accu 2023

SPOOKY ACTION AT A DISTANCE

VICTOR CIURA

Spooky Action at a Distance

ACCU

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@ciura_victor

@ciura_victor@hachyderm.io

Victor Ciura

Principal Engineer

Visual C++

Abstract

I hate the term “Design Patterns”. It implies there are universally applicable solutions to some common code scenarios. Just codifying existing practice into some rules and blindly following them is a comfortable path, but not the optimal one. It turns out it’s not as easy as following recipes. Each situation and best associated solution is unique.

However there is value in having uniform code structure throughout a project. So this topic is not to be discarded just yet, rather it needs more careful examination.

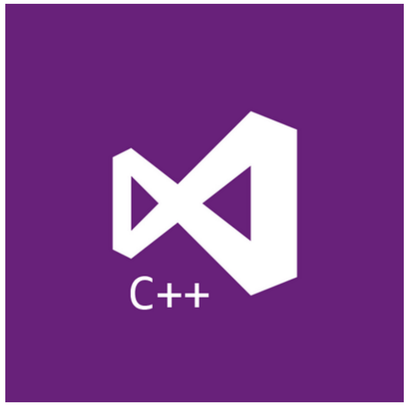
In terms of inspectable properties of objects, what have we learned from years of OO influence from other languages and frameworks? How can we leverage these borrowed techniques in a value-oriented context? Does C++ benefit from special considerations?

I think it’s time to revisit our old friend, the Observer pattern - from “theory” to practice. I’m not going to offer The Solution, rather we’re going to examine tradeoffs for several possible implementations, in various usage scenarios from a real project.

About me

Advanced Installer

Clang Power Tools



Visual C++

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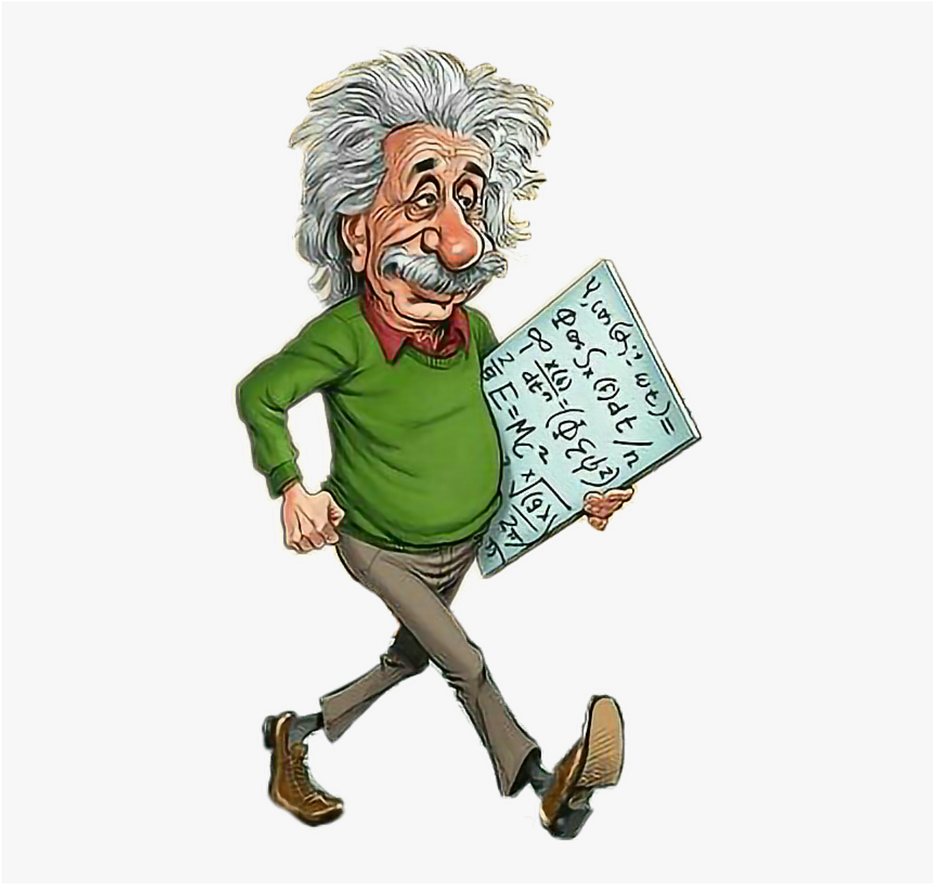
Spooky Action at a Distance

Spooky What ?

Entangled particles

Quantum entanglement or "*spooky action at a distance*" as Albert Einstein famously called it, is the idea that the fates of tiny particles are linked to each other even if they're separated by long distances.



Revisiting Observers

Alternative Title

```
Subscribe(Observer)
```

I hate the term “Design Patterns”

Design Patterns

It implies there are universally applicable solutions to some common code scenarios.

Just codifying existing practice into some rules and blindly following them is a comfortable path, but not the optimal one.

It turns out it’s not as easy as following recipes.

Each situation and best associated solution is unique.

