Testability and API Design

John Pavan, Lukas Zhao & Aram Chung

C++ now 2024

Testability and API Design

C++Now 2024
May 1, 2024

Aram Chung, Software Engineer
John Pavan, Team Lead
Lukas Zhao, Senior Software Engineer

TechAtBloomberg.com

Bloomberg Engineering

Contents

Background & Basics

- Brief testing overview
- Obligatory testing pyramid slide
- Some definitions

TechAtBloomberg.com

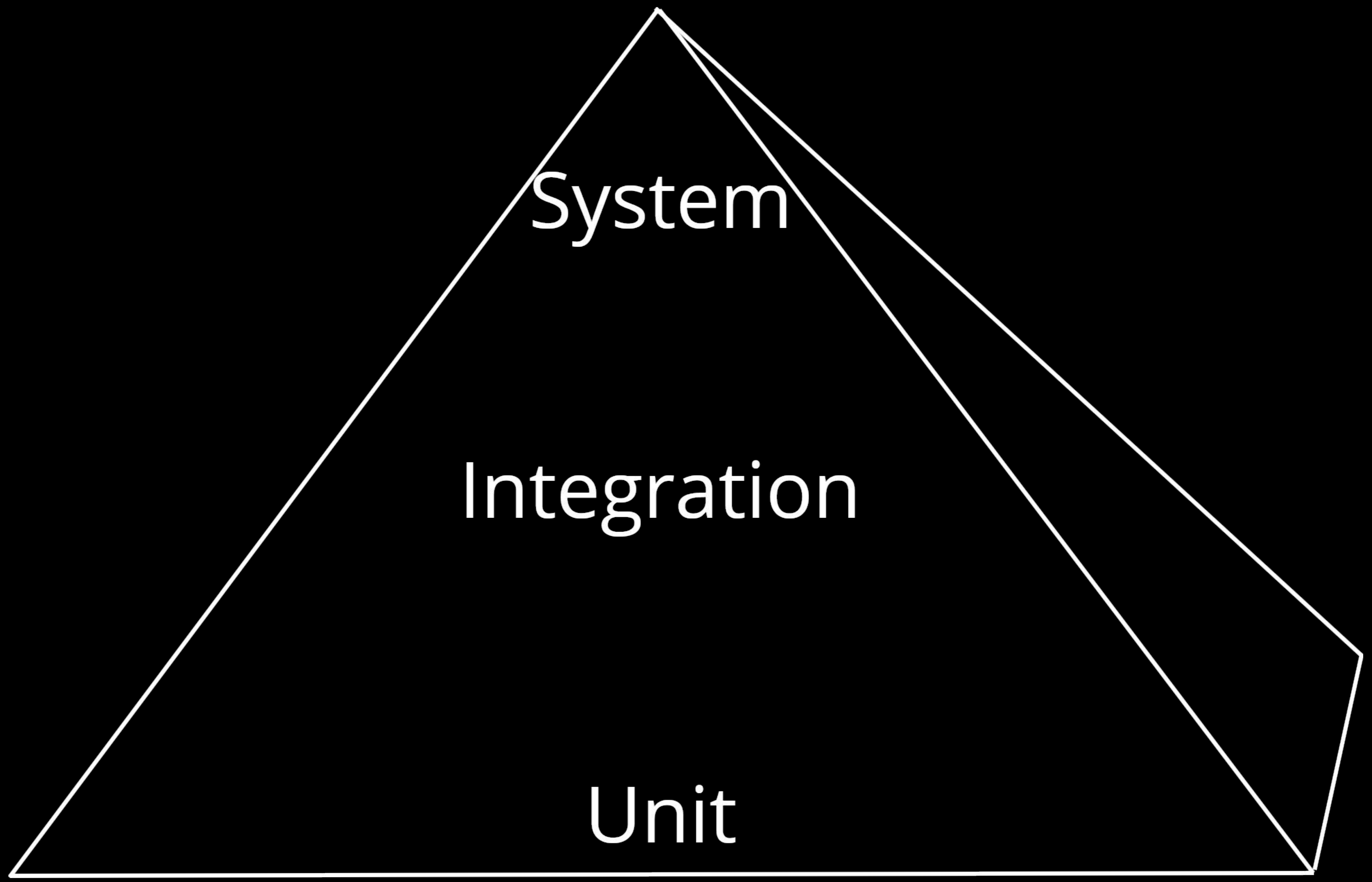
Bloomberg

Engineering

The Importance of testing

- Testing can verify both the happy-path and unhappy-path behaviors of your code
- Automated tests are run regularly, protect against regressions, and add value over time
- Unit, integration, and system tests have different roles and provide different benefits

