Coverage-Based Test Design

CS 3250 Software Testing

[Ammann and Offutt, "Introduction to Software Testing," Ch. 5]

Today's Objectives

- What is criteria-based test design?
- Why are test criteria used?
- Who will benefit from using test criteria? How?
- When are test criteria used?
- How are test criteria used?

- What are existing criteria? How are criteria categorized?
- Which criterion should be used? When? Why? How?

Later

All Possible Inputs?

- Let's try!!
- Create **all** possible test inputs for the given program

```
/**
 * Determine if the argument is a leap year in the Gregorian calendar
 * Assumes that arguments are in Gregorian calendar range (1582 and onwards)
 *
 * @param year value in range for Gregorian calendar
 * @return true iff year is a leap year
 */
public static boolean isLeap(int year)
{
   if (year % 4 != 0)          return false;
   if (year % 400 == 0)        return true;
   if (year % 100 == 0)        return false;

   return true;
}
```

- How many test inputs?
- List them all …?

Coverage Criteria

- Describe a finite subset of test cases out of the vast/infinite number of possible tests we should execute
- Divide the input space to maximize the number of faults found per test case
- Provide useful rules for when to stop testing

Benefits of Coverage Criteria

Adequate

- Have I got enough tests?

Guidance

- Where should I test more?

Automation

- Generate test that satisfies a test requirement

Two Ways to Use Test Criteria

- Directly generate test case values to satisfy the criterion
  - Often assumed by the research community
  - Most obvious way to use criteria
  - Very hard without automated tools

- Evaluate existing test sets
  - Usually favored by industry
  - Sometimes misleading
    - If tests do not reach 100% coverage, what does that mean?
    - We don't have enough data to tell how much 99% coverage is worse than 100% coverage

Implementation of Test Criteria

Generator

- A procedure that automatically generate values to satisfy a criterion
- Automated test generation tools

