CS 5154

Testing Concepts

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The following are modified versions of the publicly-available slides for Chapters 1 and 2 in the Ammann and Offutt Book, "Introduction to Software Testing"
(http://www.cs.gmu.edu/~offutt/softwaretest)

Outline for today's class

- Fundamental testing terminology
- The costs of insufficient, non-existent, or late testing
- The goals of a software tester
- Foundations of software testing
- Levels of software testing
- Types of testing activities
- Model-Driven Test Design

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Software Faults, Errors & Failures

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

A Concrete Example

Fault: Should start searching at 0, not 1

```
public static int numZero (int [ ] arr)
{  // Effects: If arr is null throw NullPointerException
   // else return the number of occurrences of 0 in arr
   int count = 0;
   for (int i = 1; i < arr.length; i++)
   {
      if (arr [ i ] == 0)
      {
         count++;
      }
   }
   return count;
}
```

Test 1
[2, 7, 0]

Expected: 1
Actual: 1

Error: i is 1, not 0, on the first iteration
Failure: none

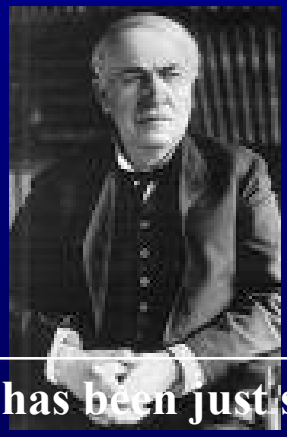
Test 2
[0, 2, 7]

Expected: 1
Actual: 0

Error: i is 1, not 0
Error propagates to the variable count
Failure: count is 0 at the return statement

The Term, "Bug"

- *Bug* is used informally
- Sometimes speakers mean fault, sometimes error, sometimes failure … often the speaker doesn't know what it means !
- This class: when needed, we will use the more precise terminology



"It has been just so in all of my inventions. The first step is an intuition, and comes with a burst, then difficulties arise—this thing gives out and *[it is]* then that 'Bugs'—as such little faults and difficulties are called—show themselves and months of intense watching, study and labor are requisite. . ." – Thomas Edison

"an analyzing process must equally have been performed in order to furnish the Analytical Engine with the necessary operative data; and that herein may also lie a possible source of error. Granted that the actual mechanism is unerring in its processes, the cards may give it wrong orders. " – Ada, Countess Lovelace (notes on Babbage's Analytical Engine)

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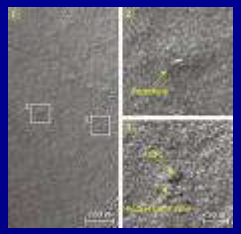
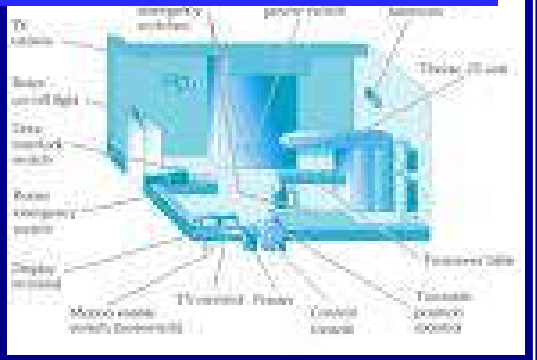
Spectacular Software Failures

