
- **1, 2, 5, 7**
- **1, 3, 5, 6, 7**
- **1, 3, 5, 7**
- **1, 3, 4, 3, 5,7**

1. Graph - FSM Example
Memory Seats in a Lexus ES 300



2. Logical Expressions

((a > b) or G) and (x < y)

Transitions

Program Decision Statements

Software Specifications

Logical Expressions

2. Logical Expressions

((a > b) or G) and (x < y)

- **Predicate Coverage : Each predicate must be true and false**
  – ***((a>b) or G) and (x < y)*** **= True, False**

- **Clause Coverage : Each clause must be true and false**
  – ***(a > b)*** **= True, False**
  – ***G*** **= True, False**
  – ***(x < y)*** **= True, False**

- **Combinatorial Coverage : Various combinations of clauses**
  – ***Active Clause Coverage*****: Each clause must determine the predicate's result**

2. Logic – Active Clause Coverage

((a > b) or G) and (x < y)

	(a > b)	G	(x < y)
1	T	F	T
2	F	F	T
3	F	T	T
4	F	F	T
5	T	T	T
6	T	T	F

With these values for G and (x<y), (a>b) determines the value of the predicate

duplicate (rows 2 and 4)

3. Input Domain Characterization

- **Describe the input domain of the software**
  - **Identify inputs, parameters, or other categorization**
  - **Partition each input into finite sets of representative values**
  - **Choose combinations of values**
- **System level**
  - **Number of students** { *0, 1, >1* }
  - **Level of course** { *600, 700, 800* }
  - **Major** { *swe, cs, isa, infs* }
- **Unit level**
  - **Parameters** *F (int X, int Y)*
  - **Possible values** X*: { <0, 0, 1, 2, >2 }, Y : { 10, 20, 30 }*
  - **Tests**
    - *F (-5, 10), F (0, 20), F (1, 30), F (2, 10), F (5, 20)*

4. Syntactic Structures

- **Based on a <u>grammar</u>, or other syntactic definition**
- **Primary example is <u>mutation testing</u>**
  1. **Induce small changes to the program: <u>mutants</u>**
  2. **Find tests that cause the mutant programs to fail: <u>killing mutants</u>**
  3. **Failure is defined as <u>different output</u> from the original program**
  4. **<u>Check the output</u> of useful tests on the original program**
- **Example program and mutants**

