Test Suite Design

- **Objectives**
  - Functional correctness
  - Nonfunctional attributes (performance, ...)


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- **Components – The Automated Testing Pyramid**
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- Components – The Automated Testing Pyramid

Diagram:
- Unit
- Integration/Component/
- API/
- System
- UI

Integrated vs. Isolated
- Slow vs. Fast
Test Suite Design

- Objectives
  - Functional correctness
  - Nonfunctional attributes (performance, ...)

- Components – The Automated Testing Pyramid
Levels of Testing

• Many different levels of testing can be considered:
  – Unit Tests
  – Integration Tests
  – System Tests
  – Acceptance Tests
  – ...

Levels of Testing

- Many different levels of testing can be considered:
  - Unit Tests
  - Integration Tests
  - System Tests
  - Acceptance Tests
  - ...
- The simplest of these is *Unit Testing*
  - Testing the smallest possible fragments of a program
Unit Testing

- Try to ensure that the *functionality* of each component works in isolation
Unit Testing

• Try to ensure that the *functionality* of each component works in isolation
  – *Unit Test* a car:
    Wheels work. Steering wheel works....
Unit Testing

- Try to ensure that the *functionality* of each component works in isolation
  - **Unit Test** a car:
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  - **Integration Test** a car:
    - Steering wheel turns the wheels....
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  - **System Test** a car:
    Driving down the highway with the air conditioning on works...
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• Not testing how well things are glued together.
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- In practice, there is a lot more debate on this than you might expect
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  - Degrees of isolation
  - Big & Small  vs  Unit & Integration
Unit Testing

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  - Unit Test a car:
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    - Big & Small
    - ...
Unit Tests

- A dual view:
  - They specify the expected behavior of individual components
Unit Tests

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  – An executable specification
Unit Tests

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● Can even be built first & used to guide development
  – Usually called Test Driven Development
Unit Tests

• A dual view:
  – They specify the expected behavior of individual components
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• Can even be built first & used to guide development
  – Usually called Test Driven Development

In practice, this has fallen out of favor (if it ever was in favor).
Unit Tests

• Some guiding principles:
  – *Focus* on one component *in isolation*
  – Be *simple* to set up & run
  – Be easy to *understand*
Unit Tests

- Some guiding principles:
  - *Focus* on one component *in isolation*
  - Be *simple* to set up & run
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- Usually managed by some automating framework ....
GoogleTest

- Increasingly used framework for C++
  - Not dissimilar from JUnit, which you have already seen.
GoogleTest

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  – Not dissimilar from JUnit, which you have already seen.
• Test cases are written as functions:

```cpp
TEST(TriangleTest, isEquilateral) {
    Triangle tri{2,2,2};
    EXPECT_TRUE(tri.isEquilateral());
}
```
GoogleTest

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The TEST macro defines individual test cases.
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}
```

The first argument names related tests.
GoogleTest

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- Test cases are written as functions:

```cpp
TEST(TriangleTest, isEquilateral) {
  Triangle tri{2,2,2};
  EXPECT_TRUE(tri.isEquilaterial());
}
```

The second argument names individual test cases.
GoogleTest

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```cpp
TEST(TriangleTest, isEquilateral) {
    Triangle tri{2,2,2};
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}
```

EXPECT and ASSERT macros provide correctness oracles.
GoogleTest

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- Test cases are written as functions:

```cpp
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  Triangle tri{2,2,2};
  EXPECT_TRUE(tri.isEquilaterial());
}
```

**ASSERT** oracles terminate the program when they fail.

**EXPECT** oracles allow the program to continue running.
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- TEST() cases are automatically registered with GoogleTest and are executed by the test driver.
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- Some tests require common setUp & tearDown
  - Group them into test fixtures
  - A fresh fixture is created for each test
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• Some tests require common setUp & tearDown
  – Group them into test fixtures
  – A fresh fixture is created for each test
  – Fixtures enable using the same configuration for multiple tests
class StackTest : public ::testing::Test {
  protected:
    void SetUp() override {
      s1.push(1);
      s2.push(2);
      s2.push(3);
    }

    void TearDown() override { }

    Stack<int> s1;
    Stack<int> s2;
};

Derive from the fixture base class
class StackTest : public ::testing::Test {
protected:
  void SetUp() override {
    s1.push(1);
    s2.push(2);
    s2.push(3);
  }

  void TearDown() override {
  }

  Stack<int> s1;
  Stack<int> s2;
};

