There Is No Silver Bullet

Klaus Iglberger, Meeting C++ 2024

klaus.iglberger@gmx.de

C++ Trainer/Consultant

Author of “C++ Software Design”

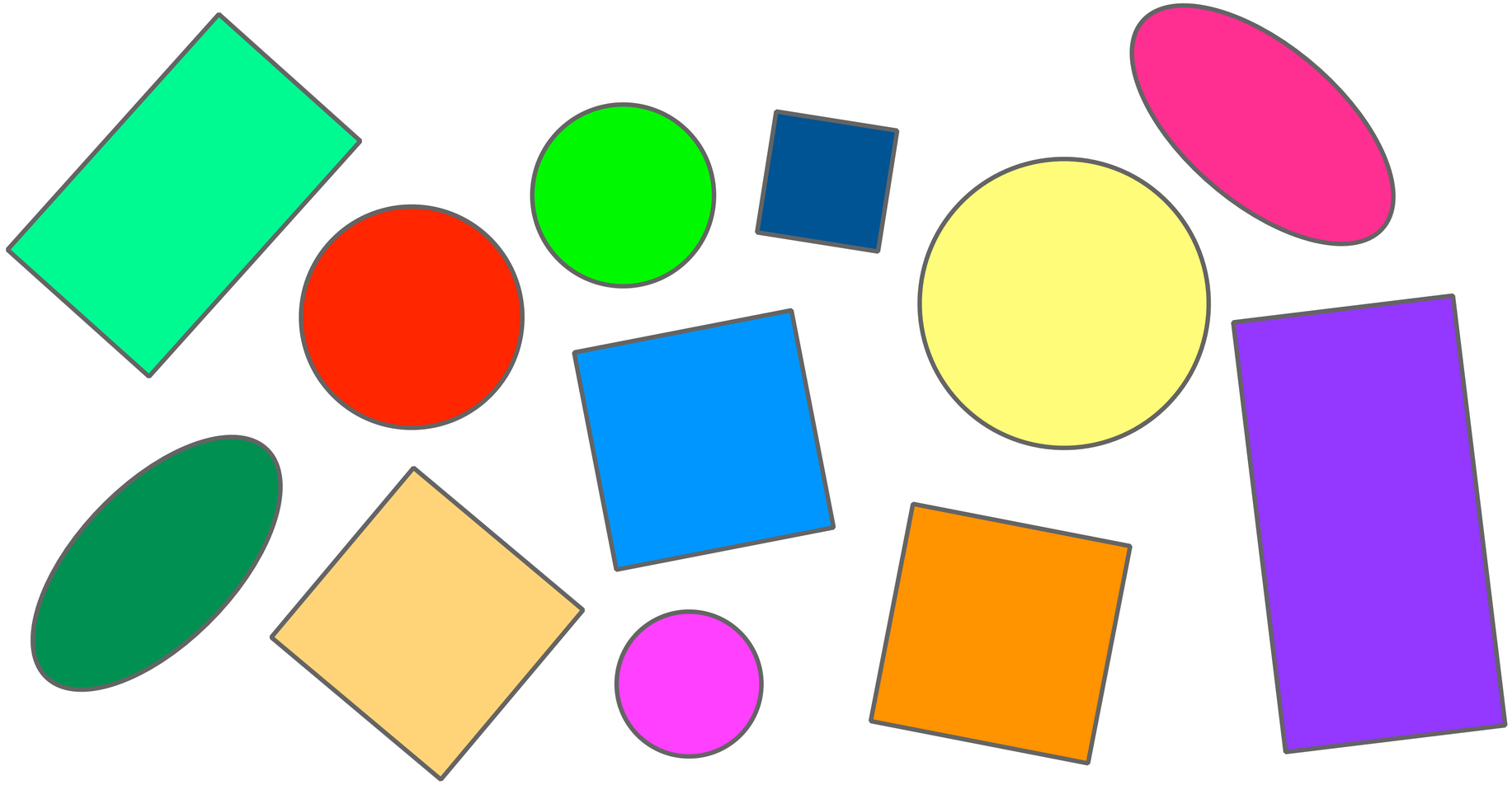
Chair of the CppCon Back-to-Basics track

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

Email: klaus.iglberger@gmx.de

Klaus Iglberger

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;
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   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;

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class Shape
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   virtual ~Shape() = default;

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      : 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
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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>>;


class ShapesFactory
```

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)

Architectural Boundary

Low level (volatile, malleable, high dependencies)

```
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

Architectural Boundary

Your Code

```
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

Architectural Boundary

Your Code

```
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{};
```

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

```
            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;
      }
};


int main()
{
   YourShapesFactory factory{};

   createAndDrawShapes( factory, “shapes.txt” );
}
```

A Modern C++ Solution?

```
   // ... 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>>;


class ShapesFactory
{
```

std::unique_ptr/smart pointers
in combination with std::make_unique

Move Semantics

override

A Modern C++ Solution?