Design Patterns

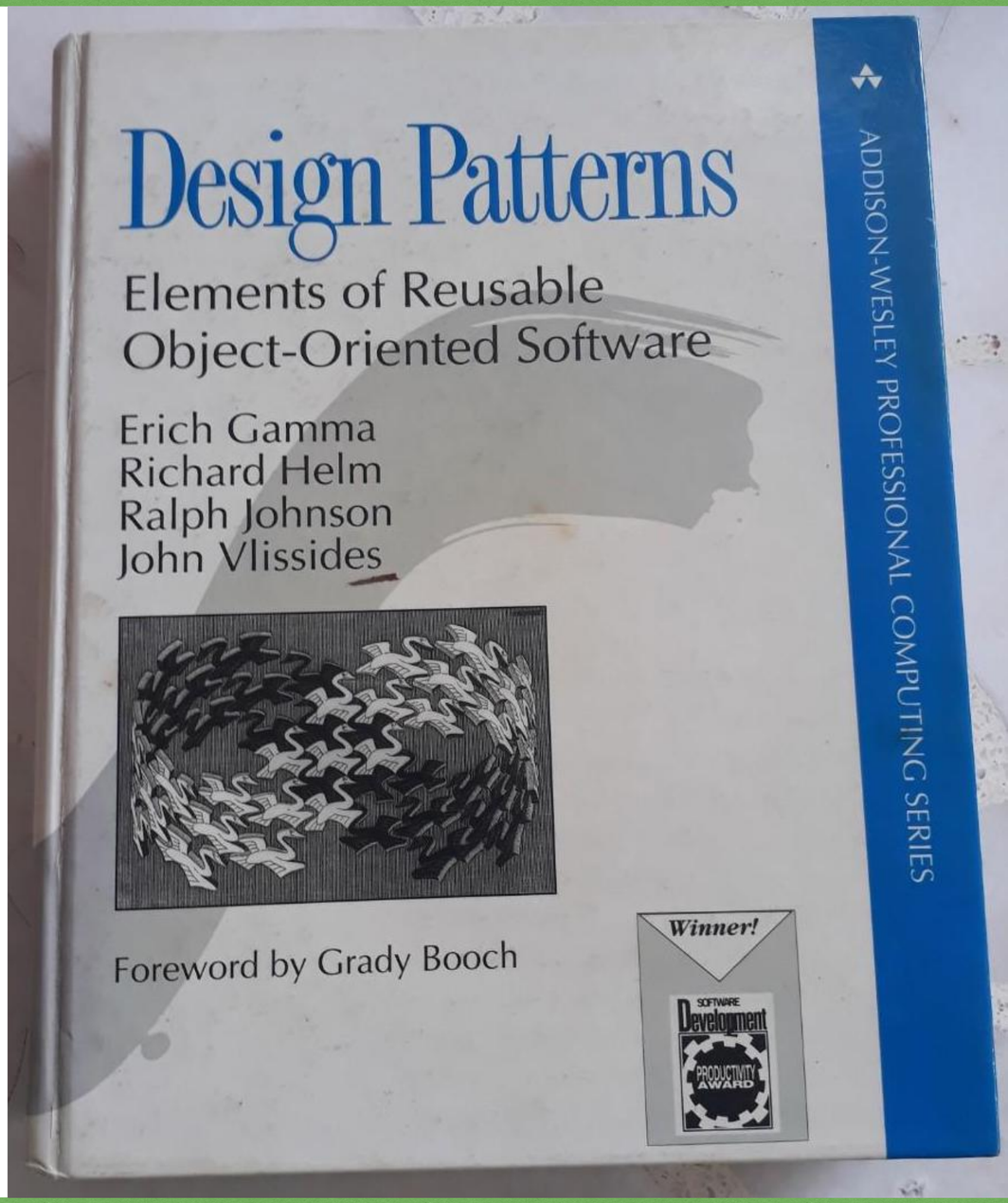
However there is value in having uniform code structure throughout a project.

So this topic is not to be discarded just yet, rather it needs more careful examination.