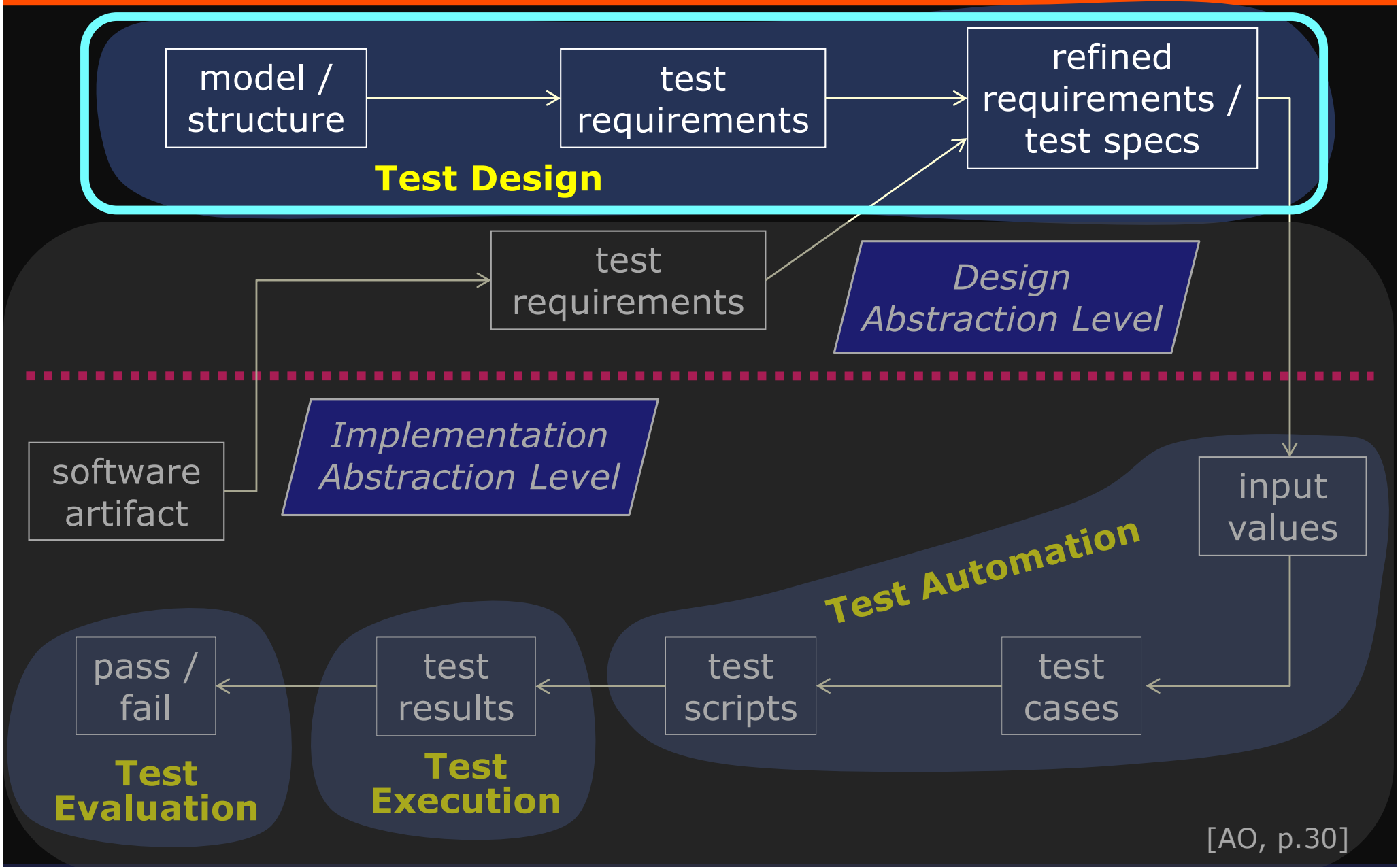
Recognizer

- A procedure that decides whether a set of test case values satisfies a criterion
- Coverage analysis tools; e.g., JaCoCo, Eclipse's coverage

It is possible to recognize whether test cases satisfy a criterion far more than it is possible to generate tests that satisfy the criterion

Model-Driven Test Design

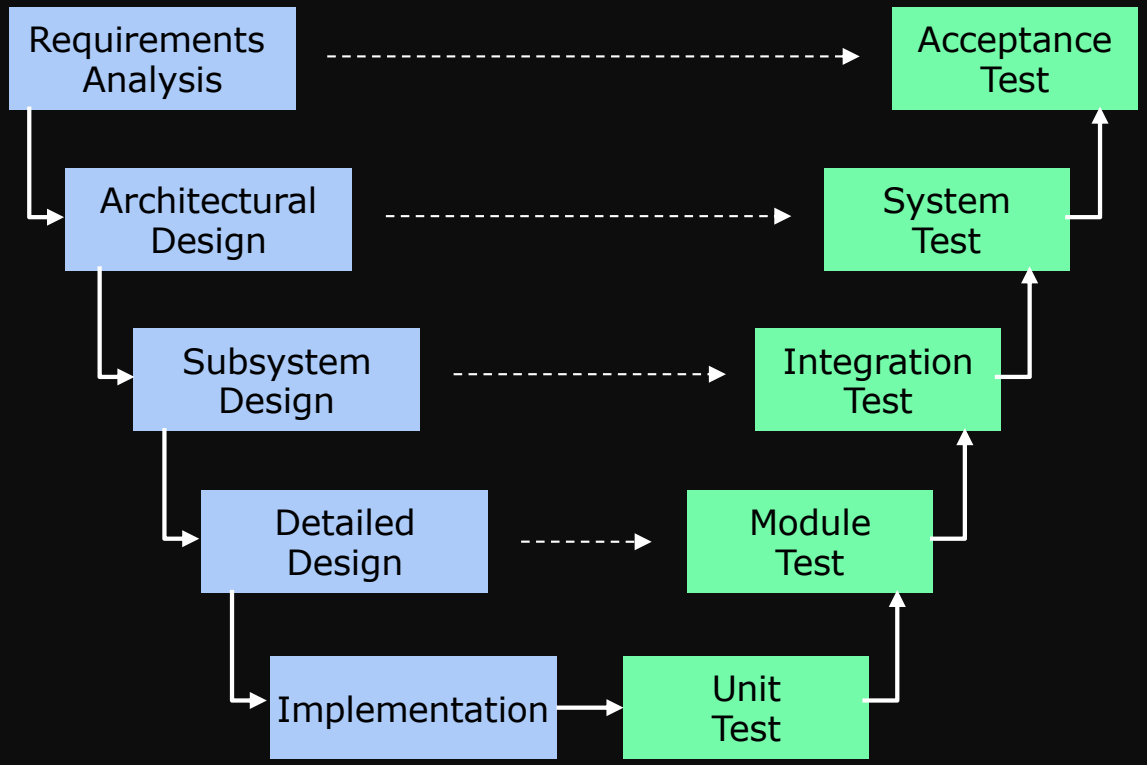
Revisit



[AO, p.30]

