



Design Patterns

The Most Common Misconceptions (2 of N)

KLAUS IGLBERGER



Cppcon
The C++ Conference

20
24



September 15 - 20

C++ Trainer/Consultant

Author of “C++ Software Design”

(Co-)Organizer of the Munich C++ user group

Chair of the CppCon Back-to-Basics track

Email: klaus.iglberger@gmx.de



Klaus Iglberger

The 2nd in a Row

The video player interface displays a presentation slide on the right and a video thumbnail on the left.

Term #1 **Builder**

Term #2 **Factory Method**

Term #3 **Bridge**

Term #4 **Design Pattern**

NDC { TechTown }

3:53 / 43:14

8

(NDC Conferences Subscribe)

The 2nd in a Row

Meeting C++ 2023
Design Patterns - the most common misconceptions (1 of n)
Klaus Iglberger

think-cell

The video player displays a presentation slide on the left and a video feed of a speaker on the right. The slide contains four terms listed vertically: "Term #1 Builder", "Term #2 Factory Method", "Term #3 Bridge", and "Term #4 Design Pattern". The video feed shows a man standing at a whiteboard, gesturing towards it while speaking to an audience. The video player interface includes a progress bar at the bottom, showing 4:31 / 49:51, and various control icons.

Let's again talk about
design patterns
and
virtual functions

The Overhead of Inheritance Hierarchies

The Hidden Performance Price
of Virtual Functions

IVICA BOGOSAVLJEVIC

Cppcon
The C++ Conference

2022 | San Jose, CA
September 12th-16th

Full screen (f)

▶ ▶ 🔍 0:00 / 49:28 · Introduction >

|| CC ⚙ HD □ □ □

The Overhead of Inheritance Hierarchies

The slide features a dark blue background with a light blue header bar. In the top right corner of the header bar is a large white plus sign icon with the number '23' next to it, and a small 'i' icon above the '23'. The main title 'Optimizing Away Virtual Functions May Be Pointless' is centered in large yellow font. Below the title, the author's name 'SHACHAR SHEMESH' is displayed in smaller yellow font. At the bottom left, the Cppcon logo (a stylized '++' inside a circle) and the text 'Cppcon' and 'The C++ Conference' are shown. At the bottom right, there is a date '2023' next to a mountain icon, and the text 'October 01 - 06'. A navigation bar at the very bottom includes icons for back, forward, search, and other presentation controls.

Optimizing Away Virtual Functions May Be Pointless

SHACHAR SHEMESH

2023 | October 01 - 06

Cppcon
The C++ Conference

Issue #1

CRTP

Issue #2

std::variant

Issue #1

C RTP

CRTP - Curiously Recurring Template Pattern

Curiously Recurring Template Patterns

James O. Coplien

Software Production Research Dept., AT&T Bell Laboratories
1000 East Warrenville Rd., Naperville, IL 60566 USA

(708) 713-5384

cope@research.att.com

Abstract

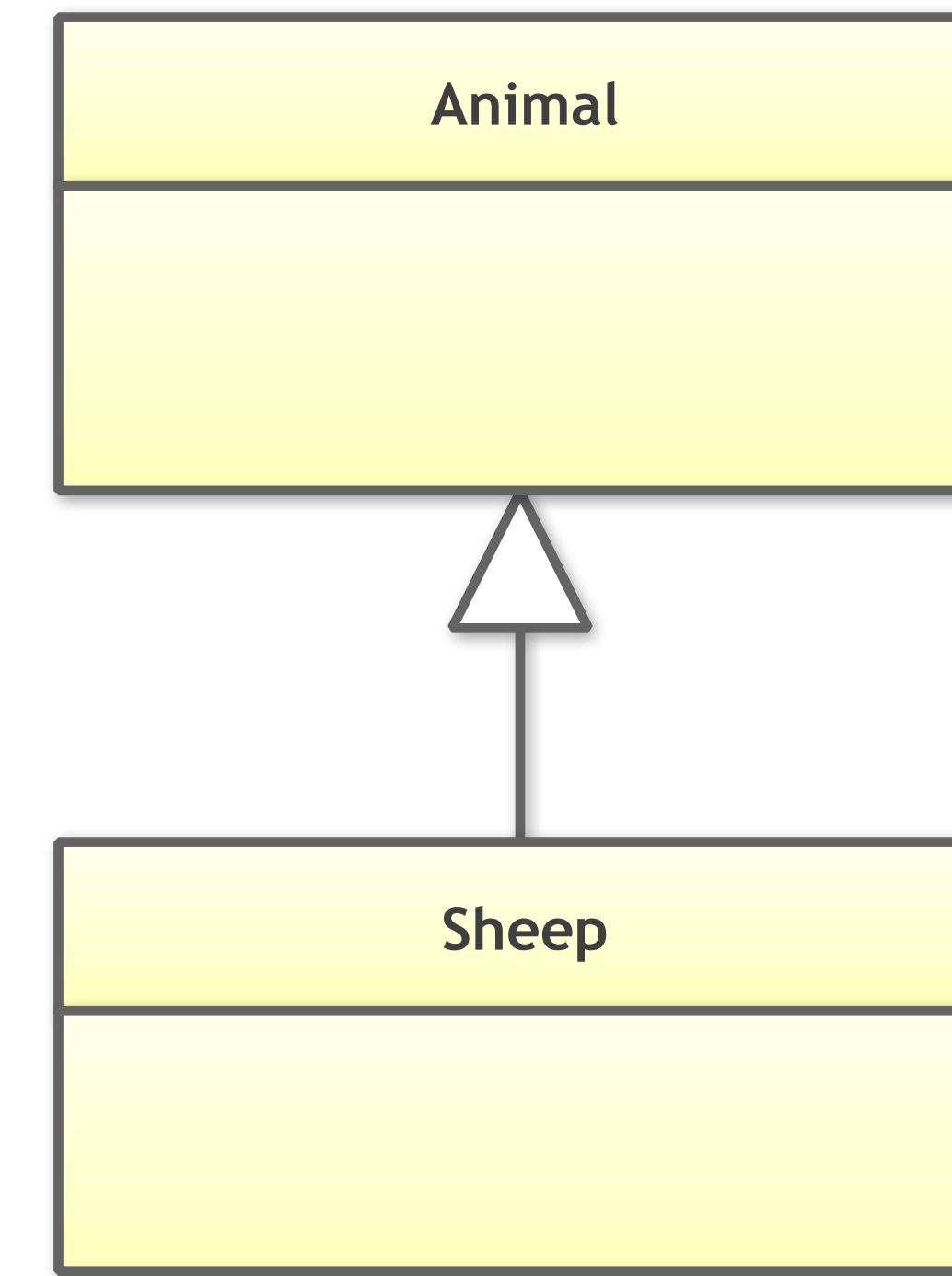
Software design patterns capture recurring good practice in a domain. Many good patterns enjoy independent discovery by different people at different times. I have now seen three distinct uses of what I thought was an obscure template pattern. Each use arose in a unique domain; one instance was outside the C++ community. We can capture the technique in a pattern that solves a problem of factoring circular dependencies in code structure and behavior. The pattern form makes an otherwise opaque framework more accessible.

CRTP - Curiously Recurring Template Pattern

```
class Animal
{
};

class Sheep
{
};

};
```

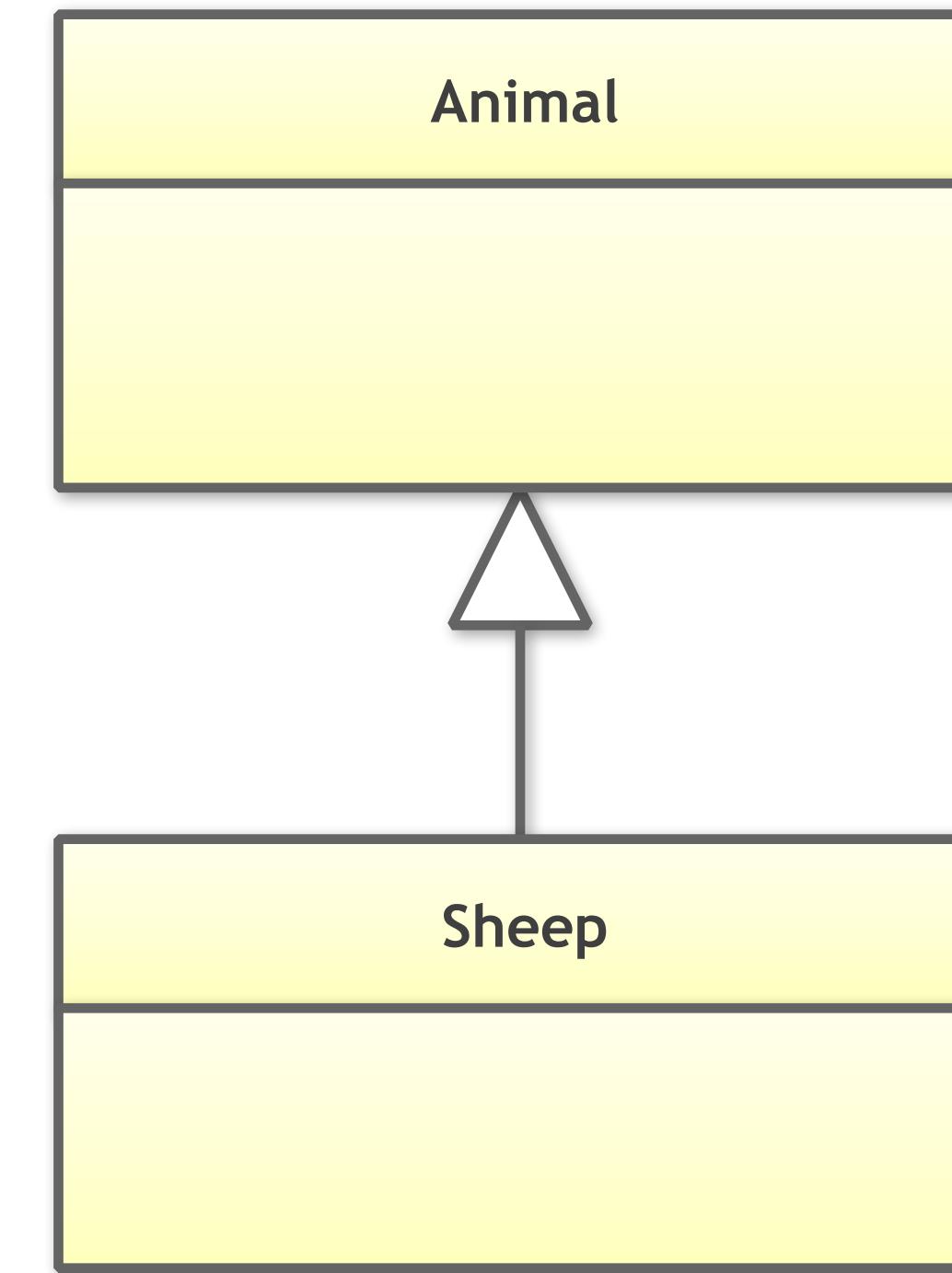


CRTP - Curiously Recurring Template Pattern

```
template< typename T >
class Animal
{
};

class Sheep
{
};

};
```

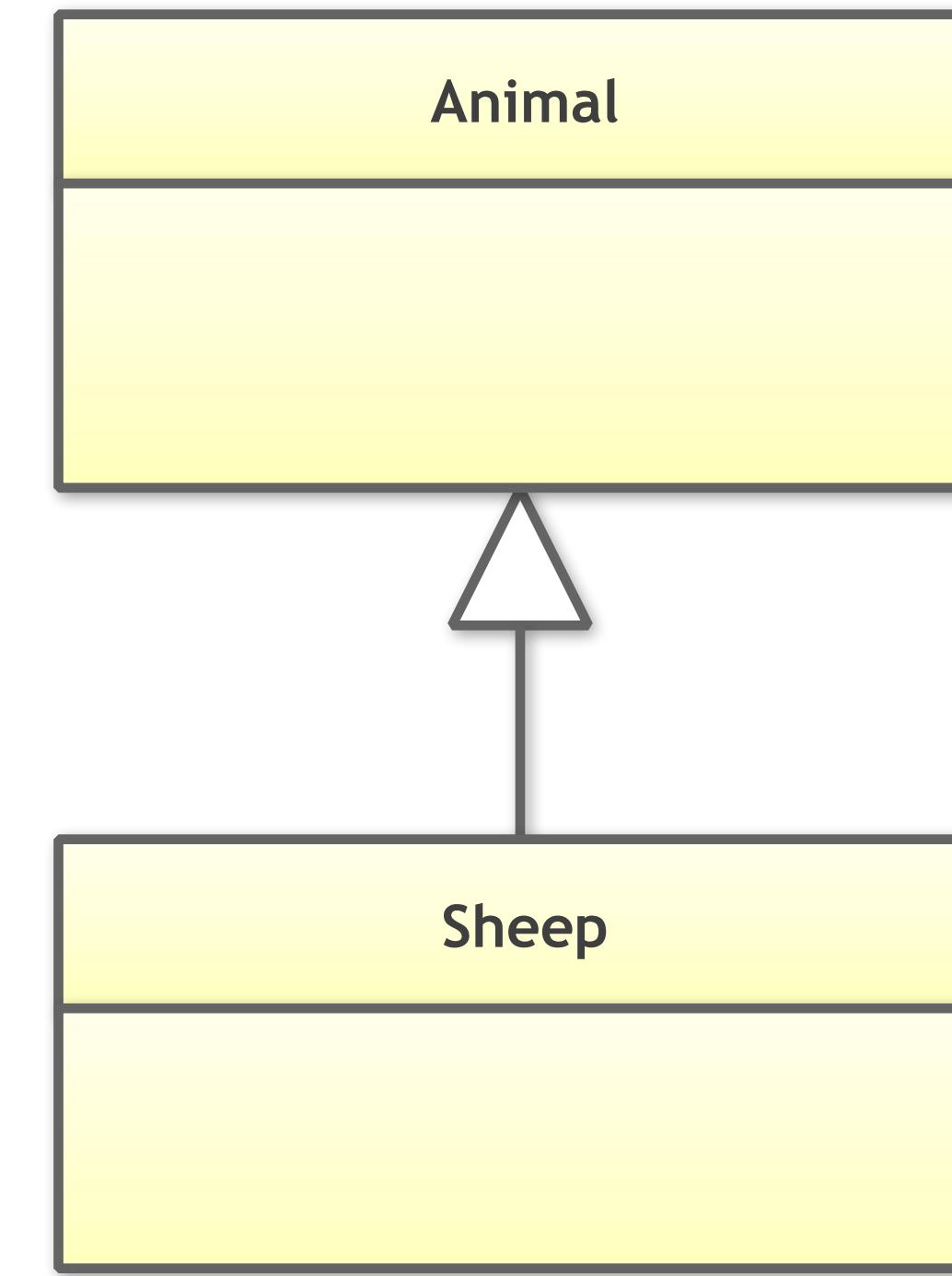


CRTP - Curiously Recurring Template Pattern

```
template< typename T >
class Animal
{
};

class Sheep : public Animal<Sheep>
{
};

};
```

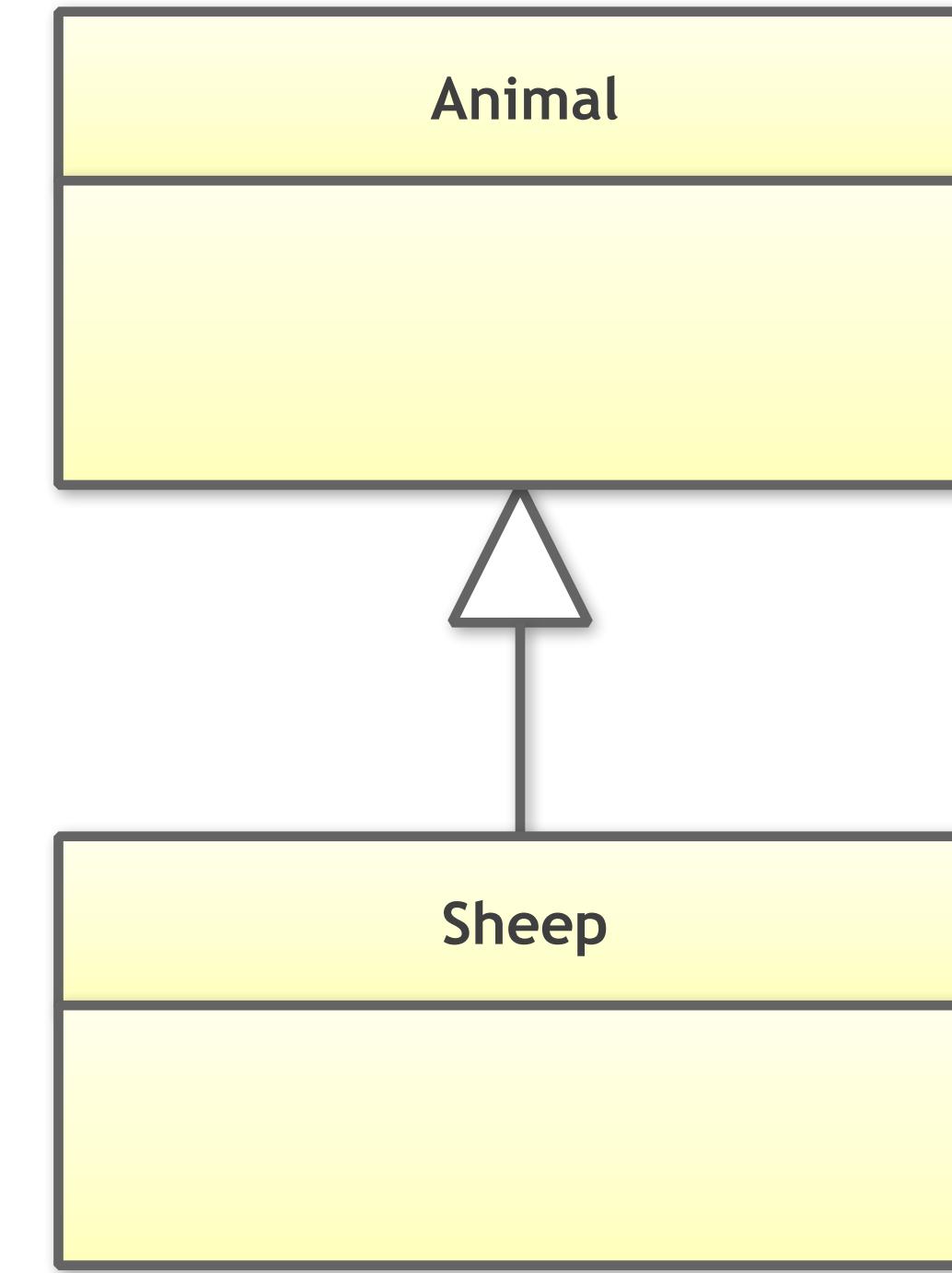


CRTP - Curiously Recurring Template Pattern

```
template< typename Derived >
class Animal
{
};

class Sheep : public Animal<Sheep>
{
};

};
```



