Intro to Software Testing
Chapter 5

Criteria-based Test Design

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Adapted from slides by Paul Ammann & Jeff Offutt

Changing Notions of Testing

Old view focused on testing at each software development **phase** as being very different from other phases

- Unit, module, integration, system…

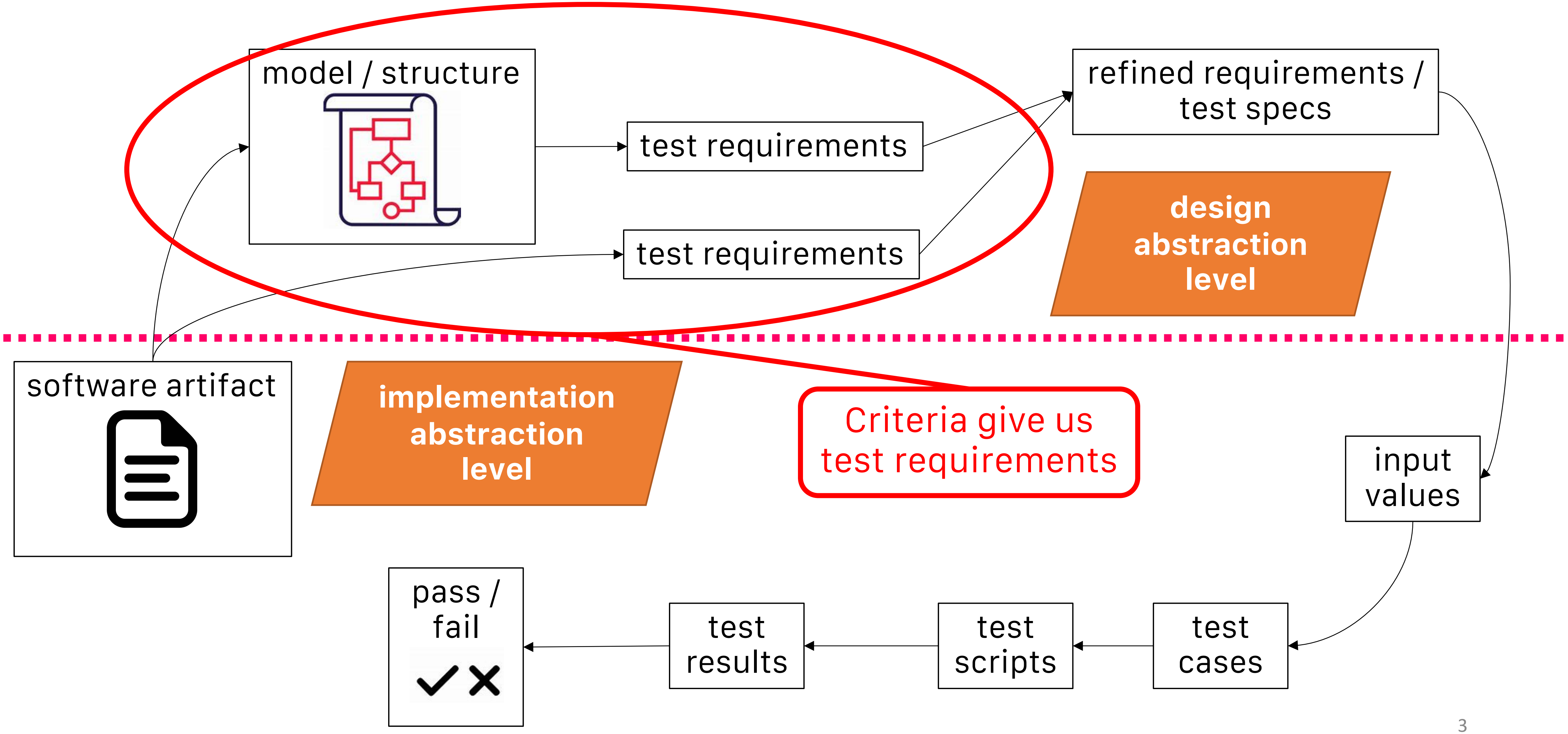
New view is in terms of **structures** and **criteria**

- Input space, graphs, logical expressions, syntax

Test design is largely the same at each phase

- Creating the **model** is different
- Choosing **values** and **automating** the tests is different

Model-driven test design



Test Coverage Criteria

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

Test requirements: A specific element of a software artifact that a test case must satisfy or cover

Coverage criterion: A rule or collection of rules that impose test requirements on a test set

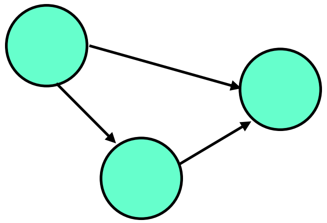
Testing researchers have defined dozens of criteria, but they are all really just a few criteria on four types of structures…