Obligatory Testing Pyramid Slide



Unit Tests

- What component is tested? A unit test tests a component in isolation, with external dependencies stubbed out
- What behaviors are tested? A unit test verifies both happy-path and unhappy-path behaviors
- What is the goal? A unit test verifies the component/class does what is expected
- What is mocked out? In a unit test, other components and classes need to be mocked out

(Did we mention that a unit test can test unhappy-path behaviors?)

Bloomberg

Engineering

Integration Tests

- What component is tested? An integration test tests a component that is running in the expected environment. This could be the full executable running in a contrived environment
- What behaviors are tested? An integration test verifies happy-path behaviors; it can be very difficult to test unhappy-path behaviors (e.g., force an I/O error) in an integration test
- What is the goal? An integration test verifies that the component behaves as expected for its expected use case
- What is mocked out? In an integration test, other executables or system-level dependencies are often mocked out

Bloomberg
Engineering

System Tests

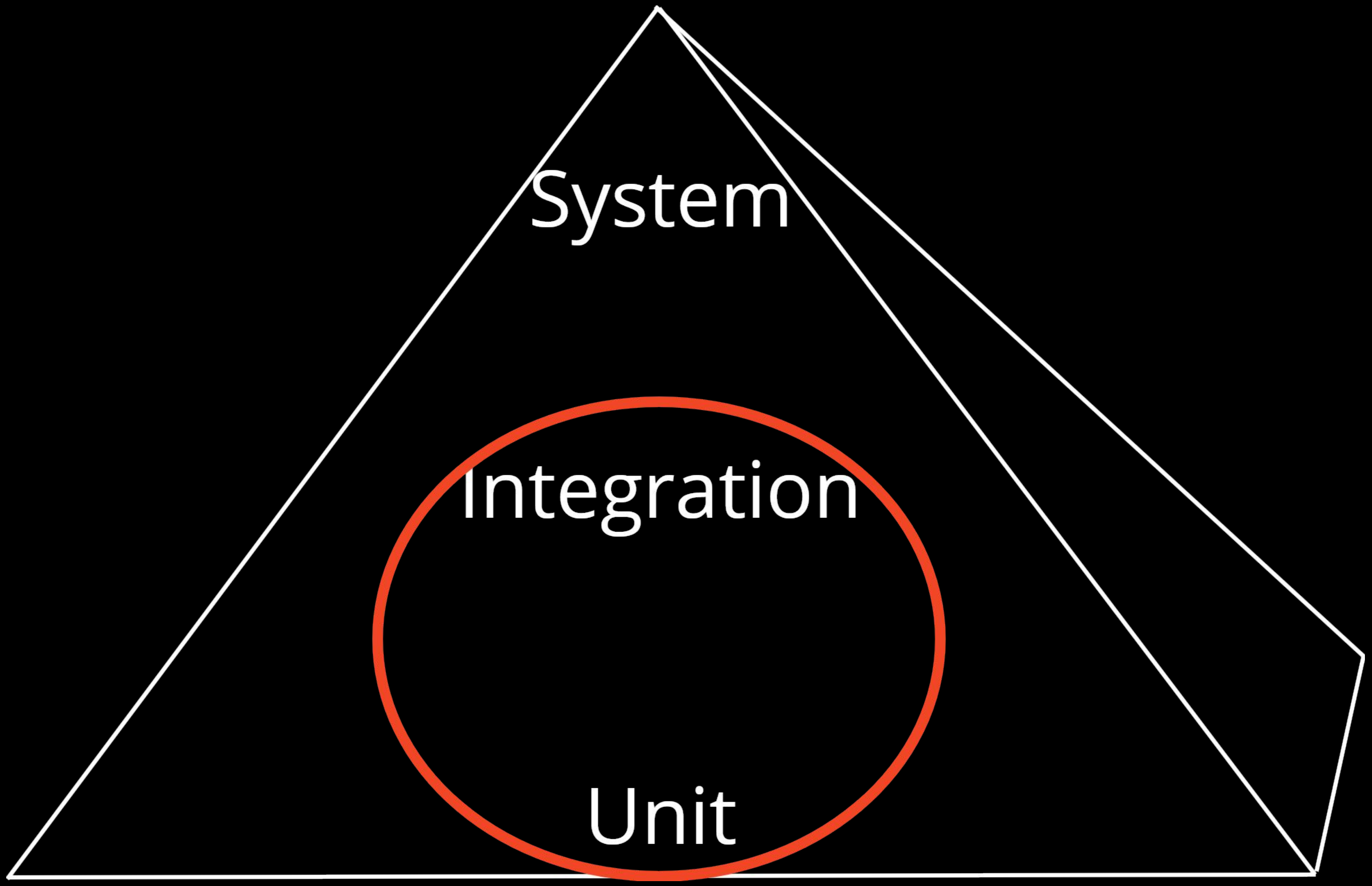
- What component is tested? A system test tests an executable deployed to a test environment