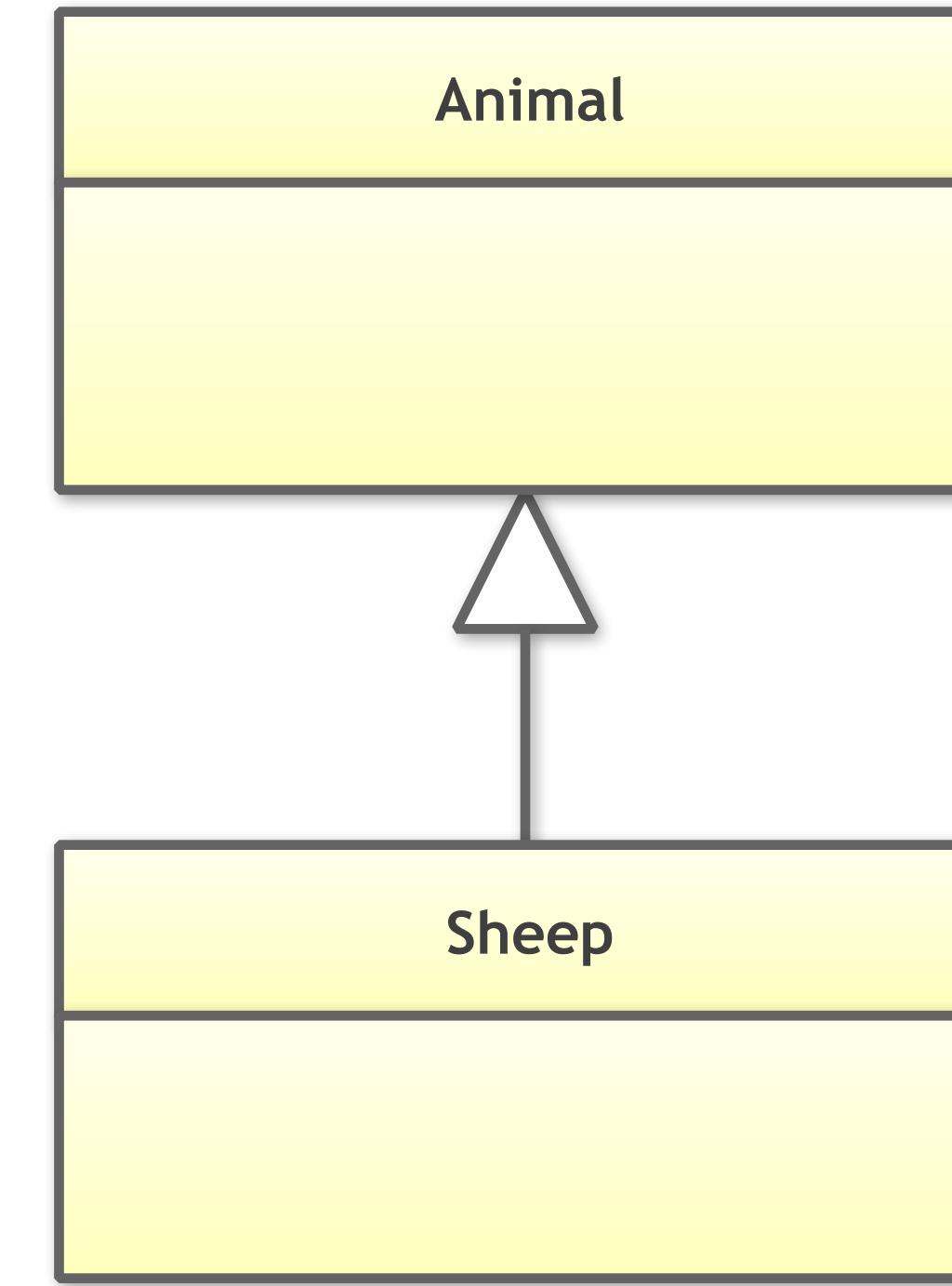
CRTP - Curiously Recurring Template Pattern

```
template< typename Derived >
class Animal
{
private:
    Animal() = default;
    ~Animal() = default;

};

class Sheep : public Animal<Sheep>
{
};

};
```



CRTP - Curiously Recurring Template Pattern

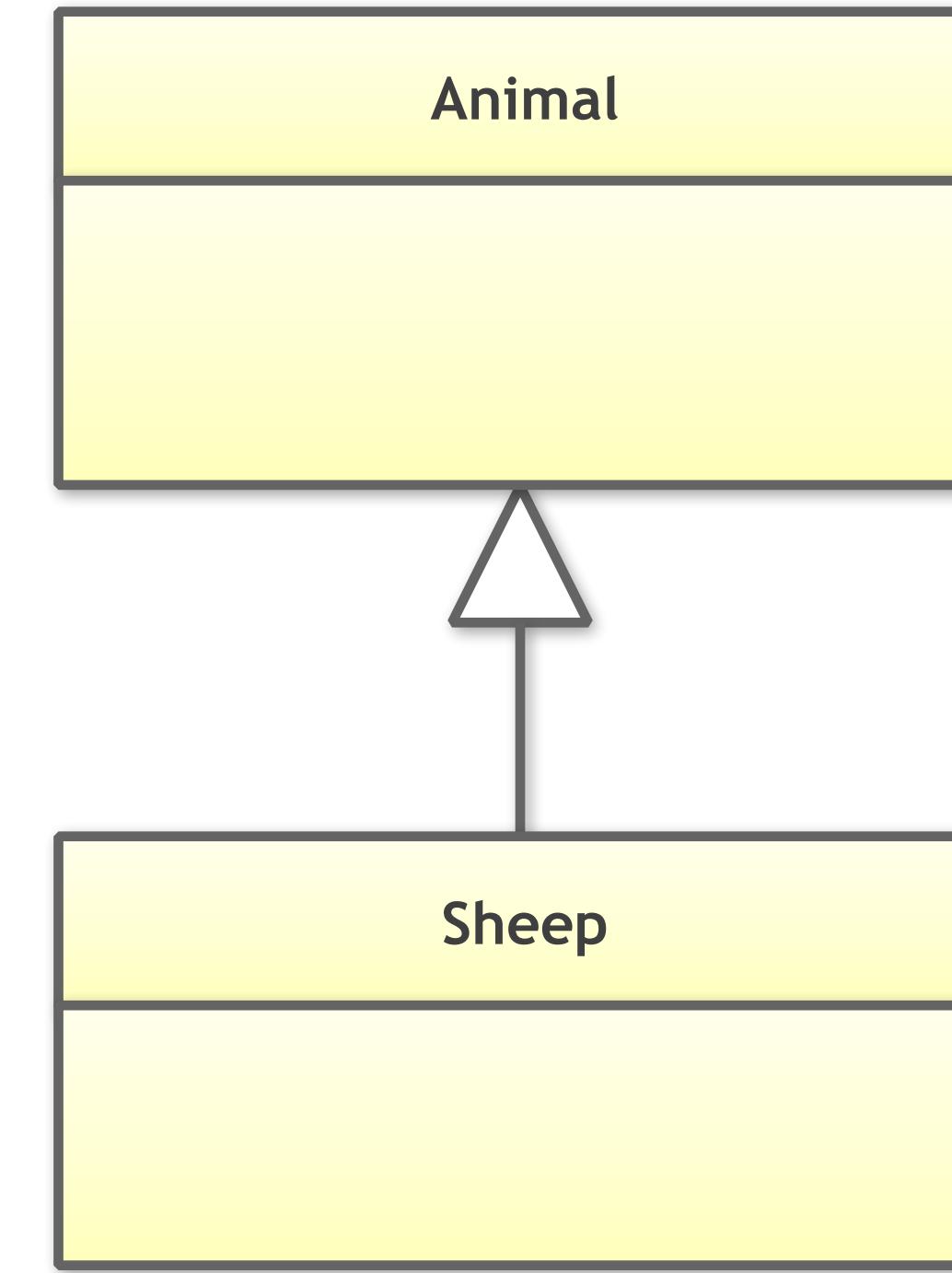
```
template< typename Derived >
class Animal
{
private:
    Animal() = default; // Protects against
    ~Animal() = default; // “wrong” Derived class
    friend Derived;

};

class Sheep : public Animal<Sheep>
{



};
```



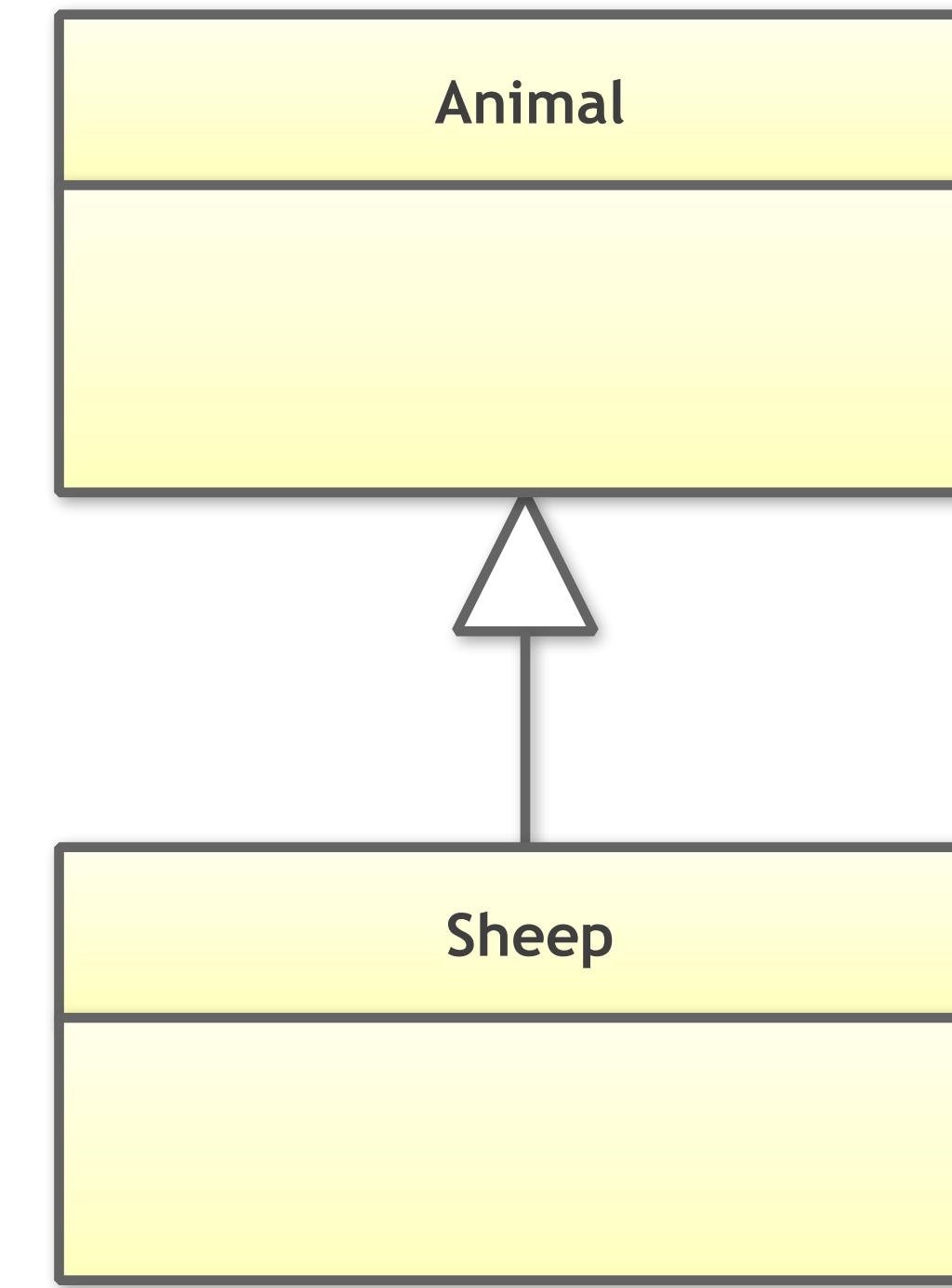
CRTP - Curiously Recurring Template Pattern

```
template< typename Derived >
class Animal
{
private:
    Animal() = default; // Protects against
    ~Animal() = default; // “wrong” Derived class
    friend Derived;

};

class Sheep : public Animal<Sheep>
{
public:
    //~Sheep(); Remember the Rule-of-5

};
```

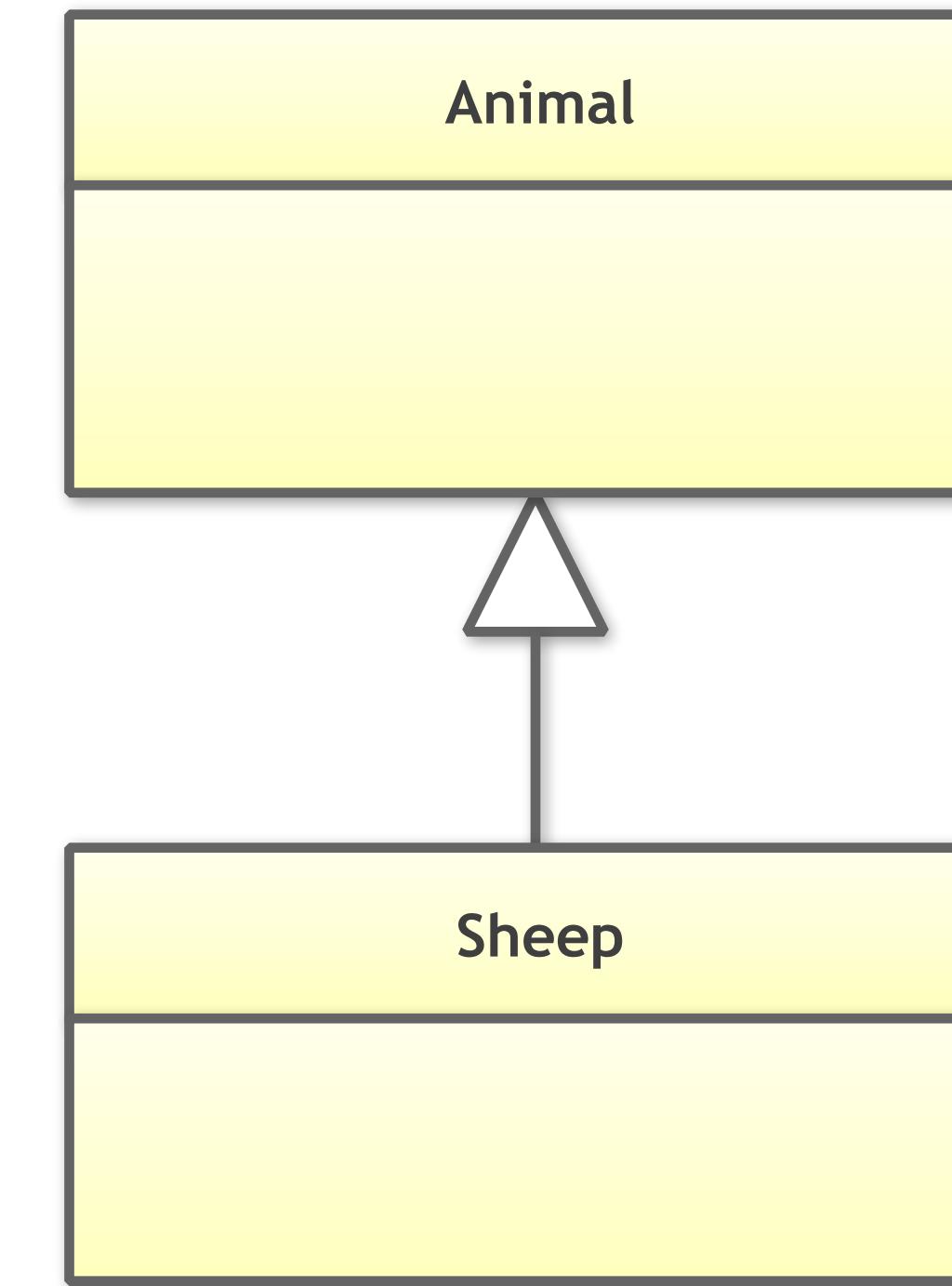


CRTP - Curiously Recurring Template Pattern

```
template< typename Derived >
class Animal
{
private:
    Animal() = default; // Protects against
    ~Animal() = default; // “wrong” Derived class
    friend Derived;

public:
    void make_sound() const {
        // ...
    }
};

class Sheep : public Animal<Sheep>
{
public:
    //~Sheep(); Remember the Rule-of-5
};
```

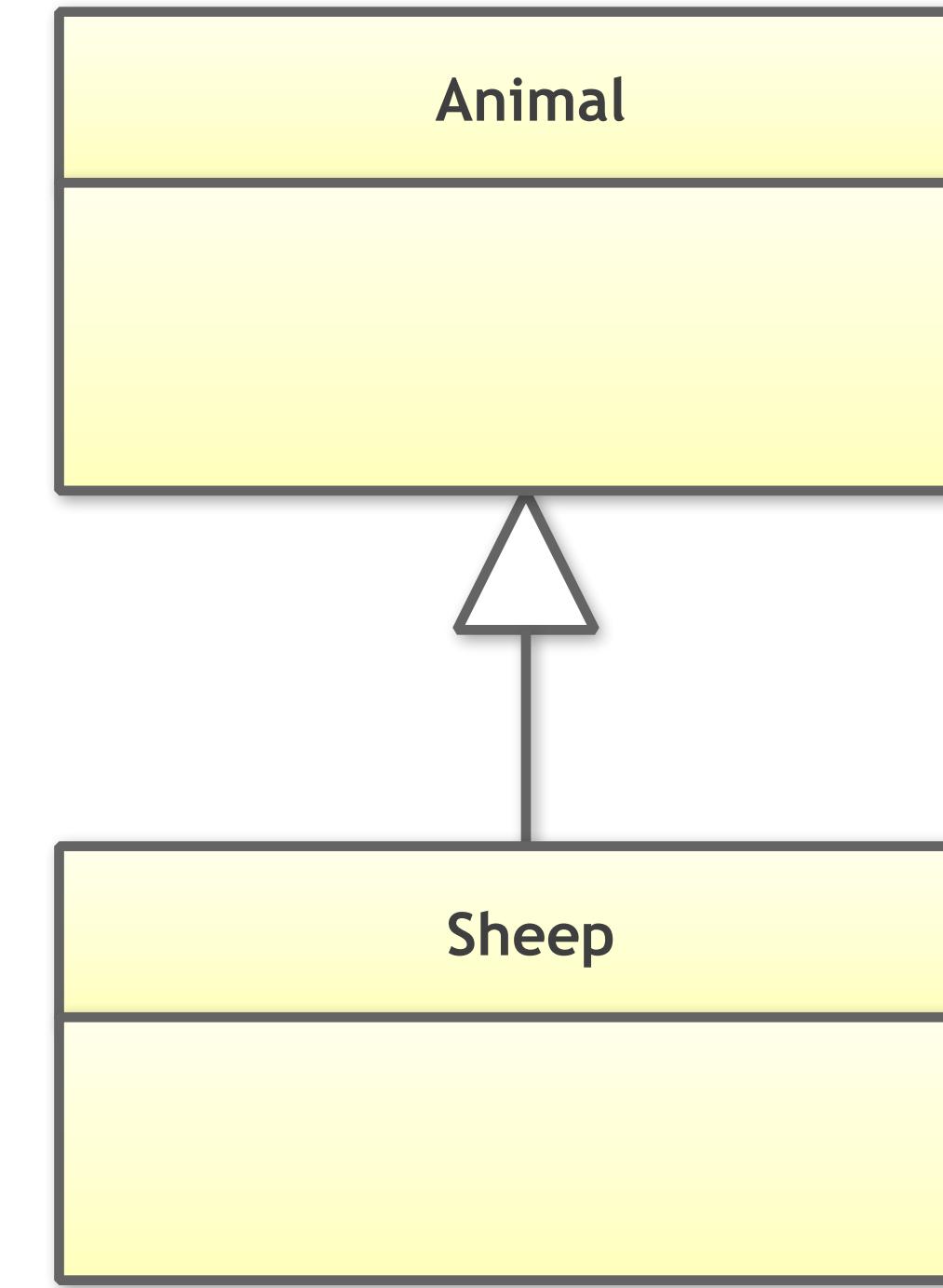


CRTP - Curiously Recurring Template Pattern

```
template< typename Derived >
class Animal
{
private:
    Animal() = default; // Protects against
    ~Animal() = default; // “wrong” Derived class
    friend Derived;

public:
    void make_sound() const {
        // ...
    }
};

class Sheep : public Animal<Sheep>
{
public:
    //~Sheep(); Remember the Rule-of-5
    // ...
    void make_sound() const { std::cout << "baa"; }
};
```