GoF Book

A classic

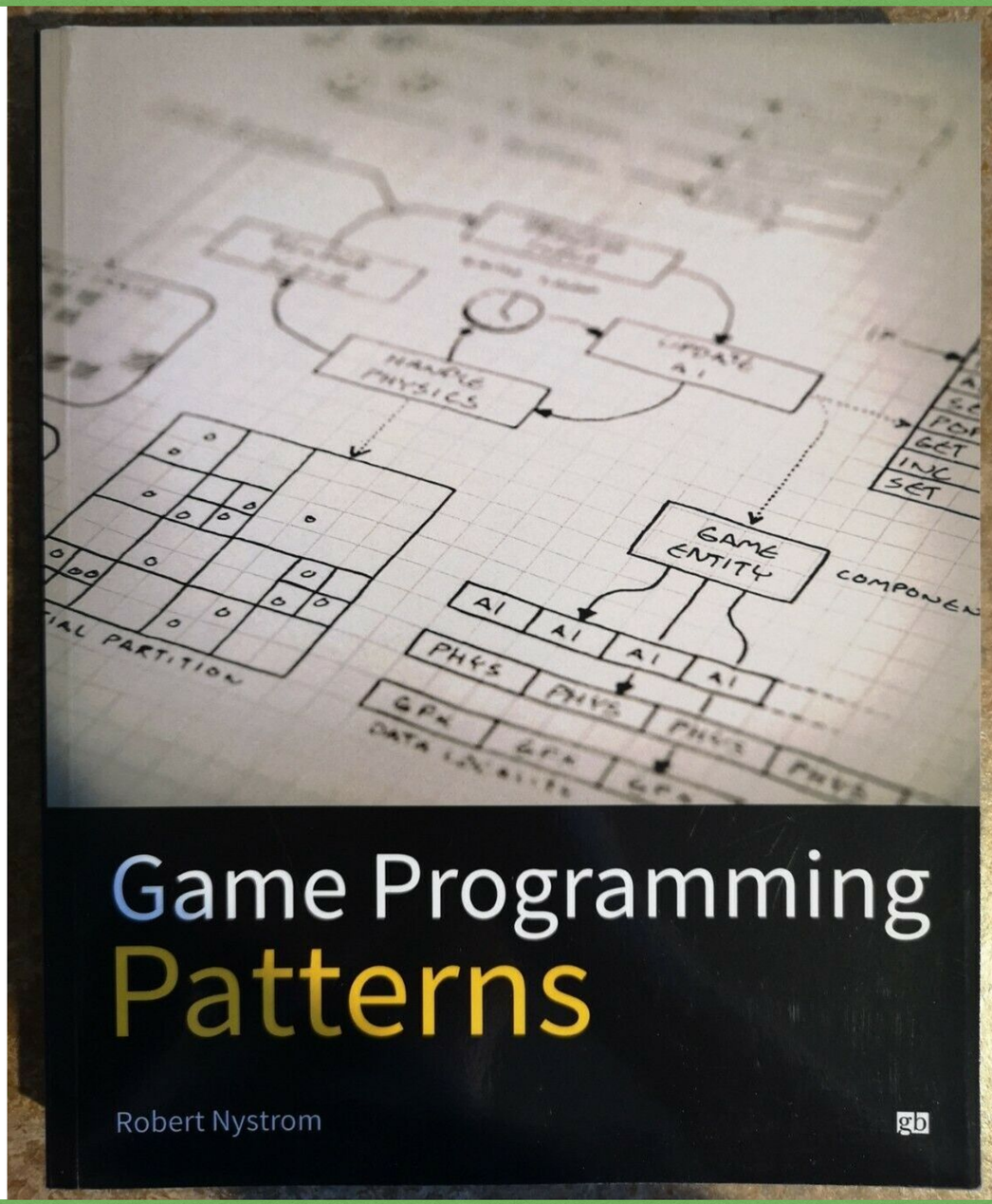
Too formal & dry



Game Programming Patterns

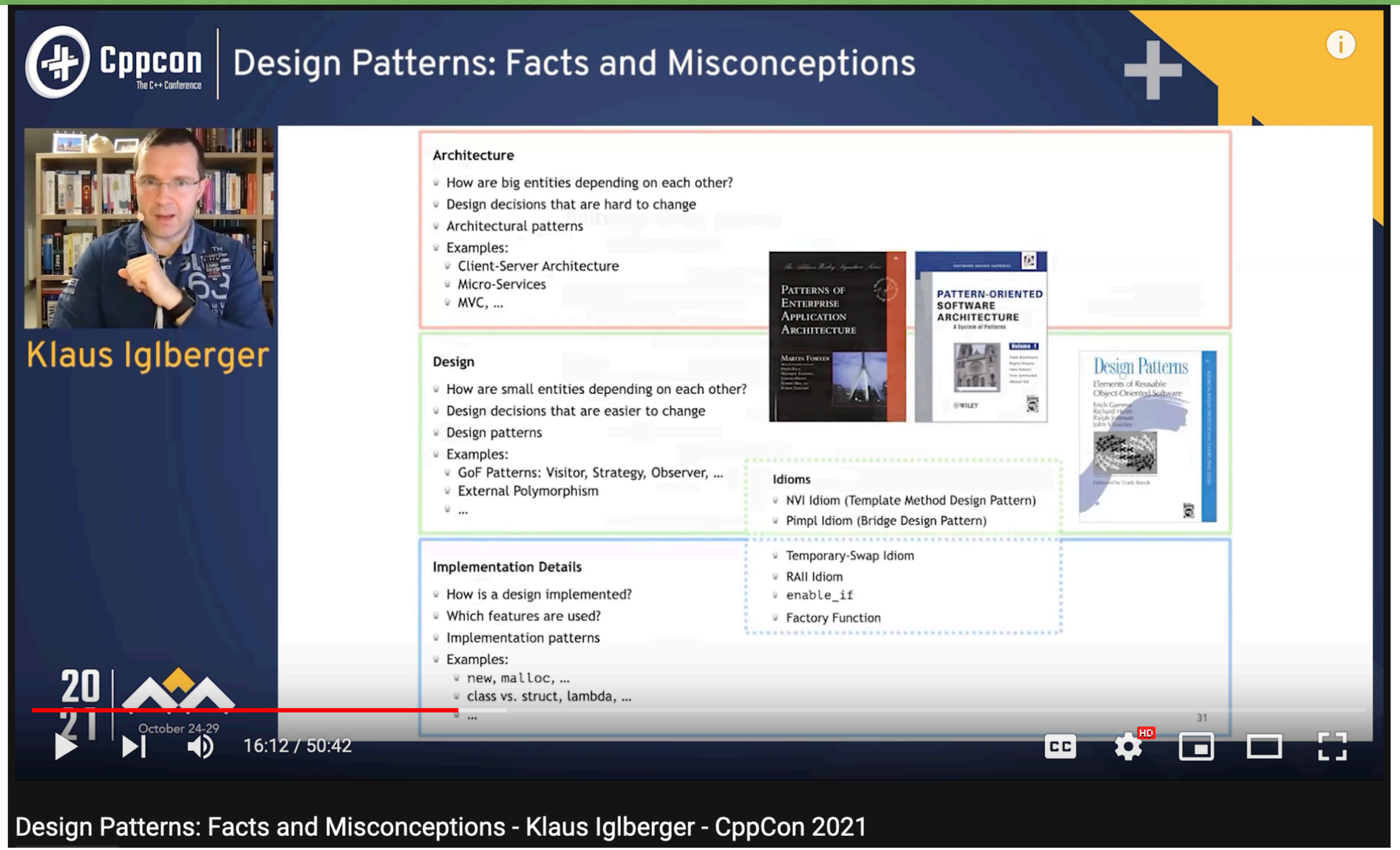
Bob Nystrom

gameprogrammingpatterns.com



amazon.com/Game-Programming-Patterns-Robert-Nystrom/dp/0990582906/

Facts and Misconceptions



youtube.com/watch?v=KGX6zhOWGAc

Facts and Misconceptions

❝

Design Patterns have proven to be useful over several decades and knowledge about them is still very important to design robust, decoupled systems.

However, in recent decades a lot of misconceptions have piled up, many based on misunderstandings about software design in general and Design Patterns in particular.

We need to separate facts from misconceptions about Design Patterns ans **idioms**.

Observer Pattern

In terms of inspectable properties of objects:

- What have we learned from years of **OO** influence from other languages and frameworks?
- How can we leverage these borrowed techniques in a value-oriented context?
- Does C++ benefit from special considerations?

Observer Pattern

Let's revisit our old friend, the Observer pattern - from theory to practice.

I’m not going to offer The Solution™

We’re going to examine tradeoffs for several possible implementations, in various usage scenarios from a real project.