SetUp() will be called before all tests using the fixture
class StackTest : public ::testing::Test {
protected:
  void SetUp() override {
    s1.push(1);
    s2.push(2);
    s2.push(3);
  }

  void TearDown() override {
  }

Stack<int> s1;
Stack<int> s2;
};

TearDown() will be called after all tests using the fixture
Use the fixture in test cases defined with TEST_F:

```cpp
TEST_F(StackTest, popOfOneIsEmpty) {
  s1.pop();
  EXPECT_EQ(0, s1.size());
}
```
GoogleTest - Fixtures

Use the fixture in test cases defined with TEST_F:

```cpp
TEST_F(StackTest, popOfOneIsEmpty) {
  s1.pop();
  EXPECT_EQ(0, s1.size());
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Use the fixture in test cases defined with TEST_F:

```cpp
TEST_F(StackTest, popOfOneIsEmpty) {
  s1.pop();
  EXPECT_EQ(0, s1.size());
}
```

Behaves like

```cpp
{
  StackTest t;
  t.SetUp();
  t.popOfOneIsEmpty();
  t.TearDown();
}
```
GoogleTest - Fixtures

Use the fixture in test cases defined with TEST_F:

```cpp
TEST_F(StackTest, popOfOneIsEmpty) {
    s1.pop();
    EXPECT_EQ(0, s1.size());
}
```

A different expectation than before!
GoogleTest - Fixtures

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    s1.pop();
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}
```

- expected value
- observed value
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- Some tests require common setUp & tearDown
- Many different assertions and expectations available

- ASSERT_TRUE(condition);
- ASSERT_FALSE(condition);
- ASSERT_EQ(expected, actual);
- ASSERT_NE(val1, val2);
- ASSERT_LT(val1, val2);
- ASSERT_LE(val1, val2);
- ASSERT_GT(val1, val2);
- ASSERT_GE(val1, val2);
- EXPECT_TRUE(condition);
- EXPECT_FALSE(condition);
- EXPECT_EQ(expected, actual);
- EXPECT_NE(val1, val2);
- EXPECT_LT(val1, val2);
- EXPECT_LE(val1, val2);
- EXPECT_GT(val1, val2);
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GoogleTest

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- Some tests require common setUp & tearDown
- Many different assertions and expectations available
- More information available online
  - github.com/google/googletest/blob/master/googletest/docs/Primer.md
  - github.com/google/googletest/blob/master/googletest/docs/AdvancedGuide.md
Designing a Unit Test

- Common structure
Designing a Unit Test

- Common structure

```cpp
TEST_CASE("empty") {
    Environment env;
    ExprTree tree;

    auto result = evaluate(tree, env);
    CHECK(!result.has_value());
}
```
Designing a Unit Test

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```cpp
TEST_CASE("empty") {
    Environment env;
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```

This specific test uses another framework called Doctest
Designing a Unit Test

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    auto result = evaluate(tree, env);
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```

Set up a scenario
Designing a Unit Test

- Common structure

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    Environment env;
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Run the scenario
Designing a Unit Test

- **Common structure**

```cpp
TEST_CASE("empty") {
    Environment env;
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    auto result = evaluate(tree, env);
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}
```

Check the outcome
Designing a Unit Test

- Common structure

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TEST_CASE("empty") {
  Environment env;
  ExprTree tree;

  auto result = evaluate(tree, env);
  CHECK(!result.has_value());
}
```

This is sometimes known as AAA:

- Arrange
- Act
- Assert
Designing a Unit Test

- Common structure
- Tests should run in isolation

```c
struct Frob {
    Frob()
    : conn{getDB().connect()}
    {
    }
    DBConnection conn;
};
```
Designing a Unit Test

- Common structure
- Tests should run in isolation

```c
struct Frob {
    Frob()
    : conn{getDB().connect()}
    {}
    DBConnection conn;
};
```

```c
TEST_CASE("bad test 1") {
    Frob frob;
    ...
}
```

```c
TEST_CASE("bad test 2") {
    Frob frob;
    ...
}
```
Designing a Unit Test

- Common structure
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```

The order of the test can affect the results!
Designing a Unit Test

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- Tests should run in isolation

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struct Frob {
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    Frob frob;
    ...
}
```

The order of the test can affect the results!