```
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 )
{
   Shapes shapes = factory.create( filename );
   drawAllShapes( shapes );
}
```

= default

auto

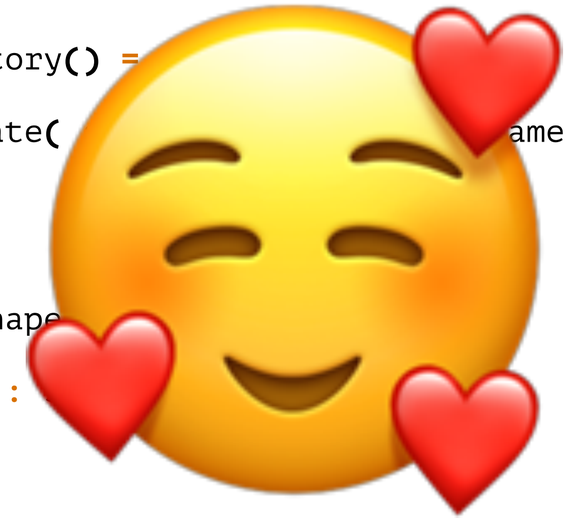
Range-based for loop

std::string_view

My Code

A Modern C++ Solution?

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


class ShapesFactory
{
 public:
   virtual ~ShapesFactory() =

   virtual Shapes create(                              ame ) const = 0;
};



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


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



My Code

A Modern C++ Solution?

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


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   virtual ~ShapesFactory() =

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};



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


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

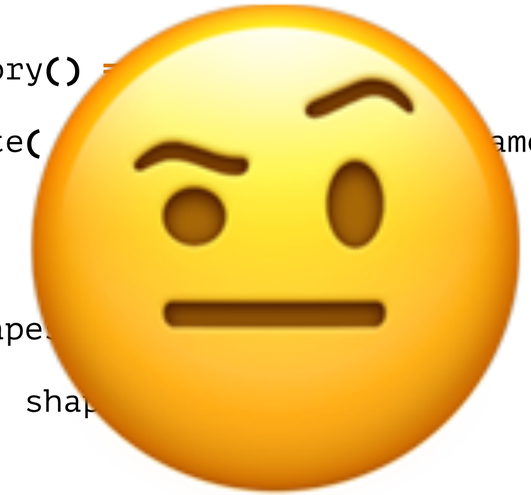

My Code

A Modern C++ Solution?

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


class ShapesFactory
{
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   virtual ~ShapesFactory() =

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};



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


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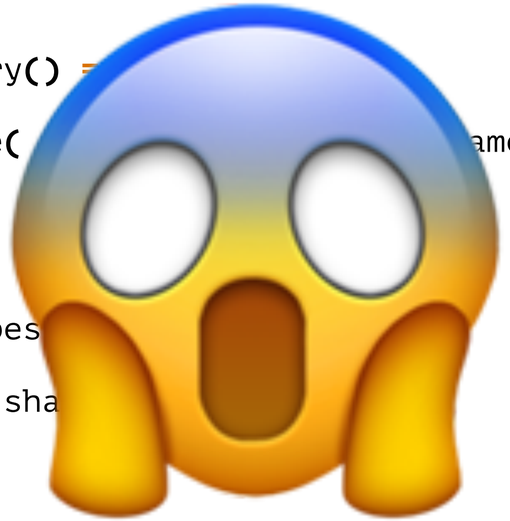
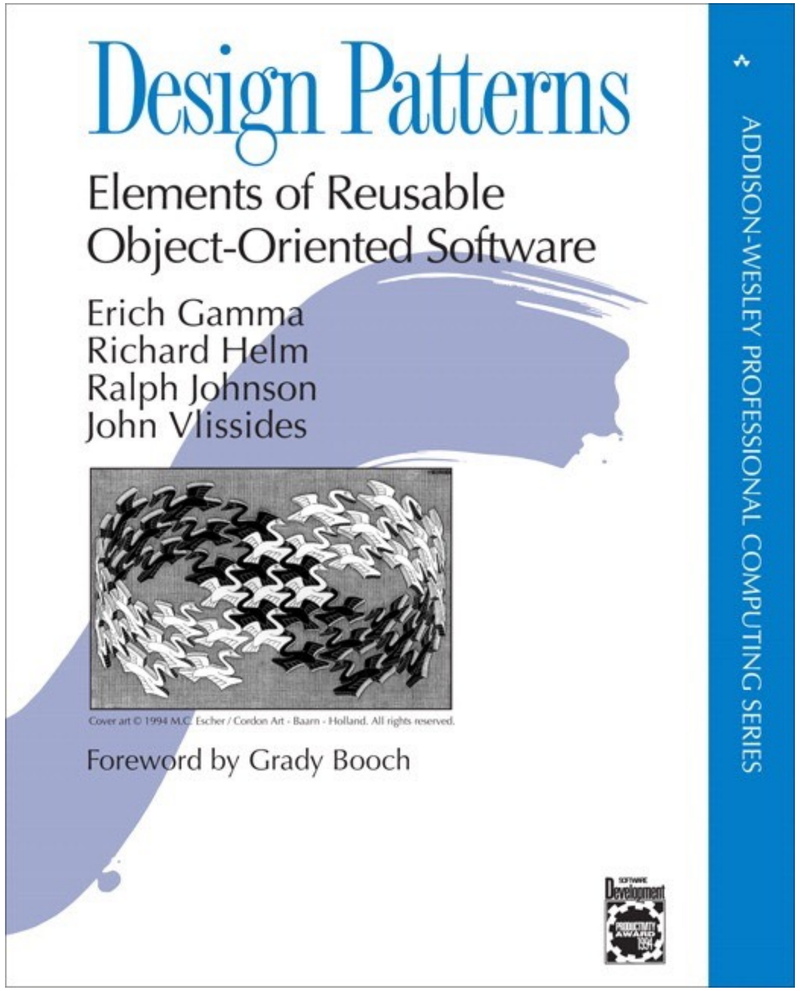



My Code

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

The Philosophy of the 90s



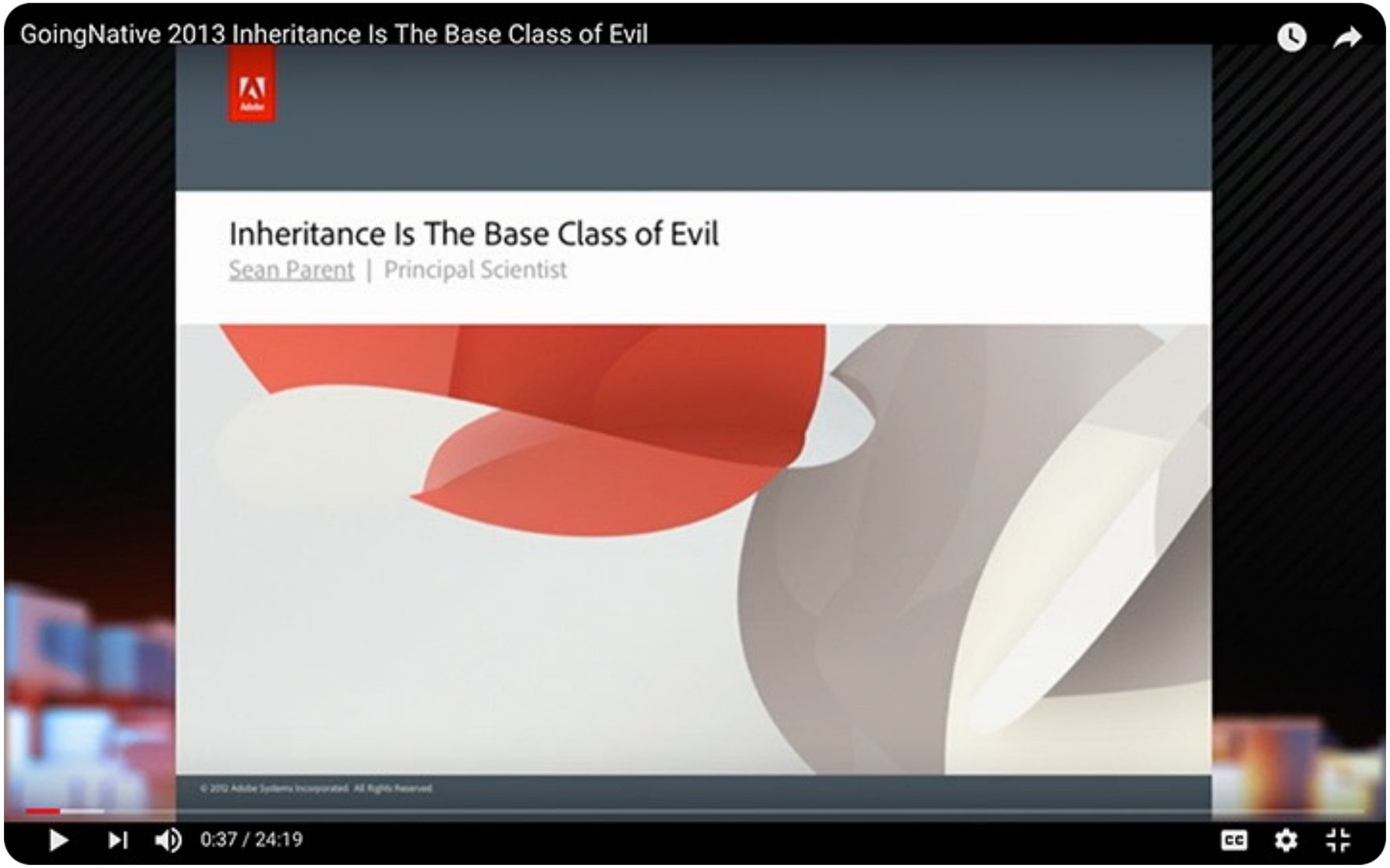
The Philosophy of the 90s

The GoF Style

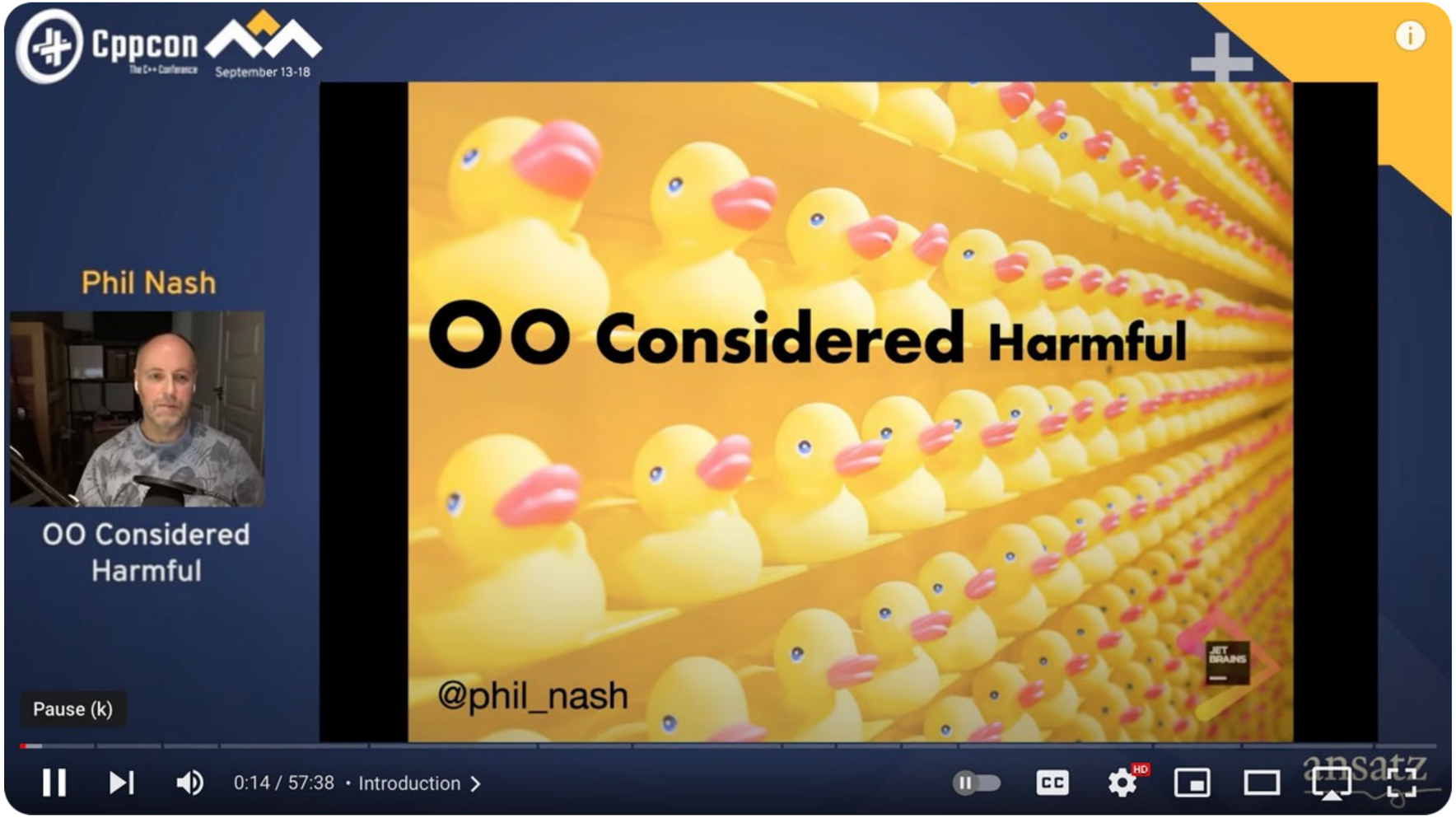
But let’s be honest:
this style is used in more than
90% of all C++ projects.

If anything about this should change, YOU have to spread the “news” …

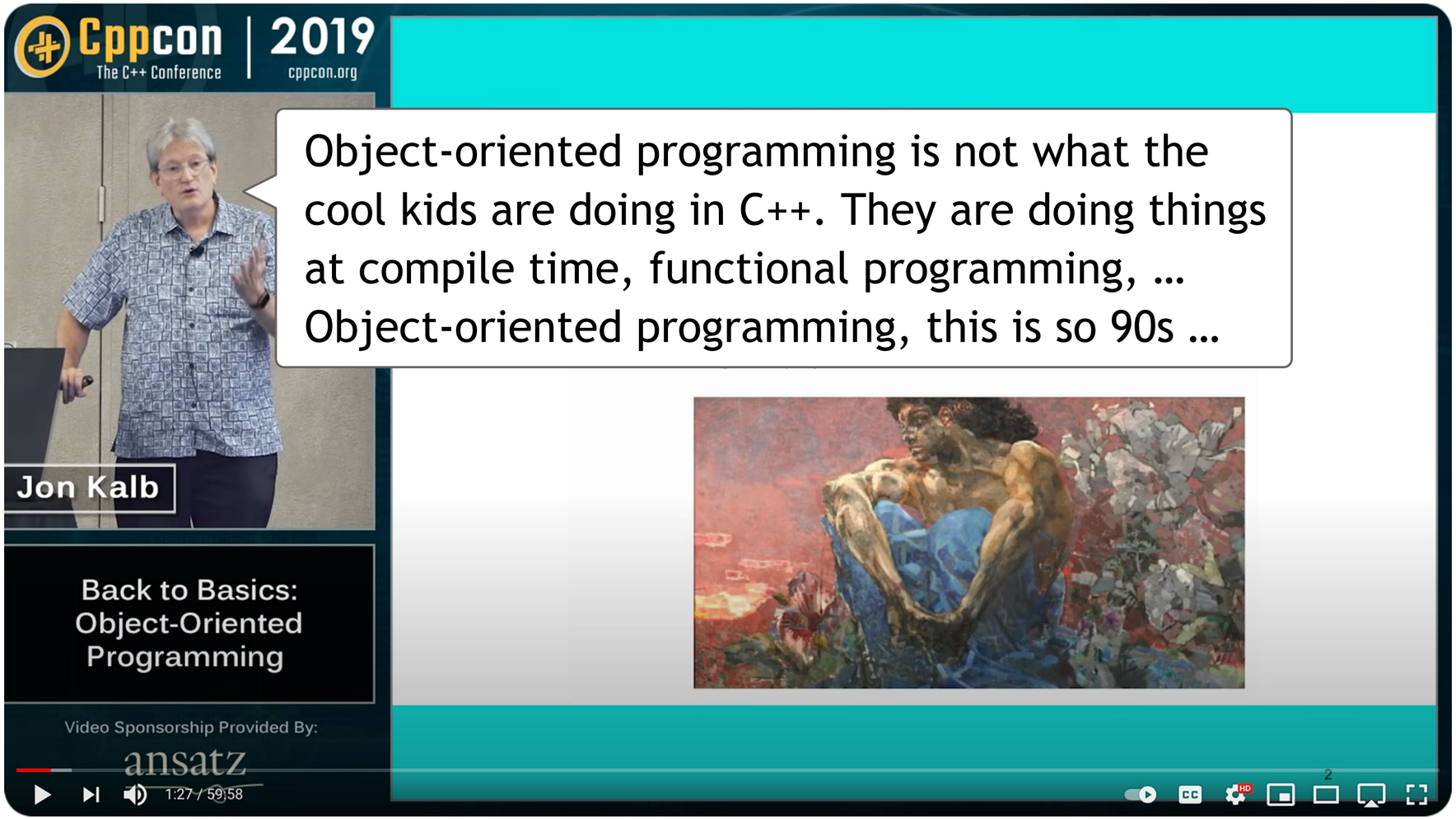
The Fallen Paradigm (?)



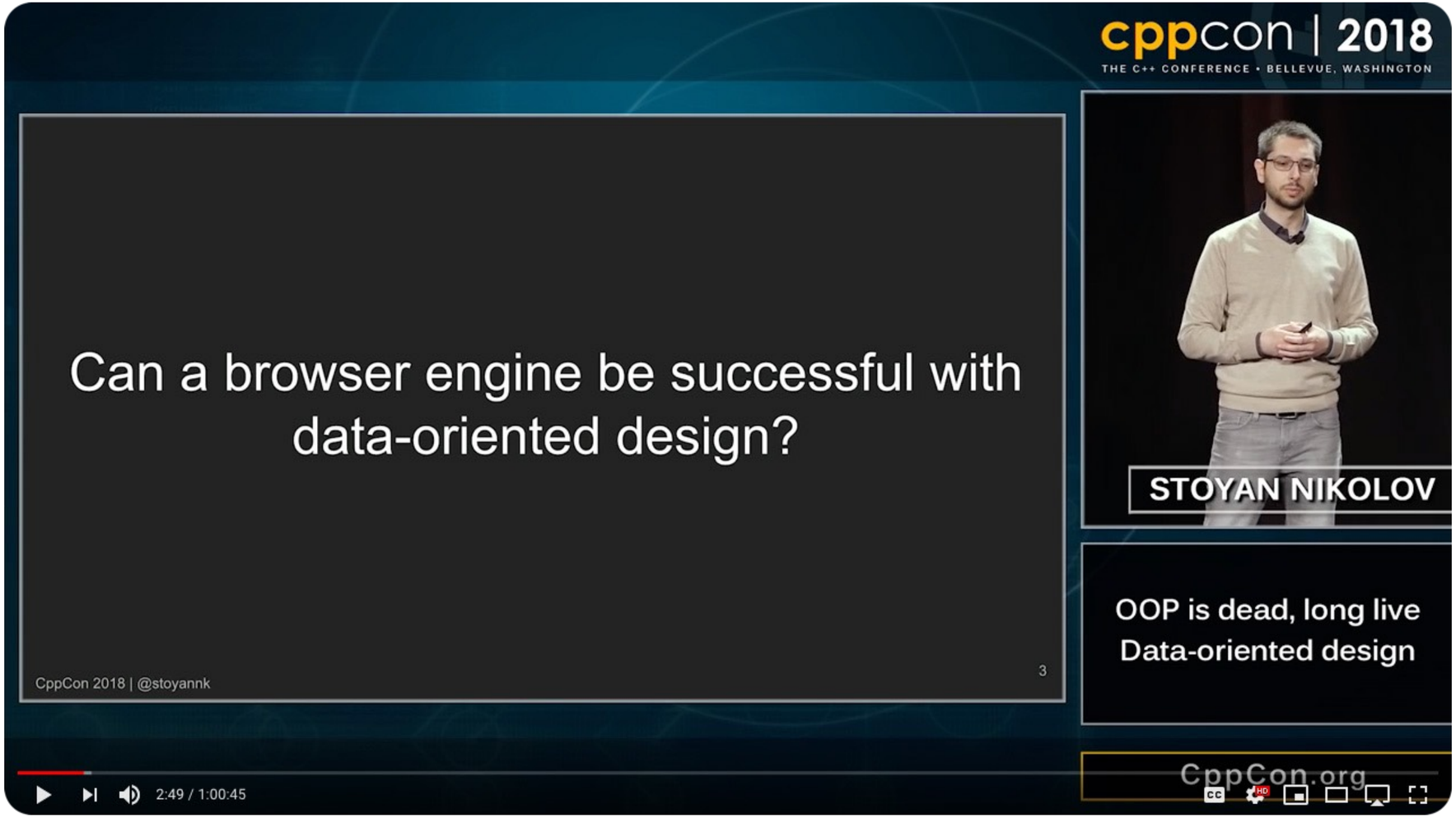
The Fallen Paradigm (?)



The Fallen Paradigm (?)



The Fallen Paradigm (?)



The Fallen Paradigm (?)

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;
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 private:
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};


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>;


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 )
      {
```