Observer Pattern

Observers are everywhere...

Think:

- MVC
- MVVM
- Qt signal-slot mechanism
- not just GUI ↔ model, also model ↔ model

Observer Pattern

It's a show with Actors and Actions

Subject/Actor doesn’t know what (type) the Observers are.

It just knows that they exist and how to notify them when certain actions occur.

Low Coupling

Subscription Model

Tune-in to a particular radio station

Remote Objects

Inspectable properties and remote objects

"*spooky action at a distance*"

```
class Widget
{
  Data mData;

public:

  void Set(const Data & d) {
    if (d != mData) {
      mData = d;
      NotifyObservers();
    }
  }
};
```

Subscription Order

Observers added in a certain order.

Do they respond in the same order?

```
class Widget
{
  ... Salient Data

  std::vector<IObserver *> mObservers;
};
```

Subscribing

```
void Widget::AddObserver(IObserver & aObserver)
{
  // too simple, right?
  mObservers.push_back(&aObserver);
}
```

Over-subscribing

Adding an observer more than once?

```
void Widget::AddObserver(IObserver & aObserver)
{
  auto found = std::find(mObservers.begin(), mObservers.end(), &aObserver);

  if (found == mObservers.end())
    mObservers.push_back(&aObserver);
}
```

Do you want to allow an observer to subscribe more than once?

Do you expect the observer to be called twice for the same event?

Over-subscribing

What about local reasoning?

```
void Func()
{
  obj->AddObserver(*this);

  ... // do something important

  obj->RemoveObserver(*this); // what if this obs was already added before?
}
```

Over-subscribing

What about local reasoning?

```
void Func()
{
  RegisterObserver obs(*this, actor); // RAII remember if we added

  ... // do something important

  // ~RegisterObserver() removes *this from observers if we added in C-tor
}
```

Over-subscribing

Signal the caller if the registration was "successful"

```
bool Widget::AddObserver(IObserver & aObserver)
{
  auto found = std::find(mObservers.begin(), mObservers.end(), &aObserver);
  if (found != mObservers.end())
    return false; // observer was already registered

  mObservers.push_back(&aObserver);
  return true;
}
```

Over-subscribing

Adding an observer more than once?

```
void Widget::AddObserver(IObserver & aObserver)
{
  mObservers.push_back(&aObserver);
}
```

We expect the observer to be called twice for the same event.

Local reasoning - restricted lifetime.

Unsubscribe

Removing an observer not in the list (already removed?)

```
void Widget::RemoveObserver(IObserver & aObserver)
{
  auto found = std::find(mObservers.begin(), mObservers.end(), &aObserver);

  if (found != mObservers.end())
    mObservers.erase(found);
}
```

For multiple registration scenario, what if we remove the wrong instance?

(sensitive to order of notification)

Unsubscribe

Removing **all** instances of this observer (multiple registration)

```
void Widget::RemoveObserver(IObserver & aObserver)
{
  mObservers.erase(
    std::remove(mObservers.begin(), mObservers.end(), &aObserver),
    mObservers.end() );
}
```

Unsubscribe

Removing **all** instances of this observer (multiple registration)

```
void Widget::RemoveObserver(IObserver & aObserver)
{
  std::erase(mObservers, &aObserver); // C++20 safer than erase-remove idiom
}
```

Priority

Who should be notified first?

```
void Widget::AddObserver(IObserver & aObserver)
{
  auto found = std::find(mObservers.begin(), mObservers.end(), &aObserver);

  if (found == mObservers.end())
    mObservers.insert(mObservers.begin(), &aObserver);
}
```

Priority

Do we need priority buckets?

```
class Widget
{
  ... mSalientData;

  std::vector<IObserver *> mObserversRing0;
  std::vector<IObserver *> mObserversRing1;
  std::vector<IObserver *> mObserversRing2;
  ...
};
```

Priority

Do we need priority buckets?

```
void Widget::AddObserver(IObserver & aObserver, Priority p)
{
  ...

  // what happens if an observer is registered (by mistake)
  // with different priorities?

}
```

Broadcast

Notify all registered observers, in order:

```
void Widget::NotifyObservers()
{
  for (auto & observer : mObservers)
    observer->WidgetChanged(this);
}
```

Tune-in

Tune-in and react to the event triggered by the actor:

```
void SomeObserver::WidgetChanged(Actor * sender)
{
  // react in some way to the changed object (actor)

  ...
}
```

Unsubscribe

Safe to deregister at any time?

What if an observer wants to remove itself after receiving a notification?

```
void SomeObserver::WidgetChanged(Actor * sender)
{
  ...  // react in some way to the changed object (actor)

  sender->RemoveObserver(*this); // WHAT?! don't care about future events
}
```

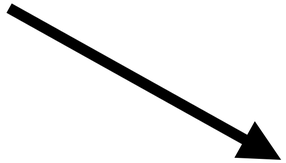
Unsubscribe

Safe to deregister at any time?

What if an observer wants to remove itself after receiving a notification?

```
for (auto & observer : mObservers)
  observer->WidgetChanged(this);
```

```
void SomeObserver::WidgetChanged(Actor * sender)
{
  ...  // react in some way to the changed object (actor)

  sender->RemoveObserver(*this); // WHAT?! don't care about future events
}
```



```
std::erase(mObservers, &aObserver);
```

Unsubscribe

How can we make *recursive remove* more resilient?

```
bool Widget::RemoveObserver(IObserver & aObserver)
{
  for(auto it = mObservers.begin(); it != mObservers.end(); ++it)
  {
    if (*it == &aObserver)
    {
      *it = nullptr; // replace observer with a sentinel
      return true;
    }
  }

  return false;
}
```

Broadcast

Notify all registered observers:

```
void Widget::NotifyObservers()
{
  for (auto & observer : mObservers)
  {
    if (observer)
      observer->WidgetChanged(this);
  }

  std::erase(mObservers, nullptr); // deferred cleanup of removed observers
}
```

Register

Recursive add observer has the same problem, but it's more rare in practice.