A flaky DB can affect results!
Designing a Unit Test

- Common structure
- Tests should run in isolation!
Designing a Unit Test

- Common structure
- Tests should run in isolation

```cpp
struct Frob {
    Frob(Connection& inConn) : conn{inConn} {
    }
    Connection& conn;
};
```
Designing a Unit Test

- Common structure
- Tests should run in isolation

```cpp
struct Frob {
    Frob(Connection& inConn)
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```

*Dependency injection* allows the user of a class to control its behavior.
Designing a Unit Test

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Designing a Unit Test

- **Common structure**

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*Dependency injection* allows the user of a class to control its behavior.
Designing a Unit Test

- Common structure

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```cpp
struct Frob {
    Frob(Connection& inConn) :
        conn{inConn}
    {
    }
    Connection& conn;
};

TEST_CASE("better test 1") {
    FakeDB db;
    FakeConnection conn = db.connect();
    Frob frob{conn};
    ...
}
```
Designing a Unit Test

- Common structure
- Tests should run in isolation

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struct Frob {
    Frob(Connection& inConn) : conn{inConn} {
    }
    Connection& conn;
};
```

```cpp
TEST_CASE("better test 1") {
    FakeDB db;
    FakeConnection conn = db.connect();
    Frob frob{conn};
    ...
}
```

More on this later!
Common Patterns (Ammonn & Offutt)

- Checking State
  - Final State
    - Prepare initial state
    - Run test
    - Check final state
Common Patterns (Ammonn & Offutt)

- Checking State
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  - Pre and Post conditions
    - Check initial state as well as final state
Common Patterns (Ammonn & Offutt)

• Checking State
  – Final State
    • Prepare initial state
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    • Check initial state as well as final state
  – Relative effects
    • Check final state relative to some initial state
Common Patterns (Ammonn & Offutt)

- Checking State
  - Final State
    - Prepare initial state
    - Run test
    - Check final state
  - Pre and Post conditions
    - Check initial state as well as final state
  - Relative effects
    - Check final state relative to some initial state
  - Round trips
    - Check behavior on transform/inverse transform pairs
Common Patterns (Ammonn & Offutt)

- Checking Interactions/Behavior
  - Use *mocks*
Common Patterns (Ammonn & Offutt)

- Checking Interactions/Behavior
  - Use *mocks*
    - Testing 'fakes' that verify expected interactions
    - http://googletesting.blogspot.ca/2013/03/testing-on-toilet-testing-state-vs.html
Common Patterns (Ammonn & Offutt)

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TEST_CASE("better test 1") {
    FakeDB db;
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```

The FakeConnection could check that DB interactions are correct.
Common Patterns (Ammonn & Offutt)

- Checking Interactions/Behavior
  - Use *mocks*
    - Testing 'fakes' that verify expected interactions
    - http://googletesting.blogspot.ca/2013/03/testing-on-toilet-testing-state-vs.html

```cpp
TEST_CASE("better test 1") {
    FakeDB db;
    FakeConnection conn = db.connect();
    Frob frob{conn};
    ...
}
```

The FakeConnection could check that DB interactions are correct.

NOTE: Test doubles for isolation are good, but mocks should be used sparingly.
Testability

- What makes testing hard?
  - Not just difficult to get adequacy
  - What makes it difficult to write tests?
Testability

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- Dependencies
  - Connections between classes
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- Dependencies
  - Connections between classes
  - Singletons
  - Nondeterminism
Testability

• What makes testing hard?
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  – What makes it difficult to write tests?

• Dependencies
  – Connections between classes
  – Singletons
  – Nondeterminism
  – Static binding (mitigated by parametric polymorphism)
Testability

• What makes testing hard?
  – Not just difficult to get adequacy
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• Dependencies
  – Connections between classes
  – Singletons
  – Nondeterminism
  – Static binding
  – Mixing construction & application logic
  – ...

81
Testability

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  – What makes it difficult to write tests?

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  – Connections between classes
  – Singletons
  – Nondeterminism
  – Static binding
  – Mixing construction & application logic
  – ...

But solutions exist!
You can design code to be testable!
Testability (by example)

• Let's work together to improve some difficult to test code....
Testability

• Keys things to notice:
  – *Mocks* & *stubs* allow us to isolate components under test
Testability

● Keys things to notice:
  – *Mocks* & *stubs* allow us to isolate components under test
  – *Dependency Injection* allows us to use mocks and stubs as necessary
Testability

- Keys things to notice:
  - *Mocks* & *stubs* allow us to isolate components under test
  - *Dependency Injection* allows us to use mocks and stubs as necessary
  - But doing this can lead to a lot more work and boilerplate code when written by hand
Testability

• Keys things to notice:
  – *Mocks* & *stubs* allow us to isolate components under test
  – *Dependency Injection* allows us to use mocks and stubs as necessary
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Given dependency injection, what happens to the way we create objects?
Testability

- Keys things to notice:
  - *Mocks* & *stubs* allow us to isolate components under test
  - *Dependency Injection* allows us to use mocks and stubs as necessary
  - But doing this can lead to a lot more work and boilerplate code when written by hand

Given dependency injection, what happens to the way we create objects? How might we mitigate boilerplate issues?
Mocking Framework Example

- Frameworks exist that can automate the boilerplate behind:
Mocking Framework Example

- Frameworks exist that can automate the boilerplate behind:
  - Mocking
    - e.g. GoogleMock, Mockito, etc.
Mocking Framework Example

- Frameworks exist that can automate the boilerplate behind:
  - Mocking
    - e.g. GoogleMock, Mockito, etc.
  - Dependency Injection
    - e.g. Google Guice, Pico Container, etc.
Using GoogleMock

• Steps:
  1) Derive a mock class from the class you wish to fake
Using GoogleMock

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  1) Derive a mock class from the class you wish to fake