std::variant replaces the Shape base class

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>;


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" ) {
```

We now utilize a vector of values instead of pointers

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;
   }
};
```

Replacing another inheritance hierarchy with 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>;
```

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 )
```

Again, no inheritance necessary!

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

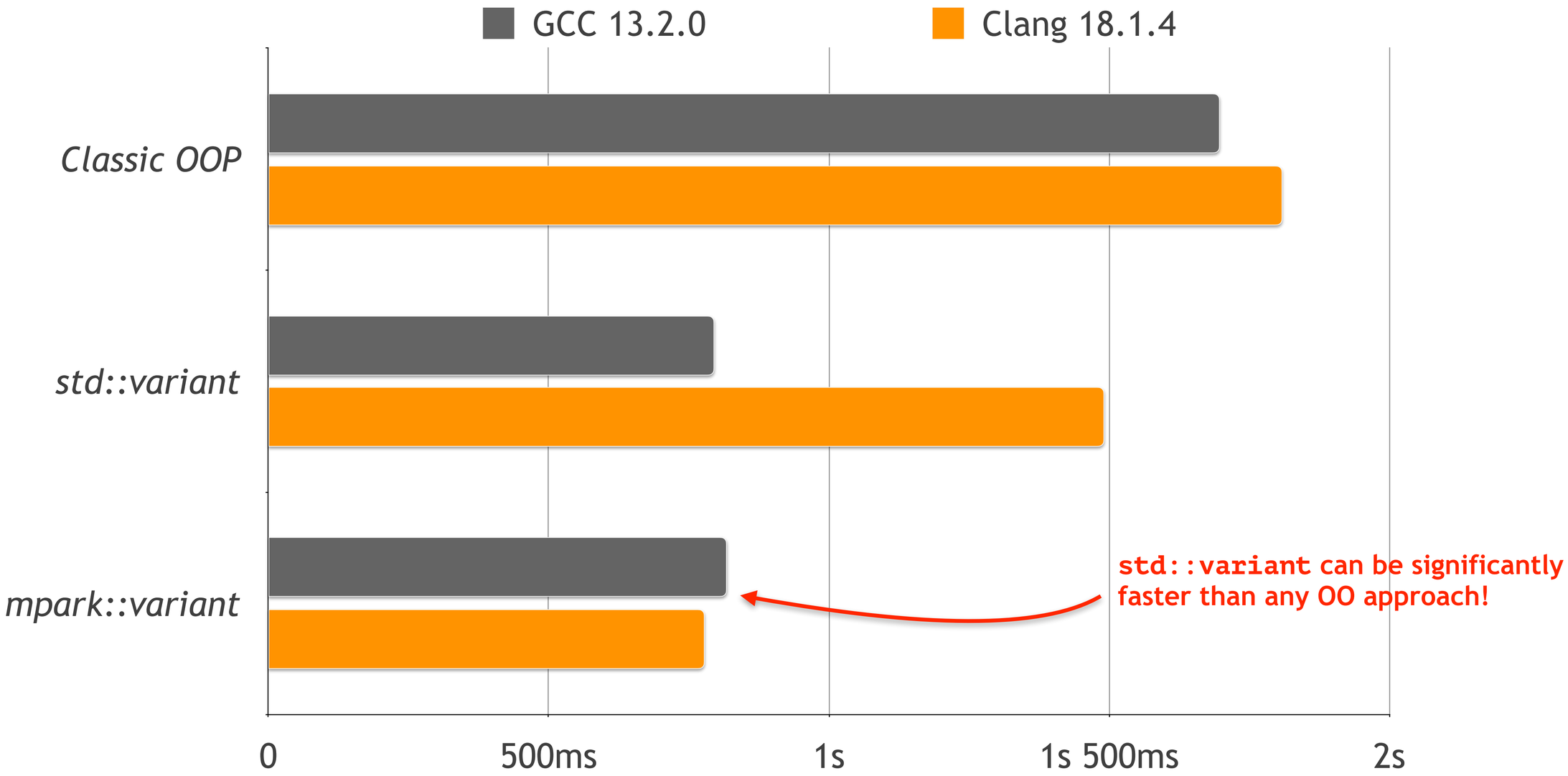
Performance … *sigh*

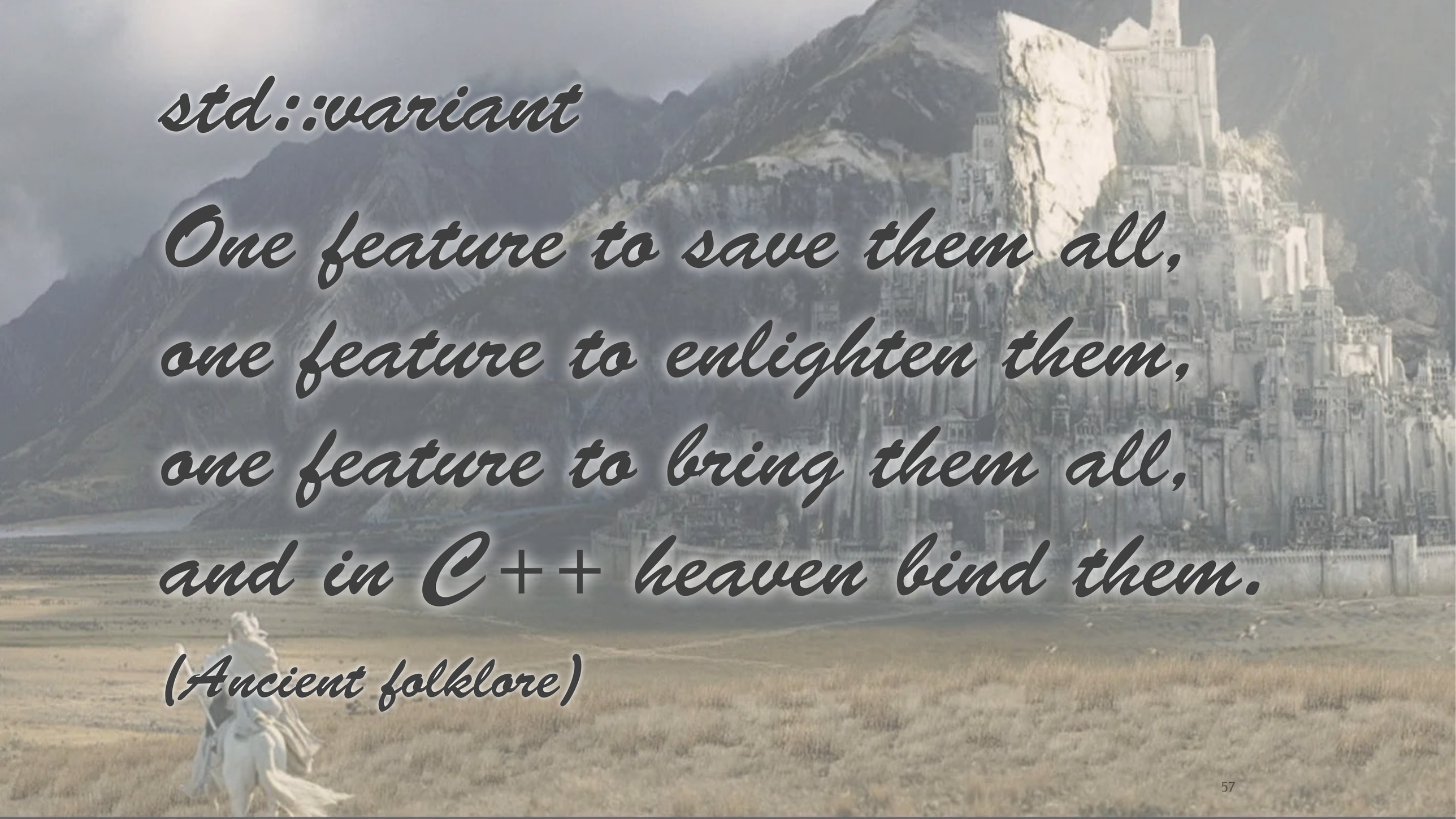
Do you promise to not take the following results too seriously and as qualitative results only?