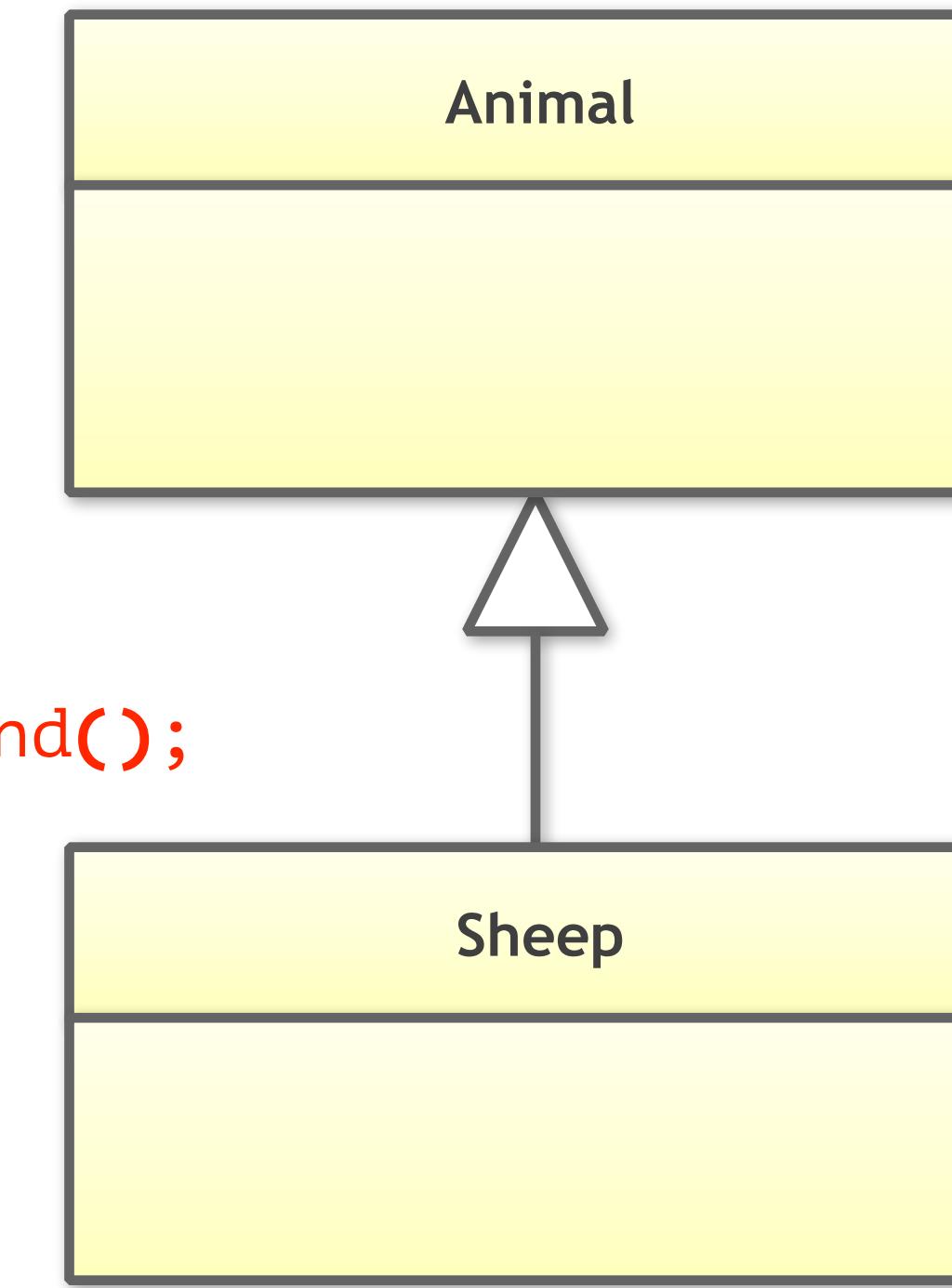


CRTP - Curiously Recurring Template Pattern

```
template< typename Derived >
class Animal
{
private:
    Animal() = default; // Protects against
    ~Animal() = default; // “wrong” Derived class
    friend Derived;

public:
    void make_sound() const {
        static_cast<Derived const&>(*this).make_sound();
    }
};

class Sheep : public Animal<Sheep>
{
public:
    //~Sheep(); Remember the Rule-of-5
    // ...
    void make_sound() const { std::cout << "baa"; }
};
```

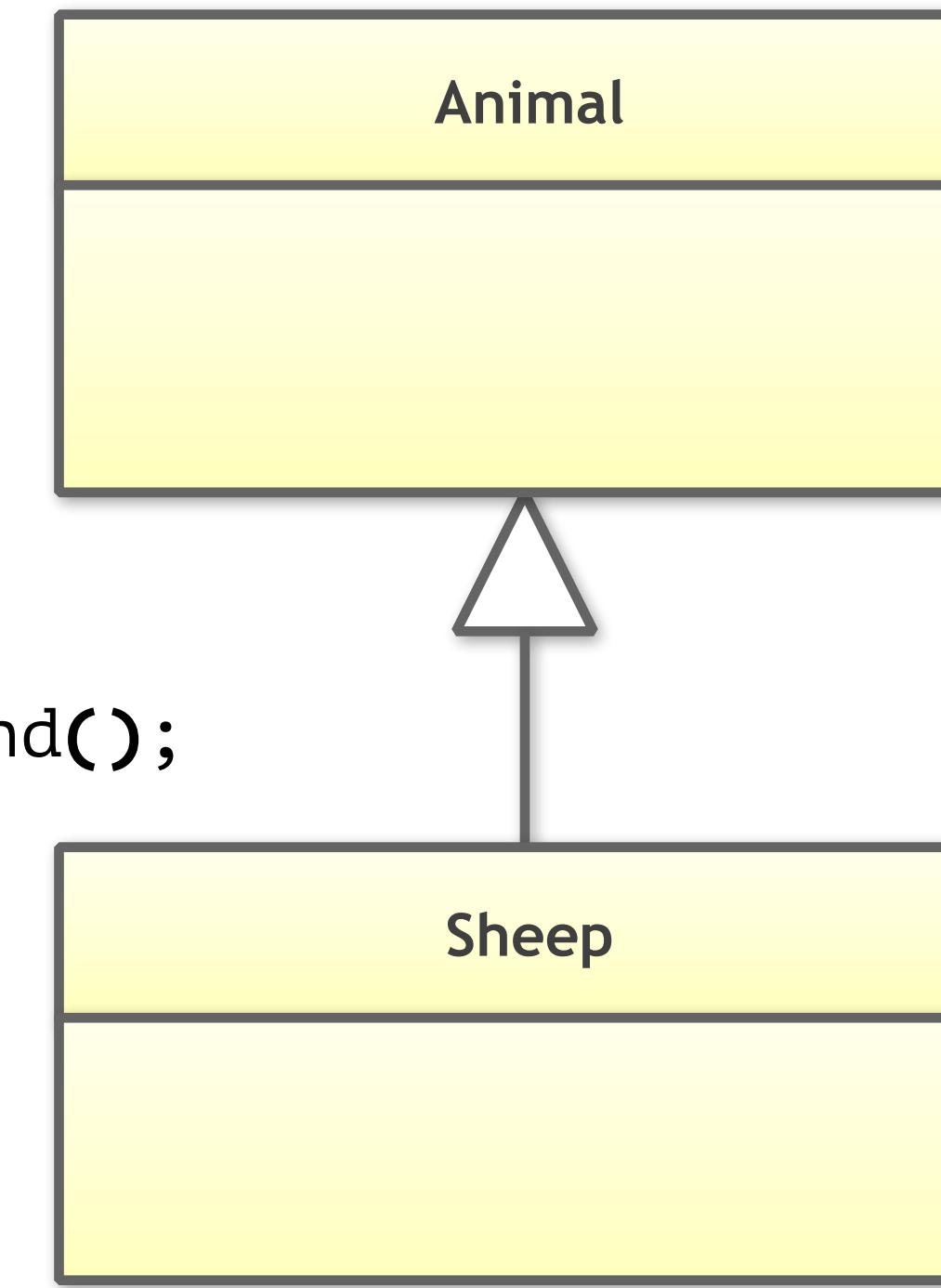


CRTP - Curiously Recurring Template Pattern

```
template< typename Derived >
class Animal
{
private:
    Animal() = default; // Protects against
    ~Animal() = default; // “wrong” Derived class
    friend Derived;

public:
    void make_sound() const {
        static_cast<Derived const&>(*this).make_sound();
    }
};

class Sheep : public Animal<Sheep>
{
public:
    //~Sheep(); Remember the Rule-of-5
    // ...
    void make_sound() const { std::cout << "baa"; }
};
```

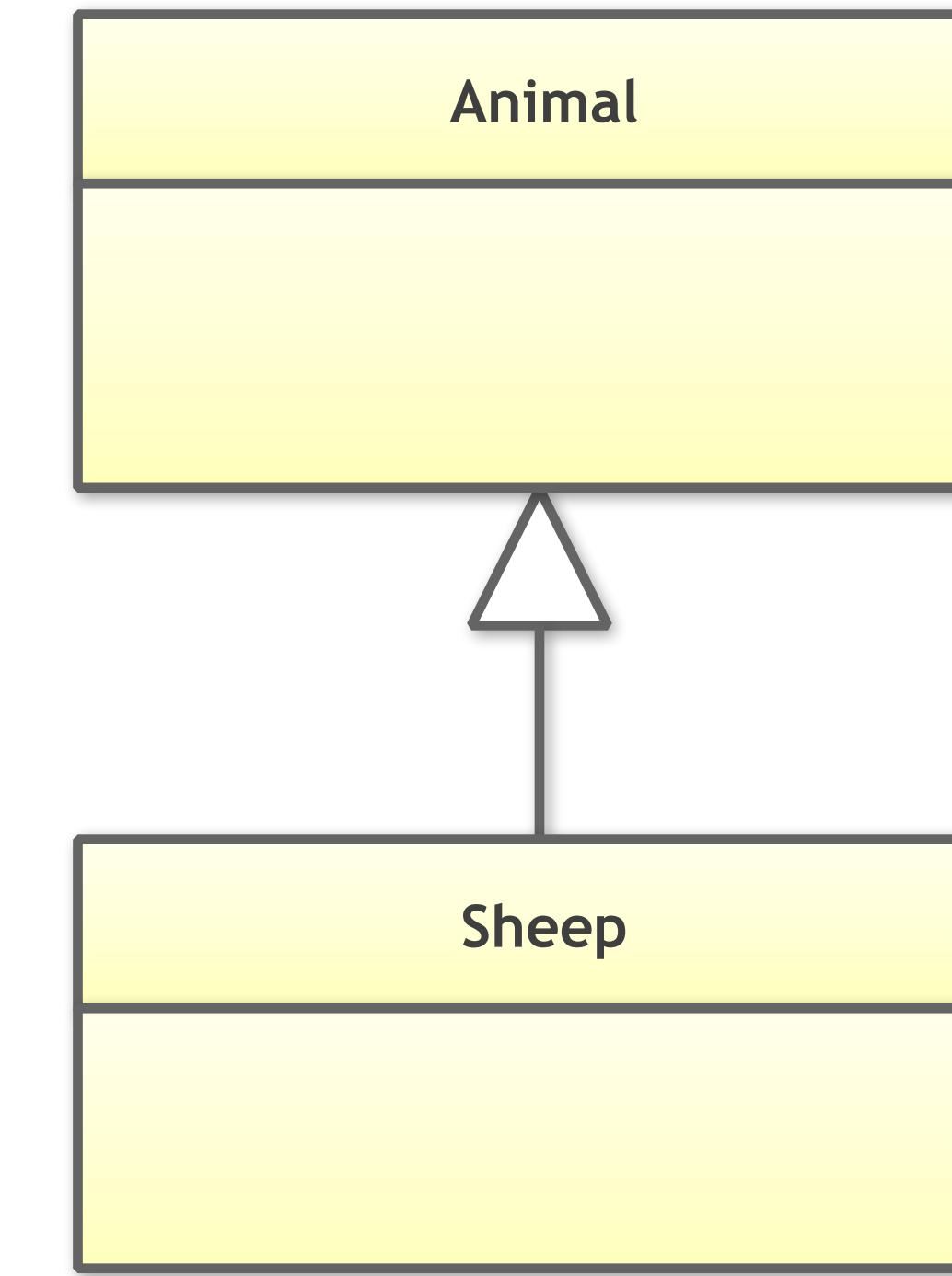


CRTP - Curiously Recurring Template Pattern

```
template< typename Derived >
class Animal
{
    // ...
};

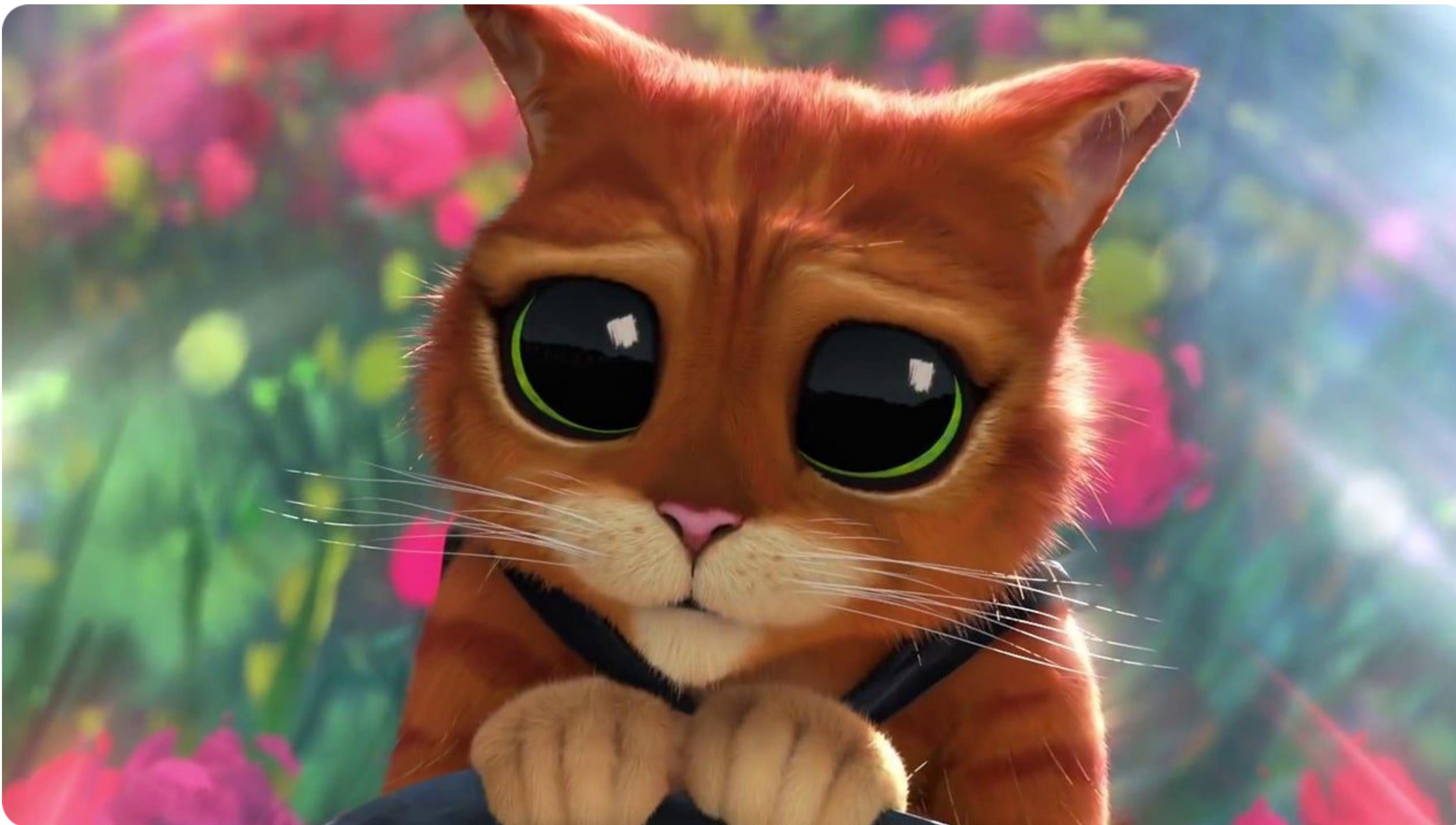
class Sheep : public Animal<Sheep>
{
    // ...
};

template< typename Derived >
void print( Animal<Derived> const& animal )
{
    // ...
}
```



Works for all animals and does not trigger any
virtual function call (functions might even be inlined)

CRTP: The Replacement for Virtual Functions?



The Limitations of CRTP

1. Limitation: There Is No Common Base Class

```
template< typename T >
class Animal
{
    // ...
};

class Sheep : public Animal<Sheep>
{
    // ...
};

class Dog : public Animal<Dog>
{
    // ...
};

class Cat : public Animal<Cat>
{
```

The diagram illustrates the limitation of having no common base class. It shows four classes: Sheep, Dog, and Cat, each inheriting from a different template instantiation of the Animal class. A red double-headed arrow connects the inheritance lines for Sheep and Dog, pointing to a red annotation that reads: // Different base classes, // i.e. no common base class.

2. Limitation: Everything Is A Template

```
template< typename Derived >
class Animal
{
    // ...
};

class Sheep : public Animal<Sheep>
{
    // ...
};

template< typename Derived >
void print( Animal<Derived> const& animal )
{
    // ...
}
```



This function must be a function template to take any kind of animal. Thus CRTP can act like a virus: Everything touching CRTP is or becomes a template (including higher compile times).

The Future of CRTP?

The screenshot shows a video player interface. At the top left is the Cppcon 2021 logo with the text "The C++ Conference" and "October 24-29". To the right is a yellow and blue graphic with a plus sign and an info icon. The main video frame on the left shows a man, Ben Deane, standing at a white podium, speaking into a microphone. Below the video frame, his name "Ben Deane" is displayed. The video title "Deducing this Patterns" is also visible. The video progress bar at the bottom indicates it is at 0:44 of 1:02:41. On the right side of the video frame, the text "DEDUCING **this** PATTERNS" is displayed above a geometric diagram consisting of overlapping rectangles in orange, white, and black. Below the diagram, the text "BEN DEANE / @ben_deane" and "CPPCON 2021" are shown. The video player has standard controls at the bottom: back, forward, volume, and a settings menu.

Cppcon 2021 | October 24-29

Ben Deane

Deducing this Patterns

1 / 64

0:44 / 1:02:41

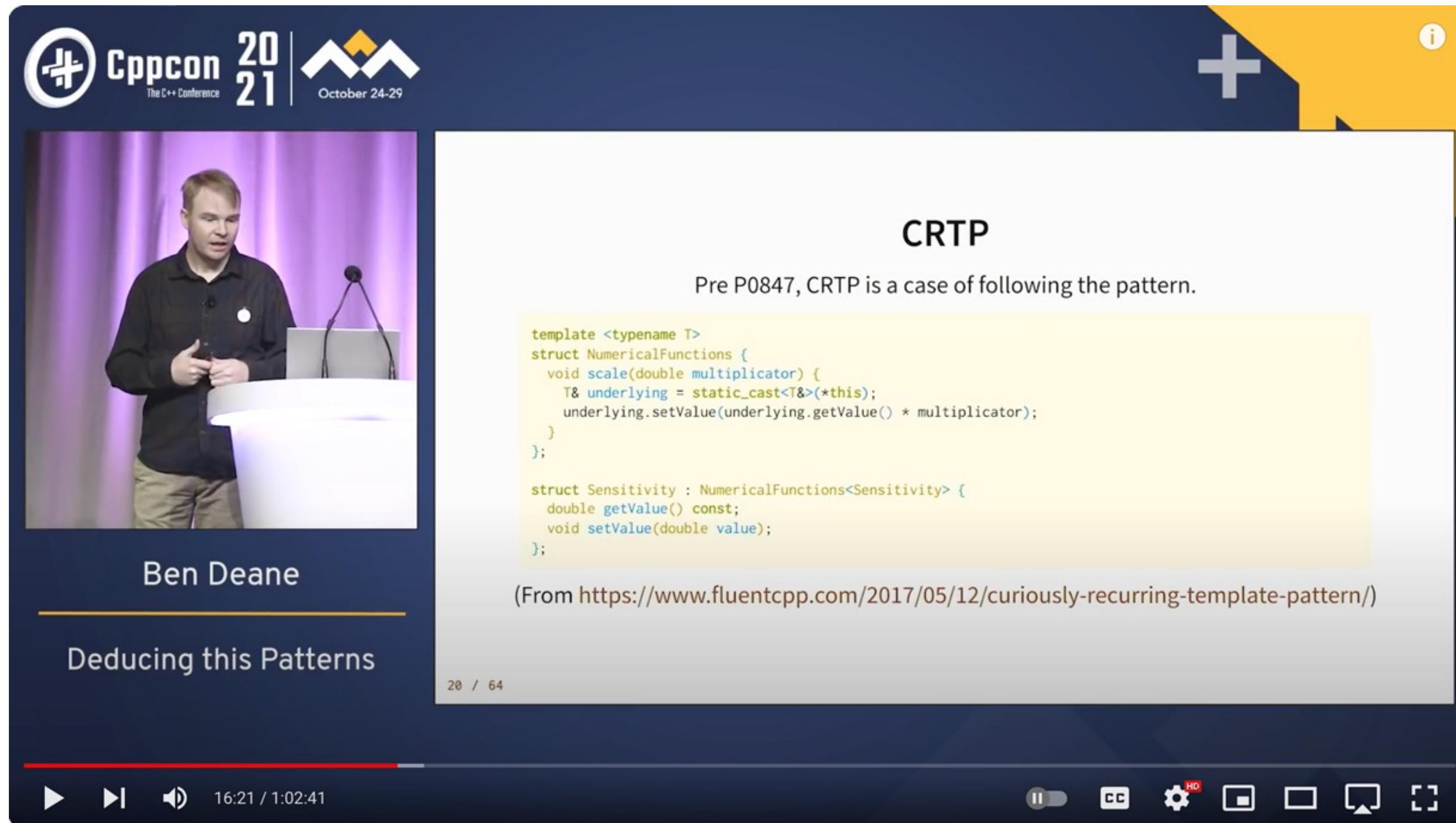
DEDUCING **this** PATTERNS

BEN DEANE / @ben_deane

CPPCON 2021

HD

The Future of CRTP?