Changing Notions in Testing

Old view (phase)



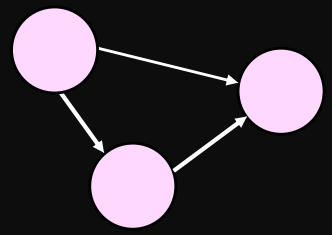
[AO, p 21]

New view (structures and criteria)

Input space (sets)

A: {0, 1, >1}
B: {undergraduate, graduate}
C: {1000, 2000, 3000, 4000}

Graphs



Logical expressions

(not X or not Y) and A and B

Syntax structures (grammar)

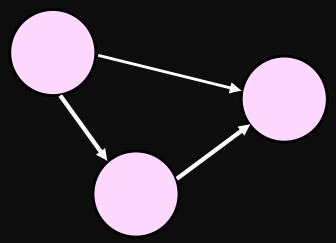
```
if (x > y)
    z = x - y;
else
   z = 2 * x;
```

New: Structures and Criteria

Input space (sets)

```
A: {0, 1, >1}
B: {undergraduate, graduate}
C: {1000, 2000, 3000, 4000}
```

Graphs



Logical expressions

```
(not X or not Y) and A and B
```

Syntax structures (grammar)

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

Test design is largely the same at each phase

- Creating the structure is different
- Choosing values and automating the tests is different

Tester defines a structure of the software and then find ways to cover it

Structures can be extracted from lots of software artifacts

- Graphs – from UML use cases, finite state machines, source code, …
- Logical expressions – from decisions in program source, guards on transitions, conditionals in use cases, ...

Test Coverage Criteria

Coverage Criterion

- A rule or collection of rules that impose test requirements on a test set

Test requirement

- A specific element of a software artifact that a test case must satisfy or cover
- Depends on the specific artifact under test

Revisit

Test case

- A set of test inputs, execution conditions, and expected results, developed for a particular test scenario to verify whether the system under test satisfies a specific requirement

Test set

- A set of test cases

Example: Blow Pop Coverage

Flavors

- Cherry
- Blue razz berry
- Strawberry
- Sour apple
- Grape
- Watermelon

Colors

- Red (Cherry, strawberry, watermelon)
- Blue (Blue razz berry)
- Green (Sour apple)
- Purple (Grape)

Possible coverage criteria:

C1: Taste one blow pop of each flavor

(deciding if red blow pop is cherry, strawberry, or watermelon is a controllability problem)

C2: Taste one blow pop of each color

Example: Blow Pop Coverage

Flavors

- Cherry
- Blue razz berry
- Strawberry
- Sour apple
- Grape
- Watermelon

Test requirements for *C1*

tr1: Cherry

tr2: Blue razz berry

tr3: Strawberry

tr4: Sour apple

tr5: Grape

tr6: Watermelon

TR1 = {Cherry, Blue razz berry, Strawberry, Sour apple, Grape, Watermelon}

Colors

- Red (Cherry, strawberry, watermelon)
- Blue (Blue razz berry)
- Green (Sour apple)
- Purple (Grape)

Test requirements for *C2*

tr1: Red

tr2: Blue

tr3: Green

tr4: Purple

TR2 = {Red, Blue, Green, Purple}

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*

Adequate test set – test set that satisfies all test requirements

Minimal test set – removing any single test from the set will cause the test set to no longer satisfy all test requirements

Blow Pop Coverage (continue)

C1: Flavor criterion

TR1 = {Cherry,
Blue razz berry,
Strawberry,
Sour apple,
Grape,
Watermelon}

C2: Color criterion

TR2 = {Red, Blue,
Green, Purple}

Adequate test set?
Minimal test set?