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



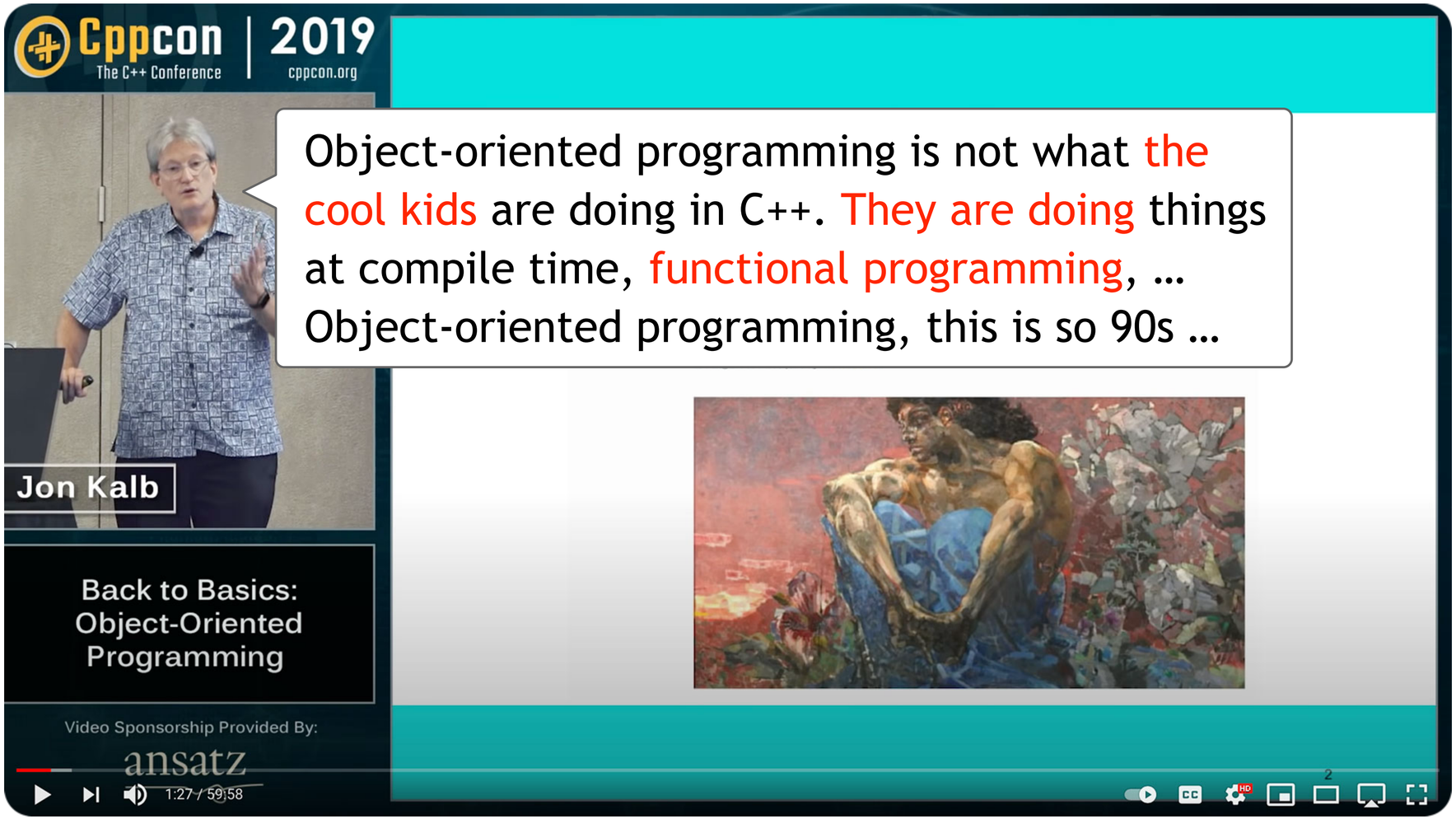


std::variant

One feature to save them all,
one feature to enlighten them,
one feature to bring them all,
and in C++ heaven bind them.

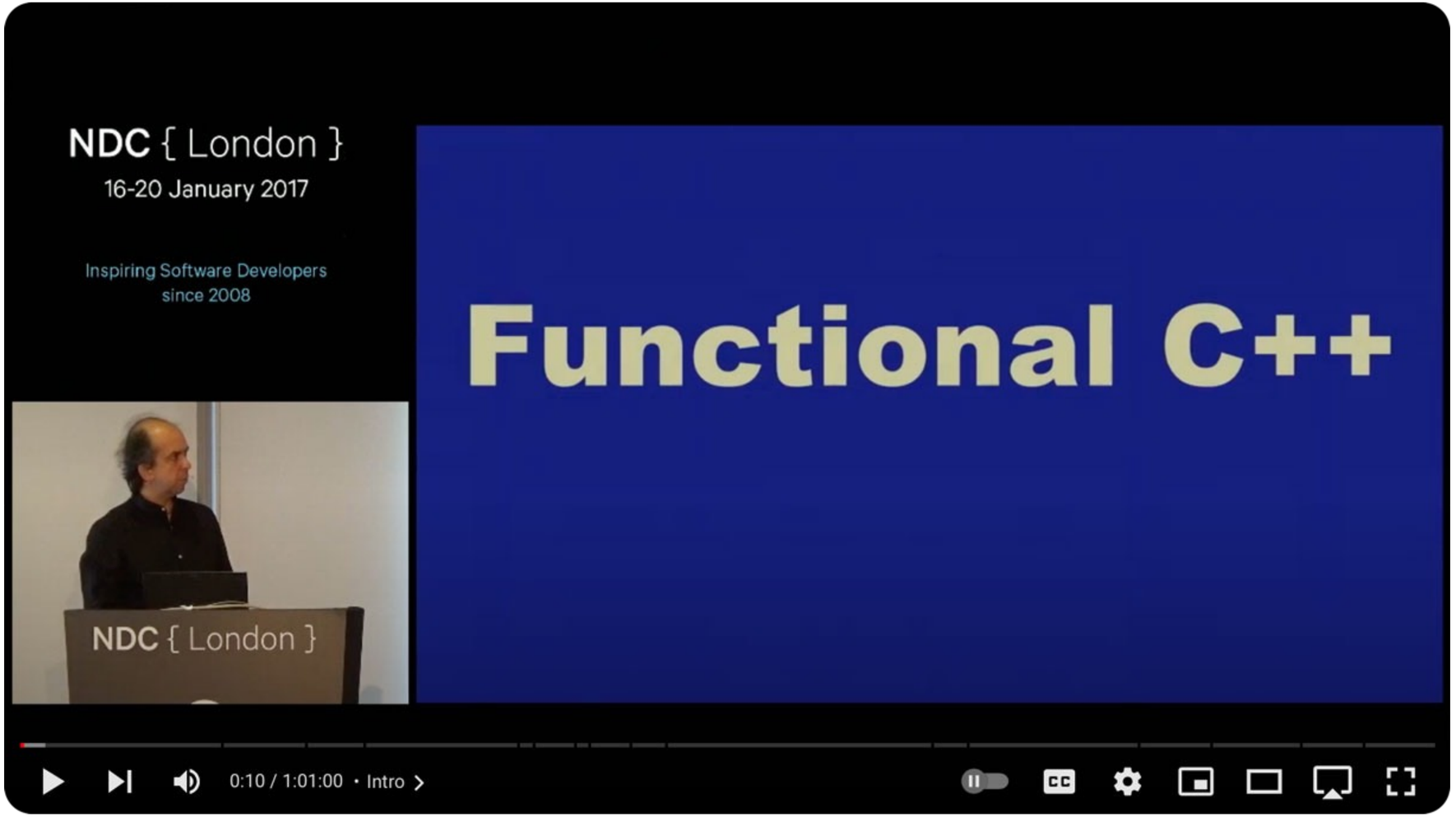
(Ancient folklore)

The Rising Paradigm (?)



The Rising Paradigm (?)

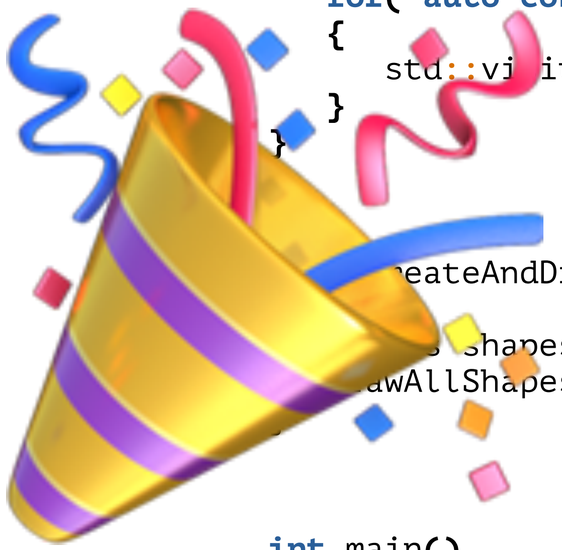
The Rising Paradigm (?)

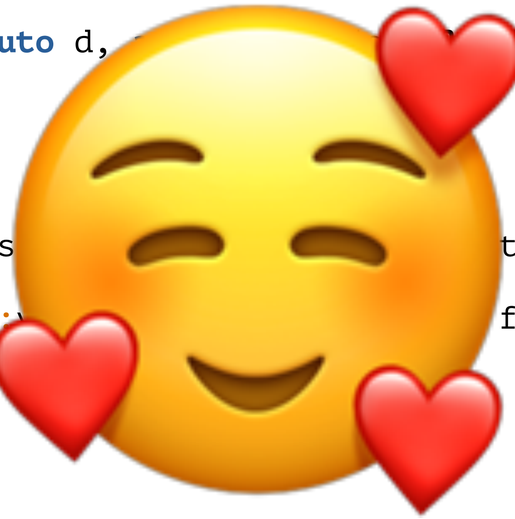


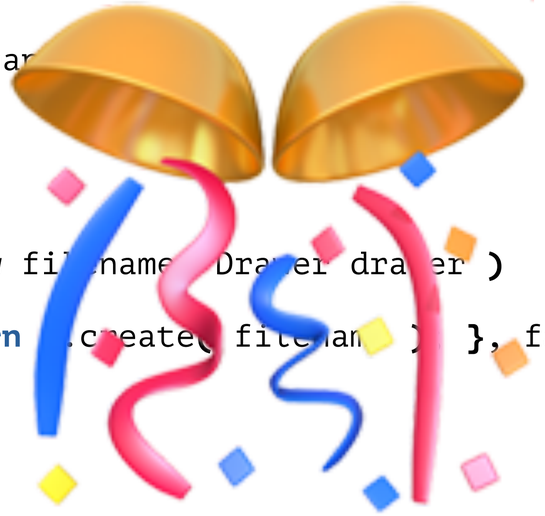
The Rising Paradigm (?)