- What behaviors are tested? A system test verifies happy-path behaviors

- What is the goal? A system test verifies functionality when integrated into a production-like system

- What is mocked out? In a system test, dependencies are not mocked out

Obligatory Testing Pyramid Slide



Motivation

- Designing for testability
- Designing for usage in test drivers
- Synergy between these & SOLID design principles

Designing for Testability

- How do I, the implementer, test my code?
- There is a deep synergy between testability and SOLID design principles

Designing for usage in test drivers

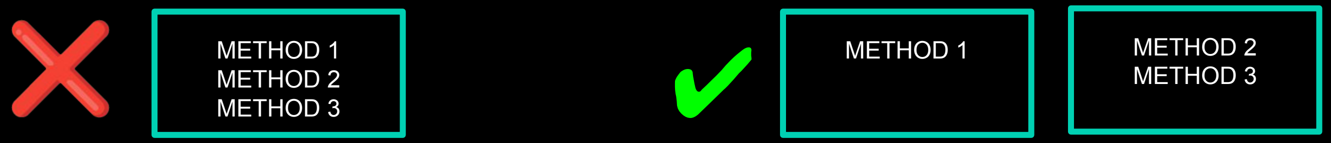
- How do the users of my library test their code?
- The API must be usable in test drivers and integration tests
- If mocking is the chosen approach, mock objects must be provided

SOLID Design Principles

- Single Responsibility principle
- Open-closed principle
- Liskov substitution principle
- Interface segregation principle
- Dependency Inversion principle

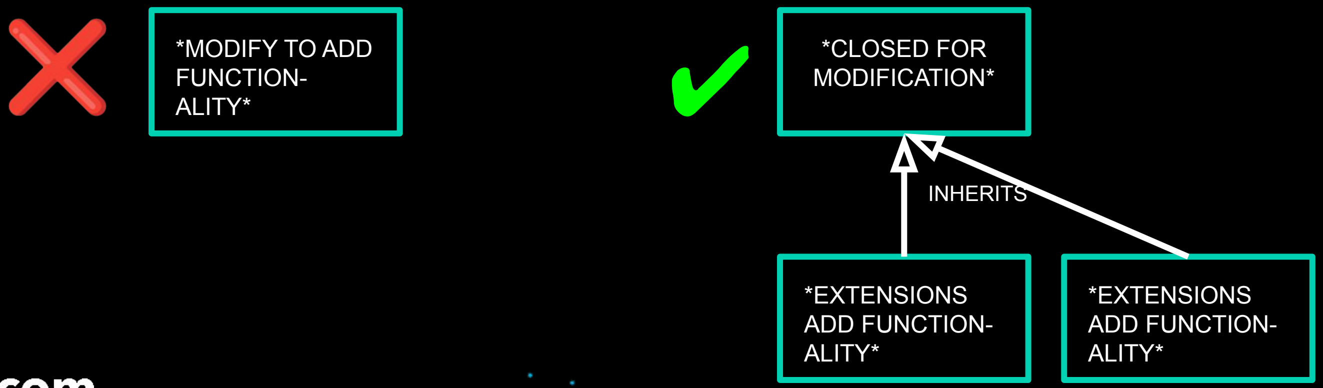
Single Responsibility Principle

- Each class should only do one thing
- The single responsibility and interface segregation principles help not only with testing, but also with overall API design