- NASA's Mars lander: September 1999, crashed due to a units integration fault



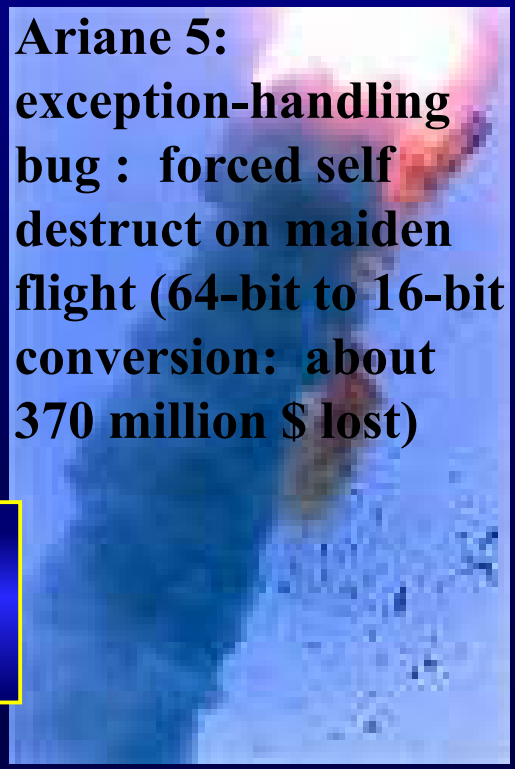
Mars Polar Lander crash site?

THERAC-25 design



- THERAC-25 radiation machine : Poor testing of safety-critical software can cost *lives* : 3 patients were killed
- Ariane 5 explosion : Millions of $$
- Intel's Pentium FDIV fault : Public relations nightmare

Ariane 5: exception-handling bug : forced self destruct on maiden flight (64-bit to 16-bit conversion: about 370 million $ lost)



We need our software to be dependable

Testing is *one* way to assess dependability

Northeast Blackout of 2003

508 generating units and 256 power plants shut down

Affected 10 million people in Ontario, Canada

Affected 40 million people in 8 US states

Financial losses of $6 Billion USD

The alarm system in the energy management system failed due to a software error and operators were not informed of the power overload in the system

More recent software Failures

- Boeing A220 : Engines failed after software update allowed excessive vibrations
- Boeing 737 Max : Crashed due to overly aggressive software flight overrides (MCAS)

- Toyota brakes : Dozens dead, thousands of crashes

- Healthcare website : Crashed repeatedly on launch—never load tested

Software testers try to find faults before the faults find users

The True Cost of Software Failure

Fail watch analyzed news articles for 2016

- 606 reported software failures
- Impacted half the world's population
- Cost a combined $1.7 trillion US dollars