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,                    rawer, shar
    }
}


    eateAndDrawShapes                              tring_view fi name   Dra er dra er )
    {
        shapes = std::                             f ){ return   create( file an   ) }, factory );
        awAllShapes( shape
    }


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

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

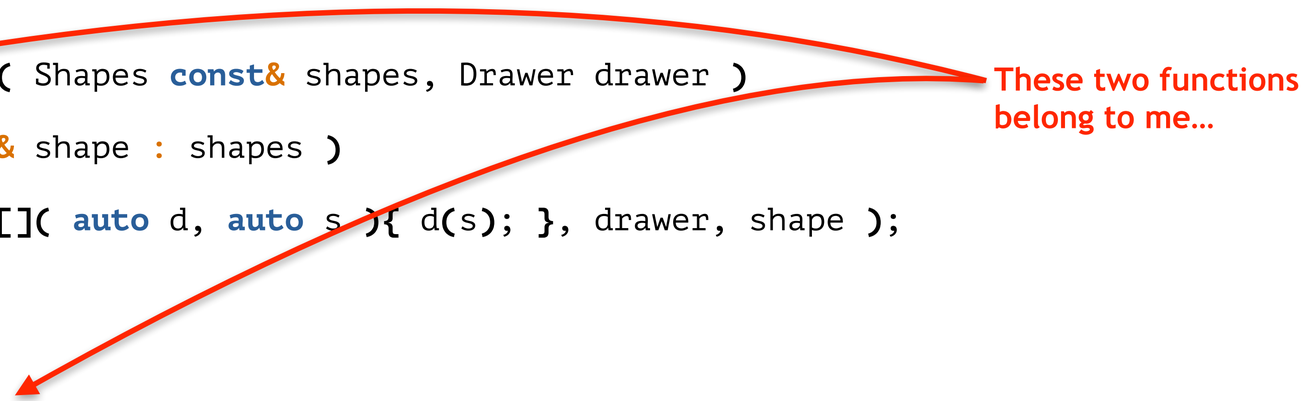






A Truly Modern C++ Solution: std::variant

```
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

```
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

Architectural Boundary

Your Code

```
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

Architectural Boundary

Your Code

```
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>;


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 );
}
```

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

My Code

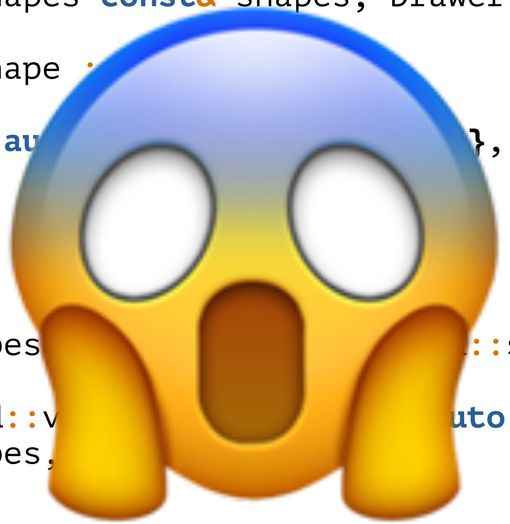
Architectural Boundary

Your Code

```
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 :
   {
      std::visit( [](  au                    }, drawer, shape );
   }
}


void createAndDrawShapes                      ::string_view filename, Drawer drawer )
{
   Shapes shapes = std::v                     uto f ){ return f.create( filename ); }, factory );
   drawAllShapes( shapes,
}
```



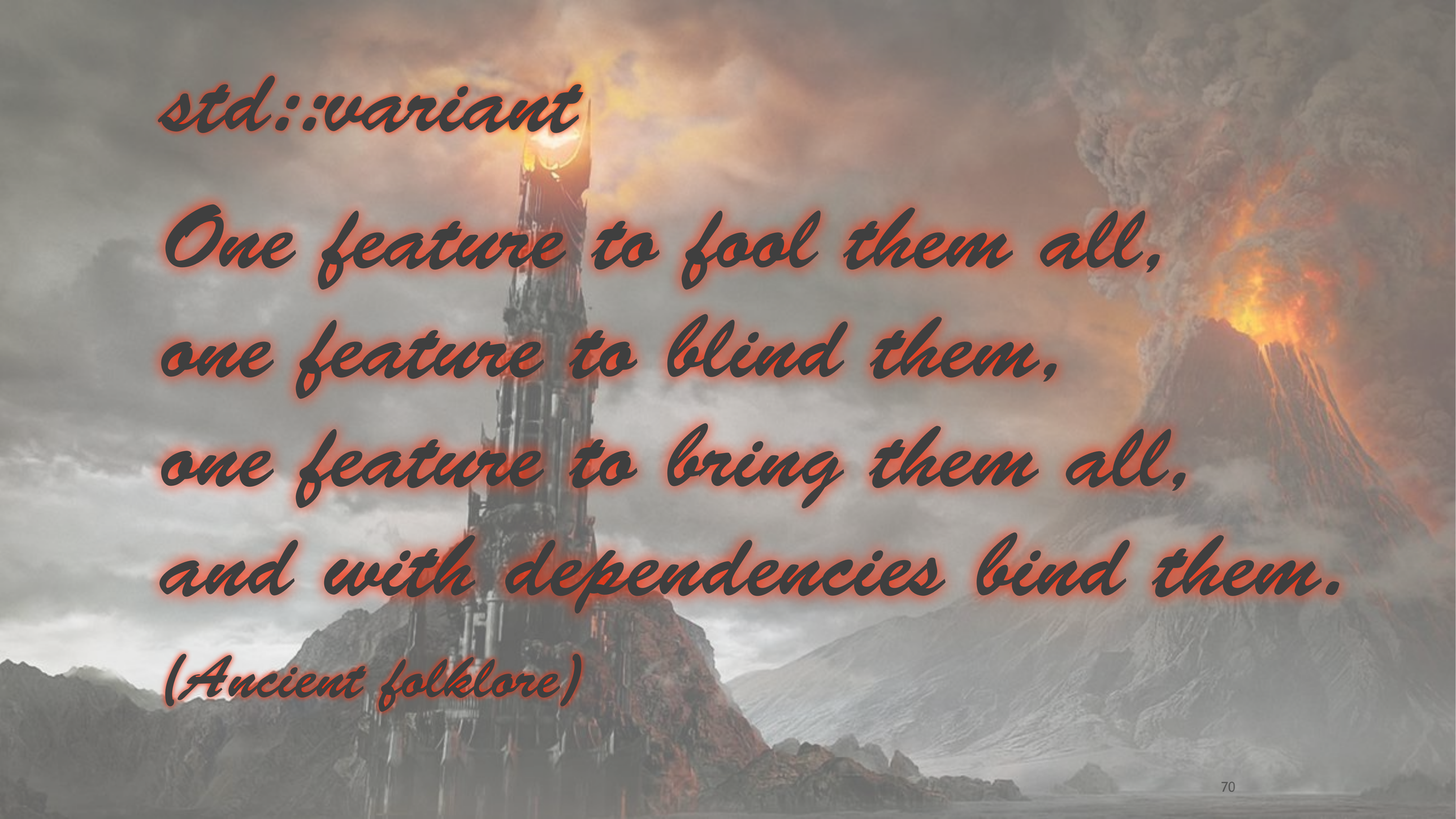
My Code

Architectural Boundary

Your Code

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

This is an architectural disaster, a total failure!


std::variant
One feature to fool them all,
one feature to blind them,
one feature to bring them all,
and with dependencies bind them.
(Ancient folklore)

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

Architectural Boundary

Your Code

```
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

Architectural Boundary

Your Code

```
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 );
   }
}
```

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

```
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

Architectural Boundary

Your Code

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

Templates to the Rescue (?)

My Code

Architectural Boundary

Your Code

```
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

Architectural Boundary

Your Code

```
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

Architectural Boundary

Your Code

```
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?

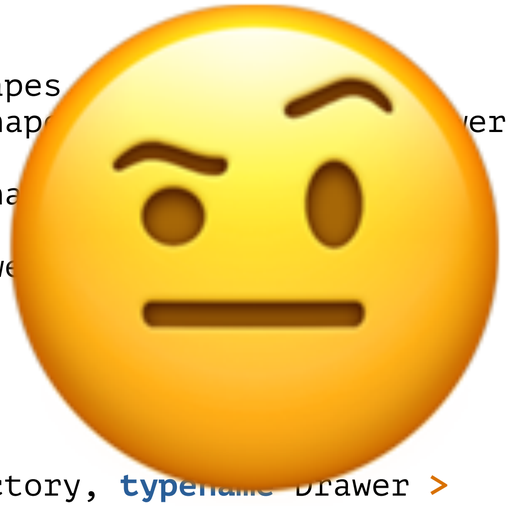
My Code

Your Code

Architectural Boundary

Templates to the Rescue (?)

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

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


template< typename Shapes
void drawAllShapes( Shap                    er drawer )
{
   for( auto const& sha
   {
      std::visit( drawe
   }
}


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

There 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

std::variant	*Virtual Functions*
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

Architecture/Design matters!

The design plays a much more central role in the success of a project than any feature could ever do.

Have you ever heard of a project that failed because some feature could not be used?

Do you happen to work in a project with a complete architectural document, including ADRs?

In C++, features and language details are at the center of attention.

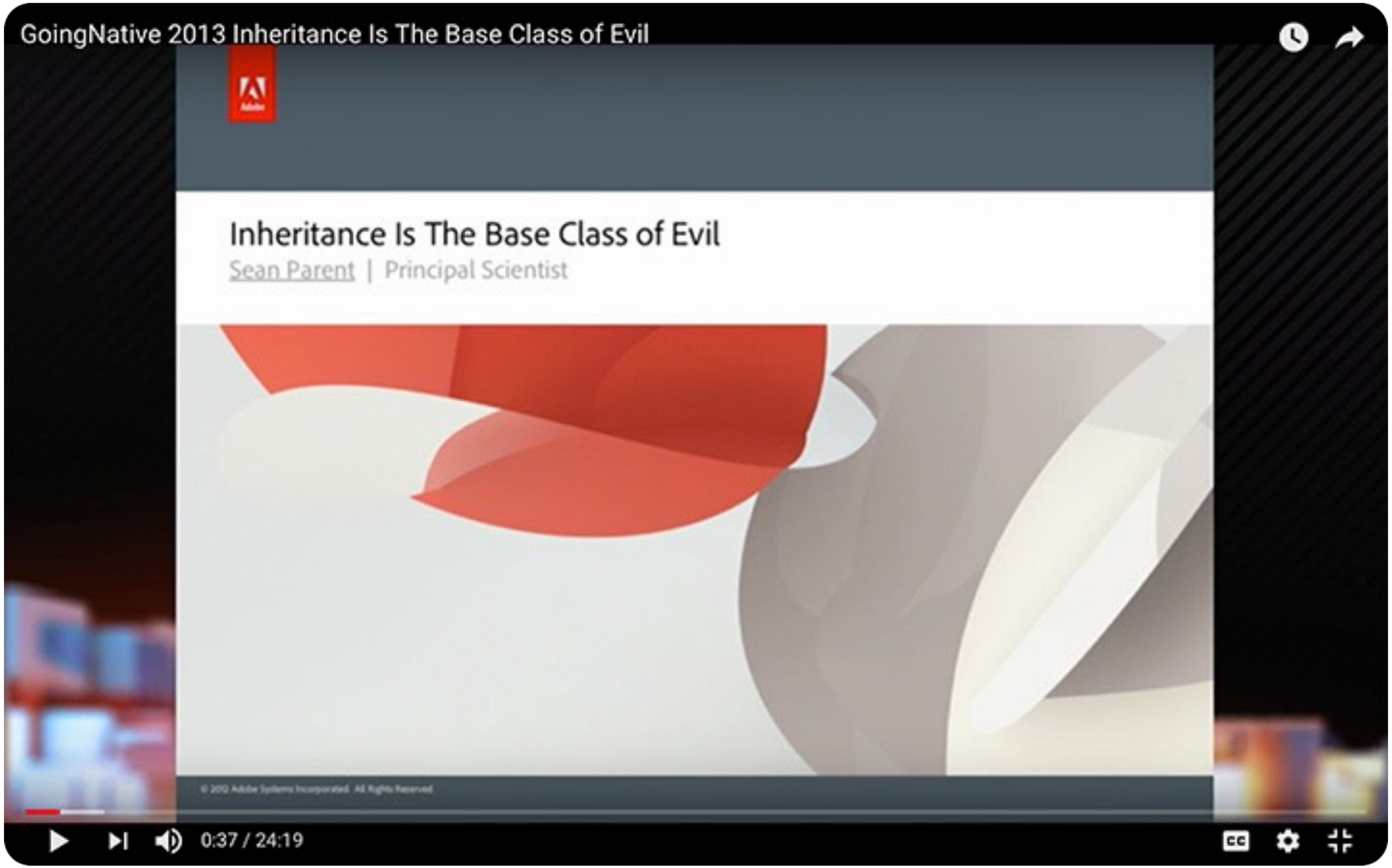
6 (?) out of 48 talks at Meeting C++ 2024 are related to Software Design.