Test sets

T1 = {one Cherry,
one Blue razz berry,
three Strawberries,
one Sour apple,
two Grapes,
four Watermelons}

Satisfy C1?	Yes
Satisfy C2?	Yes

T2 = {one Blue razz berry,
one Sour apple,
two Grapes,
three Watermelons}

Satisfy C1?	No
Satisfy C2?	Yes

Coverage Level

- It is sometimes expensive to satisfy a coverage criterion.
- Testers compromise by trying to achieve a certain coverage level.

$$\text{Coverage level} = \frac{\text{number of test requirements satisfied by } T}{\text{Size of } TR}$$

Blow Pop Coverage (continue)

C1: Flavor criterion

TR1 = {Cherry,
Blue razz berry,
Strawberry,
Sour apple,
Grape,
Watermelon}

C2: Color criterion

TR2 = {Red, Blue,
Green, Purple}

Test sets

T1 = {one Cherry,
one Blue razz berry,
three Strawberries,
one Sour apple,
two Grapes,
four Watermelons}

Satisfy C1?
Satisfy C2?

Coverage level 6 / 6
4 / 4

T2 = {one Blue razz berry,
one Sour apple,
two Grapes,
three Watermelons}

Satisfy C1?
Satisfy C2?

Coverage level 4 / 6
4 / 4

Infeasible Test Requirement

Example:

```
/**
  * @param s1, s2, s3:  sides of the putative triangle
  * @return enum describing type of triangle
  */
public static Triangle triangle (int s1, int s2, int s3)
{
```

Imagine if we have the following test requirements

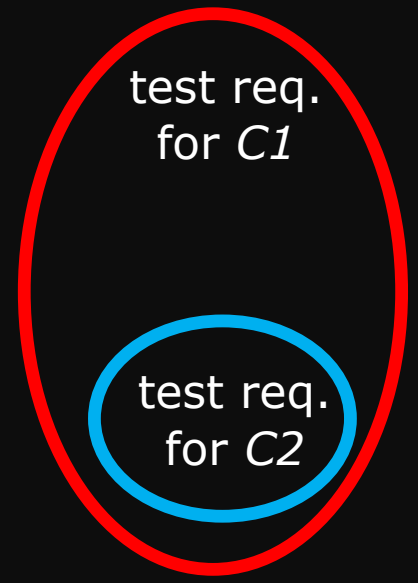
TR = {all sides > 0, all sides = 0, all sides < 0}

- Some test requirements are infeasible (i.e., cannot be satisfied)
  - No test case values exist that meet the test requirements
  - Example: dead code
  - Detection of infeasible test requirements is undecidable for most test criteria
- 100% coverage is usually impossible in practice