Cppcon 2021 | October 24-29

Ben Deane

Deducing this Patterns

20 / 64

▶ ▶ 🔍 16:21 / 1:02:41

HD

CRTP

Pre P0847, CRTP is a case of following the pattern.

```
template <typename T>
struct NumericalFunctions {
    void scale(double multiplicator) {
        T& underlying = static_cast<T&>(*this);
        underlying.setValue(underlying.getValue() * multiplicator);
    }
};

struct Sensitivity : NumericalFunctions<Sensitivity> {
    double getValue() const;
    void setValue(double value);
};
```

(From <https://www.fluentcpp.com/2017/05/12/curiously-recurring-template-pattern/>)

Adding Functionality with CRTP

```
template< typename Derived >
struct NumericalFunctions
{
    void scale( double multiplicator )
    {
        Derived& underlying = static_cast<Derived&>(*this);
        underlying.setValue( underlying.getValue() * multiplicator );
    }
};

struct Sensitivity : public NumericalFunctions<Sensitivity>
{
    double getValue() const { return value; }
    void setValue( double v ) { value = v; }
    double value;
};

int main()
{
    Sensitivity s{ 1.2 };
    s.scale( 2.0 );

    std::println( std::cout, "s.getValue() = {}", s.getValue() );
}
```

Adding Functionality with C++23

```
struct NumericalFunctions
{
    void scale( this auto&& self, double multiplicator )
    {
        self.setValue( self.getValue() * multiplicator );
    }
};

struct Sensitivity : public NumericalFunctions
{
    double getValue() const { return value; }
    void setValue( double v ) { value = v; }
    double value;
};

int main()
{
    Sensitivity s{ 1.2 };
    s.scale( 2.0 );

    std::println( std::cout, "s.getValue() = {}", s.getValue() );
}
```

Explicit object parameter (aka “Deducing This”)

No template parameter anymore 😊

The Future of CRTP?

Cppcon 2021 | October 24-29

Ben Deane

Deducing this Patterns

So CRTP really just ... I guess ... goes away.

```
Self& a(this Self& self) { /* ... */; return self; }

template <typename Self>
Self& b(this Self&& self) { /* ... */; return self; }
};

struct Special : Builder {
    template <typename Self>
    Self& c(this Self&& self) { /* ... */; return self; }

    template <typename Self>
    Self& d(this Self&& self) { /* ... */; return self; }
};

struct Super : Special {
    template <typename Self>
    Self& e(this Self&& self) { /* ... */; return self; }
};
```

All the same flat pattern.

25 / 64

▶ ▶ 🔍 19:49 / 1:02:41

HD

The Future of CRTP?

Cppcon 2023 | October 01 - 06

Rudyard Merriam

A Journey Into Non-Virtual Polymorphism

C++23: Explicit Object Parameter AKA, Deducing This

```
struct Shape {  
    template<typename T>  
    void draw(this T& self) { self.draw_impl();}  
};  
  
struct Rectangle : public Shape {  
    void draw_impl() const { std::cout << "Rectangle\n"; }  
};
```

41

Video Sponsorship Provided By:

Adobe think-cell

43:48 / 48:49

The Future of CRTP?

```
template <class Derived>
struct Animal {
    void speak(this auto&& self) { self.speak_impl(); }
};

struct Cat : public Animal<Cat> {
    void speak_impl() { std::cout << "meow"; }
};

struct Dog : public Animal<Cat> {
    void speak_impl() { std::cout << "woof"; }
};

int main() {
    std::unique_ptr<Animal> myAnimal(new Cat);
    myAnimal->speak(); // prints "meow"
}
```

Copyright (c) Timur Doumler | [@timur_audio](#) | <https://timur.audio>



56

() NDC
Conferences
Subscribe

NDC { TechTown }

▶ ▶ 🔍 19:37 / 59:24



The Future of CRTP?

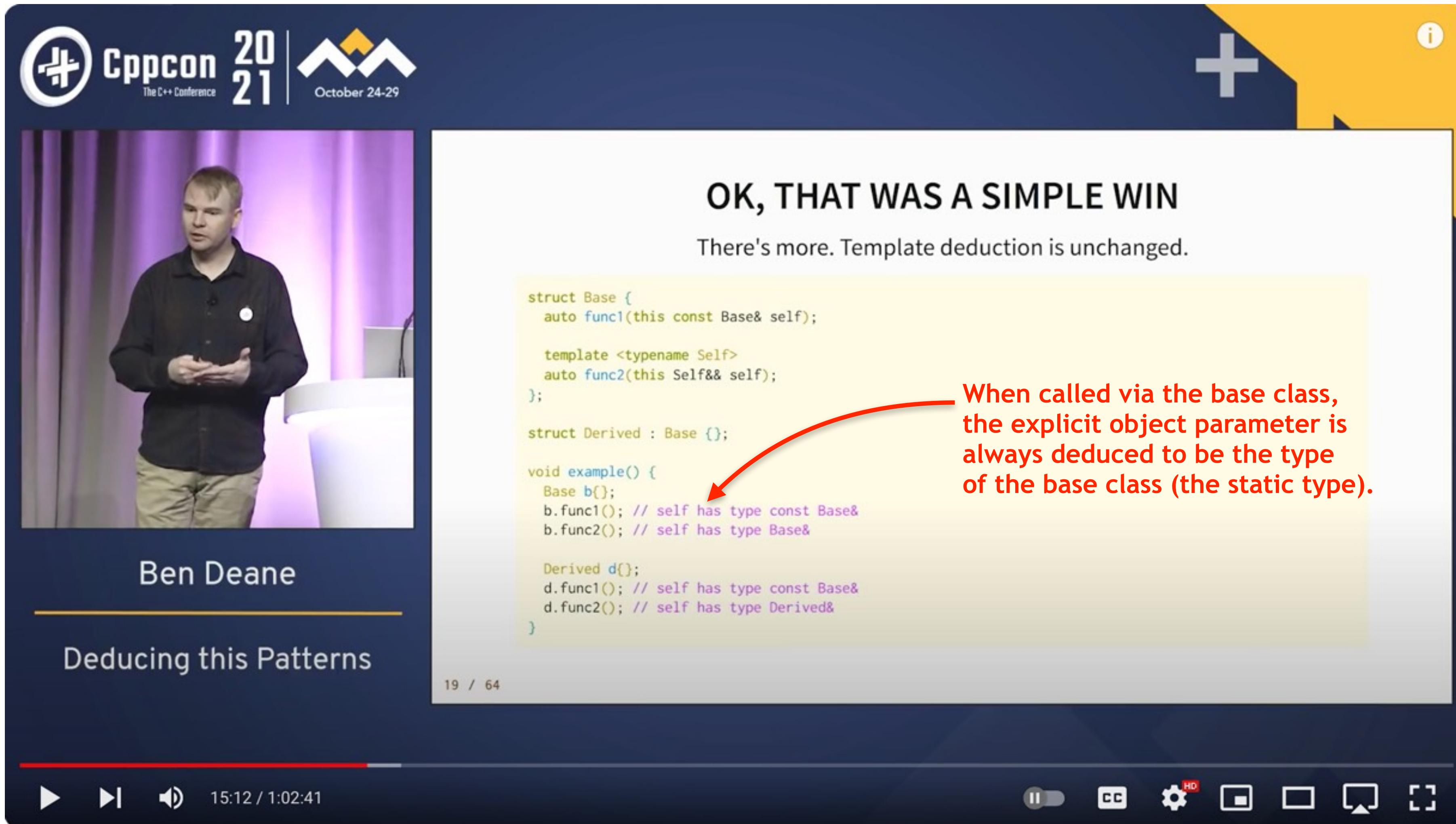
```
class Animal
{
public:
    template< typename Self >
    void make_sound( this Self const& self )
    {
        self.make_sound_impl();
    }
};

class Sheep : public Animal
{
public:
    void make_sound_impl() const { std::cout << "baa"; }
};

int main()
{
    Sheep sheep;
    Animal& animal = sheep;

    sheep.make_sound();
    animal.make_sound(); // Compilation error!
}
```

The Future of CRTP?



Cppcon 2021 | October 24-29

Ben Deane

Deducing this Patterns

15:12 / 1:02:41

OK, THAT WAS A SIMPLE WIN

There's more. Template deduction is unchanged.

```
struct Base {
    auto func1(this const Base& self);
    template <typename Self>
    auto func2(this Self&& self);
};

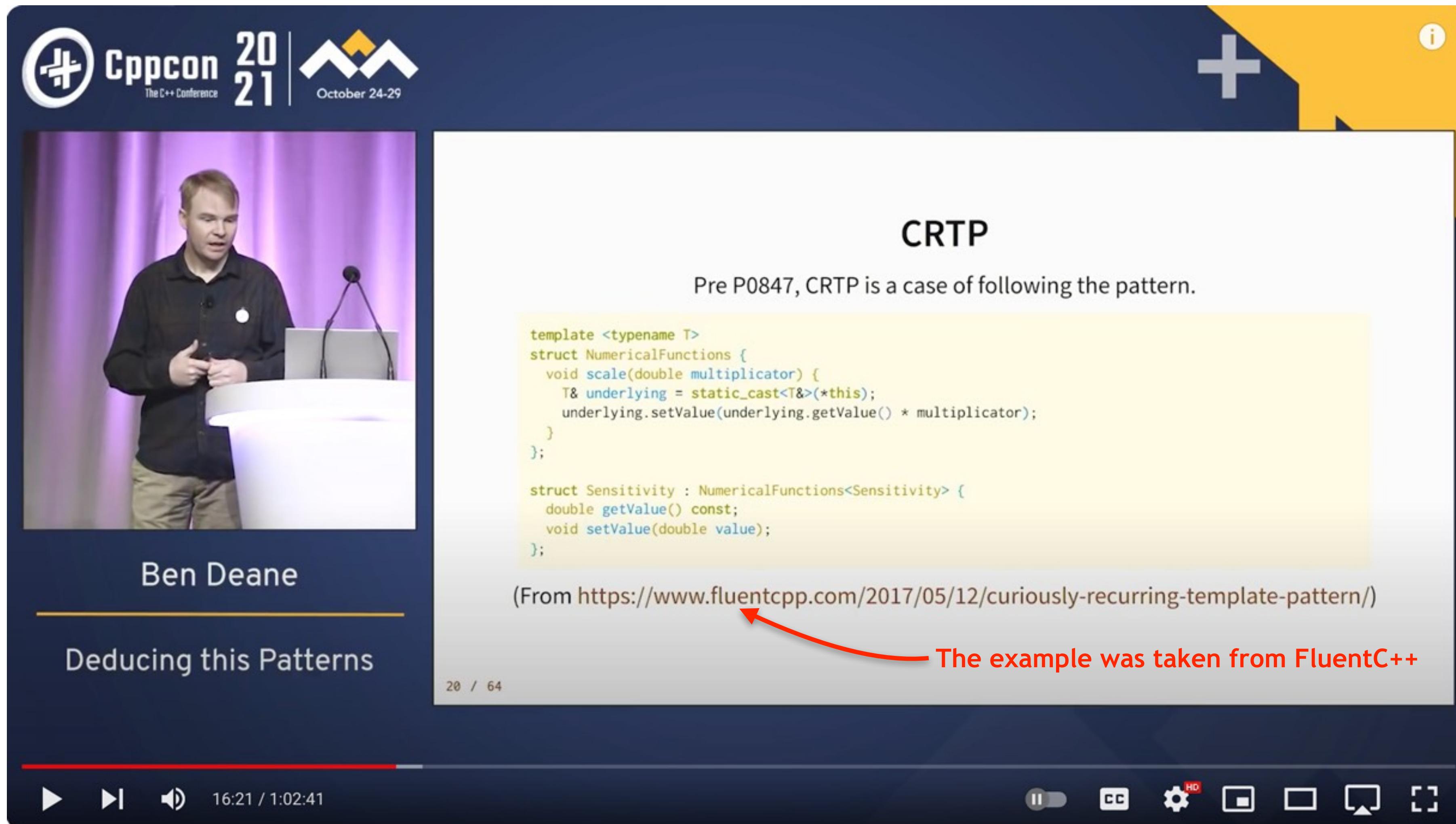
struct Derived : Base {};

void example() {
    Base b{};
    b.func1(); // self has type const Base&
    b.func2(); // self has type Base&

    Derived d{};
    d.func1(); // self has type const Base&
    d.func2(); // self has type Derived&
}
```

When called via the base class,
the explicit object parameter is
always deduced to be the type
of the base class (the static type).

The Future of CRTP?



Cppcon 2021 | October 24-29

Ben Deane

Deducing this Patterns

20 / 64

16:21 / 1:02:41

CRTP

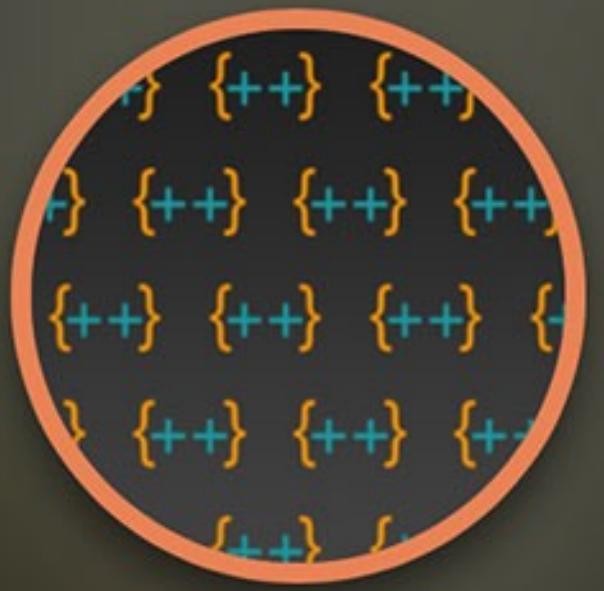
Pre P0847, CRTP is a case of following the pattern.

```
template <typename T>
struct NumericalFunctions {
    void scale(double multiplicator) {
        T& underlying = static_cast<T&>(*this);
        underlying.setValue(underlying.getValue() * multiplicator);
    }
};

struct Sensitivity : NumericalFunctions<Sensitivity> {
    double getValue() const;
    void setValue(double value);
};
```

(From <https://www.fluentcpp.com/2017/05/12/curiously-recurring-template-pattern/>)

The example was taken from FluentC++



Jonathan Boccaro's blog



POSTS

THE WORLD MAP OF C++
STL ALGORITHMS

DAILY C++

STORE

ABOUT

RECENT POSTS

What the Curiously Recurring Template Pattern can bring to your code

Published May 16, 2017 - 16 Comments



After having defined the basics on the CRTP in episode #1 of the series, let's now consider how the CRTP can be helpful in day-to-day code.

The episodes in this series are:

- The CRTP, episode One: [Definition](#)
- The CRTP, episode Two: What the CRTP can bring to your code

Usage First, Implementation After: A Principle of Software Development

Design Patterns VS Design Principles: Factory method

How to Store an lvalue or an rvalue in the Same Object

Copy-Paste Developments

Design Patterns VS Design Principles: Abstract Factory

How to Generate All the Combinations from Several Collections

After having defined the basics on the CRTP in episode #1 of the series, let's now consider how the CRTP can be helpful in day-to-day code.

The episodes in this series are:

- The CRTP, episode One: [Definition](#)
- The CRTP, episode Two: What the CRTP can bring to your code
- The CRTP, episode Three: [An implementation helper for the CRTP](#)

I don't know about you, but the first few times I figured how the CRTP worked I ended up forgetting soon after, and in the end could never remember what the CRTP exactly was. This happened because a lot of definitions of CRTP stop there, and don't show you *what value* the CRTP can bring to your code.

But there are several ways the CRTP can be useful. Here I am presenting the one that I see most in code, **Adding Functionality**, and another one that is interesting but that I don't encounter as often: creating **Static Interfaces**.

 There are two forms of CRTP!

In order to make the code examples shorter, I have omitted the private-constructor-and-template-friend trick seen in episode One. But in practice you would find it useful to prevent the wrong class from being passed to the CRTP template.

Adding functionality

Adding Functionality with CRTP

```
template< typename Derived >
struct NumericalFunctions
{
    void scale( double multiplicator )
    {
        Derived& underlying = static_cast<Derived&>(*this);
        underlying.setValue( underlying.getValue() * multiplicator );
    }
};

struct Sensitivity : public NumericalFunctions<Sensitivity>
{
    double getValue() const { return value; }
    void setValue( double v ) { value = v; }
    double value;
};

int main()
{
    Sensitivity s{ 1.2 };
    s.scale( 2.0 );

    std::println( std::cout, "s.getValue() = {}", s.getValue() );
}
```

Adding Functionality with C++23

```
struct NumericalFunctions
{
    void scale( this auto&& self, double multiplicator )
    {
        self.setValue( self.getValue() * multiplicator );
    }
};

struct Sensitivity : public NumericalFunctions
{
    double getValue() const { return value; }
    void setValue( double v ) { value = v; }
    double value;
};

int main()
{
    Sensitivity s{ 1.2 };
    s.scale( 2.0 );

    std::println( std::cout, "s.getValue() = {}", s.getValue() );
}
```



Static Interfaces with CRTP

```
template< typename Derived >
class Animal
{
private:
    // ... Private default ctor and dtor

public:
    void make_sound() const {
        static_cast<Derived const&>(*this).make_sound_impl();
    }
};

class Sheep : public Animal<Sheep>
{
public:
    void make_sound_impl() const { std::cout << "baa"; }
};

int main()
{
    Sheep sheep;
    Animal<Sheep>& animal = sheep;

    sheep.make_sound();
    animal.make_sound();
}
```

Static Interfaces with C++23

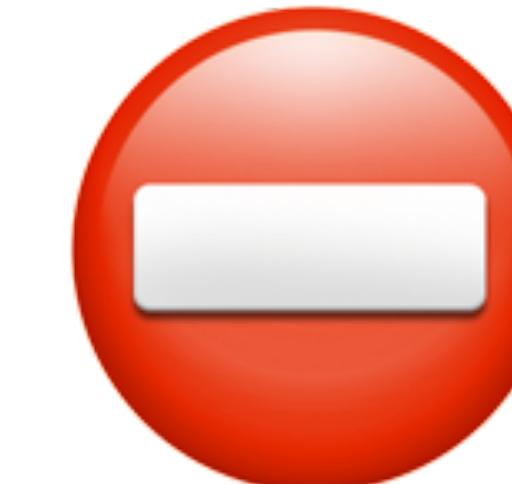
```
class Animal
{
public:
    template< typename Self >
    void make_sound( this Self const& self )
    {
        self.make_sound_impl();
    }
};

class Sheep : public Animal
{
public:
    void make_sound_impl() const { std::cout << "baa"; }
};

int main()
{
    Sheep sheep;
    Animal& animal = sheep;

    sheep.make_sound();
    animal.make_sound(); ←
}

Cannot compile since the 'Self' type  
cannot be deduced to be the dynamic  
type
```



Two Forms of CRTP ...