But… std::variant is so much faster. I still want to use it…

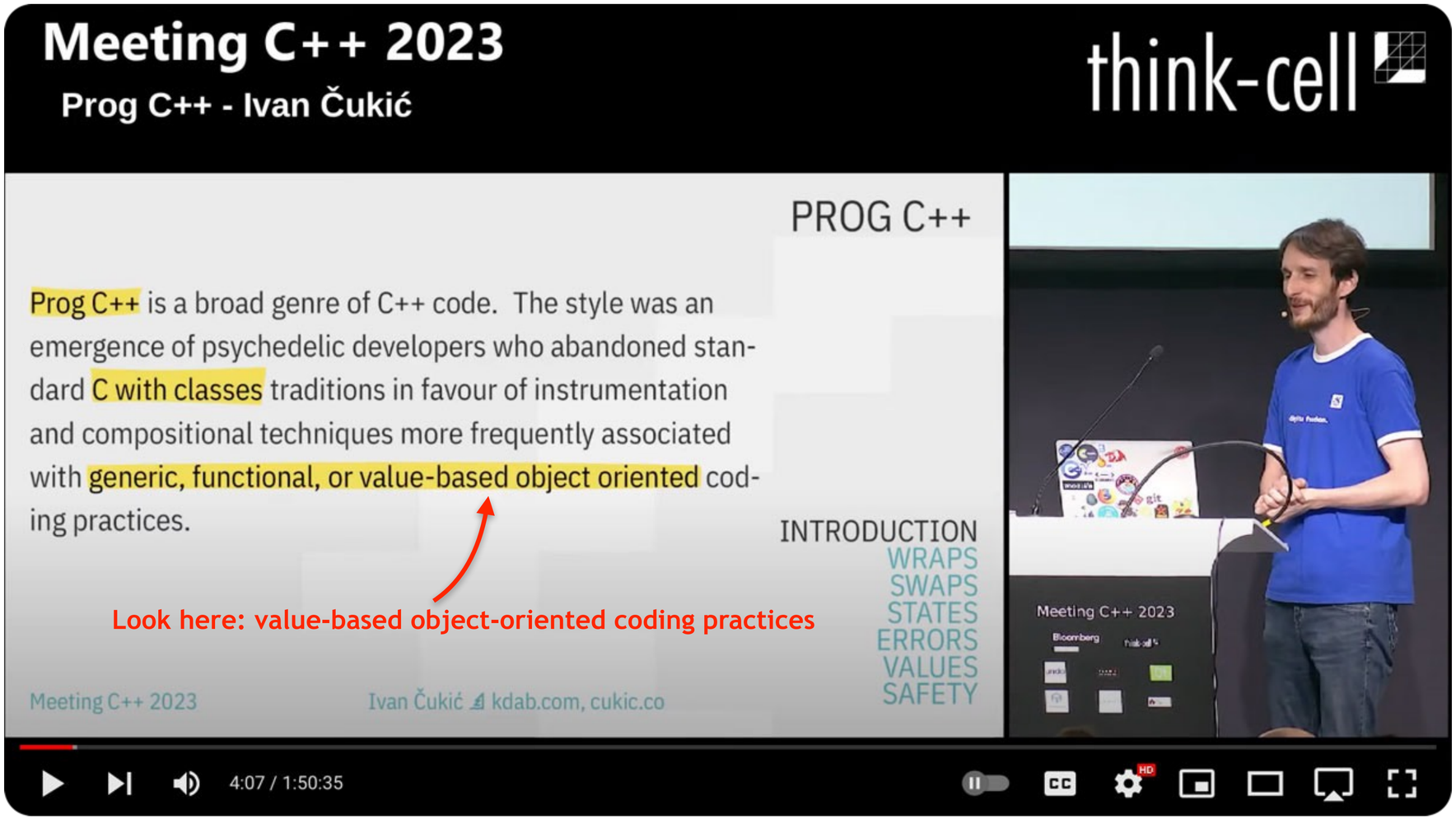
Well, then use it, but create an **Architectural Decision Record (ADR)**

Does this mean we have to go back to object-oriented programming?

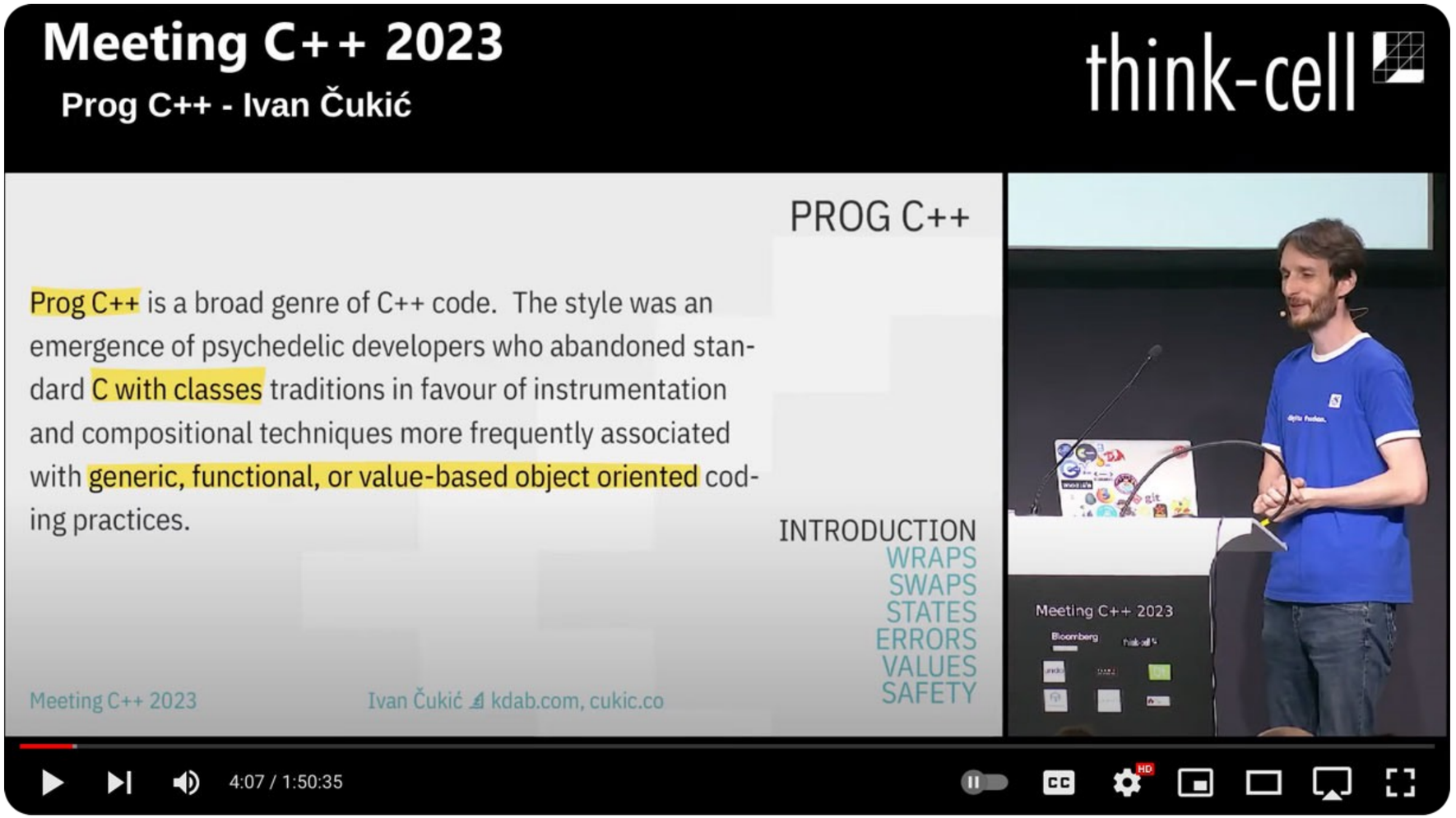
Do We Have to Use the Fallen Paradigm?



Value-Based Object-Oriented Programming



Interlude: A new Era of C++



Are you tired of the term
Modern C++?

Do you also feel that after 13 years **modern** is not modern anymore?

Do you also feel that the term is misused for any C++ code?

Modern C++ is not about features, not about standards, it’s about a philosophy.

We should rename

Modern C++!

What about **Progressive C++**?

Ivan Čukić

(Creator of the term “Progressive C++”)

A Value-Based Object-Oriented Solution

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

   virtual void draw() const = 0;
   // ... several other virtual functions, including ‘clone()’
};


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 Value-Based Object-Oriented Solution

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

   virtual void draw() const = 0;
   // ... several other virtual functions, including ‘clone()’
};


class Circle : public ShapeConcept
{
 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 Value-Based Object-Oriented Solution

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

   virtual void draw() const = 0;
   // ... several other virtual functions, including ‘clone()’
};

template< typename ConcreteShape >
class ShapeModel : public ShapeConcept
{
 public:
   explicit ShapeModel( ConcreteShape shape )
      : shape_{shape}
   {}

   void draw() const override { /*...*/ }
   // ... several other virtual functions, including ‘clone()’

 private:
   ConcreteShape shape_;
};
```

How does a model draw its shape?

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

A Value-Based Object-Oriented Solution

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

   virtual void draw() const = 0;
   // ... several other virtual functions, including ‘clone()’
};

template< typename ConcreteShape, typename DrawStrategy >
class ShapeModel : public ShapeConcept
{
 public:
   explicit ShapeModel( ConcreteShape shape, DrawStrategy drawer )
       : shape_{shape}
       , drawer_{drawer}
   {}

   void draw() const override { drawer_(shape_); }
   // ... several other virtual functions, including ‘clone()’

 private:
   ConcreteShape shape_;
   DrawStrategy drawer_;
};

class Circle : public ShapeConcept
{
 public:
   Circle( double rad, std::unique_ptr<DrawStrategy<Circle>>&& ds )
      : radius{ rad }
```

A Value-Based Object-Oriented Solution

```
      , drawer_{drawer}
   {}

   void draw() const override { drawer_(shape_); }
   // ... several other virtual functions, including 'clone()'

 private:
   ConcreteShape shape_;
   DrawStrategy drawer_;
};


class Circle : public ShapeConcept
{
 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 Value-Based Object-Oriented Solution