Open-closed principle

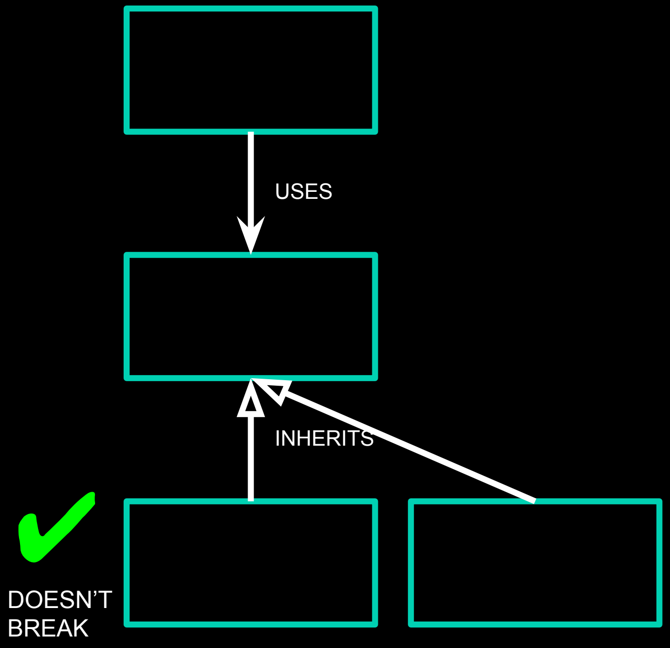
- “Software entities should be open for extension, but closed for modification.”
- “Be able to add new functionality without changing existing code.”
- Polymorphic: Abstract interface with multiple implementations



Liskov Substitution Principle

- a.k.a. Strong Behavioral Subtyping

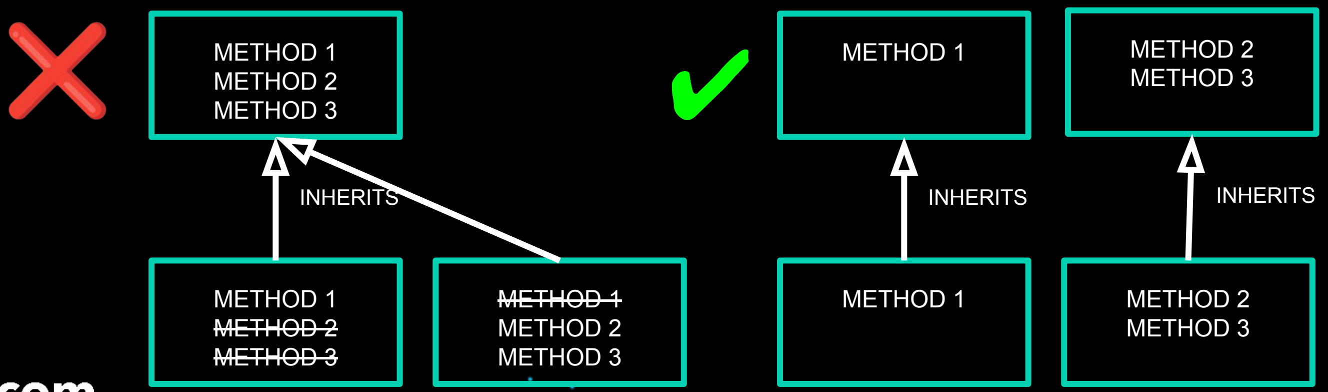
- Should be able to replace any class with any class derived from it without breaking what's using it