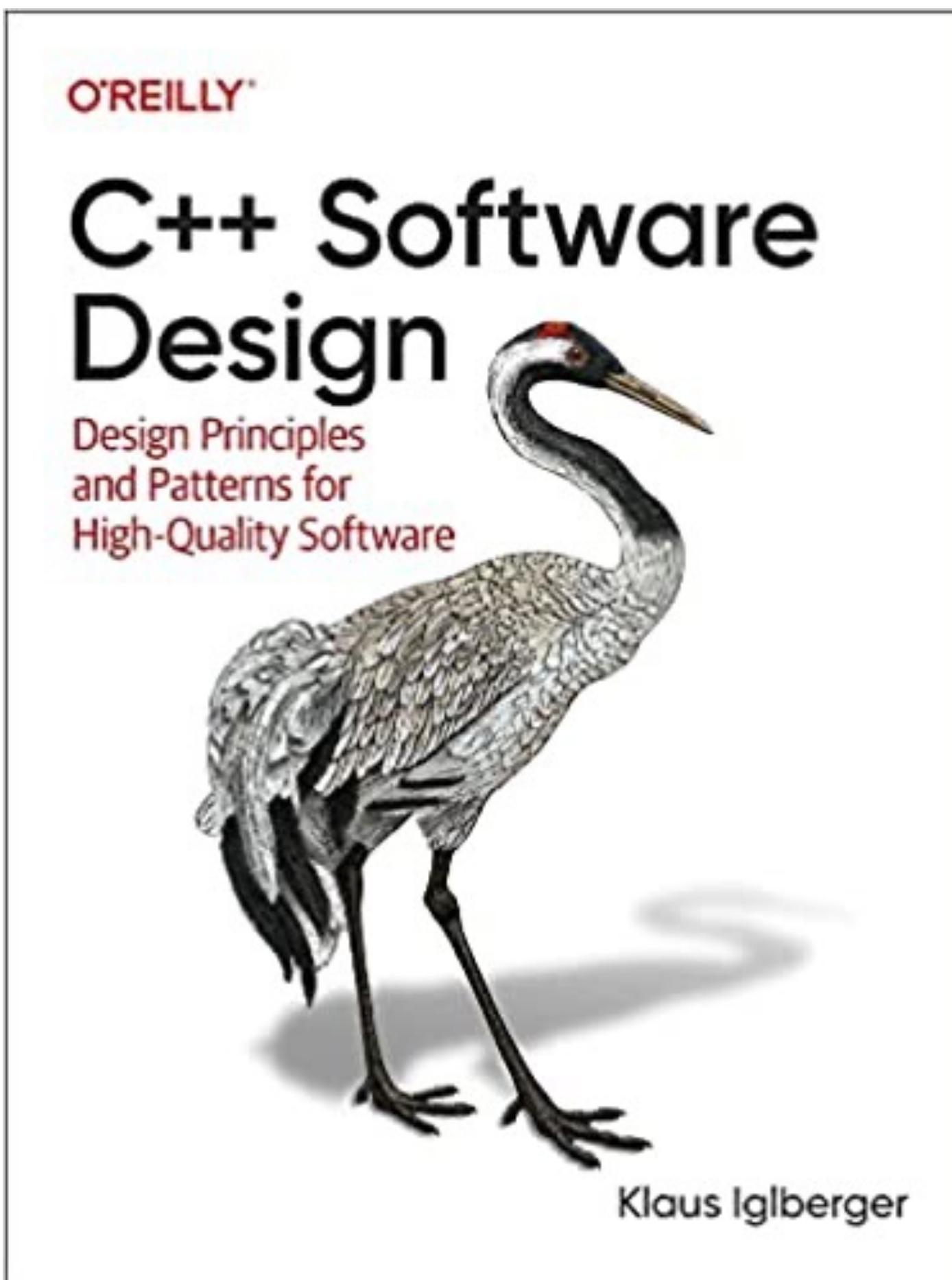
The term CRTP is ambiguous ...

The ambiguity leads to
misunderstandings ...

We need new terms!

I apologize!

I failed to provide these two terms.



www.oreilly.com

The Two Forms of CRTP

CRTPO for Static Interfaces ...

- ... provides a base class for a related set/family of types;
- ... defines a common interface;
- ... is used via the base class interface;
- ... introduces an abstraction and is a design pattern.
- ... should be called “**Static Interface**”

Adding Functionality via CRTP ...

- ... provides implementation details for the derived class;
- ... does **not** define a common interface;
- ... is not used via the base class interface;
- ... does not introduce an abstraction, hence is no design pattern.
- ... should be called “**Mixin**”

Guidelines

Guideline: Prefer to use the term “**Static Interface**” to express the intent to create a static family of types.

Guideline: “**Static Interface**” is a design pattern. Explicit object parameters (an implementation detail) cannot replace CRTP.

Guideline: Prefer to use the term “**Mixin**” to express the intent to inherit implementation details from a base class.

Guideline: “**Mixins**” are an implementation detail. Explicit object parameters are an alternative and can be a replacement for CRTP.

Wait a second! ...

Couldn't we just replace
CRTP for static interfaces
with a C++20 concept?

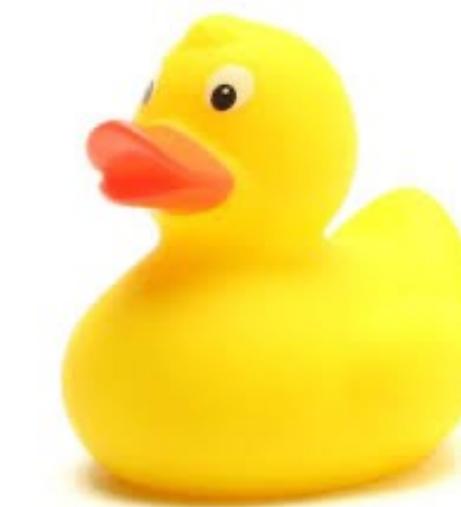
Static Interfaces with Concepts

```
template< typename T >
concept Animal =
    requires( T animal ) { animal.make_sound(); };
```

```
template< Animal T >
void print( T const& animal )
{
    animal.make_sound();
}
```

```
class Sheep
{
public:
    void make_sound() const { std::cout << "baa"; }
};
```

```
int main()
{
    Sheep sheep;
    print( sheep );
}
```



"I can be printed, too!" "Hooo...pahhh, me too!" "It is logical to assume that I can be printed, too!"

This is not the same as Static Interfaces!
Anything can be passed, not just a specified set of types.
Static Interfaces are about an explicit opt-in.

Static Interfaces with Concepts

```
class AnimalTag {};  
  
template< typename T >  
concept Animal =  
    requires( T animal ) { animal.make_sound(); } &&  
    std::derived_from<T,AnimalTag>;  
  
template< Animal T >  
void print( T const& animal )  
{  
    animal.make_sound();  
}  
  
class Sheep : public AnimalTag  
{  
public:  
    void make_sound() const { std::cout << "baa"; }  
};  
  
int main()  
{  
    Sheep sheep;  
    print( sheep );  
}
```



"I can't be printed anymore 😞"

"Hooo...pahhh, me neither!"

"It is logical to assume that now I'm unprintable as well!"

This is a CRTP-free Static Interface: the Sheep class explicitly opts-in to be an animal.

This could not be achieved with a nested type/member. Only the base cannot be present by coincident.

Guidelines

Guideline: Prefer to use the term “**Static Interface**” to express the intent to create a static family of types.

Guideline: “**Static Interface**” is a design pattern. Explicit object parameters (an implementation detail) are not an alternative.

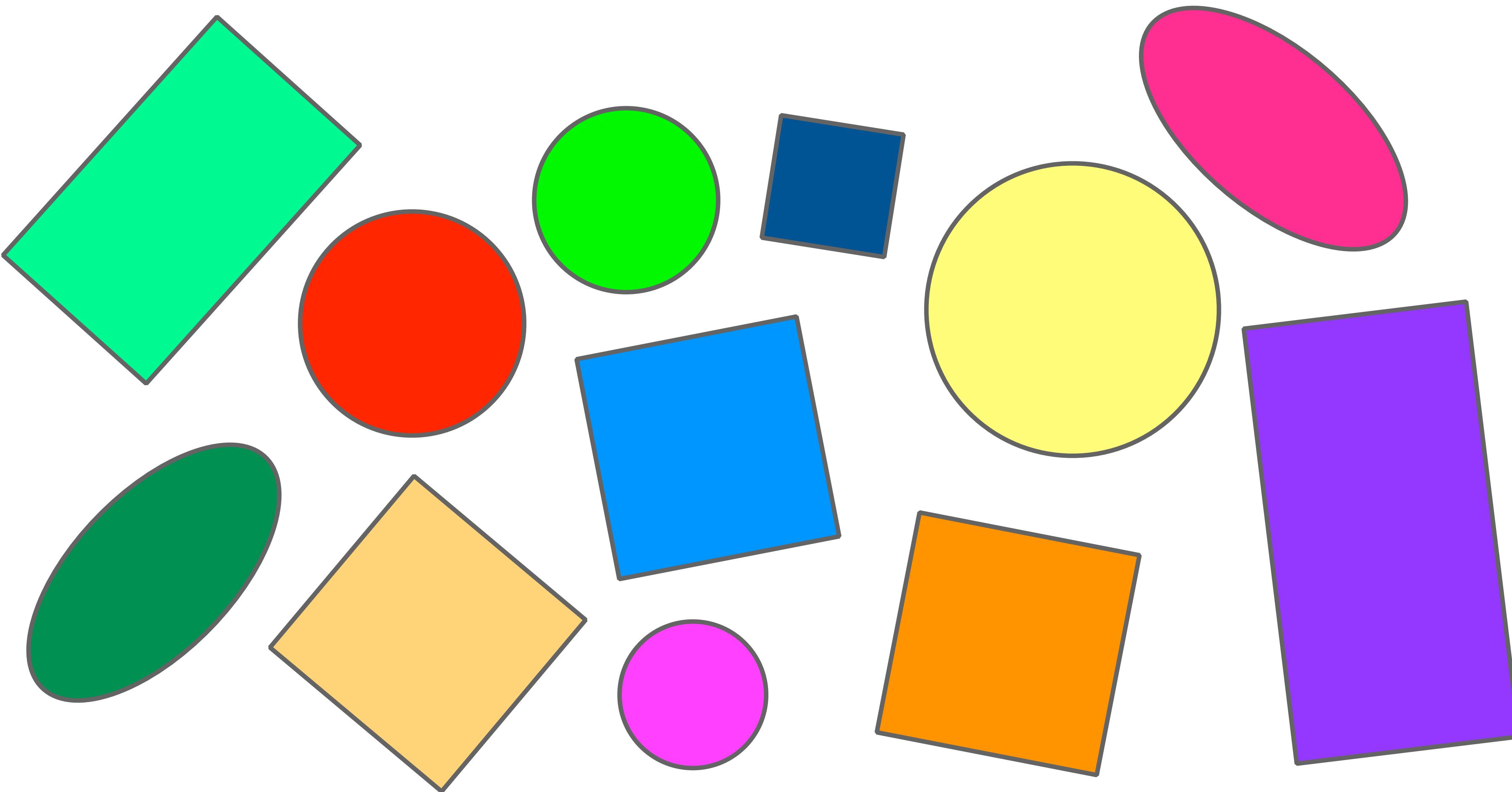
Guideline: Prefer to use the term “**Mixin**” to express the intent to inherit implementation details from a base class.

Guideline: “**Mixins**” are an implementation detail. Explicit object parameters are an alternative and can be a replacement for CRTP.

Issue #2

std::variant

Our Toy Problem: Drawing Shapes



Our Toy Problem: Drawing Shapes

Requirements:

- Extensible by new kinds of shapes
- 10M+ lines of code
- 100+ developers



A Classic Object-Oriented Solution

```
template< typename ConcreteShape >
class DrawStrategy
{
public:
    virtual ~DrawStrategy() = default;

    virtual void draw( ConcreteShape const& shape ) const = 0;
};

class Shape
{
public:
    virtual ~Shape() = default;

    virtual void draw() const = 0;
    // ... several other virtual functions
};

class Circle : public Shape
{
public:
    Circle( double rad, std::unique_ptr<DrawStrategy<Circle>>&& ds )
        : radius{ rad }
        , // ... Remaining data members
        , drawer{ std::move(ds) }
    {}

    double getRadius() const;
    // ... getCenter(), getRotation(), ...
}
```

A Classic Object-Oriented Solution

```
template< typename ConcreteShape >
class DrawStrategy
{
public:
    virtual ~DrawStrategy() = default;

    virtual void draw( ConcreteShape const& shape ) const = 0;
};

class Shape
{
public:
    virtual ~Shape() = default;

    virtual void draw() const = 0;
    // ... several other virtual functions
};

class Circle : public Shape
{
public:
    Circle( double rad, std::unique_ptr<DrawStrategy<Circle>>&& ds )
        : radius{ rad }
        , // ... Remaining data members
        , drawer{ std::move(ds) }
    {}

    double getRadius() const;
    // ... getCenter(), getRotation(), ...
}
```

A Classic Object-Oriented Solution

```
class Shape
{
public:
    virtual ~Shape() = default;

    virtual void draw() const = 0;
    // ... several other virtual functions
};

class Circle : public Shape
{
public:
    Circle( double rad, std::unique_ptr<DrawStrategy<Circle>>&& ds )
        : radius{ rad }
        , // ... Remaining data members
        , drawer{ std::move(ds) }
    {}

    double getRadius() const;
    // ... getCenter(), getRotation(), ...

    void draw() const override;
    // ... several other virtual functions

private:
    double radius;
    // ... Remaining data members
    std::unique_ptr<DrawStrategy<Circle>> drawer;
};
```

A Classic Object-Oriented Solution

```
template< typename ConcreteShape >
class DrawStrategy
{
public:
    virtual ~DrawStrategy() = default;

    virtual void draw( ConcreteShape const& shape ) const = 0;
};

class Shape
{
public:
    virtual ~Shape() = default;

    virtual void draw() const = 0;
    // ... several other virtual functions
};

class Circle : public Shape
{
public:
    Circle( double rad, std::unique_ptr<DrawStrategy<Circle>>&& ds )
        : radius{ rad }
        , // ... Remaining data members
        , drawer{ std::move(ds) }
    {}

    double getRadius() const;
    // ... getCenter(), getRotation(), ...
}
```

A Classic Object-Oriented Solution

```
virtual void draw() const = 0;
// ... several other virtual functions
};

class Circle : public Shape
{
public:
    Circle( double rad, std::unique_ptr<DrawStrategy<Circle>>&& ds )
        : radius{ rad }
        , // ... Remaining data members
        , drawer{ std::move(ds) }
    {}

    double getRadius() const;
    // ... getCenter(), getRotation(), ...

    void draw() const override;
    // ... several other virtual functions

private:
    double radius;
    // ... Remaining data members
    std::unique_ptr<DrawStrategy<Circle>> drawer;
};

class Square : public Shape
{
public:
    Square( double s, std::unique_ptr<DrawStrategy<Square>>&& ds )
        : side{ s }
```

A Classic Object-Oriented Solution

```
    double radius;
    // ... Remaining data members
    std::unique_ptr<DrawStrategy<Circle>> drawer;
};

class Square : public Shape
{
public:
    Square( double s, std::unique_ptr<DrawStrategy<Square>>&& ds )
        : side{ s }
        , // ... Remaining data members
        , drawer{ std::move(ds) }
    {}

    double getSide() const;
    // ... getCenter(), getRotation(), ...

    void draw() const override;
    // ... several other virtual functions

private:
    double side;
    // ... Remaining data members
    std::unique_ptr<DrawStrategy<Square>> drawer;
};

using Shapes = std::vector<std::unique_ptr<Shape>>;
```

A Classic Object-Oriented Solution

```
double getSide() const;
// ... getCenter(), getRotation(), ...

void draw() const override;
// ... several other virtual functions

private:
    double side;
    // ... Remaining data members
    std::unique_ptr<DrawStrategy<Square>> drawer;
};

using Shapes = std::vector<std::unique_ptr<Shape>>;

class ShapesFactory
{
public:
    virtual ~ShapesFactory() = default;

    virtual Shapes create( std::string_view filename ) const = 0;
};

void drawAllShapes( Shapes const& shapes )
{
    for( auto const& s : shapes )
    {
        s->draw();
    }
}
```

A Classic Object-Oriented Solution

```
private:  
    double side;  
    // ... Remaining data members  
    std::unique_ptr<DrawStrategy<Square>> drawer;  
};  
  
using Shapes = std::vector<std::unique_ptr<Shape>>;  
  
class ShapesFactory  
{  
public:  
    virtual ~ShapesFactory() = default;  
  
    virtual Shapes create( std::string_view filename ) const = 0;  
};  
  
void drawAllShapes( Shapes const& shapes )  
{  
    for( auto const& s : shapes )  
    {  
        s->draw();  
    }  
}  
  
void createAndDrawShapes( ShapesFactory const& factory, std::string_view filename )  
{
```

A Classic Object-Oriented Solution

```
class ShapesFactory
{
public:
    virtual ~ShapesFactory() = default;

    virtual Shapes create( std::string_view filename ) const = 0;
};

void drawAllShapes( Shapes const& shapes )
{
    for( auto const& s : shapes )
    {
        s->draw();
    }
}

void createAndDrawShapes( ShapesFactory const& factory, std::string_view filename )
{
    Shapes shapes = factory.create( filename );
    drawAllShapes( shapes );
}

class OpenGLDrawer : public DrawStrategy<Circle>
                    , public DrawStrategy<Square>
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}
```

A Classic Object-Oriented Solution

```
void drawAllShapes( Shapes const& shapes )
{
    for( auto const& s : shapes )
    {
        s->draw();
    }
}

void createAndDrawShapes( ShapesFactory const& factory, std::string_view filename )
{
    Shapes shapes = factory.create( filename );
    drawAllShapes( shapes );
}

class OpenGLDrawer : public DrawStrategy<Circle>
                    , public DrawStrategy<Square>
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}

    void draw( Circle const& circle ) const override;

    void draw( Square const& square ) const override;

private:
    // ... Data members (color, texture, transparency, ...)
};
```

A Classic Object-Oriented Solution

```
void createAndDrawShapes( ShapesFactory const& factory, std::string_view filename )
{
    Shapes shapes = factory.create( filename );
    drawAllShapes( shapes );
}

class OpenGLDrawer : public DrawStrategy<Circle>
                    , public DrawStrategy<Square>
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}

    void draw( Circle const& circle ) const override;

    void draw( Square const& square ) const override;

private:
    // ... Data members (color, texture, transparency, ...)
};

class YourShapesFactory : public ShapesFactory
{
public:
    Shapes create( std::string_view filename ) const override
    {
        Shapes shapes{};
        std::string shape{};
        std::ifstream shape_file{ filename };
        // ...
    }
}
```

A Classic Object-Oriented Solution

```
class YourShapesFactory : public ShapesFactory
{
public:
    Shapes create( std::string_view filename ) const override
    {
        Shapes shapes{};
        std::string shape{};
        std::ifstream shape_file{ filename };

        while( shape_file >> shape )
        {
            if( shape == "circle" )
            {
                double radius;
                shape_file >> radius /* >> color, texture, transparency, ... */;
                shapes.emplace_back(
                    std::make_unique<Circle>( radius
                                              , std::make_unique<OpenGLDrawer>(/*...*/)));
            }
            else if( shape == "square" )
            {
                double side;
                shape_file >> side /* >> color, texture, transparency, ... */;
                shapes.emplace_back(
                    std::make_unique<Square>( side
                                              , std::make_unique<OpenGLDrawer>(/*...*/)));
            }
            else {
                break;
            }
        }

        return shapes;
    }
};
```

A Classic Object-Oriented Solution

```
        else if( shape == "square" ) {
            double side;
            shape_file >> side /* >> color, texture, transparency, ... */;
            shapes.emplace_back(
                std::make_unique<Square>( side
                    , std::make_unique<OpenGLDrawer>(/*...*/) ) );
        }
        else {
            break;
        }
    }

    return shapes;
}
};

int main()
{
    YourShapesFactory factory{};
    createAndDrawShapes( factory, "shapes.txt" );
}
```

A Classic Object-Oriented Solution

```
void drawAllShapes( Shapes const& shapes )
{
    for( auto const& s : shapes )
    {
        s->draw();
    }
}

void createAndDrawShapes( ShapesFactory const& factory, std::string_view filename )
{
    Shapes shapes = factory.create( filename );
    drawAllShapes( shapes );
}

class OpenGLDrawer : public DrawStrategy<Circle>
                    , public DrawStrategy<Square>
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}

    void draw( Circle const& circle ) const override;

    void draw( Square const& square ) const override;

private:
    // ... Data members (color, texture, transparency, ...)
};
```

A Classic Object-Oriented Solution

```
void drawAllShapes( Shapes const& shapes )
{
    for( auto const& s : shapes )
    {
        s->draw();
    }
}

void createAndDrawShapes( ShapesFactory const& factory, std::string_view filename )
{
    Shapes shapes = factory.create( filename );
    drawAllShapes( shapes );
}
```

High level (stable, low dependencies)

Low level (volatile, malleable, high dependencies)