Criteria based on structures

Structures: Four ways to model software

1. Input domain characterization (sets)
2. Graphs
3. Logical expressions
4. Syntactic structures

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



(not X or not Y) and A and B

```
if (x > y)
   z = x - y;
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, …

This is not the same as "***model-based testing***" which 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 explicitly ***not*** considered a model

Example: jelly bean coverage

Flavors:

1. Lemon
2. Pistachio
3. Cantaloupe
4. Pear
5. Tangerine
6. Apricot

Colors:

1. Yellow (Lemon, Apricot)
2. Green (Pistachio)
3. Orange (Cantaloupe, Tangerine)
4. White (Pear)

Possible coverage criteria:

1. Taste one jelly bean of **each flavor**
   - Deciding if yellow jelly bean is Lemon or Apricot is a controllability problem
2. Taste one jelly bean of **each color**

Coverage

Given a set of test requirements ***TR*** for coverage criteria ***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
- Example: dead code
- Detection of infeasible test requirements is formally undecidable for most test criteria

Thus, 100% coverage is **impossible** in practice

More jelly beans

T1 = { three Lemons, one Pistachio, two Cantaloupes, one Pear, one Tangerine, four Apricots }

Does test set T1 satisfy the **flavor criterion**?

T2 = { One Lemon, two Pistachios, one Pear, three Tangerines }

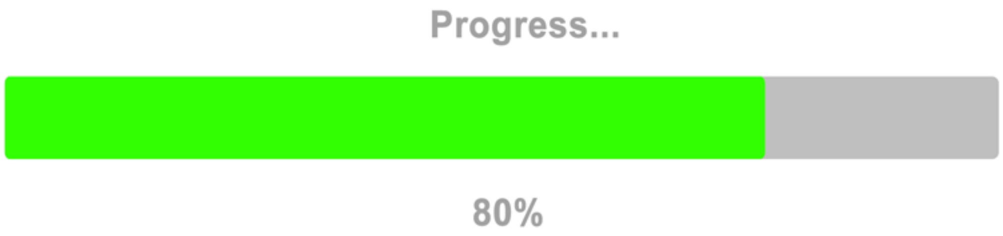
Does test set T2 satisfy the **flavor criterion**?

Does test set T2 satisfy the **color criterion**?

Coverage level

The ratio of the number of test requirements satisfied by *T* to the size of *TR*

T2 on the previous slide satisfies 4 of 6 test requirements



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 <u>metrics</u>

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

Cobertura

A code coverage utility for Java.

EMMA

CodeCover

Comparing criteria with subsumption (5.2)

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

Examples:

- The flavor criterion on jelly beans subsumes the color criterion…if we taste every flavor, we taste every color
- If a test set has covered every branch in program (satisfied branch criterion), the test set is guaranteed to also have covered every statement

Advantages of criteria-based test design (5.3)

Criteria maximize the "**bang for the buck**"

- Fewer tests that are more effective at finding faults

Comprehensive test set with minimal overlap

Traceability from software artifacts to tests

- The "**why**" for each test is answered
- Built-in support for **regression testing**

A "**stopping rule**" for testing – advance knowledge of **how many tests** are needed

Natural to **automate**

Characteristics of a good coverage criterion

1. It should be fairly easy to compute test requirements **automatically**
2. It should be **efficient to generate** test values
3. The resulting tests should reveal as many **faults** as possible

Subsumption is only a **rough approximation** of fault revealing capability

Researchers still need to give us more data on how to **compare** coverage criteria

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 test 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**