Poor software is a significant drag on the world's economy

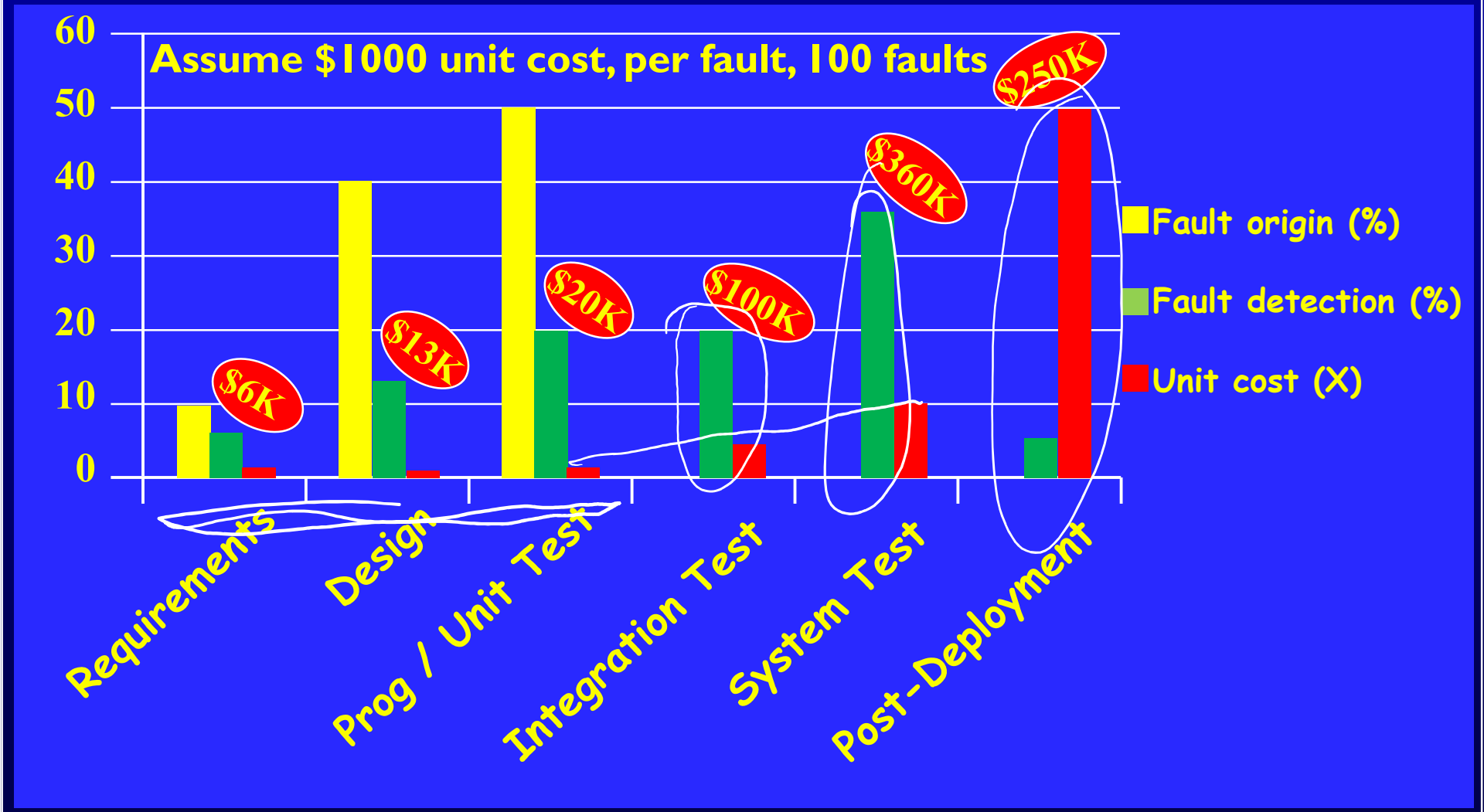
Not to mention frustrating

Cost of Not Testing

Poor Program Managers might say:
"Testing is too expensive."

- Testing is the most time consuming and expensive part of software development
- Not testing is even more expensive
- If we have too little testing effort early, the cost of testing increases
- Planning for testing after development is prohibitively expensive

Cost of Late Testing



Software Engineering Institute; Carnegie Mellon University; Handbook CMU/SEI-96-HB-002

Implications for Software Testing

Software testing is getting more important

What are we trying to do when we test ?

What are our goals ?

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Testing Goals Based on Test Process Maturity

- Level 0 : There's no difference between testing & 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 level is usually taught in 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?
- Software engineers have no:
  - Strict goal
  - Real stopping rule
  - Formal test technique
  - Test managers are powerless

Level 2 Thinking

- Purpose is to show failures
- Looking for failures can be a negative activity
- It can put testers and developers into an adversarial relationship
- What if there are no failures?

This describes many software organizations.

How can we move to a *team approach* ??

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 consequences catastrophic
- Testers and developers cooperate to reduce risk

This describes relatively few "enlightened" software organizations

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

What testing level are you at?

In-class activity: Poll

We hope to teach you to become "change agents" in your workplace …

Advocates for level 4 thinking

What should testers aim for ?

A tester should aim to eliminate faults as early as possible

- **Improve quality**
- **Reduce cost of finding bugs**
- **Preserve customer satisfaction**

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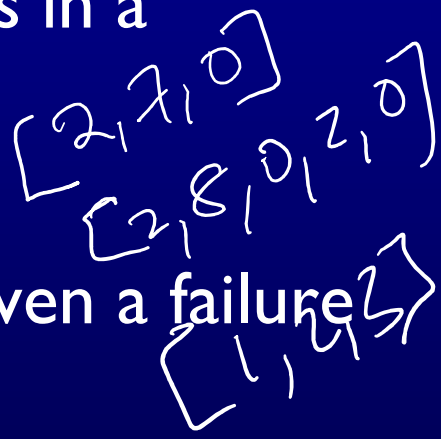
A key Software Testing Limitation