BREAKS

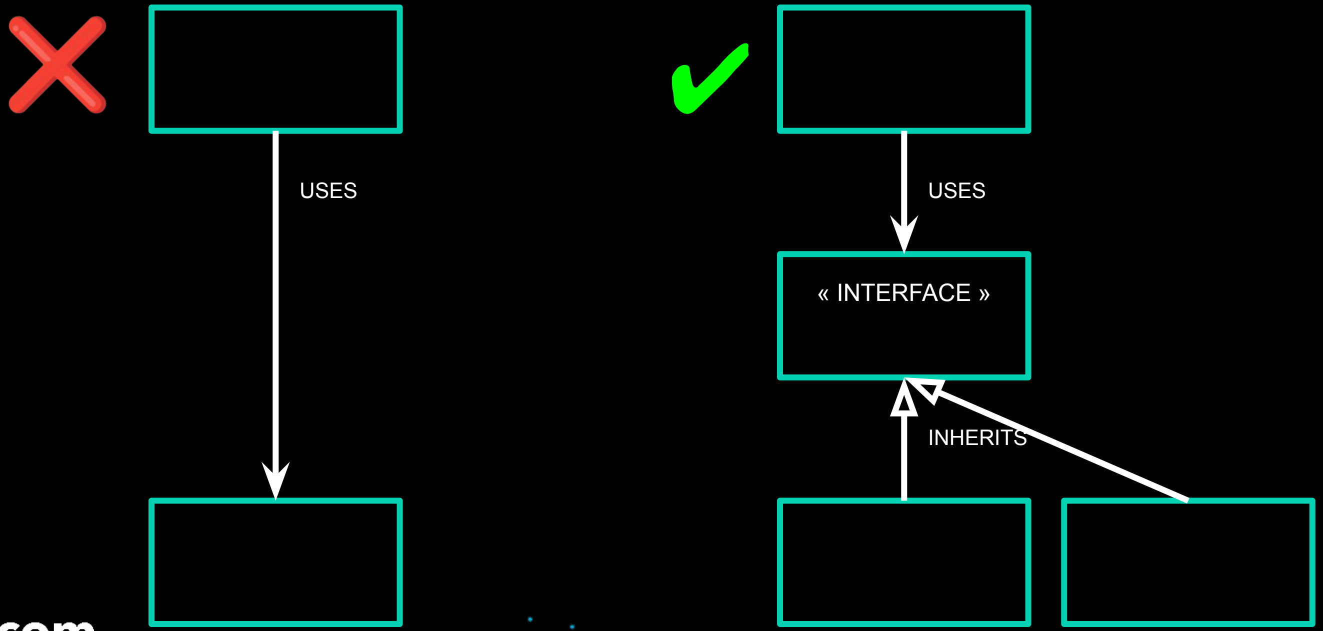
Interface Segregation Principle

- “No code should be forced to depend on methods that it does not use.”
- Split large interfaces into smaller ones



Dependency inversion principle

- "High-level modules should not import anything from low-level modules. Both should depend on abstractions (interfaces)."
- "Abstractions should not depend on details. Details (concrete implementations) should depend on abstractions."



Additional Considerations

- The API shouldn’t have features that exist only for testing
- API choices shouldn’t prevent testing
- You may need a way to stub out system dependencies

Techniques

- PImpl Idiom
- Depend only on interfaces
- Adding test APIs via ‘guards’
- Abstract Factory Methods

Interfaces and the PImpl idiom (1 of 2)

- “Pointer to implementation”
- Implementation details are stored in a separate class
- Allows different implementations for different systems and tests
- Implementations can be tested independently of the API
- Unit tests can have full access to the internals of the implementation

Interfaces and the Pimpl idiom (2 of 2)

```
// Without PImpl:
class Foo {
  // …
  public:
    void func1()
    { // … }
    // …
};
```

```
struct FooImpl {
    void func1()
    {  //…  }
    // …
};

class Foo {
  std::unique_ptr<FooImpl> d_impl;
  public:
    void func1() { d_impl->func1(); }
    // …
};
```

Example (Good): BlazingMQ's CRC32 checksums (1 of 2)

```
// public API:
struct Crc32c {
    static unsigned int calculate(
                  const void* data,
                  unsigned int length,
                  unsigned int crc = k_NULL_CRC32C);
    //...
};
```