Architectural
Boundary

```
class OpenGLDrawer : public DrawStrategy<Circle>
                    , public DrawStrategy<Square>
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}

    void draw( Circle const& circle ) const override;

    void draw( Square const& square ) const override;

private:
```

A Classic Object-Oriented Solution

```
void drawAllShapes( Shapes const& shapes )
{
    for( auto const& s : shapes )
    {
        s->draw();
    }
}

void createAndDrawShapes( ShapesFactory const& factory, std::string_view filename )
{
    Shapes shapes = factory.create( filename );
    drawAllShapes( shapes );
}
```

My Code

Your Code

Architectural
Boundary

```
class OpenGLDrawer : public DrawStrategy<Circle>
                    , public DrawStrategy<Square>
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}

    void draw( Circle const& circle ) const override;

    void draw( Square const& square ) const override;

private:
```

A Classic Object-Oriented Solution

My Code

Your Code

Architectural
Boundary

```
class Rectangle : public Shape
{
public:
    Rectangle( double width, double height
               , std::unique_ptr<DrawStrategy<Rectangle>>&& drawer )
        : width_{ width }
        , height_{ height }
        , // ... Remaining data members
        , drawer_{ std::move(drawer) }
    {}

    double width() const { return width_; }
    double height() const { return height_; }
    // ... getCenter(), getRotation(), ...

    void draw() const override { drawer_->draw(*this); }
    // ... several other virtual functions

private:
    double width_;
    double height_;
    // ... Remaining data members
    std::unique_ptr<DrawStrategy<Rectangle>> drawer_;
};
```

A Classic Object-Oriented Solution

```
private:  
    double width_;  
    double height_;  
    // ... Remaining data members  
    std::unique_ptr<DrawStrategy<Rectangle>> drawer_;  
};  
  
  
class OpenGLDrawer : public DrawStrategy<Circle>  
    , public DrawStrategy<Square>  
    , public DrawStrategy<Rectangle>  
{  
    public:  
        explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}  
  
        void draw( Circle const& circle ) const override;  
  
        void draw( Square const& square ) const override;  
  
        void draw( Rectangle const& rectangle ) const override;  
  
    private:  
        // ... Data members (color, texture, transparency, ...)  
};  
  
  
class YourShapesFactory : public ShapesFactory  
{  
    public:  
        Shapes create( std::string_view filename ) const override  
    {  
        Shapes shapes{  
            std::make_unique<Circle>( filename ),  
            std::make_unique<Square>( filename ),  
            std::make_unique<Rectangle>( filename )  
        };  
        return shapes;  
    }  
};
```

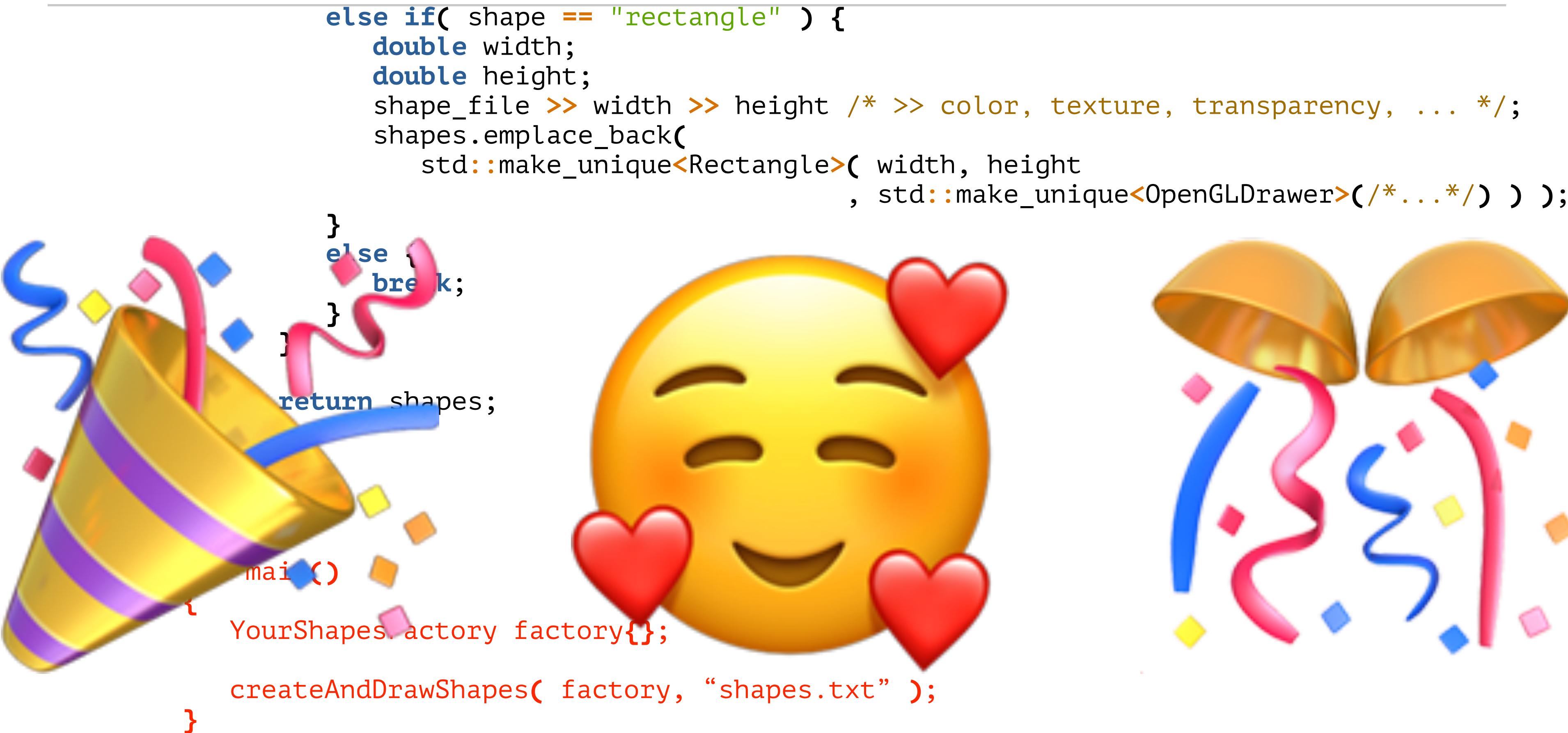
A Classic Object-Oriented Solution

```
class YourShapesFactory : public ShapesFactory
{
public:
    Shapes create( std::string_view filename ) const override
    {
        Shapes shapes{};
        std::string shape{};
        std::ifstream shape_file{ filename };

        while( shape_file >> shape )
        {
            if( shape == "circle" ) {
                // ... Creating a circle
            }
            else if( shape == "square" ) {
                // ... Creating a square
            }
            else if( shape == "rectangle" ) {
                double width;
                double height;
                shape_file >> width >> height /* >> color, texture, transparency, ... */;
                shapes.emplace_back(
                    std::make_unique<Rectangle>( width, height
                                                , std::make_unique<OpenGLDrawer>(/*...*/)));
            }
            else {
                break;
            }
        }

        return shapes;
    }
};
```

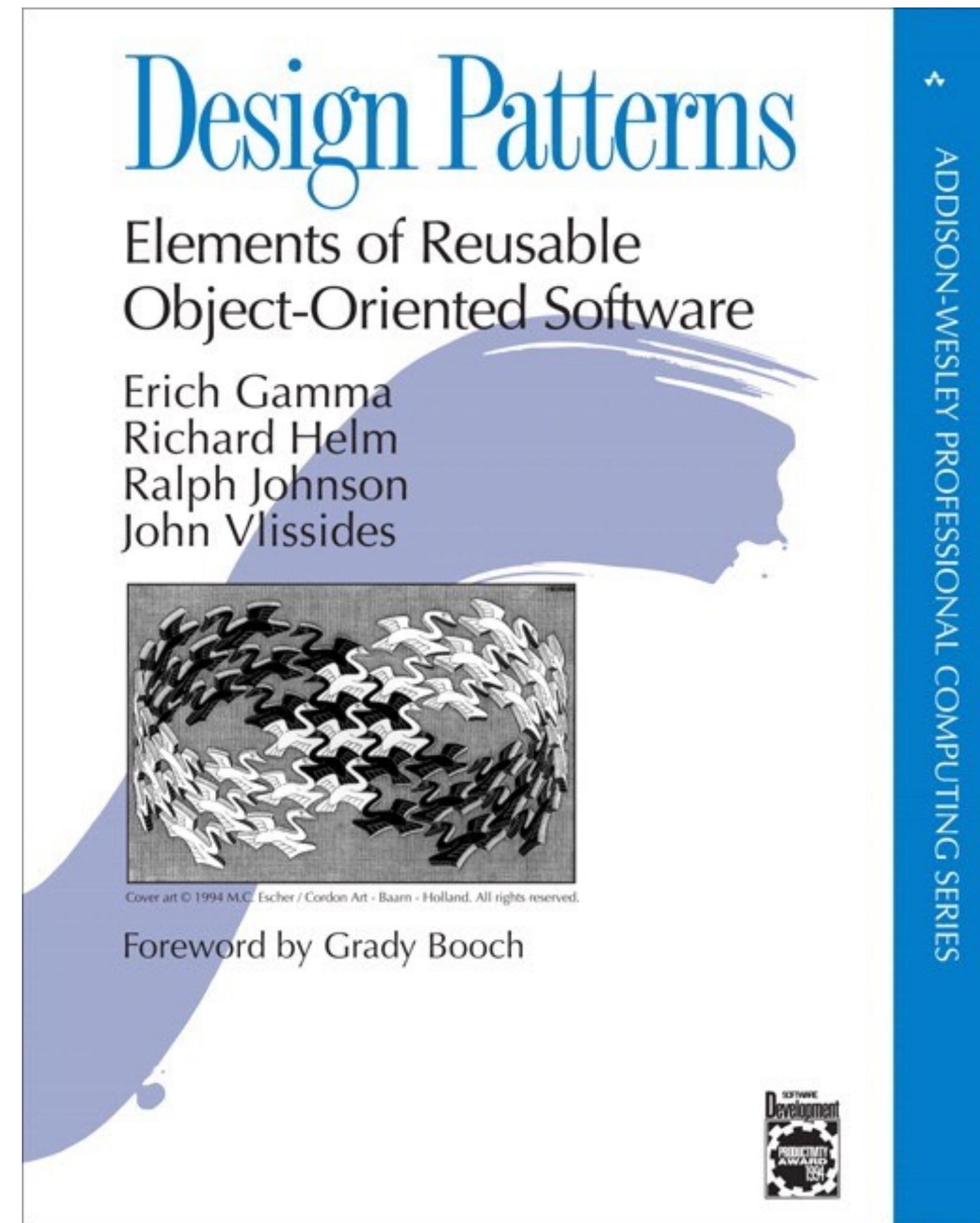
A Classic Object-Oriented Solution



Yes... some of you are unhappy
about this style of programming.



The Philosophy of the 90s

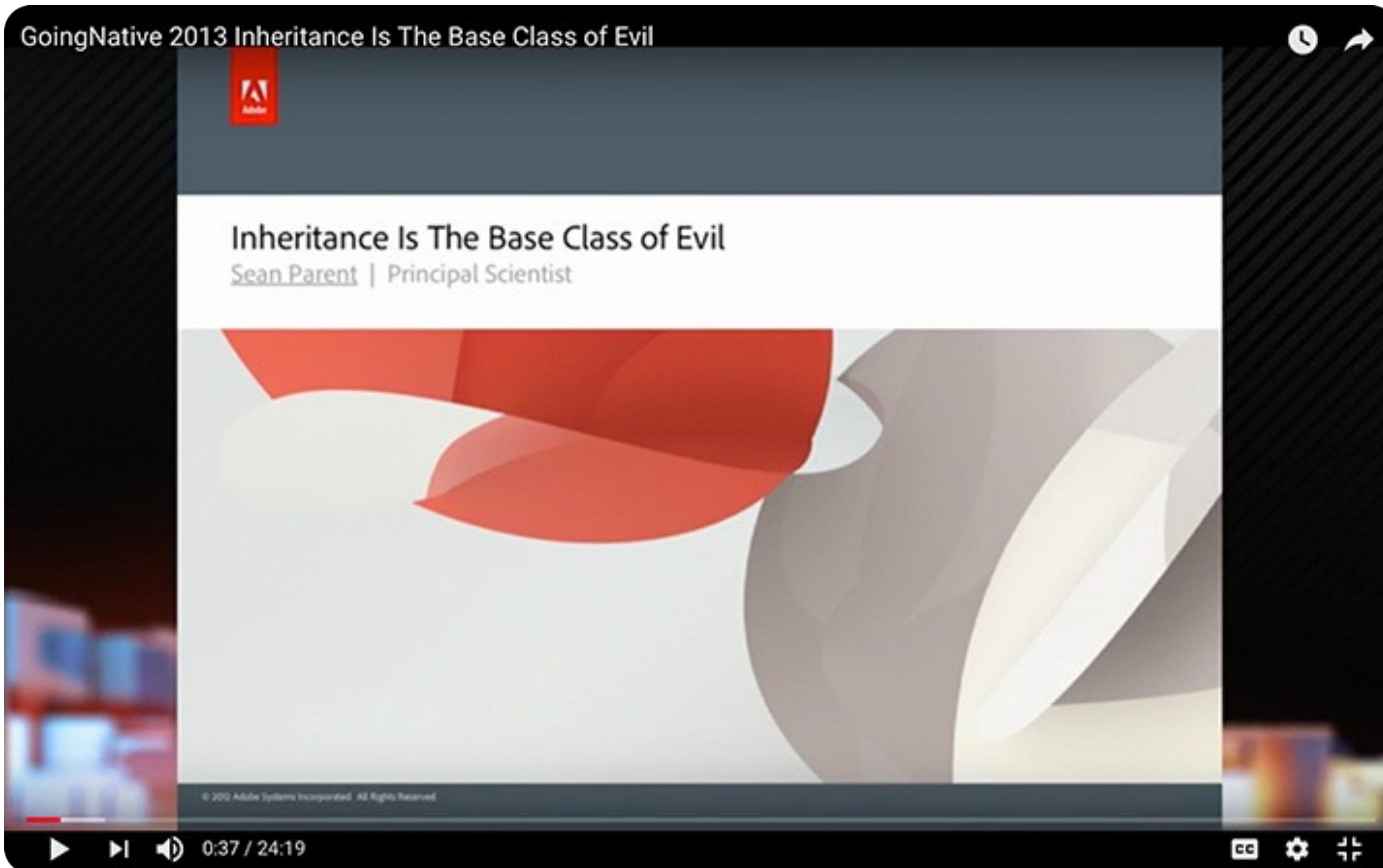


The Philosophy of the 90s

The GOF Style
Inheritance and
virtual functions
as the answer



The Fallen Paradigm (?)



The Fallen Paradigm (?)



A presentation slide from Cppcon 2022. The slide has a dark blue background with a pink and white graphic in the top right corner featuring a plus sign and the number '22'. The title 'Using Modern C++ to Eliminate Virtual Functions' is centered in yellow text. Below it, the speaker's name 'JONATHAN GOPEL' is also in yellow. At the bottom left is the Cppcon logo with the text 'The C++ Conference'. At the bottom right is the date '2022' next to a mountain icon, with 'September 12th-16th' written below it.

**Using Modern C++ to
Eliminate Virtual Functions**

JONATHAN GOPEL

2022 |  September 12th-16th

Cppcon
The C++ Conference

The Fallen Paradigm (?)



”I believe that object-oriented programming and especially its theory is overestimated. ... C++ always had templates, and now also has std::variant, which makes most of the use of inheritance unnecessary.”

(Unknown Reviewer)

The Fallen Paradigm (?)



*”I believe that object-oriented programming and especially its theory is overestimated. ... C++ always had templates, and now also has **std::variant**, which makes most of the use of inheritance unnecessary.”*

(Unknown Reviewer)

A Truly Modern C++ Solution: std::variant (?)

```
class Circle
{
public:
    explicit Circle( double rad )
        : radius{ rad }
        , // ... Remaining data members
    {}

    double getRadius() const noexcept;
    // ... getCenter(), getRotation(), ...
}
```

```
private:
    double radius;
    // ... Remaining data members
};
```

```
class Square
{
public:
    explicit Square( double s )
        : side{ s }
        , // ... Remaining data members
    {}

    double getSide() const noexcept;
    // ... getCenter(), getRotation(), ...
}
```

```
private:
    double side;
    // ... Remaining data members
};
```

A Truly Modern C++ Solution: std::variant (?)

```
class Circle
{
public:
    explicit Circle( double rad )
        : radius{ rad }
        , // ... Remaining data members
    {}

    double getRadius() const noexcept;
    // ... getCenter(), getRotation(), ...

private:
    double radius;
    // ... Remaining data members
};
```

```
class Square
{
public:
    explicit Square( double s )
        : side{ s }
        , // ... Remaining data members
    {}

    double getSide() const noexcept;
    // ... getCenter(), getRotation(), ...

private:
    double side;
    // ... Remaining data members
};
```

A Truly Modern C++ Solution: std::variant (?)

```
    double getRadius() const noexcept;
    // ... getCenter(), getRotation(), ...

private:
    double radius;
    // ... Remaining data members
};

class Square
{
public:
    explicit Square( double s )
        : side{ s }
        , // ... Remaining data members
    {}

    double getSide() const noexcept;
    // ... getCenter(), getRotation(), ...

private:
    double side;
    // ... Remaining data members
};

using Shape = std::variant<Circle,Square>;
using Shapes = std::vector<Shape>;
```

Circle and Square are soooo much simpler!

- no inheritance
- no dependency on graphics code
- no (base) pointers
- no manual life-time management
- less code to write

A Truly Modern C++ Solution: std::variant (?)

```
explicit Square( double s )
    : side{ s }
    , // ... Remaining data members
{}

double getSide() const noexcept;
// ... getCenter(), getRotation(), ...

private:
    double side;
    // ... Remaining data members
};

using Shape = std::variant<Circle, Square>; std::variant replaces the Shape base class

using Shapes = std::vector<Shape>;
```

```
class ShapesFactory
{
public:
    Shapes create( std::string_view filename )
    {
        Shapes shapes{};
        std::string shape{};

        std::ifstream shape_file{ filename };

        while( shape_file >> shape )
        {
            if( shape == "circle" ) {
```

A Truly Modern C++ Solution: std::variant (?)

```
explicit Square( double s )
    : side{ s }
    , // ... Remaining data members
{}

double getSide() const noexcept;
// ... getCenter(), getRotation(), ...

private:
    double side;
    // ... Remaining data members
};
```

```
using Shape = std::variant<Circle, Square>;
```

```
using Shapes = std::vector<Shape>;
```

We now utilize a vector of values instead of pointers

```
class ShapesFactory
{
public:
    Shapes create( std::string_view filename )
    {
        Shapes shapes{};
        std::string shape{};

        std::ifstream shape_file{ filename };

        while( shape_file >> shape )
        {
            if( shape == "circle" ) {
```

A Truly Modern C++ Solution: std::variant (?)

```
class ShapesFactory {  
public:  
    Shapes create( std::string_view filename )  
    {  
        Shapes shapes{};  
        std::string shape{};  
  
        std::ifstream shape_file{ filename };  
  
        while( shape_file >> shape )  
        {  
            if( shape == "circle" ) {  
                double radius;  
                shape_file >> radius;  
                shapes.emplace_back( Circle{radius} );  
            }  
            else if( shape == "square" ) {  
                double side;  
                shape_file >> side;  
                shapes.emplace_back( Square{side} );  
            }  
            else {  
                break;  
            }  
        }  
  
        return shapes;  
    }  
};
```

No inheritance necessary!

No need to allocate dynamic memory!