Small Objects

Can small objects afford to have observers?

```
class SmallObject
{
  ... mSalientData;

  std::vector<IObserver *> mObservers;
};
```

Small Objects

Can small objects afford to have observers?

```
class SmallObject
{
  ... mSalientData;

  std::vector<IObserver *> mObservers;
};
```

What if some instances will never have a registered observer?

An **empty** std::vector is not tiny.

Small Objects

Small objects can be register observers lazily

```
class SmallObject
{
  ... mSalientData;

  LazyVector<IObserver *> mObservers;
};
```

We can use an indirection to "*fault-in*" the std::vector creation when first needed:

```
operator*()
operator->()
```

```
{
  if (mPtr == nullptr)
    mPtr = new std::vector<Type>();
  return mPtr;
}
```

Lots of Objects

What if we have lots of these small objects?

We need to use some additional aside structure to keep a record of all observers for each object.

```
class GlobalBottleneck
{
  (Un)RegisterOrbserverFor(const Actor *, IObserver *);

  std::unordered_map<const Actor*, std::vector<IObserver *>> mObservers;
};
```

Threads

Multi-lane highway to... crashes 🔥

... or congestion 🐌

Threads

Put a ~~mutex~~ bottleneck on it !

Guard each function with a **mutex**:

- `Widget::Set()`
- `Widget::AddObserver()`
- `Widget::RemoveObserver()`
- `Widget::NotifyObservers()`

Recursive add/remove observers, bites again!

`recursive_mutex` ? 😄

Threads

```
class Widget
{
  Data mData;
  std::recursive_mutex mMtx;

public:

  void Set(const Data & d)
  {
    std::lock_guard<recursive_mutex> lock(mMtx);

    if (d != mData) {
      mData = d;
      NotifyObservers();
    }
  }
};
```

Threads

Not bulletproof!

You can get in a dead-lock situation. 

`recursive_mutex` 😔

Our Values

What about Squaring the Circle ?

Our Values

What about Squaring the Circle ?

Value-oriented design in an Object-oriented system

Our Values

Value-oriented design in an object-oriented system - Juan Pedro Bolivar Puente [C++ on Sea 2020]

youtube.com/watch?v=SAMR5GJ_GqA

Threads

When in doubt, always make **copies**.

Threads

```
void Widget::NotifyObservers()
{
  std::vector<IObserver *> cpy;
  {
    std::lock_guard<mutex> lock(mMtx);
    cpy = mObservers;
  }

  size_t count = cpy.size();
  for (size_t i = 0; i < count; ++i) // avoid the issues with iter invalidation
  {
    if (mObservers[i])
      cpy[i]->WidgetChanged(this);
  }

  {
    std::lock_guard<mutex> lock(mMtx);
    std::erase(mObservers, nullptr); // deferred cleanup of removed observers
  }
}
```

Threads

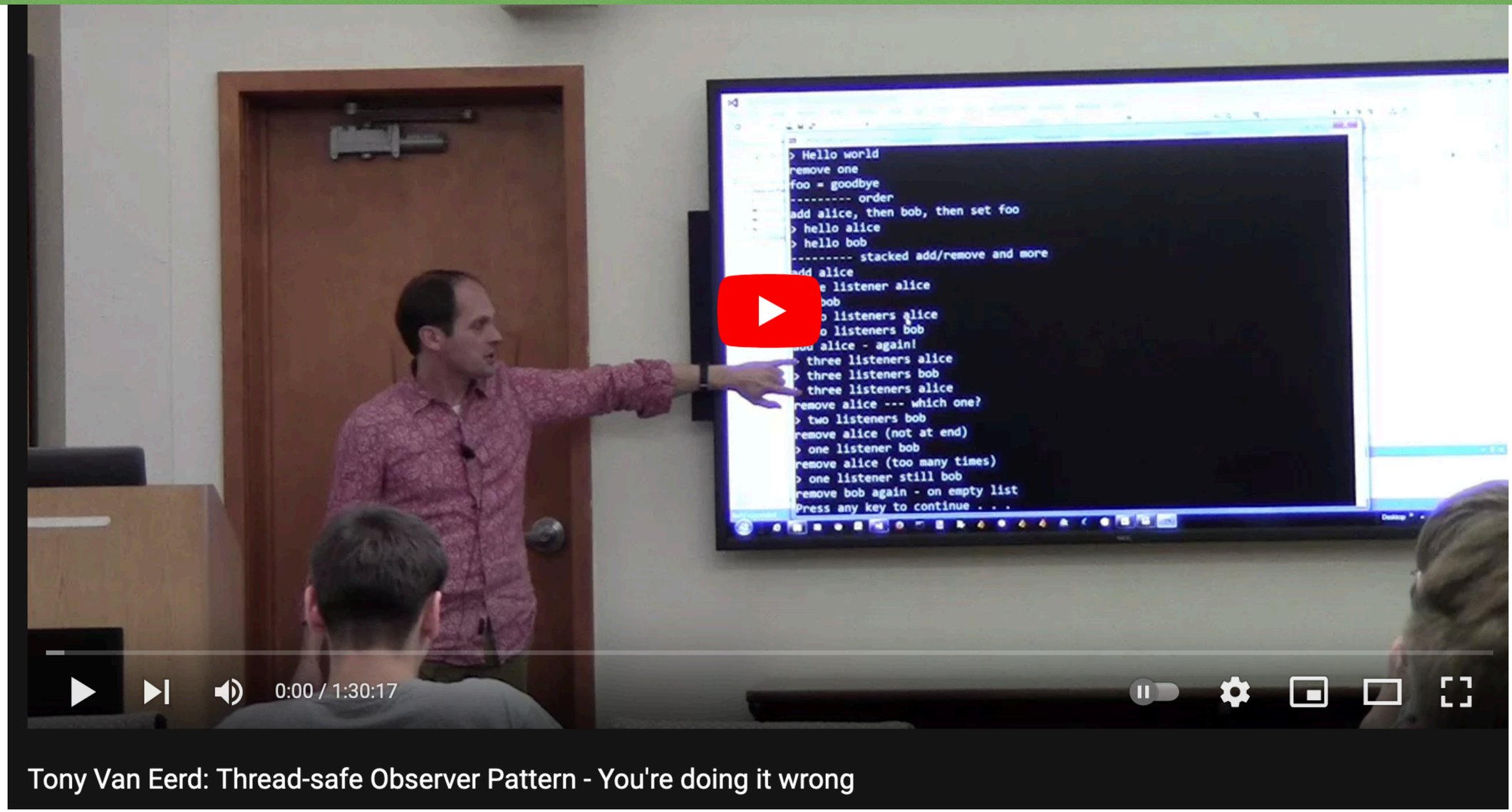
We probably need something like:

```
QObject::deleteLater()
```