Example (Good): BlazingMQ’s CRC32 checksums (2 of 2)

```
struct Crc32c_Impl {
    static unsigned int calculateSoftware(
      const void* data,
      unsigned int length,
      unsigned int crc = Crc32c::k_NULL_CRC32C);

    static unsigned int calculateHardwareSerial(
      const void* data,
      unsigned int length,
      unsigned int crc = Crc32c::k_NULL_CRC32C);
     // ...
};
```

Depend only on interfaces (1 of 6)

- Calls back to the (polymorphic) open-closed, Liskov substitution, and dependency-inversion principles
- Makes mocks and stubs easier to implement
- Create interfaces for anything needed to write tests
  - Including system calls

Depend only on interfaces (2 of 6)

Pass interfaces into the Ctor

```
class Foo {
    Interface1* d_interface1_p;
    Interface2* d_interface2_p;
  public:
    Foo(Interface1* intrf1, Interface2* intrf2);
    void func1();
    // ...
};
```

Depend only on interfaces (3 of 6)

What if you depend on something that isn’t an interface?

```
class Foo {
  // ...
  public:
    using bsl::function<void()> FooFunctor;
  private:
    FooFunctor d_fooFunctor;
  public:
    Foo(FooFunctor fooFunctor =
ProdBehavior());
  // ...
};
```

Depend only on interfaces (4 of 6)

Provide interfaces for those using your library

```
class FooIntrf {
    virtual void func1() = 0;
    // ...
};

class Foo : public FooIntrf {
    // ...
  public:
    virtual void func1();
    // ...
};
```

Depend only on interfaces (5 of 6)

Templates as a workaround to avoid heap allocation

```
template <typename BAR>
class Foo {
    BAR* d_bar_p;
  public:
    Foo(BAR* bar);
    void func1();
    // …
};

using Foo<RealBar> RealFoo;
using Foo<TestBar> TestFoo;
```

```
class FooIntrf {
    virtual void func1() = 0;
    // …
};

template<typename BAR>
class Foo : public FooIntrf {
 // …
};

using Foo<RealBar> RealFoo;
using Foo<TestBar> TestFoo;
```

Depend only on interfaces (6 of 6)

Example (Good): things that use bslma::Allocator

```
bdlbb::PooledBlobBufferFactory(
           int bufferSize,
           bslma::Allocator *basicAllocator = 0);
```

How to add test APIs (1 of 4)

- Single responsibility and interface segregation principles mean we shouldn't have test-specific functions/methods in the public API

- Resource-Acquisition-Is-Initialization (RAII) style guard that adds the test methods and functions

How to add test APIs (2 of 4)

Good Example: bdlmt::EventScheduler and EventSchedulerTestTimeSource

```
bdlmt::EventScheduler schdlr;
bdlmt::EventSchedulerTestTimeSource tstTmSrc(&schdlr);
// ...
schdlr.start()
// ...
tstTmSrc.advanceTime(bsls::TimeInterval(40));
// ...
```

How to add test APIs (3 of 4)

```
class Foo {
  // ...
    ThingFunctor d_thingFunctor;
    friend class FooTestGrd;
  public:
    Foo();
    void func1();
    void func2();
  // ...
};
```

```
class FooTestGrd {
  // ...
  public:
    FooTestGrd(Foo* foo);
    void testAPI1();
    void testAPI2();
    // ...
};
```

How to add test APIs (4 of 4)

```
class OwnsFoo {
    Foo d_foo; // no way to install FooTestGrd
  public:
    OwnsFoo();
};
```

```
class UsesFoo {
    Foo* d_foo_p;
  public:
    UsesFoo(Foo* foo); // pass in w/ FooTestGrd
};
```

Abstract Factory Pattern (1 of 2)

```
class FactoryIntf {
  public:
    FactoryIntf();
    virtual ~FactoryIntf();

    virtual FooIntf* makeFoo() const;
    virtual BarIntf* makeBar() const;
    virtual BazIntf* makeBaz() const;
    // …
};
```