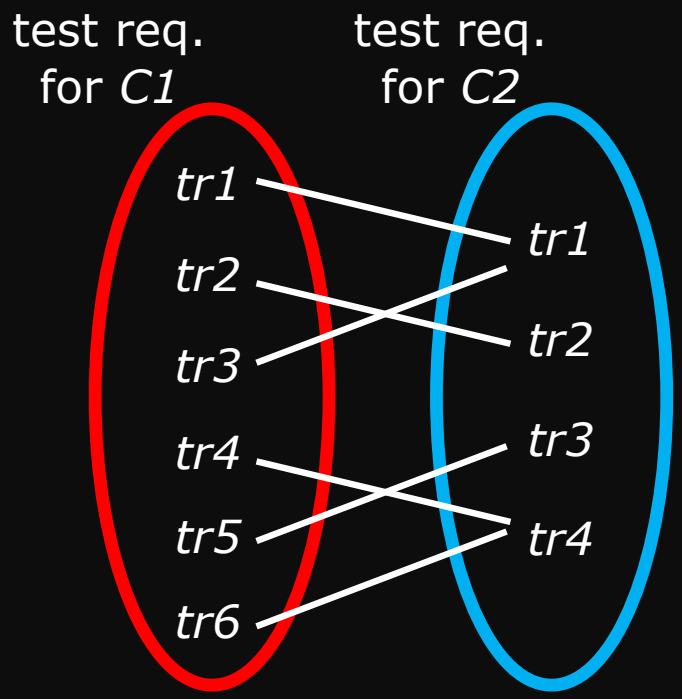
Comparing Criteria

Criteria Subsumption

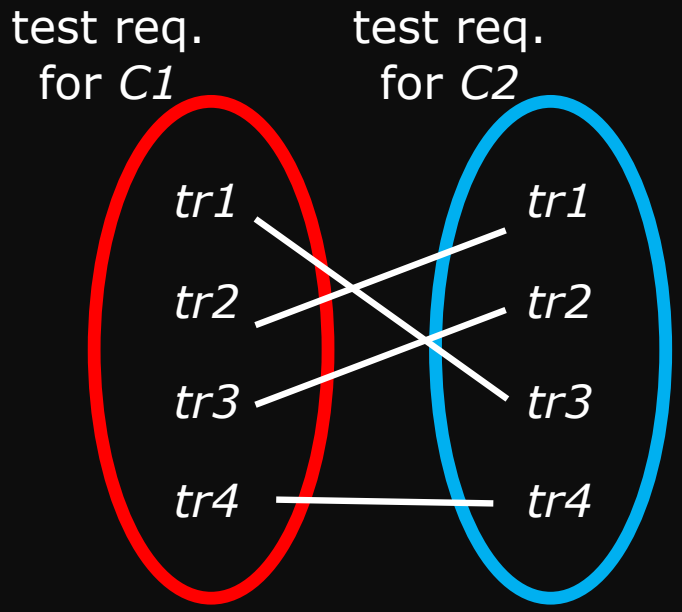
- A test criterion *C1* subsumes *C2* if and only if every set of test cases that satisfies criterion *C1* also satisfies *C2*
- Must be true for every test set



C1 subsumes *C2*
(superset)



C1 subsumes *C2*
(many-to-one)



C1 subsumes *C2*
C2 subsumes *C1*
(one-to-one)

Blow Pop Coverage (Subsume)

_C1_: Flavor criterion

TR1 = {Cherry,
Blue razz berry,
Strawberry,
Sour apple,
Grape,
Watermelon}

C1 subsumes C2

C2: Color criterion

TR2 = {Red, Blue,
Green, Purple}

Test sets
(considering 2 test sets, T1 and T2)

T1 = {one Cherry, one Blue razz berry,
three Strawberries,
one Sour apple, two Grapes,
four Watermelons}

Satisfy C1?	Yes (C1 adequate tests)
Satisfy C2?	Yes (C2 adequate tests)

T2 = {one Blue razz berry,
one Sour apple, two Grapes,
three Watermelons}

Satisfy C1?	No
Satisfy C2?	Yes (C2 adequate tests)

Good Coverage Criterion

- It should be fairly easy compute test requirements automatically
- It should be efficient to generate test values
- The resulting tests should reveal as many faults as possible

Additional notes:

- Subsumption is only a rough approximation of fault revealing capability
- Researchers still need to gives us more data on how to compare coverage criteria

Advantages of Using Criteria

- Yield fewer tests that are more effective at finding faults
  - Design test inputs that are more likely to find problems
- Increase traceability
  - Answer the "why" for each test
  - Support regression testing
- Provide stopping rules for testing – "how many test" are needed
- Support test automation
- Make testing more efficient and effective
- Provide grater assurance that the software is of high quality and reliability

More comprehensive
Less overlap

How do we start applying these ideas in practice

How to Improve Testing?

- Test engineers need more and better software tools
- Test engineers need to adopt practices and techniques that lead to more efficient and effective testing
  - More education
  - Different management organizational strategies
- Testing / QA teams need more technical expertise
  - Developer expertise has been increasing dramatically
- Testing / QA teams need to specialize more

Changes in Practice

- Reorganize test and QA teams to make effective use of individual abilities – one math-head can support many testers
- Retrain test and QA teams
  - Use a process like MDTD
  - Learn more testing concepts
- Encourage researchers to
  - Invent processes and techniques
  - Embed theoretical ideas in tools
  - Demonstrate economic value of criteria testing
    - Which criteria should be used and when?
    - When does the extra effort pay off?
- Get involved in curricular design efforts through industrial advisory boards

Summary

- Many companies still use "monkey testing"
  - A human sits at the keyboard, wiggles the mouse and bangs the keyboard
  - No automation
  - Minimal training required
- Some companies automate human-designed tests
- But companies that use both automation and criteria-based testing save money, find more faults, and build better software

What's Next?

Structures for Criteria-Based Testing