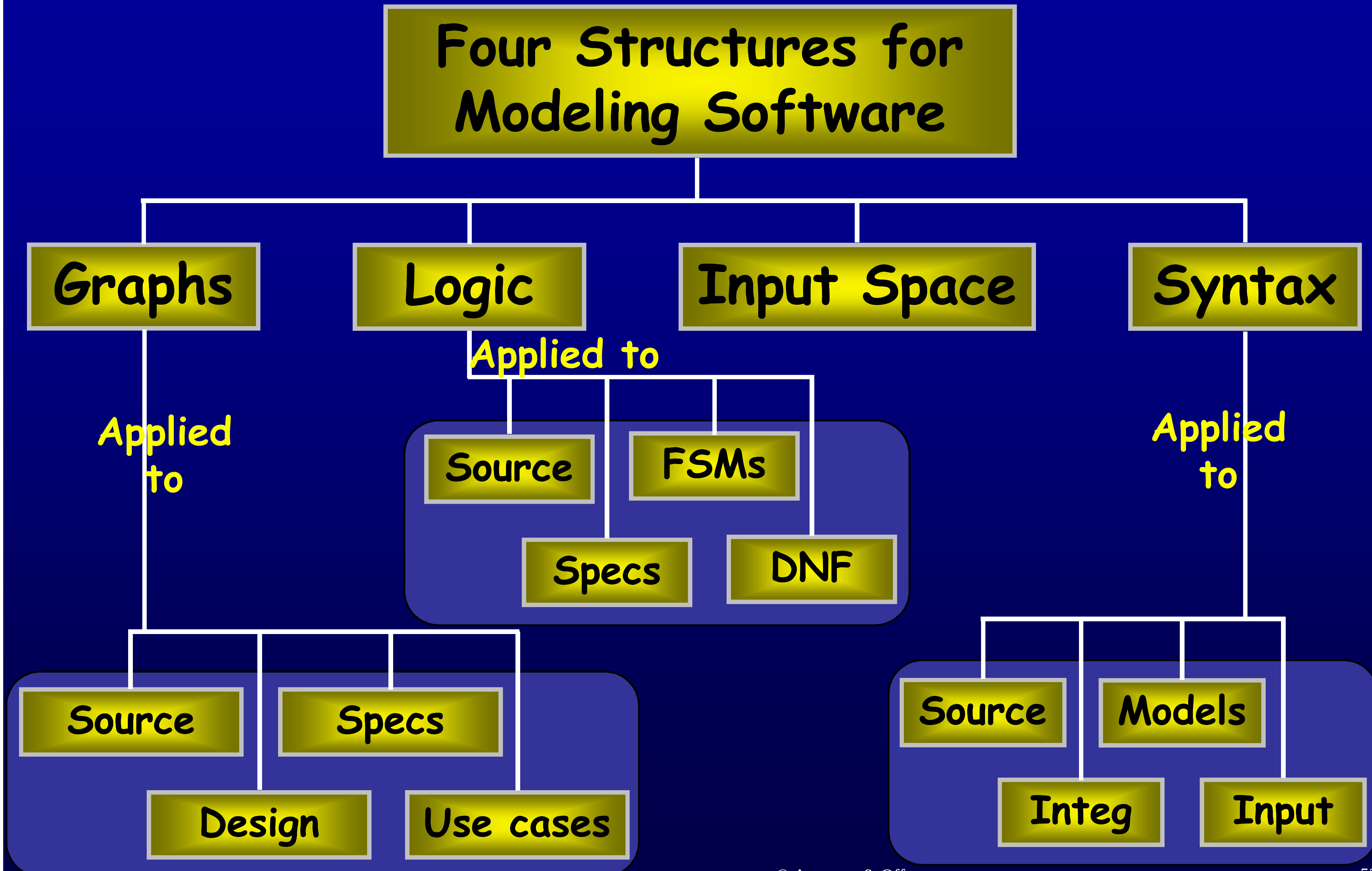
```
if (x > y)
   z = x - y;
else
  z = 2 * x;
```

```
if (x > y)
Δif (x >= y)
   z = x - y;
   Δ z = x + y;
   Δ z = x – m;
else
    z = 2 * x;
```

Source of Structures

- These structures can be **extracted** from lots of software artifacts
  - **Graphs** can be extracted from UML use cases, finite state machines, source code, …
  - **Logical expressions** can be extracted from decisions in program source, guards on transitions, conditionals in use cases, …
- ***Model-based testing*** derives tests from a model that describes some aspects of the system under test
  - The model usually describes part of the **behavior**
  - The **source** is usually ***not*** considered a model

Coverage Overview



Coverage

Given a set of test requirements *TR* for coverage criterion *C*, a test set *T* satisfies *C* coverage if and only if for every test requirement *tr* in *TR*, there is at least one test *t* in *T* such that *t* satisfies *tr*

- **Infeasible test requirements : test requirements that cannot be satisfied**
  - No test case values exist that meet the test requirements
  - Dead code
  - Detection of infeasible test requirements is formally undecidable for most test criteria
- **Thus, 100% coverage is impossible in practice**

Two Ways to Use Test Criteria

1. **Directly generate test values to satisfy the criterion often assumed by the research community most obvious way to use criteria very hard without automated tools**

2. **Generate test values externally and measure against the criterion usually favored by industry**
   - **sometimes misleading**
   - **if tests do not reach 100% coverage, what does that mean?**