```
      , drawer_{drawer}
   {}

   void draw() const override { drawer_(shape_); }
   // ... several other virtual functions, including 'clone()'

 private:
   ConcreteShape shape_;
   DrawStrategy drawer_;
};


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

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

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

A Value-Based Object-Oriented Solution

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

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

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

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

   virtual void draw() const = 0;
   // ... several other virtual functions, including 'clone()'
};

template< typename ConcreteShape, typename DrawStrategy >
class ShapeModel : public ShapeConcept
{
 public:
   explicit ShapeModel( ConcreteShape shape, DrawStrategy drawer )
```

A Value-Based Object-Oriented Solution

```
    // ... Remaining data members
};


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

   virtual void draw() const = 0;
   // ... several other virtual functions, including 'clone()'
};

template< typename ConcreteShape, typename DrawStrategy >
class ShapeModel : public ShapeConcept
{
 public:
   explicit ShapeModel( ConcreteShape shape, DrawStrategy drawer )
       : shape_{shape}
       , drawer_{drawer}
   {}

   void draw() const override { drawer_(shape_); }
   // ... several other virtual functions, including 'clone()'

 private:
   ConcreteShape shape_;
   DrawStrategy drawer_;
};
```

The ShapeModel wraps the polymorphic drawing behavior around any concrete shape type

A Value-Based Object-Oriented Solution

```
class Shape
{
 public:
   // ...

 private:
  class ShapeConcept
  {
   public:
     virtual ~ShapeConcept() = default;

     virtual void draw() const = 0;
     // ... several other virtual functions, including ‘clone()’
  };

  template< typename ConcreteShape, typename DrawStrategy >
  class ShapeModel : public ShapeConcept
  {
   public:
     explicit ShapeModel( ConcreteShape shape, DrawStrategy drawer )
         : shape_{shape}
         , drawer_{drawer}
     {}

     void draw() const override { drawer_(shape_); }
     // ... several other virtual functions, including ‘clone()’

   private:
     ConcreteShape shape_;
     DrawStrategy drawer_;
  };
```

A Value-Based Object-Oriented Solution

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

     virtual void draw() const = 0;
     // ... several other virtual functions, including ‘clone()’
  };

  template< typename ConcreteShape, typename DrawStrategy >
  class ShapeModel : public ShapeConcept
  {
   public:
     explicit ShapeModel( ConcreteShape shape, DrawStrategy drawer )
         : shape_{shape}
         , drawer_{drawer}
     {}

     void draw() const override { drawer_(shape_); }
     // ... several other virtual functions, including ‘clone()’

   private:
     ConcreteShape shape_;
     DrawStrategy drawer_;
  };

  std::unique_ptr<ShapeConcept> pimpl_;
};
```

A Value-Based Object-Oriented Solution

```
class Shape
{
 public:
   // ...

 private:
  class ShapeConcept
  {
   public:
     virtual ~ShapeConcept() = default;

     virtual void draw() const = 0;
     // ... several other virtual functions, including ‘clone()’
  };

  template< typename ConcreteShape, typename DrawStrategy >
  class ShapeModel : public ShapeConcept
  {
   public:
     explicit ShapeModel( ConcreteShape shape, DrawStrategy drawer )
         : shape_{shape}
         , drawer_{drawer}
     {}

     void draw() const override { drawer_(shape_); }
     // ... several other virtual functions, including ‘clone()’

   private:
     ConcreteShape shape_;
     DrawStrategy drawer_;
  };
```

A Value-Based Object-Oriented Solution

```
class Shape
{
 public:
   template< typename ConcreteShape, typename DrawStrategy >
   Shape( ConcreteShape shape, DrawStrategy drawer )
      : pimpl_{ std::make_unique<ShapeModel<ConcreteShape,DrawStrategy>>(shape, drawer) }
   {}

   // ...
```

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

     virtual void draw() const = 0;
     // ... several other virtual functions, including ‘clone()’
  };

  template< typename ConcreteShape, typename DrawStrategy >
  class ShapeModel : public ShapeConcept
  {
   public:
     explicit ShapeModel( ConcreteShape shape, DrawStrategy drawer )
         : shape {shape}
```

A Value-Based Object-Oriented Solution

```
class Shape
{
 public:
   template< typename ConcreteShape, typename DrawStrategy >
   Shape( ConcreteShape shape, DrawStrategy drawer )
      : pimpl_{ std::make_unique<ShapeModel<ConcreteShape,DrawStrategy>>(shape, drawer) }
   {}

   void draw() const { pimpl_->draw(); }

   // ...



 private:
  class ShapeConcept
  {
   public:
     virtual ~ShapeConcept() = default;

     virtual void draw() const = 0;
     // ... several other virtual functions, including 'clone()'
  };

  template< typename ConcreteShape, typename DrawStrategy >
  class ShapeModel : public ShapeConcept
  {
   public:
     explicit ShapeModel( ConcreteShape shape, DrawStrategy drawer )
        : shape {shape}
```

A Value-Based Object-Oriented Solution

```
class Shape
{
 public:
   template< typename ConcreteShape, typename DrawStrategy >
   Shape( ConcreteShape shape, DrawStrategy drawer )
      : pimpl_{ std::make_unique<ShapeModel<ConcreteShape,DrawStrategy>>(shape, drawer) }
   {}

   void draw() const { pimpl_->draw(); }

   Shape( Shape const& );
   Shape( Shape&& );
   ~Shape() = default;
   Shape& operator=( Shape const& );
   Shape& operator=( Shape&& );

 private:
  class ShapeConcept
  {
   public:
     virtual ~ShapeConcept() = default;

     virtual void draw() const = 0;
     // ... several other virtual functions, including 'clone()'
  };

  template< typename ConcreteShape, typename DrawStrategy >
  class ShapeModel : public ShapeConcept
  {
   public:
     explicit ShapeModel( ConcreteShape shape, DrawStrategy drawer )
        : shape {shape}
```

The copy operations are based on the virtual clone() function of the ShapeConcept abstraction

A Value-Based Object-Oriented Solution

```
class Shape
{
 public:
   template< typename ConcreteShape, typename DrawStrategy >
   Shape( ConcreteShape shape, DrawStrategy drawer )
      : pimpl_{ std::make_unique<ShapeModel<ConcreteShape,DrawStrategy>>(shape, drawer) }
   {}

   void draw() const { pimpl_->draw(); }

   Shape( Shape const& );
   Shape( Shape&& );
   ~Shape() = default;
   Shape& operator=( Shape const& );
   Shape& operator=( Shape&& );

 private:
  class ShapeConcept
  {
   public:
     virtual ~ShapeConcept() = default;

     virtual void draw() const = 0;
     // ... several other virtual functions, including 'clone()'
  };

  template< typename ConcreteShape, typename DrawStrategy >
  class ShapeModel : public ShapeConcept
  {
   public:
     explicit ShapeModel( ConcreteShape shape, DrawStrategy drawer )
         : shape {shape}
```

The Shape abstraction …

- … can do the same as the Shape base class.
- … is faster due to fewer indirections.
- … is a value (i.e. can be copied, moved, …).
- … simplifies the surrounding code.

This is Type Erasure.

A Value-Based Object-Oriented Solution

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

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

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


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

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

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

A Value-Based Object-Oriented Solution

```
      // ... several other virtual functions, including 'clone()'

   private:
     ConcreteShape shape_;
     DrawStrategy drawer_;
  };

  std::unique_ptr<ShapeConcept> pimpl_;
};


using Shapes = std::vector<Shape>;

using ShapesFactory = std::function<Shapes(std::string_view)>;

void drawAllShapes( Shapes const& shapes )
{
   for( auto const& shape : shapes )
   {
      shape.draw();
   }
}

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


class OpenGLDrawer
{
```

A vector of values, not pointers

A Value-Based Object-Oriented Solution

```
      // ... several other virtual functions, including 'clone()'

   private:
     ConcreteShape shape_;
     DrawStrategy drawer_;
  };

  std::unique_ptr<ShapeConcept> pimpl_;
};


using Shapes = std::vector<Shape>;

using ShapesFactory = std::function<Shapes(std::string_view)>;

void drawAllShapes( Shapes const& shapes )
{
   for( auto const& shape : shapes )
   {
      shape.draw();
   }
}

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


class OpenGLDrawer
{
```

Another Type Erasure abstraction

A Value-Based Object-Oriented Solution

```
  std::unique_ptr<ShapeConcept> pimpl_;
};


using Shapes = std::vector<Shape>;

using ShapesFactory = std::function<Shapes(std::string_view)>;

void drawAllShapes( Shapes const& shapes )
{
   for( auto const& shape : shapes )
   {
      shape.draw();
   }
}

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


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

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

   void operator()( Square const& square ) const;
```

Value syntax, not pointer syntax

A Value-Based Object-Oriented Solution

```
  std::unique_ptr<ShapeConcept> pimpl_;
};


using Shapes = std::vector<Shape>;

using ShapesFactory = std::function<Shapes(std::string_view)>;

void drawAllShapes( Shapes const& shapes )
{
   for( auto const& shape : shapes )
   {
      shape.draw();
   }
}

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


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

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

   void operator()( Square const& square ) const;
```

A Value-Based Object-Oriented Solution

```
    }
}

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

No inheritance, but value-semantics.
The same OpenGLDrawer as in the std::variant solution.

```
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, ...)
};


class YourShapesFactory
{
 public:
   Shapes operator()( std::string_view filename ) const
   {
      Shapes shapes{};
      std::string shape{};

      std::istringstream shape_file{ filename };
```

A Value-Based Object-Oriented Solution

```
class YourShapesFactory
{
 public:
   Shapes operator()( std::string_view filename ) const
   {
      Shapes shapes{};
      std::string shape{};

      std::istringstream shape_file{ filename };

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

      return shapes;
   }
};
```

Again, no inheritance, but value-semantics.

Creating values, storing values …
No dynamic memory allocation in our code.

A Value-Based Object-Oriented Solution

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

        return shapes;
    }
};


int main()
{
    YourShapesFactory factory{};

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

A Value-Based Object-Oriented Solution

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

        return shapes;
     }
};


int main()
{
   YourShapesFactory factory{};

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

A Value-Based Object-Oriented Solution

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


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, ...)
};


class YourShapesFactory
{
 public:
   Shapes operator()( std::string_view filename ) const
   {
      Shapes shapes{};
      std::string shape{};

      std::istringstream shape_file{ filename };

      while( iss >> shape )
      {
```

A Value-Based Object-Oriented Solution

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

My Code

Architectural Boundary

Your Code

```
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, ...)
};


class YourShapesFactory
{
 public:
   Shapes operator()( std::string_view filename ) const
   {
      Shapes shapes{};
      std::string shape{};
```

A Value-Based Object-Oriented Solution

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

My Code

Architectural Boundary

Your Code

```
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
};
```

Adding new shape types is easily possible

```
class OpenGLDrawer
{
```

A Value-Based Object-Oriented Solution

```
   // ... getCenter(), getRotation(), ...

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


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, ...)
};


class YourShapesFactory
{
 public:
   Shapes operator()( std::string_view filename ) const
   {
      Shapes shapes{};
      std::string shape{};

      std::istringstream shape_file{ filename };

      while( iss >> shape )
```

A Value-Based Object-Oriented Solution

```
    // ... getCenter(), getRotation(), ...