In general, even if you're not using **Qt**,

I think it's very instructive to learn how UI observers are designed to work in Qt.

C++ Now 2016



www.youtube.com/watch?v=RVvVQpIy6zc

Threads

In a multi-threaded context, it's almost impossible to implement a solid Observer pattern.

In real code you can't see the deadlocks... until they happen.

Rule of thumb

Don't hold a lock

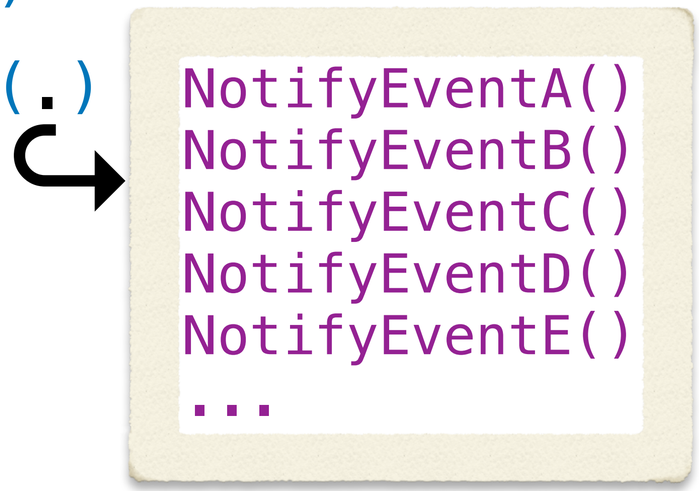
while calling *unknown* code.

Intrusive

Anyway, we don't want all this mess inside our type:

- `Widget::AddObserver()`
- `Widget::RemoveObserver()`
- `Widget::NotifyObservers(.)`

```
...
```



And we want a generic/reusable template as a base.

```
class Widget : public Actor<Widget>
{
```

Remote Objects

Inspectable properties and remote objects

```
class Widget : public Actor<Widget>
{
  Data mData;

public:

  void Set(const Data & d) {
    if (d != mData) {
      mData = d;
      NotifyObservers();
    }
  }
};
```

"*spooky action at a distance*"

Remote Observer

```
class RemoteObserver : public IObserver
{
  RemoteObserver() {
    mWidget->AddObserver(*this);
  }

  ~RemoteObserver(){
    mWidget->RemoveObserver(*this);
  }

  void WidgetChanged(Actor * sender) override
  {
    // react in some way to the changed object (actor)
    sender->Query???();
  }
  ...
  Actor * mWidget;
};
```

```
EventA()
EventB()
EventC()
EventD()
EventE()
...
```

Dangling

```
class RemoteObserver : public IObserver
{
  RemoteObserver() {
    mWidget->AddObserver(*this);
  }

  ~RemoteObserver(){
    mWidget->RemoveObserver(*this);
  }

...
  Actor * mWidget;
};
```

Don't forget to cancel...

```
// RAII
RegisterObserver obs(*this, mWidget);
```

Optional Protocol Methods

```
class IStuffObserver
{
public:
  virtual void StuffAdded(const Stuff & stuff) = 0;
  virtual void StuffRemoved(const Stuff & stuff) = 0;
  virtual void StuffWillChange(const Stuff & stuff) = 0;
  virtual void StuffChanged(const Stuff & stuff) = 0;
  virtual void GoingToSleep(const Stuff & stuff) = 0;
  virtual void WakingUp(const Stuff & stuff) = 0;
  ...
};
```

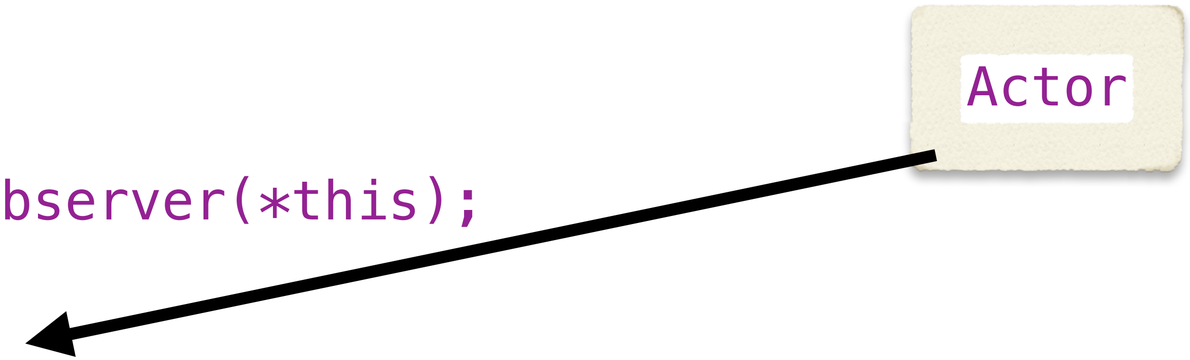
Optional Protocol Methods

```
class StuffObserver : public IStuffObserver
{
public:
  void StuffAdded(const Stuff & stuff) override { ... }
  void StuffRemoved(const Stuff & stuff) override { ... }
  void StuffWillChange(const Stuff & stuff) override { ... }
  void StuffChanged(const Stuff & stuff) override { ... }
  void GoingToSleep(const Stuff & stuff) override { ... }
  void WakingUp(const Stuff & stuff) override { ... }
  ...
};
```

```
class Spectator : public StuffObserver
{
  void GoingToSleep(const Stuff & stuff) override
  {
    ...
  }
};
```