Testing can only show the presence of failures

Not their absence

Moving beyond Level 0: Testing vs. 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



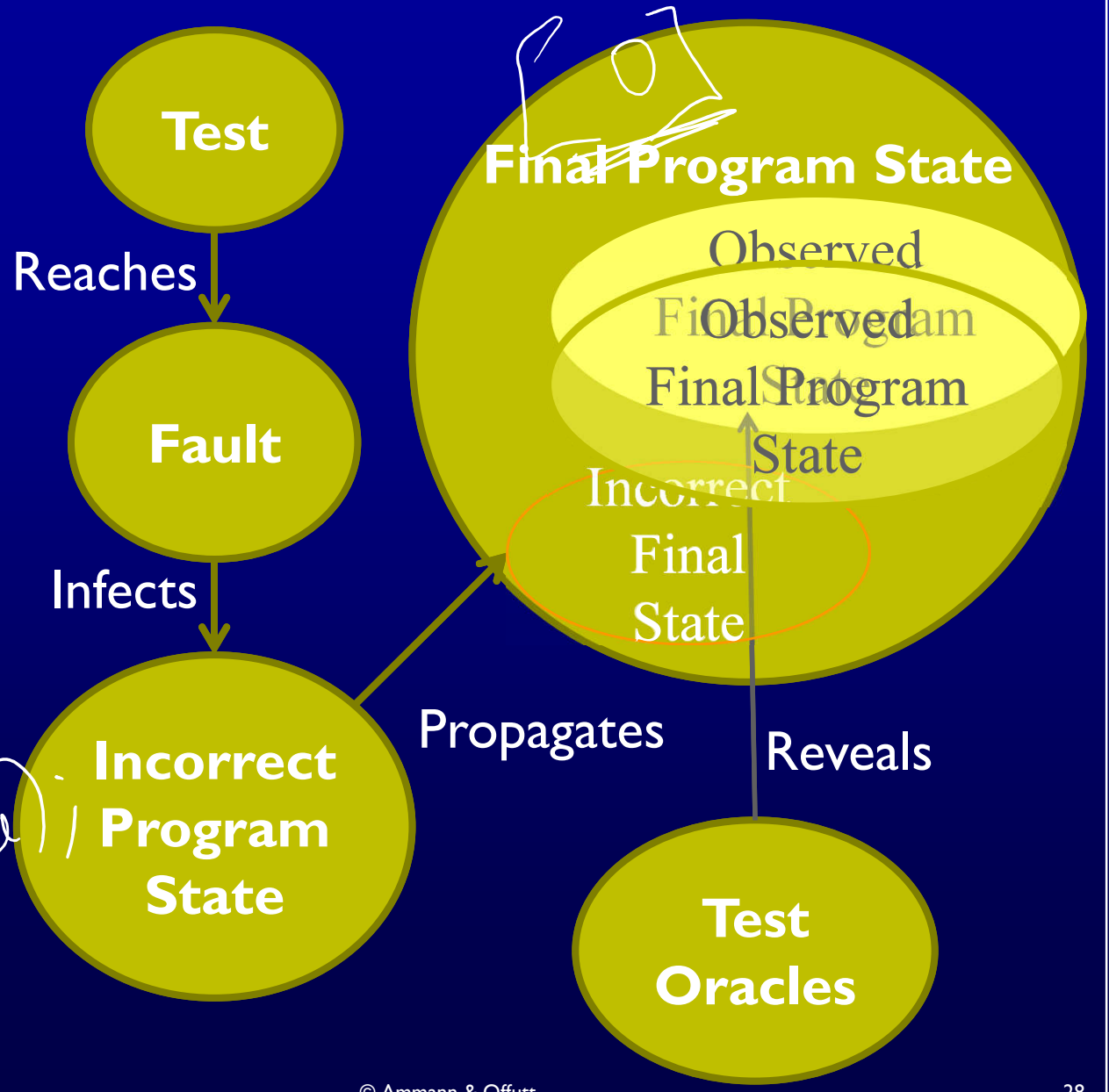
Not all inputs will "trigger" a fault into causing a failure