Abstract Factory Pattern (2 of 2)

```
class RealFactory : public FactoryIntf
{
  //…
    FooImpl* makeFoo() const;
    BarImpl* makeBar() const;
    BazImpl* makeBaz() const;
    // …
};
class TestFactory : public FactoryIntf
{
  //…
    FooImpl* makeFoo() const;
    BarImpl* makeBar() const;
    BazImpl* makeBaz() const;
    // …
};
```

Example (good) - mwcio::ChannelFactory (1 of 2)

```
ChannelFactory {
  // …
    virtual void listen (
            Status* status,
            bslma::ManagedPtr<OpHandle>* handle,
            const ListenOptions& options,
            const ResultCallback& cb) = 0;
  // …
};
```

Example (good) - mwcio::ChannelFactory (2 of 2)

```
class TestChannelFactory : public ChannelFactory {
  // …
    void reset();
    void setListenStatus();
    void setConnectStatus();
    mwct::PropertyBag& newHandleProperties();
    bsl::deque<ListenCall>& listenCalls();
    bsl::deque<ConnectCall>& connectCalls();
    bsl::deque<HandleCancelCall>& handleCancelCalls();
  // …
};
```

Generalized Mocking & Testing

- Techniques
- Challenges
- A proposal for life quality improvement

Technique

- Mocking with DI via an abstract interface

- Mocking with DI via a template type

- Who is responsible for DI?
    - PImpl idiom
    - Poor man's DI

Technique - via an abstract interface

```
class DogI {
  public:
    virtual ~DogI() = default;
    virtual int bark() = 0;
};
```

```
class Dog : public DogI {
  public:
    int bark() override;
};
```

```
class DogMock : public DogI {
  public:
    MOCK_METHOD(int, bark, (),
                          (override));
};
```

```
class MyBusiness {
  private:
    shared_ptr<DogI> d_dogI;

  public:
    MyBusiness(shared_ptr<DogI> dogI)
    : d_dogI(move(dogI)) {}

    bool doSomething() {
        auto rc = d_dogI->bark();
        // ...
    }
};
```

Technique - via an abstract interface

```
class TestMyBusiness : public Test {
  protected:
    // mocks
    shared_ptr<DogMock> d_dogMock;

    // Subject Under Test (SUT)
    unique_ptr<MyBusiness> d_myBusiness;

    void SetUp() {
        // instantiate mocks
        d_dogMock = make_shared<DogMock>();

        // instantiate SUT, inject mocks
        d_myBusiness =
           make_unique<MyBusiness>(d_dogMock);
    }
};
```

```
TEST_F(TestMyBusiness, test_doSomthing)
{
    // Given
    EXPECT_CALL(*d_dogMock, bark())
        .Times(1).WillOnce(Return(0));

    // When
    bool success =
        d_myBusiness->doSomething();

    // Then
    EXPECT_TRUE(success);
}
```

Technique - via a template type

```
class Dog {
  public:
    int bark();
};
```

```
class DogMock {
  public:
    MOCK_METHOD(int, bark, ());
};
```

```
template<typename DOG_TYPE>
class MyBusiness {
  private:
    DOG_TYPE d_dog;

  public:
    MyBusiness(const DOG_TYPE& dog)
    : d_dog(dog) {}

    bool doSomething() {
        d_dog.bark();
        // ...
    }
};
```

```
TEST(TestMyBusiness, test_doSomething)
{
    // Given SUT
    MyBusiness<DogMock> myBusiness(dogMock);
    // ...
}
```

TechAtBloomberg.com

Bloomberg

Engineering

Technique - who's responsible for injecting dependencies


```
class AwesomeLib {
  private:
    int d_uuid;
    Dog d_dog;
    Cat d_cat;

  public:
    AwesomeLib(int uuid,
               shared_ptr<AsvcI> asvcI,
               shared_ptr<BsvcI> bsvcI,
               shared_ptr<CsvcI> csvcI)
    : d_uuid(uuid)
    , d_dog(uuid, asvcI)
    , d_cat(bsvcI, csvcI)
    {}

    bool talk() {
        // ...
    }
};
```

AwesomeLib user: "Do I need to inject Asvc, Bsvc, Csvc?!"