```cpp
class Thing {
  public:
    virtual int foo(int x);
    virtual void bar(int y);
};
```
Using GoogleMock

• Steps:

  1) Derive a mock class from the class you wish to fake

```cpp
class Thing {
public:
    virtual int foo(int x);
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};
```

```cpp
class MockThing : public Thing {
public:
    ... 
};
```
Using GoogleMock

- **Steps:**

  1) Derive a mock class from the class you wish to fake

  2) Replace *virtual* calls with uses of `MOCK_METHOD()`.

```cpp
class Thing {
    public:
        virtual int foo(int x);
        virtual void bar(int y);
};

class MockThing : public Thing {
    public:
        ...
        MOCK_METHOD(int, foo, (int x), (override));
        MOCK_METHOD(void, bar, (int y), (override));
};
```
Using GoogleMock

• Steps:
  1) Derive a mock class from the class you wish to fake
  2) Replace virtual calls with uses of MOCK_METHOD().
  3) Use the mock class in your tests.
Using GoogleMock

- Steps:
  1) Derive a mock class from the class you wish to fake
  2) Replace virtual calls with uses of MOCK_METHOD().
  3) Use the mock class in your tests.
  4) Specify expectations before use via EXPECT_CALL().
     - What arguments? How many times? In what order?

```
InSequence dummy;
EXPECT_CALL(mockThing, foo(Ge(20))).Times(2)
    .WillOnce(Return(100))
    .WillOnce(Return(200));
EXPECT_CALL(mockThing, bar(Lt(5)));
```
Using GoogleMock

• Steps:
  1) Derive a mock class from the class you wish to fake
  2) Replace virtual calls with uses of `MOCK_METHOD()`.
  3) Use the mock class in your tests.
  4) Specify expectations before use via `EXPECT_CALL()`.
     • What arguments? How many times? In what order?
  5) Expectations are automatically checked in the destructor of the mock.
Using GoogleMock

- Precisely specifying mock behavior

```cpp
InSequence dummy;
EXPECT_CALL(mockThing, foo(Ge(20)))
  .Times(2) // Can be omitted here
  .WillOnce(Return(100))
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EXPECT_CALL(mockThing, bar(Lt(5)));```

99
Using GoogleMock

- Precisely specifying mock behavior

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EXPECT_CALL(mockThing, bar(Lt(5)));
```
Using GoogleMock

- Precisely specifying mock behavior

```cpp
InSequence dummy;
EXPECT_CALL(mockThing, foo(Ge(20)))
  .Times(2) // Can be omitted here
  .WillOnce(Return(100))
  .WillOnce(Return(200));
EXPECT_CALL(mockThing, bar(Lt(5)));
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Complex behaviors can be checked using these basic pieces.
Using GoogleMock

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Using GoogleMock

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- A stub will prevent interaction with external resources and possibly return fake data.

What might this imply about where you use mocks vs where you use stubs?
Summary

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- Testing small components *bootstraps confidence* in the system on confidence in its constituents.
- Tests can verify *state* or *behaviors*.
- Software must be *designed for testing* (or designed by testing)