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



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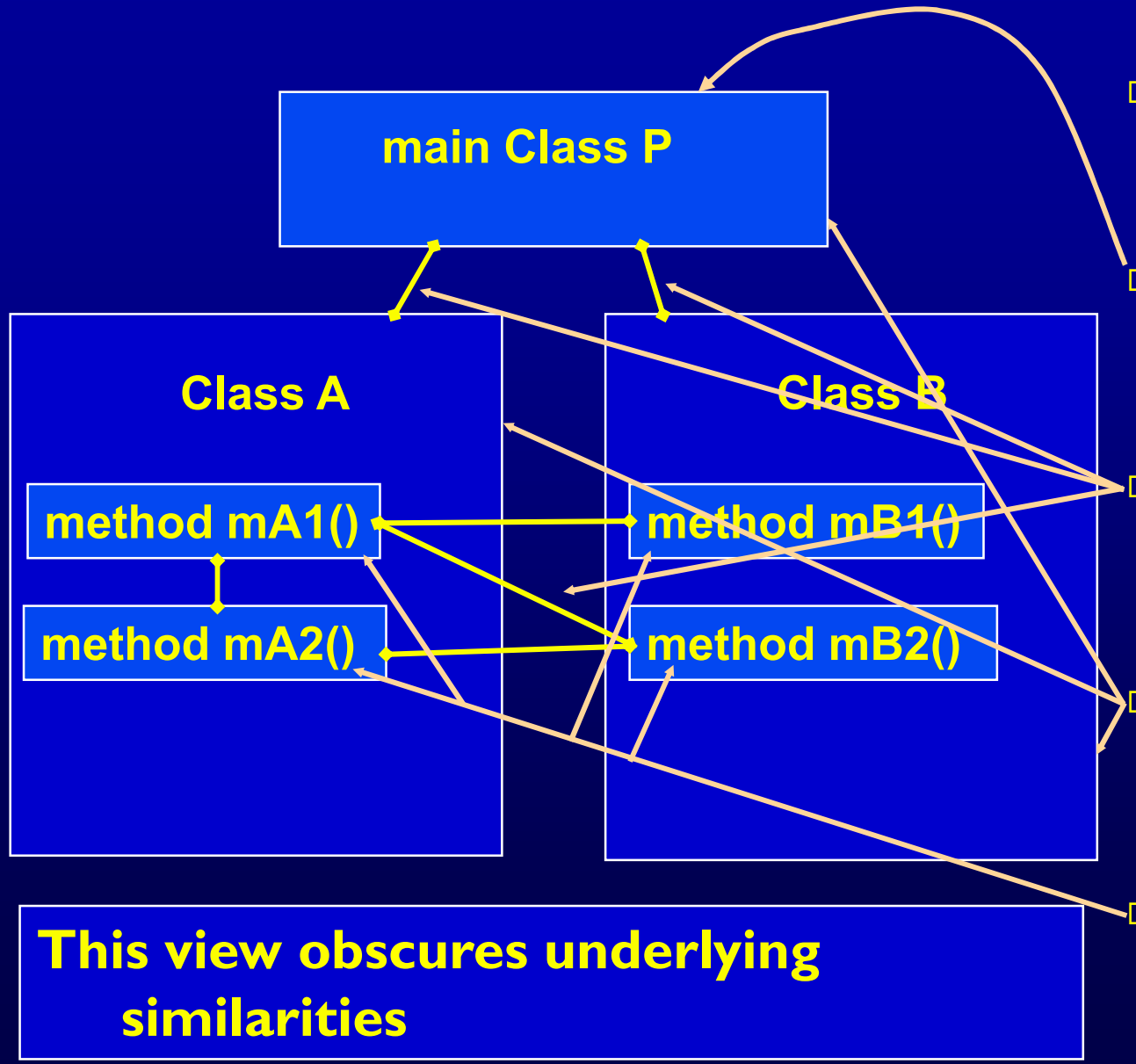
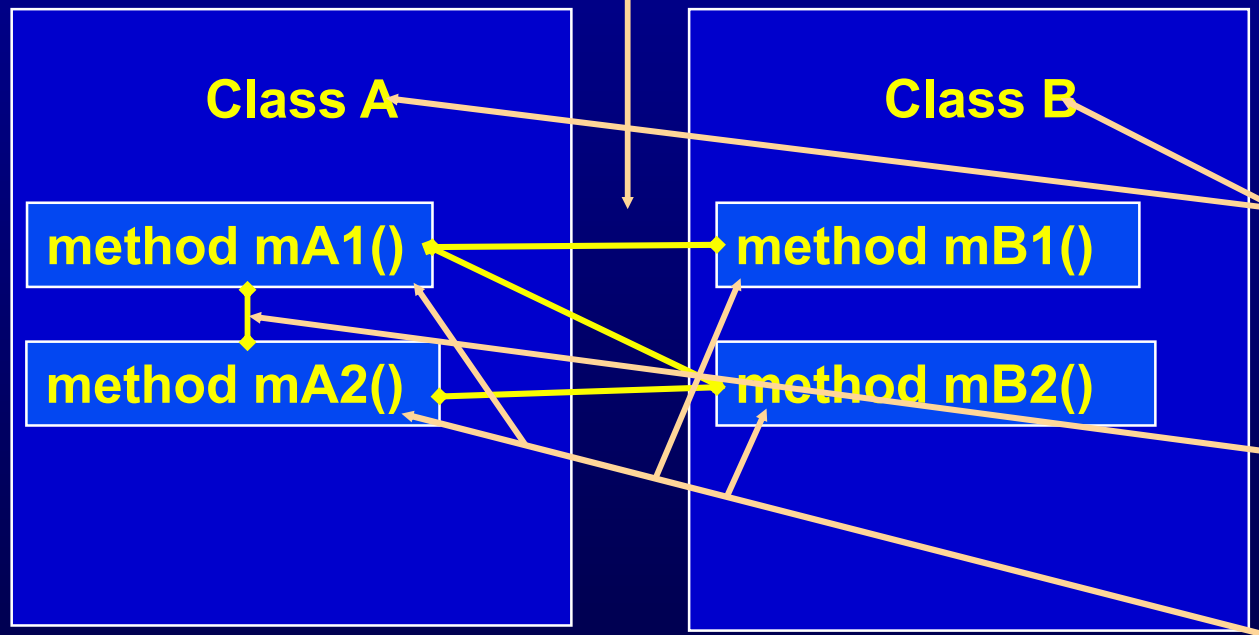
Traditional Testing Levels



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

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

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)

Model-Driven Test Design makes these distinctions less important.

The more general question is:

from what abstraction level do we derive tests?

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Types of Test Activities

- Testing can be broken up into four 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
- This class: you will learn something about each of these types of activities

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
- Assigning this task to people who are not trained 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 design 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

2. Test Automation

Embed test values into executable scripts

- Often requires solutions to difficult problems related to observability and controllability
- Another challenge: how to determine, embed, and maintain the expected outputs ?

3. Test Execution

Run tests on the software and record the results

- This is easy – and trivial if the tests are well automated
- These days, many organizations utilize a CI server for test execution
  - Travis
  - Jenkins
  - ??

Other Testing Activities

- Test management : Sets policy, organizes team, interfaces with development, chooses criteria, decides how much automation is needed, …

- Test maintenance : Reuse tests as software evolves
  - Regression testing
  - Deciding when to trim the test suite is partly policy and partly technical – and very hard !

- Test documentation :
  - Keep documentation in the automated tests

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- Model-Driven Test Design ⇒ Next lecture

Next Class

- Test Automation
  - JUnit
  - We may cover some Maven as well