Test criteria are sometimes called metrics

Generators and Recognizers

- **Generator : A procedure that automatically generates values to satisfy a criterion**
- **Recognizer : A procedure that decides whether a given set of test values satisfies a criterion**

- **Both problems are provably undecidable for most criteria**
- **It is possible to recognize whether test cases satisfy a criterion far more often than it is possible to generate tests that satisfy the criterion**
- **Coverage analysis tools are quite plentiful**

Comparing Criteria with Subsumption

- **Criteria Subsumption : A test criterion *C1* subsumes *C2* if and only if every set of test cases that satisfies criterion *C1* also satisfies *C2***

- **Must be true for every set of test cases**
- ***Example* : If a test set has covered every branch in a program (satisfied the branch criterion), then the test set is guaranteed to also have covered every statement**

Test Coverage Criteria

- Traditional software testing is expensive and labor-intensive
- Formal coverage criteria are used to decide which test inputs to use
- More likely that the tester will find problems
- Greater assurance that the software is of high quality and reliability
- A goal or stopping rule for testing
- Criteria makes testing more efficient and effective

But how do we start to apply these ideas in practice?

Part 3 : How ?

Now we know why and what …

How do we get there ?

Testing Levels Based on Test Process Maturity

- **Level 0 : There's no difference between testing and debugging**
- **Level 1 : The purpose of testing is to show correctness**
- **Level 2 : The purpose of testing is to show that the software doesn't work**
- **Level 3 : The purpose of testing is not to prove anything specific, but to reduce the risk of using the software**
- **Level 4 : Testing is a mental discipline that helps all IT professionals develop higher quality software**

Level 0 Thinking

- **Testing is the same as debugging**
- **Does not distinguish between incorrect behavior and mistakes in the program**
- **Does not help develop software that is reliable or safe**

This is what we teach undergraduate CS majors

Level 1 Thinking

- Purpose is to show correctness
- Correctness is impossible to achieve
- What do we know if no failures?
  - Good software or bad tests?
- Test engineers have no:
  - Strict goal
  - Real stopping rule
  - Formal test technique
  - Test managers are powerless

This is what hardware engineers often expect

Level 2 Thinking

- Purpose is to show <u>failures</u>
- Looking for failures is a <u>negative</u> activity
- Puts testers and developers into an <u>adversarial</u> relationship
- What if there are <u>no failures</u>?

This describes most software companies.

How can we move to a *<u>team approach</u>* ??

Level 3 Thinking

- Testing can only show the presence of failures
- Whenever we use software, we incur some risk
- Risk may be small and consequences unimportant
- Risk may be great and the consequences catastrophic
- Testers and developers work together to reduce risk

This describes a few "enlightened" software companies

Level 4 Thinking

A mental discipline that increases quality

- Testing is only one way to increase quality
- Test engineers can become technical leaders of the project
- Primary responsibility to measure and improve software quality
- Their expertise should help the developers

This is the way "traditional" engineering works

Summary

- **More testing saves money**
  - **Planning for testing saves lots of money**
- **Testing is no longer an "art form"**
  - **Engineers have a tool box of test criteria**
- **When testers become engineers, the product gets better**
  - **The developers get better**

Open Questions

- Which criteria work best on embedded, highly reliable software?
  - Which software structure to use?
- How can we best automate this testing with robust tools?
  - Deriving the software structure
  - Constructing the test requirements
  - Creating values from test requirements
  - Creating full test scripts
  - Solution to the “mapping problem”
- Empirical validation
- Technology transition
- Application to new domains

Summary of Today's New Ideas

- **Why** do we test – to **reduce the risk** of using the software
- Four types of **test activities** – test design, automation, execution and evaluation
- Software **terms** – faults, failures, the RIP model, observability and controllability
- **Four structures** – test **requirements** and **criteria**
- Test **process maturity** levels – level 4 is a **mental discipline** that improves the **quality** of the software

Earlier and better testing can <u>empower</u> the test manager