A Truly Modern C++ Solution: std::variant (?)

```
        shape_file >> side;
        shapes.emplace_back( Square{side} );
    }
    else {
        break;
    }
}

return shapes;
};

using Factory = std::variant<ShapesFactory>;
```

Replacing another inheritance hierarchy with std::variant

```
class OpenGLDrawer
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}

    void operator()( Circle const& circle ) const;
    void operator()( Square const& square ) const;

private:
    // ... Data members (color, texture, transparency, ...)
};
```

```
using Drawer = std::variant<OpenGLDrawer>;
```

A Truly Modern C++ Solution: std::variant (?)

```
using Factory = std::variant<ShapesFactory>;  
  
class OpenGLDrawer  
{  
public:  
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}  
  
    void operator()( Circle const& circle ) const;  
  
    void operator()( Square const& square ) const;  
  
private:  
    // ... Data members (color, texture, transparency, ...)  
};
```

```
using Drawer = std::variant<OpenGLDrawer>;
```

```
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( []( auto d, auto s ){ d(s); }, drawer, shape );  
    }  
}
```

Again, no inheritance necessary!

```
void createAndDrawShapes( Factory factory, std::string view filename, Drawer drawer )
```

A Truly Modern C++ Solution: std::variant (?)

```
using Factory = std::variant<ShapesFactory>;  
  
class OpenGLDrawer  
{  
public:  
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}  
  
    void operator()( Circle const& circle ) const;  
  
    void operator()( Square const& square ) const;  
  
private:  
    // ... Data members (color, texture, transparency, ...)  
};  
  
using Drawer = std::variant<OpenGLDrawer>;  
  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( []( auto d, auto s ){ d(s); }, drawer, shape );  
    }  
}  
  
void createAndDrawShapes( Factory factory, std::string view filename, Drawer drawer )
```

And another inheritance hierarchy gone!

A Truly Modern C++ Solution: std::variant (?)

```
using Drawer = std::variant<OpenGLDrawer>;  
  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( []( auto d, auto s ){ d(s); }, drawer, shape );  
    }  
}  
  
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )  
{  
    Shapes shapes = std::visit( [&filename]( auto f ){ return f.create( filename ); }, factory );  
    drawAllShapes( shapes, drawer );  
}  
  
int main()  
{  
    ShapesFactory factory{};  
    OpenGLDrawer drawer{/*...*/};  
  
    createAndDrawShapes( factory, "shapes.txt", drawer );  
}
```

A runtime dispatch on two variants!

A Truly Modern C++ Solution: std::variant (?)

```
using Drawer = std::variant<OpenGLDrawer>;  
  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( []( auto d, auto s ){ d(s); }, drawer, shape );  
    }  
}  
  
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )  
{  
    Shapes shapes = std::visit( [&filename]( auto f ){ return f.create( filename ); }, factory );  
    drawAllShapes( shapes, drawer );  
}  
  
int main()  
{  
    ShapesFactory factory{};  
    OpenGLDrawer drawer{/*...*/};  
  
    createAndDrawShapes( factory, "shapes.txt", drawer );  
}
```

A Truly Modern C++ Solution: std::variant (?)

```
using Drawer = std::variant<OpenGLDrawer>;  
  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( []( auto d, auto s ){ d(s); }, drawer, shape );  
    }  
}  
  
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )  
{  
    Shapes shapes = std::visit( [&filename]( auto f ){ return f.create( filename ); }, factory );  
    drawAllShapes( shapes, drawer );  
}  
  
int main()  
{  
    ShapesFactory factory{};  
    OpenGLDrawer drawer{/*...*/};  
  
    createAndDrawShapes( factory, "shapes.txt", drawer );  
}
```

A Truly Modern C++ Solution: std::variant (?)

This solution is soooo much better:

- No inheritance, but a functional approach
- No (smart) pointers, but values
- Proper management of graphics code
- Automatic, elegant life-time management
- Less code to write
- Soooo much simpler
- Better performance

Performance Comparison

Performance ... *sigh*

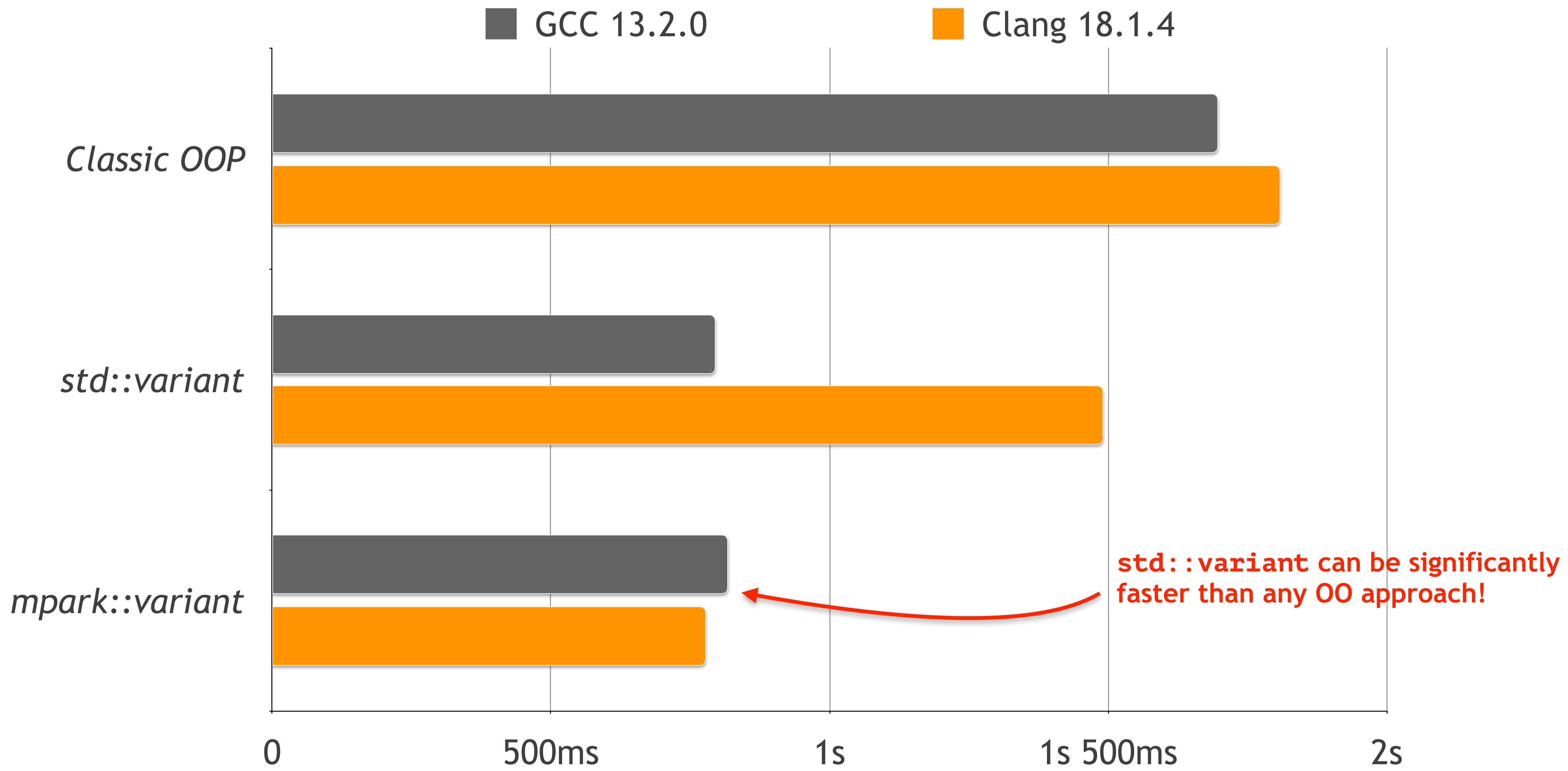
Do you promise to not take the
following results too seriously
and as qualitative results only?



Performance Comparison

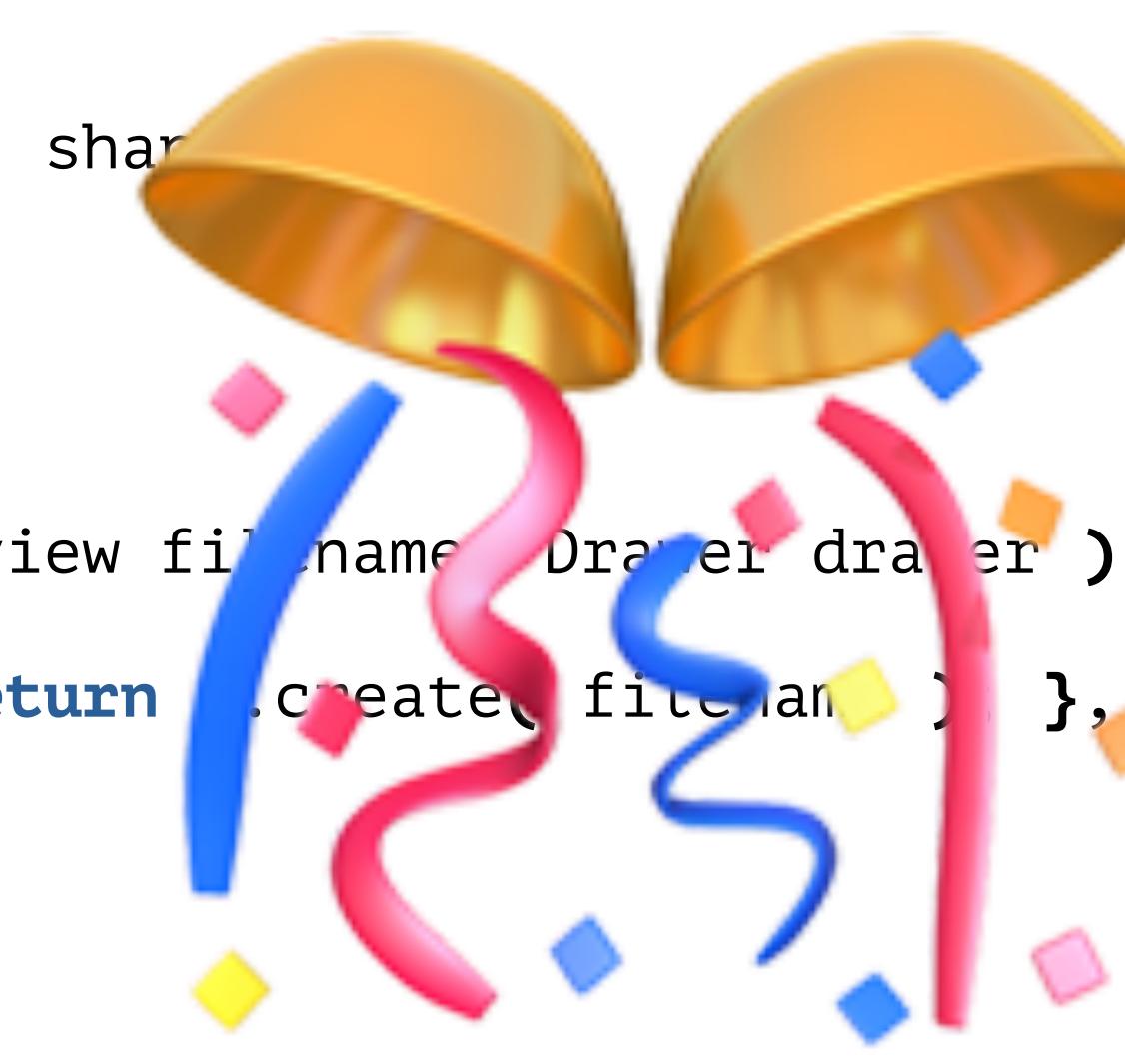
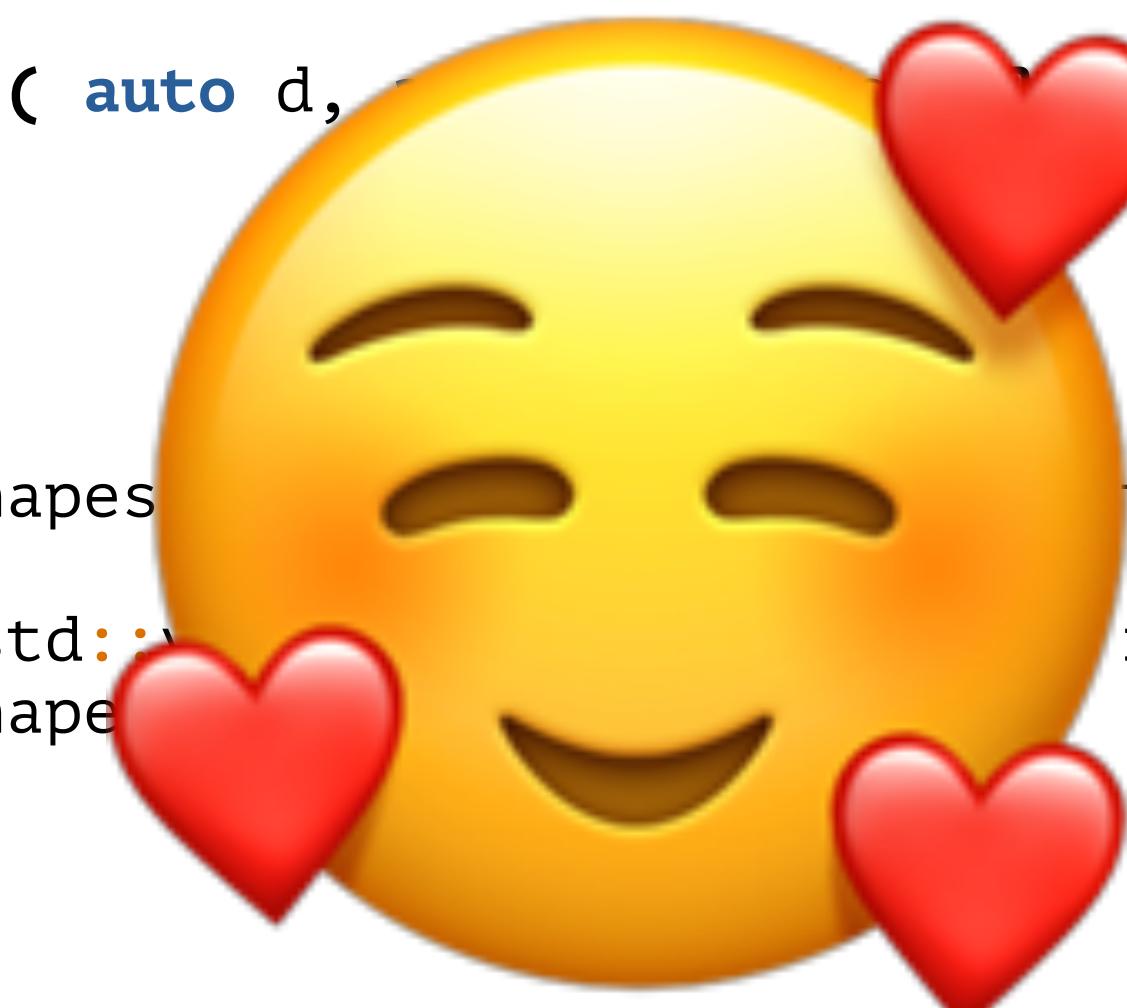
- ⌚ 6 different shapes: circles, squares, ellipses, rectangles, hexagons and pentagons
- ⌚ Using 10000 randomly generated shapes
- ⌚ Performing 25000 translate() operations each
- ⌚ Benchmarks with GCC-13.2.0 and Clang-18.1.4
- ⌚ 8-core Intel Core i7 with 3.8 Ghz, 64 GB of main memory

Performance Comparison



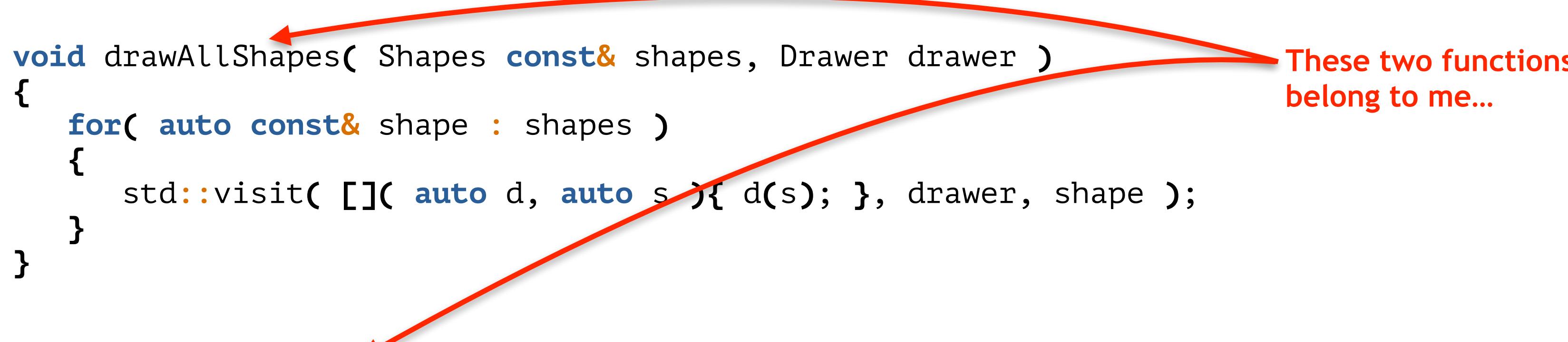
A Truly Modern C++ Solution: std::variant (?)

```
using Drawer = std::variant<OpenGLDrawer>;  
  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( []( auto d,  
                     Shapes const& shapes, Drawer drawer, string_view filename ) {  
            if( auto const& drawer = std::get<OpenGLDrawer>( d );  
                drawer )  
            {  
                drawer->drawAllShapes( shape );  
            }  
        },  
        shapes, drawer, filename );  
    }  
}  
  
int main()  
{  
    ShapesFactory factory{};  
    OpenGLDrawer drawer{ /*...*/ };  
  
    createAndDrawShapes( factory, "shapes.txt", drawer );  
}
```



A Truly Modern C++ Solution: std::variant (?)

```
using Drawer = std::variant<OpenGLDrawer>;  
  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( []( auto d, auto s ){ d(s); }, drawer, shape );  
    }  
}  
  
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )  
{  
    Shapes shapes = std::visit( [&filename]( auto f ){ return f.create( filename ); }, factory );  
    drawAllShapes( shapes, drawer );  
}  
  
int main()  
{  
    ShapesFactory factory{};  
    OpenGLDrawer drawer{/*...*/};  
  
    createAndDrawShapes( factory, "shapes.txt", drawer );  
}
```



These two functions belong to me...

A Truly Modern C++ Solution: std::variant (?)

```
using Drawer = std::variant<OpenGLDrawer>;
```

```
void drawAllShapes( Shapes const& shapes, Drawer drawer )
{
    for( auto const& shape : shapes )
    {
        std::visit( []( auto d, auto s ){ d(s); }, drawer, shape );
    }
}

void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )
{
    Shapes shapes = std::visit( [&filename]( auto f ){ return f.create( filename ); }, factory );
    drawAllShapes( shapes, drawer );
}
```

My Code

Your Code

Architectural
Boundary

```
int main()
{
    ShapesFactory factory{};
    OpenGLDrawer drawer{/*...*/};

    createAndDrawShapes( factory, "shapes.txt", drawer );
}
```

A Truly Modern C++ Solution: std::variant (?)

```
    return shapes,
} };
```



```
using Factory = std::variant<ShapesFactory>;
```



```
class OpenGLDrawer
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}

    void operator()( Circle const& circle ) const;
    void operator()( Square const& square ) const;

private:
    // ... Data members (color, texture, transparency, ...)
};
```



```
using Drawer = std::variant<OpenGLDrawer>;
```



```
void drawAllShapes( Shapes const& shapes, Drawer drawer )
{
    for( auto const& shape : shapes )
    {
        std::visit( []( auto d, auto s ){ d(s); }, drawer, shape );
    }
}
```

However, this is an implementation detail, so this is your code ...

A Truly Modern C++ Solution: std::variant (?)

```
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )
{
    Shapes shapes = std::visit( [&filename]( auto f ){ return f.create( filename ); }, factory );
    drawAllShapes( shapes, drawer );
}
```

Oh, but how can I use the Drawer when it is in your code...