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


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, ...)
};


class YourShapesFactory
{
  public:
    Shapes operator()( std::string_view filename ) const
    {
        Shapes shapes{};
        std::string shape{};

        std::istringstream shape_file{ filename };
```

Easy extension in your code only 😊

A Value-Based Object-Oriented Solution

```
class YourShapesFactory
{
 public:
   Shapes operator()( std::string_view filename ) const
   {
      Shapes shapes{};
      std::string shape{};

      std::istringstream shape_file{ filename };

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

      return shapes;
   }
};
```

A Value-Based Object-Oriented Solution

```
class YourShapesFactory
{
 public:
   Shapes operator()( std::string_view filename ) const
   {
      Shapes shapes{};
      std::string shape{};

      std::istringstream shape_file{ filename };

      while( iss >> shape )
      {
         if( shape == "circle" ) {
            double radius{};
            shape_file >> radius /* >> color, texture, transparency, ... */;
            shapes.emplace_back( Circle{radius}, OpenGLDrawer{/*...*/} );
         }
         else if( shape == "square" ) {
            double side{};
            iss >> side >> /* >> color, texture, transparency, ... */;
            shapes.emplace_back( Square{side}, OpenGLDrawer{/*...*/} );
         }
         else if( shape == "rectangle" ) {
            double width{}, height{};
            iss >> width >> height >> /* >> color, texture, transparency, ... */;
            shapes.emplace_back( Rectangle{width,height}, OpenGLDrawer{/*...*/} );
         }
         else {
            break;
         }
      }
```

Again, easy extension in your code only 😊

A Value-Based Object-Oriented Solution

```
class YourShapesFactory
{
 public:
   Shapes operator()( std::string_view filename ) const
   {
      Shapes shapes{};
      std::string shape{};

      std::istringstream shape_file{ filename };

      while( iss >> shape )
      {
         if( shape == "circle" ) {
            double radius{};
            shape_file >> radius /* >> color, texture, transparency, ... */;
            shapes.emplace_back( Circle{radius}, OpenGLDrawer{/*...*/} );
         }
         else if( shape == "square" ) {
            double side{};
            iss >> side >> /* >> color, texture, transparency, ... */;
            shapes.emplace_back( Square{side}, OpenGLDrawer{/*...*/} );
         }
         else if( shape == "rectangle" ) {
            double width{}, height{};
            iss >> width >> height >> /* >> color, texture, transparency, ... */;
            shapes.emplace_back( Rectangle{width,height}, OpenGLDrawer{/*...*/} );
         }
         else {
            break;
         }
      }
```

A Value-Based Object-Oriented Solution

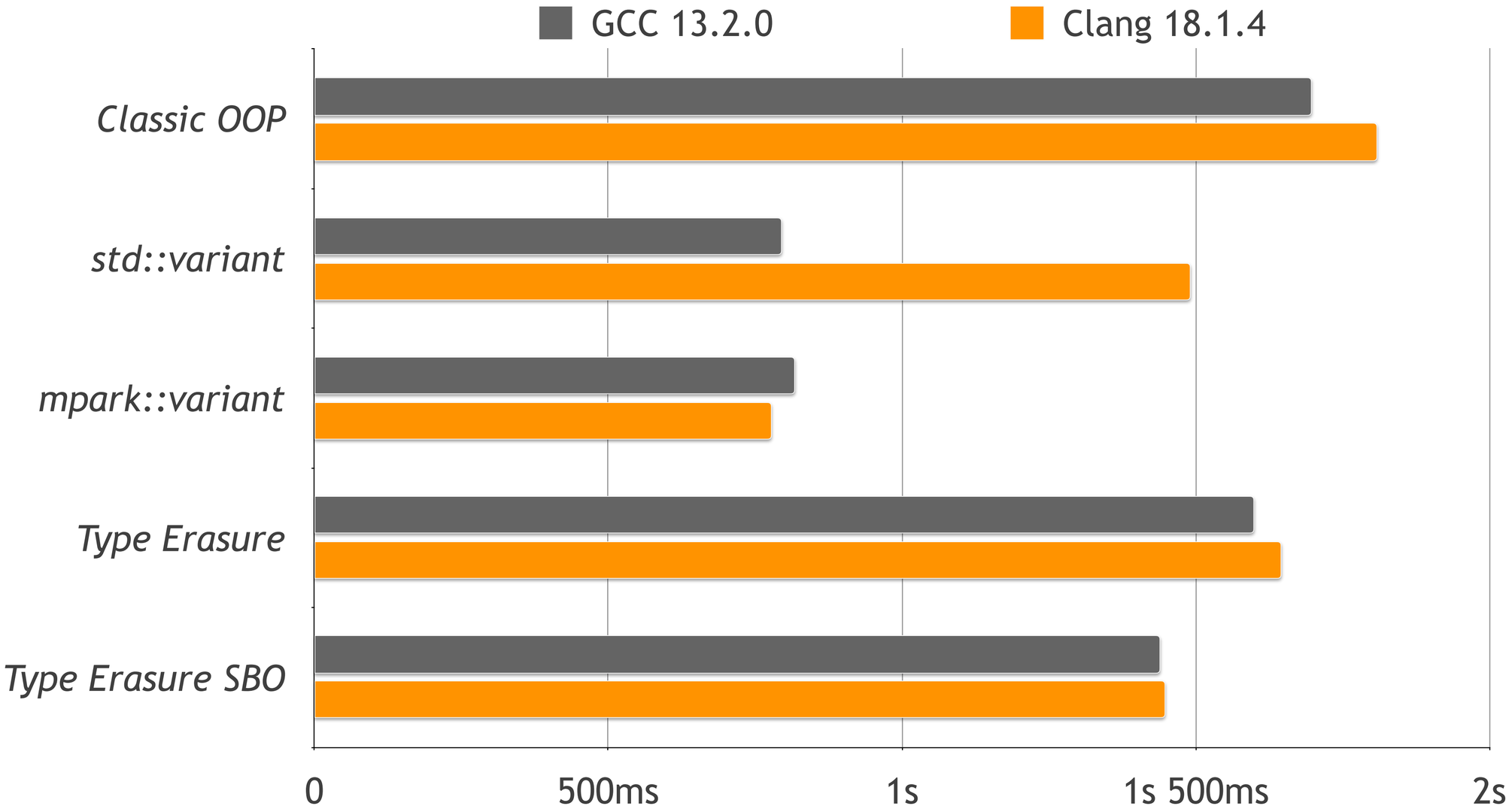
This solution is amazing:

- Changes/extensions work as expected
- The architectural boundaries are adhered to
- Fewer pointers
- Fewer virtual functions (i.e. only one indirection instead of two)
- Less inheritance
- Less manual memory management
- Better performance

Performance Comparison

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

Performance Comparison



So, should we now use only value-based object-oriented programming?

No, of course not.
Please also use functional programming solutions.

So, then, when should we use functional programming or object-oriented programming?

Of course the answer is:

It depends

std::variant vs. Type Erasure

std::variant	*Type Erasure*
Functional programming	Object-oriented programming
Fixed set of types	Open set of types
Open set of operations	Closed set of operations
Best used in lower levels of the architecture (implementation details)	Best used in higher levels of the architecture

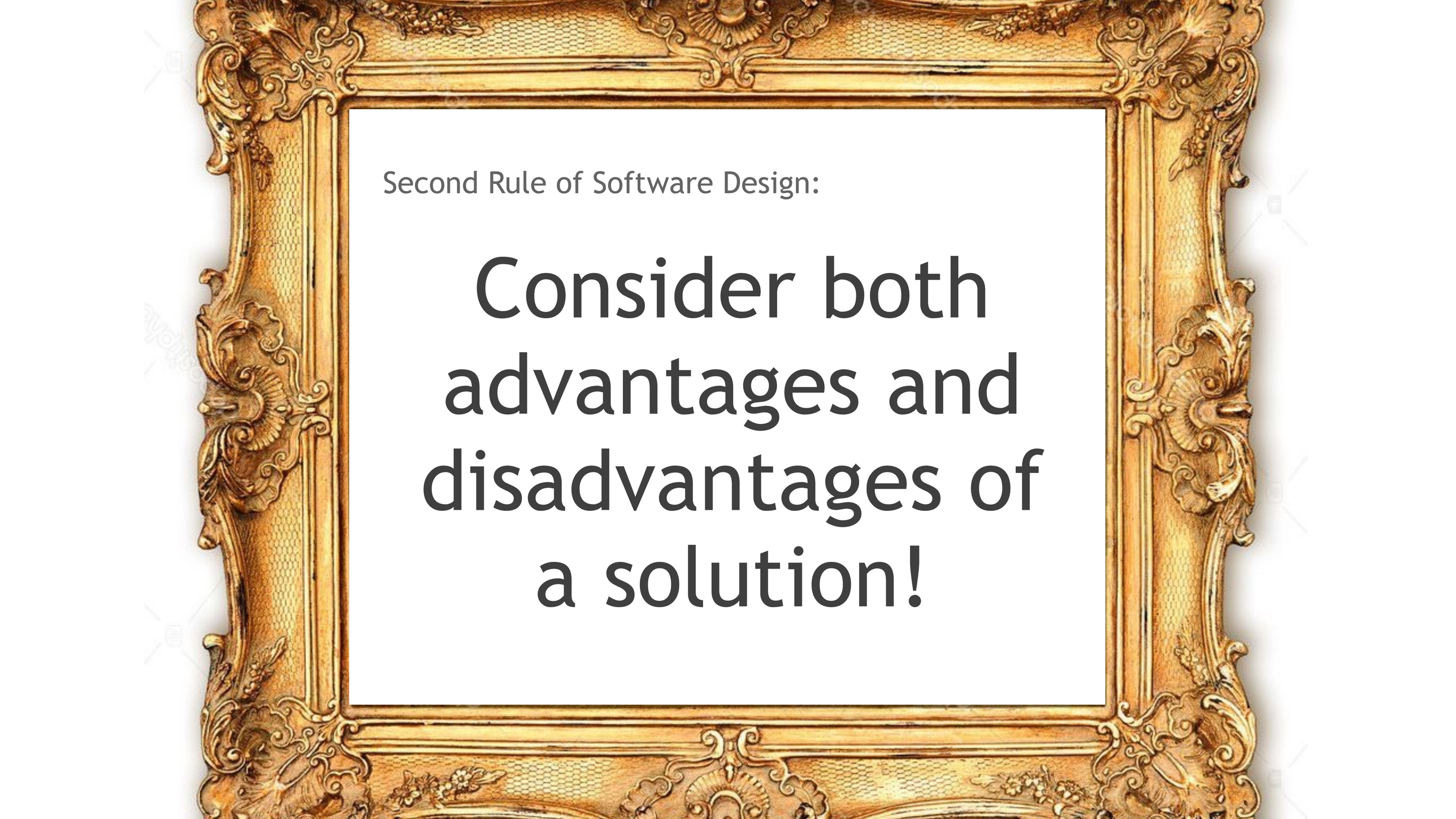
The Two Sides of the Same Coin

This side: Object-Oriented Programming with Type Erasure

The other side: Functional Programming with std::variant


First Rule of Software Design:
Think about the architectural properties of a solution first!

Think About the Architectural Properties First


Second Rule of Software Design:
Consider both advantages and disadvantages of a solution!

There is no silver bullet.

There are always pros and cons.

It always depends.

Thank you!

There Is No Silver Bullet

Klaus Iglberger, Meeting C++ 2024

klaus.iglberger@gmx.de

TODOs

- “Don’t Throw Coins, but think about the architectural properties of a solution”