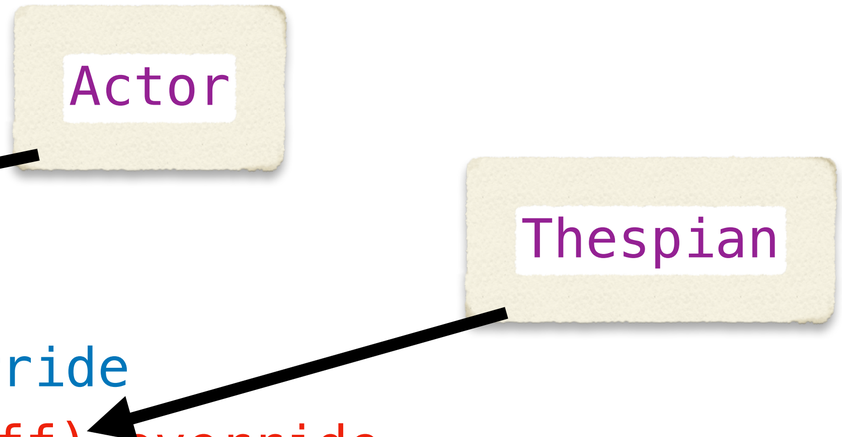
Observe Multiple Actors

```
class Spectator : public StuffObserver
{
  Spectator(Actor & actor)
  : mActor(actor)
  {
    mActor.AddObserver(*this);
  }
  ~Spectator()
  {
    mActor.RemoveObserver(*this);
  }

  void GoingToSleep(const Stuff & stuff) override
  {
    ...
  }
};
```



Observe Multiple Actors

```
class Spectator : public StuffObserver
{
  Spectator(Actor & actor, Thespian & thespian)
  : mActor(actor), mThespian(thespian)
  {
    mActor.AddObserver(*this);
    mThespian.AddObserver(*this);
  }
  ~Spectator()
  {
    mActor.RemoveObserver(*this);
    mThespian.RemoveObserver(*this);
  }

  void GoingToSleep(const Stuff & stuff) override
  {
    ...
  }
};
```



Observer Proxies

> There is no problem in computer science that can't be solved using another level of indirection

Observer Proxies

```
template<int ObserverIndex>
class StuffObserver
{
public:
  using TypeId = Int2Type<ObserverIndex>;

  void StuffAdded(TypeId, const Stuff & stuff) override { ... }
  void StuffRemoved(TypeId, const Stuff & stuff) override { ... }
  void StuffWillChange(TypeId, const Stuff & stuff) override { ... }
  void StuffChanged(TypeId, const Stuff & stuff) override { ... }
  void GoingToSleep(TypeId, const Stuff & stuff) override { ... }
  void WakingUp(TypeId, const Stuff & stuff) override { ... }
  ...
};
```

Observer Proxies

```
template<int ObserverIndex>
class StuffObserver
{
public:
  using TypeId = Int2Type<ObserverIndex>;

  void StuffAdded(TypeId, const Stuff & stuff) override { ... }
  void StuffRemoved(TypeId, const Stuff & stuff) override { ... }
  void StuffWillChange(TypeId, const Stuff & stuff) override { ... }
  void StuffChanged(TypeId, const Stuff & stuff) override { ... }
  void GoingToSleep(TypeId, const Stuff & stuff) override { ... }
  void WakingUp(TypeId, const Stuff & stuff) override { ... }
  ...
};
```

```
template <int v>
struct Int2Type
{
  enum {
    value = v
  };
};
```

Observer Proxies

```
template<int ObserverIndex>
class StuffObserver
{
public:
  using TypeId = Int2Type<ObserverIndex>;

  void StuffAdded(TypeId, const Stuff & stuff) override { ... }
  void StuffRemoved(TypeId, const Stuff & stuff) override { ... }
  void StuffWillChange(TypeId, const Stuff & stuff) override { ... }
  void StuffChanged(TypeId, const Stuff & stuff) override { ... }
  void GoingToSleep(TypeId, const Stuff & stuff) override { ... }
  void WakingUp(TypeId, const Stuff & stuff) override { ... }
  ...
};
```

```
template <int v>
struct Int2Type
{
  enum {
    value = v
  };
};
```

If you recognize this, you've been writing C++ for a while... (**Loki** by A.A.)

Observer Proxies

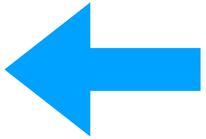
```
template<typename ObserverT, int ObserverIndex>
class StuffObserverProxy : public IStuffObserver
{
public:
  using TypeId = Int2Type<ObserverIndex>;
  using ReceiverType = StuffObserver<ObserverIndex>;

  StuffObserverProxy(ObserverT & observer)
  : mObserver(observer)
  {}

  void StuffAdded(const Stuff & stuff) override {
    static_cast<ReceiverType &>(mObserver).StuffAdded(TypeId(), stuff);
  }
  void StuffRemoved(const Stuff & stuff) override {
    static_cast<ReceiverType &>(mObserver).StuffRemoved(TypeId(), stuff);
  }
  ...
  ObserverT & mObserver;
};
```

Observer Proxies

```
namespace SpectatorObserverProxies
{
  using Actor         = StuffObserver<0>;
  using ActorProxy    = StuffObserverProxy<Spectator, 0>;

  using Thespian      = StuffObserver<1>;
  using ThespianProxy = StuffObserverProxy<Spectator, 1>;
  ...
}
```