Technique - who’s responsible for DI? Pimpl idiom

TechAtBloomberg.com

Bloomberg
Engineering

Technique - who's responsible for DI? Pimpl idiom

```
class AwesomeLib : public AwesomeLibI {
  private:
    unique_ptr<AwesomeLibImp> d_awesomeLibImp;

  public:
    AwesomeLib(int uuid)
    {
        // construct real dependencies
        auto asvc = make_shared<Asvc>();
        auto bsvc = make_shared<Bsvc>();
        auto csvc = make_shared<Csvc>();

        // inject dependencies into Imp
        d_awesomeLibImp = make_unique<AwesomeLibImp>(
            uuid, asvc, bsvc, csvc);
    }

    bool talk()
    {
        return d_awesomeLibImp->talk();
    }
};
```

```
class AwesomeLibImp {
  private:
    int d_uuid;
    Dog d_dog;
    Cat d_cat;

  public:
    AwesomeLibImp(int uuid,
                  shared_ptr<AsvcI> asvcI,
                  shared_ptr<BsvcI> bsvcI,
                  shared_ptr<CsvcI> csvcI)
    : d_uuid(uuid)
    , d_dog(uuid, asvcI)
    , d_cat(bsvcI, csvcI) {}
        // AwesomeLibImp ctor opens up for
        // dependency injection, so
        // AwesomeLibImp can be unit-tested

    bool talk() {
        // real logic of talk() function
        // ...
    }
};
```

Technique - who's responsible for DI? Poor man's DI

```
class AwesomeLib : public AwesomeLibI {
  private:
    int d_uuid;
    shared_ptr<Dog> d_dog;
    shared_ptr<Cat> d_cat;

  public:
    // ctor, instantiate all deps as real impls
    AwesomeLib(int uuid) : d_uuid(uuid)
    {
        auto asvc = make_shared<Asvc>();
        auto bsvc = make_shared<Bsvc>();
        auto csvc = make_shared<Csvc>();

        d_dog = make_shared<Dog>(uuid, asvc);
        d_cat = make_shared<Cat>(bsvc, csvc);
    }
```

```
    // ctor, opens up for dep injection
    AwesomeLib(int uuid,
               shared_ptr<AsvcI> asvcI,
               shared_ptr<BsvcI> bsvcI,
               shared_ptr<CsvcI> csvcI) :
        d_uuid(uuid),
        d_dog(make_shared<Dog>(uuid, asvcI)),
        d_cat(make_shared<Cat>(bsvcI, csvcI))
    {}

    bool talk()
    {
        // ...
    }
};
```

Challenges

- Upfront investment is unpleasant; proper testable code requires more boilerplate code and more files

- New C++ engineers may not be familiar with various patterns and techniques

- Isn't it just much easier ***not*** to do the right things?

  → Make it easier to do the right things
  → "One-click" design patterns

Propose a new tool

Use a script to write boilerplate code for creating interfaces, mocks, unit tests, pimpl idiom, dependency injection, etc.

- Asks you a few questions
- Generates all boilerplate code with tests and specified patterns

Propose a new tool

Faster to do it right and better

- + No need to write boilerplate → encourage small classes
- + No need to set up unit tests → write tests as you write new functions
- + Create interface and mock
- + Create PImpl to isolate dependencies
- + Hints
- + Modern C++

Thank you!

https://techatbloomberg.com/cplusplus

https://www.bloomberg.com/careers

Contact Us!
Aram - achung118@bloomberg.net
John - jpavan@bloomberg.net
Lukas - zzhao106@bloomberg.net

TechAtBloomberg.com

Bloomberg Engineering

Extra Slides

TechAtBloomberg.com

Bloomberg

Engineering

Definitions

- Mock
  - Implements the interface
  - Provides a way to set return values and/or expectations
  - Provides a way to determine success or failure based on if it was called

- Stub
  - Implements the interface
  - Provides a way to set return values and/or expectations

- Fake
  - Satisfies the interface, but contains minimal logic and fixed data

- Happy Path
  - How the component behaves for the intended use case

- Unhappy Path
  - How the component behaves under unexpected conditions: I/O failures, time going backwards, etc.