How do we start applying these ideas in practice?

How to improve testing?

Testers need more and better **software tools**

Testers 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

- This same trend happened for **development** in the 1990s

Four roadblocks to adoption

1. **Lack of test education**

   Microsoft and Google say half their engineers are testers, programmers test half the time
   Number of UG CS programs that require testing? **0**
   Number of MS CS programs that require testing? **0**
   Number of UG testing classes in the US? **~50**

2. **Necessity to change process**

   Adoption of many test techniques and tools require changes in development process
   This is expensive for most software companies

3. **Usability of tools**

   Many testing tools require the user to know the underlying theory to use them
   Do we need to know how an internal combustion engine works to drive?
   Do we need to understand parsing and code generation to use a compiler?

4. **Weak and ineffective tools**

   Most test tools don't do much – but most users do not realize they could be better
   Few tools solve the key technical problem -- **generating test values automatically**

Needs from researchers

1. **Isolate:** Invent processes and techniques that isolate the theory from most test practitioners
2. **Disguise:** Discover engineering techniques, standards and frameworks that disguise the theory
3. **Embed:** Theoretical ideas in tools
4. **Experiment:** Demonstrate economic value of criteria-based testing and ATDG (*ROI*)
   - Which criteria should be used and when?
   - When does the extra effort pay off?
5. **Integrate** high-end testing with development

Needs from educators

1. **Disguise** theory from engineers in classes

2. **Omit** theory when it is not needed

3. **Restructure** curricula to teach more than test design and theory
   - Test **automation**
   - Test **evaluation**
   - **Human-based** testing
   - **Test-driven** development

Changes in practice

1. **Reorganize** test and QA teams to make effective use of individual abilities
   - One math-head can support many testers
2. **Retrain** test and QA teams
   - Use a process like MDTD
   - Learn more testing concepts
3. **Encourage** researchers to embed and isolate
4. **Get involved** in curricular design efforts through industrial advisory boards

Criteria 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

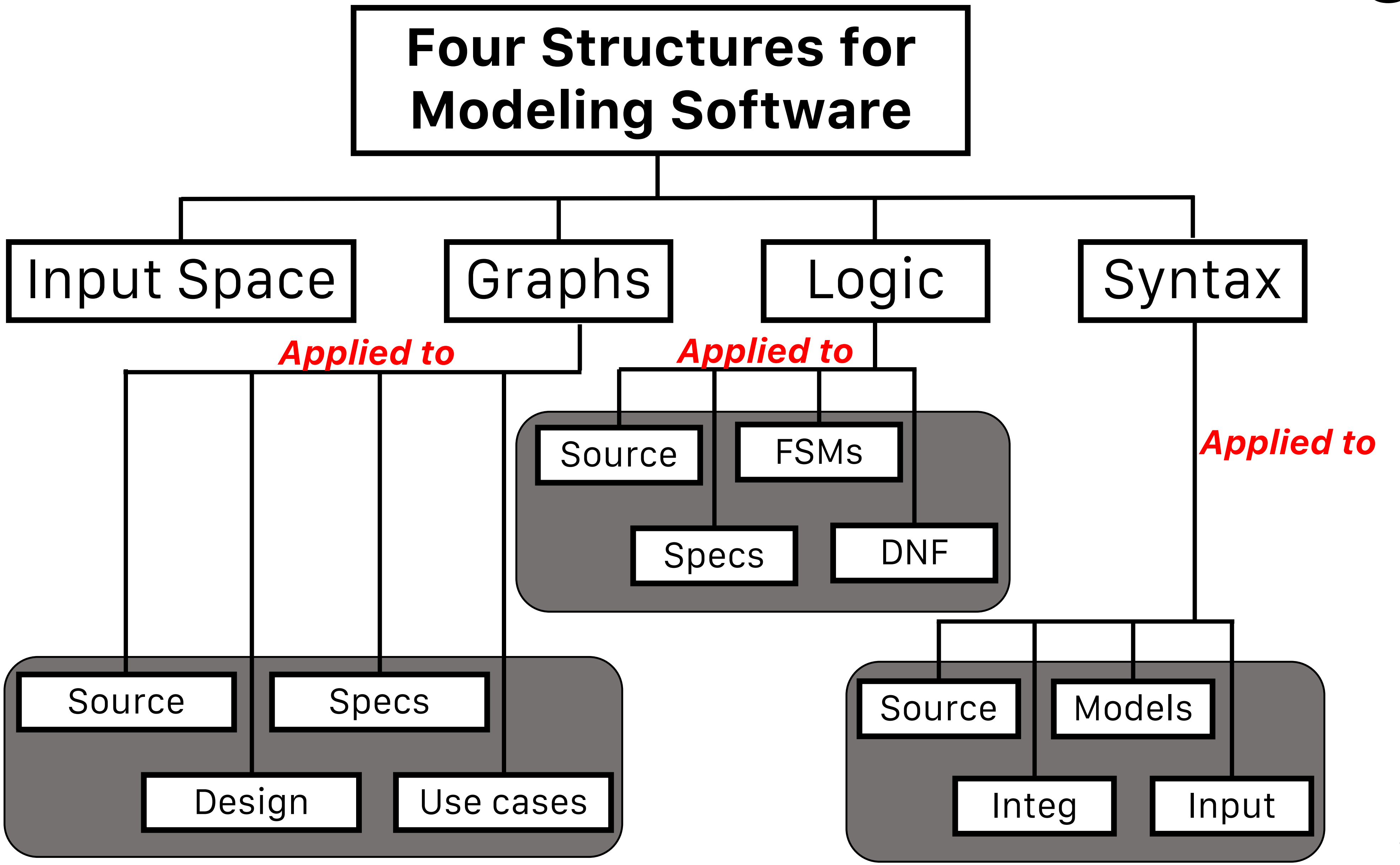
But companies that use both automation and criteria-based testing

Save money

Find more faults

Build better software

Structures for criteria-based testing



Summary of Part 1's new ideas

1. **Why** do we test – to **reduce the risk** of using software
   - faults, failures, the RIPR model
   - Test **process maturity** levels – level 4 is a **mental discipline** that improves the **quality** of the software
2. Model-driven test design
   - Four types of test **activities** – test design, automation, execution, and evaluation
3. Test automation
   - Testability, observability and controllability, test automation frameworks (e.g., JUnit)
4. Test-driven development
5. Criteria-based test design
   - **Four structures** – test **requirements** and **criteria**

Earlier and better testing <u>empowers</u> test managers