Observer Proxies

```
class Spectator : public SpectatorObserverProxies::Actor,
                  public SpectatorObserverProxies::Thespian
{
public:

  Spectator()
  : mActorProxy(*this), mThespianProxy(*this)
  {
    mActor.AddObserver(mActorProxy);
    mThespian.AddObserver(mThespianProxy);
  }

private:

  SpectatorObserverProxies::ActorProxy    mActorProxy;
  SpectatorObserverProxies::ThespianProxy mThespianProxy;
};
```



Observer Proxies

```
class Spectator : public SpectatorObserverProxies::Actor,
                  public SpectatorObserverProxies::Thespian
{
  void GoingToSleep(SpectatorObserverProxies::Actor::TypeId,
                    const Stuff & stuff) override
  {
    ... // actor goes to sleep
  }
  void GoingToSleep(SpectatorObserverProxies::Thespian::TypeId,
                    const Stuff & stuff) override
  {
    ... // thespian goes to sleep
  }
  void StuffAdded(SpectatorObserverProxies::Actor::TypeId,
                  const Stuff & stuff) override
  {
    ... // actor added some new stuff
  }
```

Observer Proxies

`StuffObserver` and `StuffObserverProxy` can be ♻ reused for any other

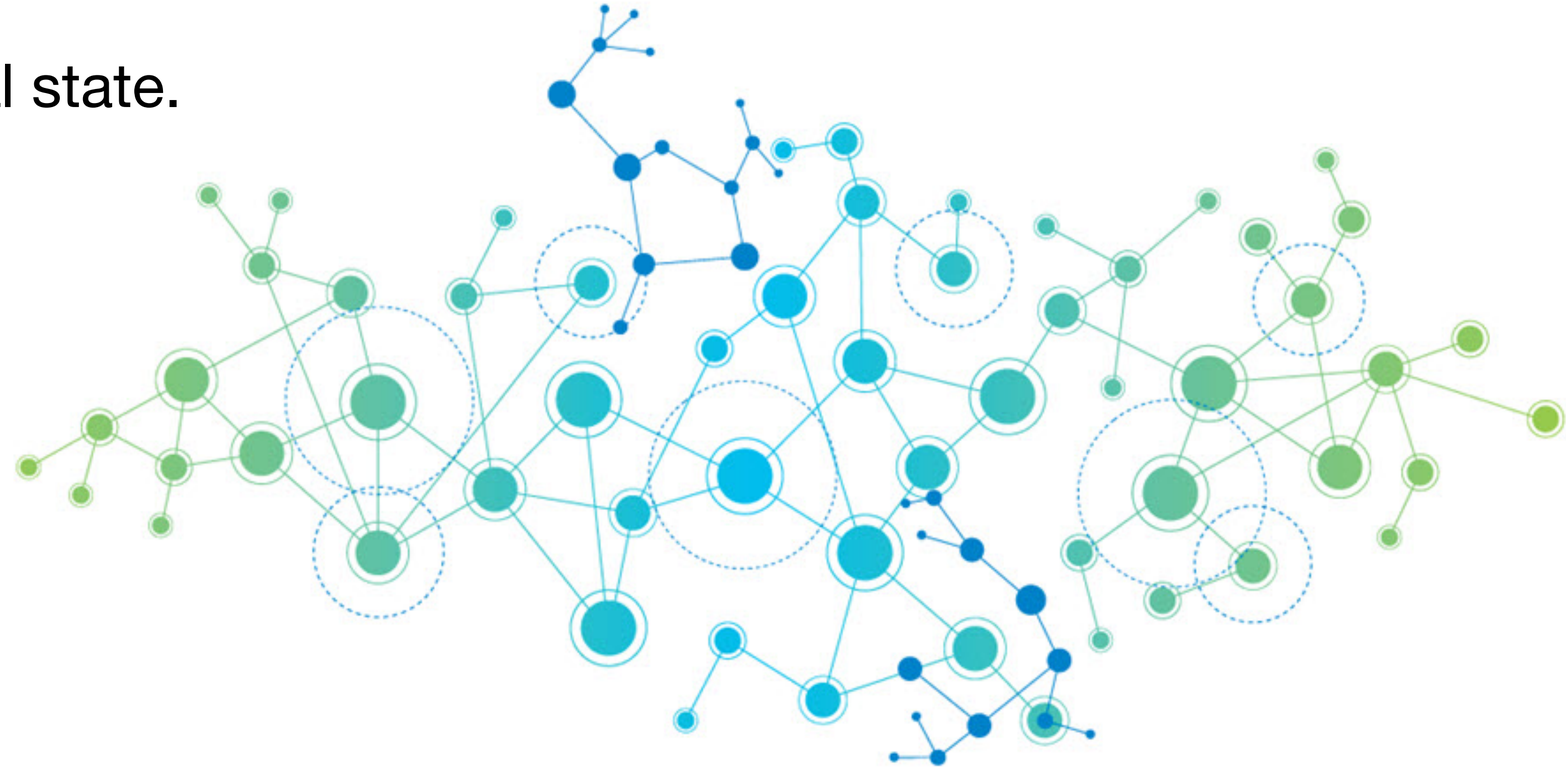
`Spectator` type and for any observed subjects/actors, conforming to the defined

`IStuffObserver` interface.

```
namespace SpectatorObserverProxies
{
  using Actor         = StuffObserver<0>;
  using ActorProxy    = StuffObserverProxy<Spectator, 0>;

  using Thespian      = StuffObserver<1>;
  using ThespianProxy = StuffObserverProxy<Spectator, 1>;
  ...
}
```

Global State

Observer networks form a global state.



The same reason I dislike `std::shared_ptr<>`

Pushing up the daisies

Memory management issues:

- dead subjects
- missing observers

Blissfully dangling...

Pushing up the daisies

Spooky Action at a Distance

ACCU

April 2023

@ciura_victor

@ciura_victor@hachyderm.io

Victor Ciura

Principal Engineer

Visual C++