My Code

Your Code

Architectural
Boundary

```
class OpenGLDrawer
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}

    void operator()( Circle const& circle ) const;
    void operator()( Square const& square ) const;
}
```

```
private:
    // ... Data members (color, texture, transparency, ...)
};
```

```
using Drawer = std::variant<OpenGLDrawer>;
```

```
int main()
{
```

A Truly Modern C++ Solution: std::variant (?)

```
using Factory = std::variant<ShapesFactory>;
```

```
using Drawer = std::variant<OpenGLDrawer>;
```

But no! Now I have to know about the OpenGLDrawer again!

```
void drawAllShapes( Shapes const& shapes, Drawer drawer )
{
    for( auto const& shape : shapes )
    {
        std::visit( []( auto d, auto s ){ d(s); }, drawer, shape );
    }
}
```

```
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )
{
    Shapes shapes = std::visit( [&filename]( auto f ){ return f.create( filename ); }, factory );
    drawAllShapes( shapes, drawer );
}
```

My Code

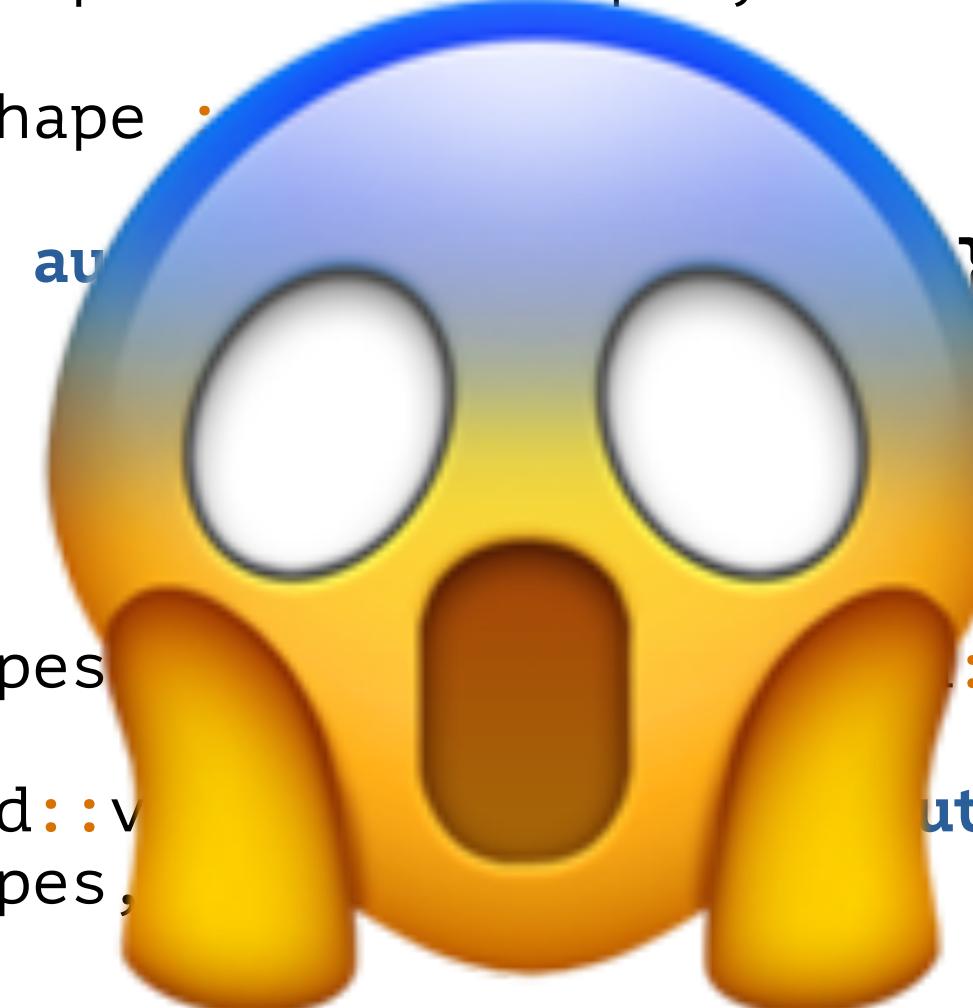
Your Code

Architectural
Boundary

```
class OpenGLDrawer
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}
```

A Truly Modern C++ Solution: std::variant (?)

```
using Factory = std::variant<ShapesFactory>;  
  
using Drawer = std::variant<OpenGLDrawer>;  
  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( []( auto& s ) { s.draw( drawer ); }, drawer, shape );  
    }  
}  
  
void createAndDrawShapes( std::string_view filename, Drawer drawer )  
{  
    Shapes shapes = std::visit( [ ]( auto f ) { return f.create( filename ); }, factory );  
    drawAllShapes( shapes, drawer );  
}
```



My Code

Your Code

Architectural
Boundary

```
class OpenGLDrawer  
{  
public:  
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}
```

This is an architectural
disaster, a total failure!



There is no architecture!



Templates to the Rescue (?)



*”I believe that object-oriented programming and especially its theory is overestimated. ... C++ always had **templates**, and now also has std::variant, which makes most of the use of inheritance unnecessary.”*

(Unknown Reviewer)

Templates to the Rescue (?)

```
private:  
    double side;  
    // ... Remaining data members  
};  
  
template< typename Shapes, typename Drawer >  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( drawer, shape );  
    }  
}  
  
template< typename Factory, typename Drawer >  
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )  
{  
    auto shapes = factory.create( filename );  
    drawAllShapes( shapes, drawer );  
}
```

My Code

Your Code

Architectural
Boundary

```
using Shape = std::variant<Circle,Square>;
```

Templates to the Rescue (?)

```
private:  
    double side;  
    // ... Remaining data members  
};
```

Let's make this a function template.
This way we invert the dependencies ...

```
template< typename Shapes, typename Drawer >  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( drawer, shape );  
    }  
}
```

```
template< typename Factory, typename Drawer >  
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )  
{  
    auto shapes = factory.create( filename );  
    drawAllShapes( shapes, drawer );  
}
```

My Code

Your Code

Architectural
Boundary

```
using Shape = std::variant<Circle,Square>;
```

Templates to the Rescue (?)

```
private:  
    double side;  
    // ... Remaining data members  
};  
  
template< typename Shapes, typename Drawer >  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( drawer, shape );  
    }  
}  
  
template< typename Factory, typename Drawer >  
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )  
{  
    auto shapes = factory.create( filename );  
    drawAllShapes( shapes, drawer );  
}
```

Let's make this a function template, too.
Again, this inverts the dependencies ...

My Code

Your Code

Architectural
Boundary

using Shape = std::variant<Circle, Square>;

Templates to the Rescue (?)

My Code

Your Code

Architectural
Boundary

```
using Shape = std::variant<Circle,Square>;  
  
using Shapes = std::vector<Shape>;  
  
class ShapesFactory  
{  
public:  
    Shapes create( std::string_view filename )  
    {  
        Shapes shapes{};  
        std::string shape{};  
  
        std::ifstream shape_file{ filename };  
  
        while( shape_file >> shape )  
        {  
            if( shape == "circle" ) {  
                double radius;  
                shape_file >> radius;  
                shapes.emplace_back( Circle{radius} );  
            }  
            else if( shape == "square" ) {  
                double side;  
                shape_file >> side;  
            }  
        }  
    }  
};
```

Templates to the Rescue (?)

My Code

Your Code

Architectural
Boundary

```
using Shape = std::variant<Circle,Square>;  
  
using Shapes = std::vector<Shape>;  
  
class ShapesFactory  
{  
public:  
    Shapes create( std::string_view filename )  
    {  
        Shapes shapes{};  
        std::string shape{};  
  
        std::ifstream shape_file{ filename };  
  
        while( shape_file >> shape )  
        {  
            if( shape == "circle" ) {  
                double radius;  
                shape_file >> radius;  
                shapes.emplace_back( Circle{radius} );  
            }  
            else if( shape == "square" ) {  
                double side;  
                shape_file >> side;  
            }  
        }  
    }  
};
```

Templates to the Rescue (?)

My Code

Your Code

Architectural
Boundary

```
class Rectangle
{
public:
    Rectangle( double width, double height )
        : width_{ width }
        , height_{ height }
        , // ... Remaining data members
    {}

    double width() const { return width_; }
    double height() const { return height_; }
    // ... getCenter(), getRotation(), ...
}
```

```
private:
    double width_;
    double height_;
    // ... Remaining data members
};
```

```
using Shape = std::variant<Circle,Square>;
```

```
using Shapes = std::vector<Shape>;
```

Templates to the Rescue (?)

My Code

Your Code

Architectural
Boundary

```
class Rectangle
{
public:
    Rectangle( double width, double height )
        : width_{ width }
        , height_{ height }
        , // ... Remaining data members
    {}

    double width() const { return width_; }
    double height() const { return height_; }
    // ... getCenter(), getRotation(), ...
}
```

```
private:
    double width_;
    double height_;
    // ... Remaining data members
};
```

```
using Shape = std::variant<Circle, Square, Rectangle>;
```

```
using Shapes = std::vector<Shape>;
```

Templates to the Rescue (?)

```
class ShapesFactory
{
public:
    Shapes create( std::string_view filename )
    {
        Shapes shapes{};
        std::string shape{};

        std::ifstream shape_file{ filename };

        while( shape_file >> shape )
        {
            if( shape == "circle" ) {
                // ...
            }
            else if( shape == "square" ) {
                // ...
            }
            else if( shape == "rectangle" )
            {
                double width, height;
                shape_file >> width >> height;
                shapes.emplace_back( Rectangle{width,height} );
            }
            else {
                break;
            }
        }

        return shapes;
    }
};
```

Templates to the Rescue (?)

```
        return shapes;
    }
};

class OpenGLDrawer
{
public:
    explicit OpenGLDrawer( /*... color, texture, transparency, ...*/ ) {}

    void operator()( Circle const& circle ) const;
    void operator()( Square const& square ) const;
    void operator()( Rectangle const& rectangle ) const;

private:
    // ... Data members (color, texture, transparency, ...)
};

int main()
{
    ShapesFactory factory{};
    OpenGLDrawer drawer{/*...*/};

    createAndDrawShapes( factory, "shapes.txt", drawer );
}
```

Templates to the Rescue (?)

```
double getSide() const noexcept;  
// ... getCenter(), getRotation(), ...  
  
private:  
    double side;  
    // ... Remaining data members  
};  
  
template< typename Shapes, typename Drawer >  
void drawAllShapes( Shapes const& shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( drawer, shape );  
    }  
}  
  
template< typename Factory, typename Drawer >  
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )  
{  
    auto shapes = factory.create( filename );  
    drawAllShapes( shapes, drawer );  
}
```

The template approach could work...
in a small code base.
But in 10M+ lines of code?

My Code

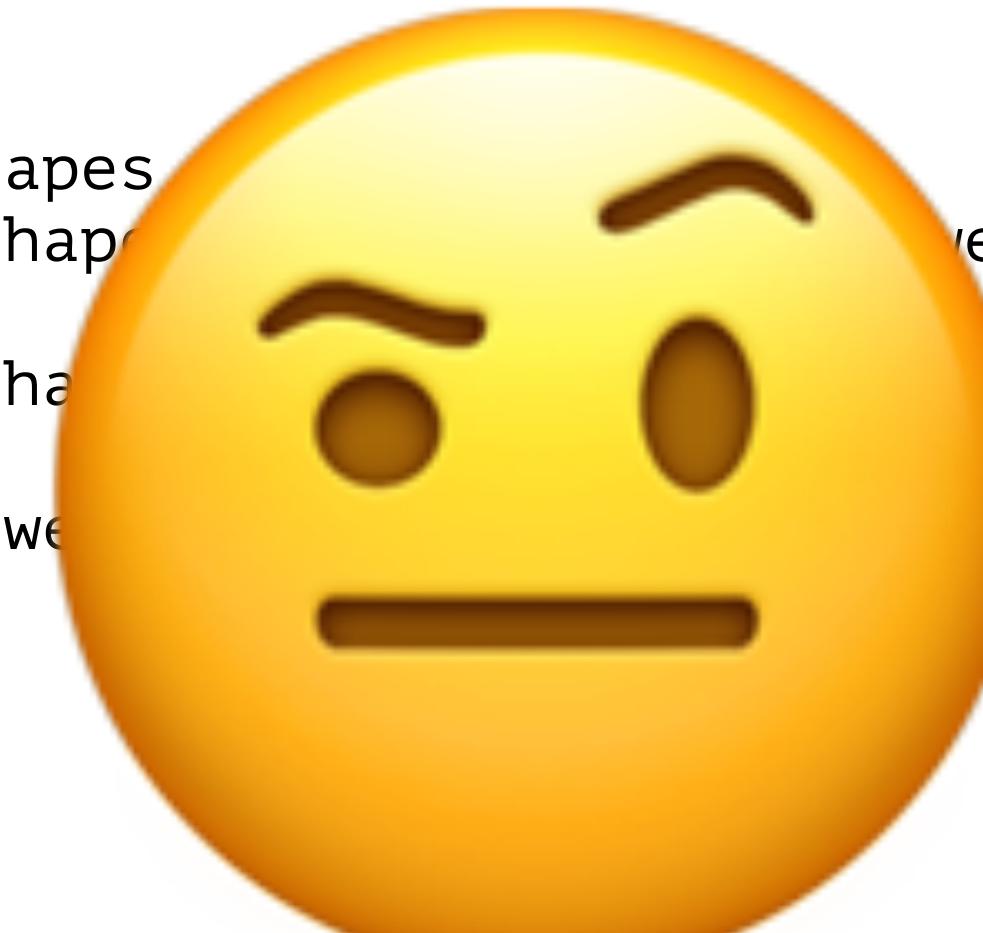
Your Code

Architectural
Boundary

119

Templates to the Rescue (?)

```
double getSide() const noexcept;  
// ... getCenter(), getRotation(), ...  
  
private:  
    double side;  
    // ... Remaining data members  
};  
  
template< typename Shapes >  
void drawAllShapes( Shapes shapes, Drawer drawer )  
{  
    for( auto const& shape : shapes )  
    {  
        std::visit( drawer, shape );  
    }  
}  
  
template< typename Factory, typename Drawer >  
void createAndDrawShapes( Factory factory, std::string_view filename, Drawer drawer )  
{  
    auto shapes = factory.create( filename );  
    drawAllShapes( shapes, drawer );  
}
```



My Code

Your Code

Architectural
Boundary

120

`std::variant` is no silver bullet!



std::variant is not a
replacement for virtual
functions!



`std::variant` is the
architectural antipode of
virtual functions!



`std::variant` vs. Virtual Functions

<i><code>std::variant</code></i>	<i>Virtual Functions</i>
Dynamic polymorphism	Dynamic polymorphism
Functional programming	Object-oriented programming
Fixed set of types	Open set of types
Open set of operations	Closed set of operations

`std::variant` vs. Virtual Functions

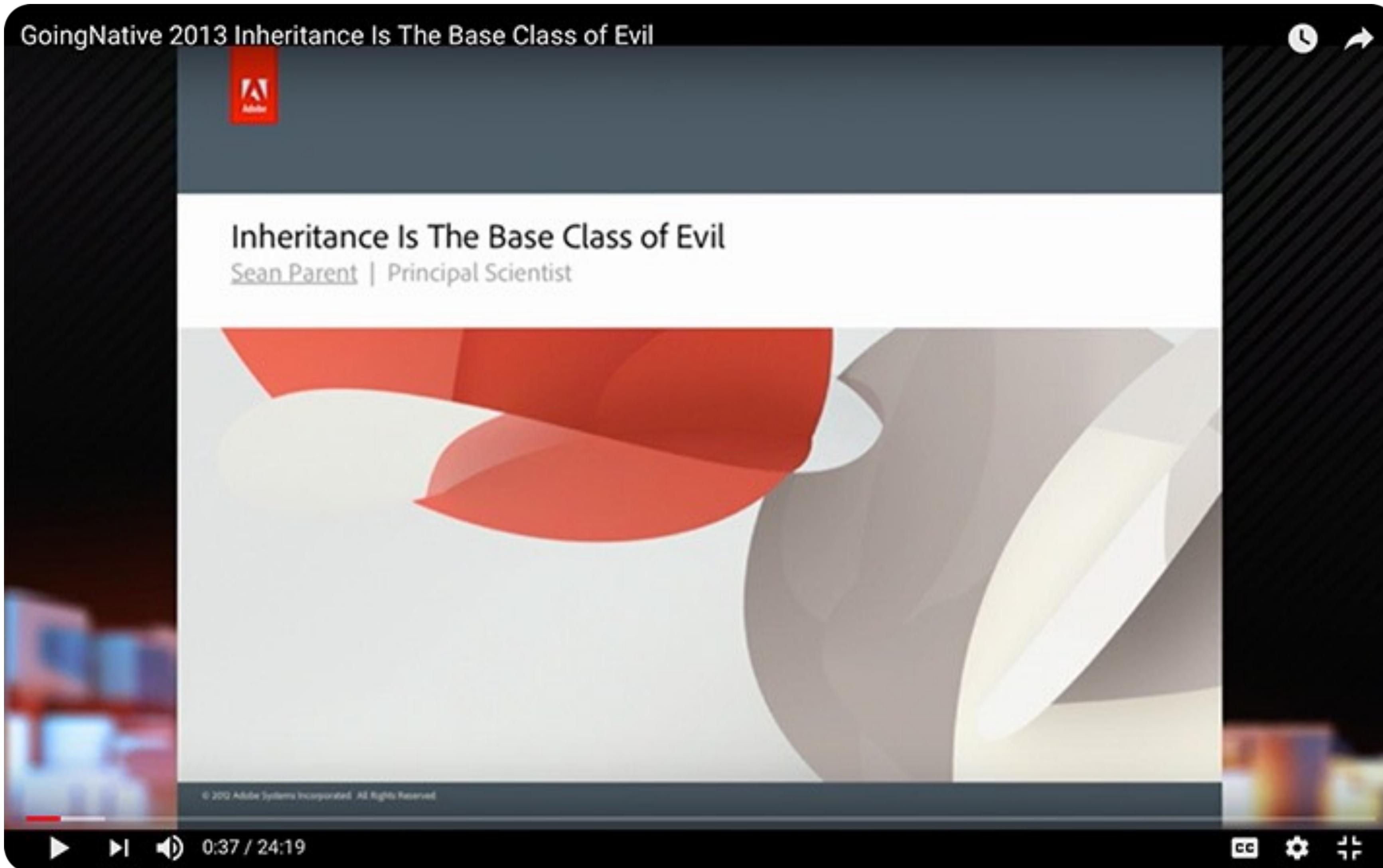
<i><code>std::variant</code> (aka Visitor pattern)</i>	<i>Virtual Functions</i>
Dynamic polymorphism	Dynamic polymorphism
Functional programming	Object-oriented programming
Fixed set of types	Open set of types
Open set of operations	Closed set of operations

Guidelines

Guideline: std::variant is not a replacement for virtual functions and shouldn't be used as such.

Wait a second! ...

But Isn't Inheritance Evil?



Issue #1

CRTP

Issue #2

std::variant

Neither CRTP nor std::variant
are replacements for virtual
functions



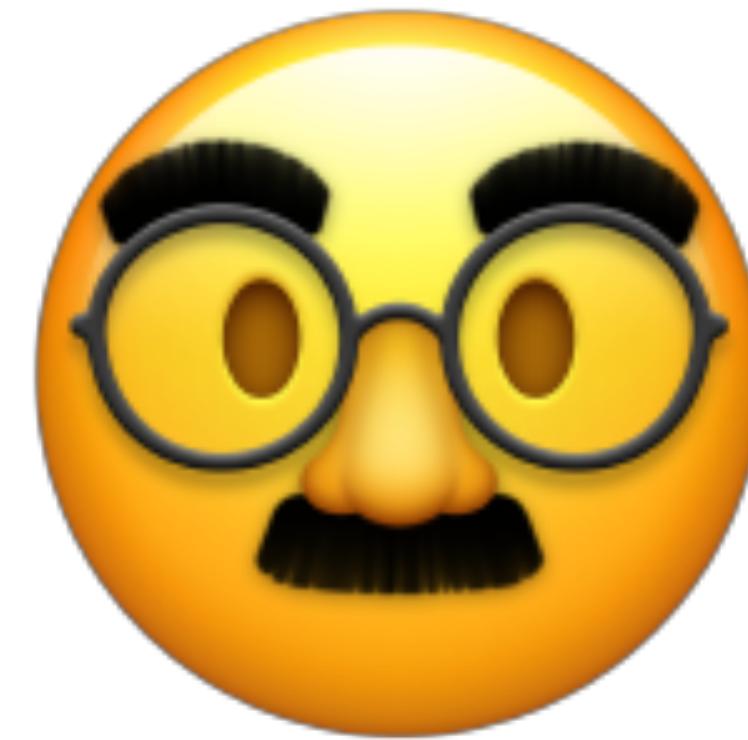
Design patterns represent
dependency structures



Thus design patterns have architectural properties



You cannot just replace one
design pattern with another one



Guidelines

Guideline: Think about your design/architecture first and about implementation details second.

Guideline: Consider only the patterns/abstractions that fit your design.

Guideline: Don't design based on performance requirements.

Architecture
and Design
first!



Design Patterns

The Most Common Misconceptions (2 of N)

KLAUS IGLBERGER



Cppcon
The C++ Conference

20
24



September 15 - 20