Breaking Dependencies:

Type Erasure - A Design Analysis

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Klaus Iglberger

Content

- The Challenge of Software Design
- The Naive Solution: Inheritance
- The Classic Solution: Design Patterns
- The Modern Solution: Type Erasure

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- The Challenge of Software Design
- The Naive Solution: Inheritance
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What is the root source of all problems in software development?

Change

The truth in our industry:

Software must be adaptable to frequent changes

The truth in our industry:

Software must be adaptable to frequent changes

What is the core problem of adaptable software
and software development in general?

Dependencies

”Dependency is the key problem in software development at all scales.”
(Kent Beck, TDD by Example)

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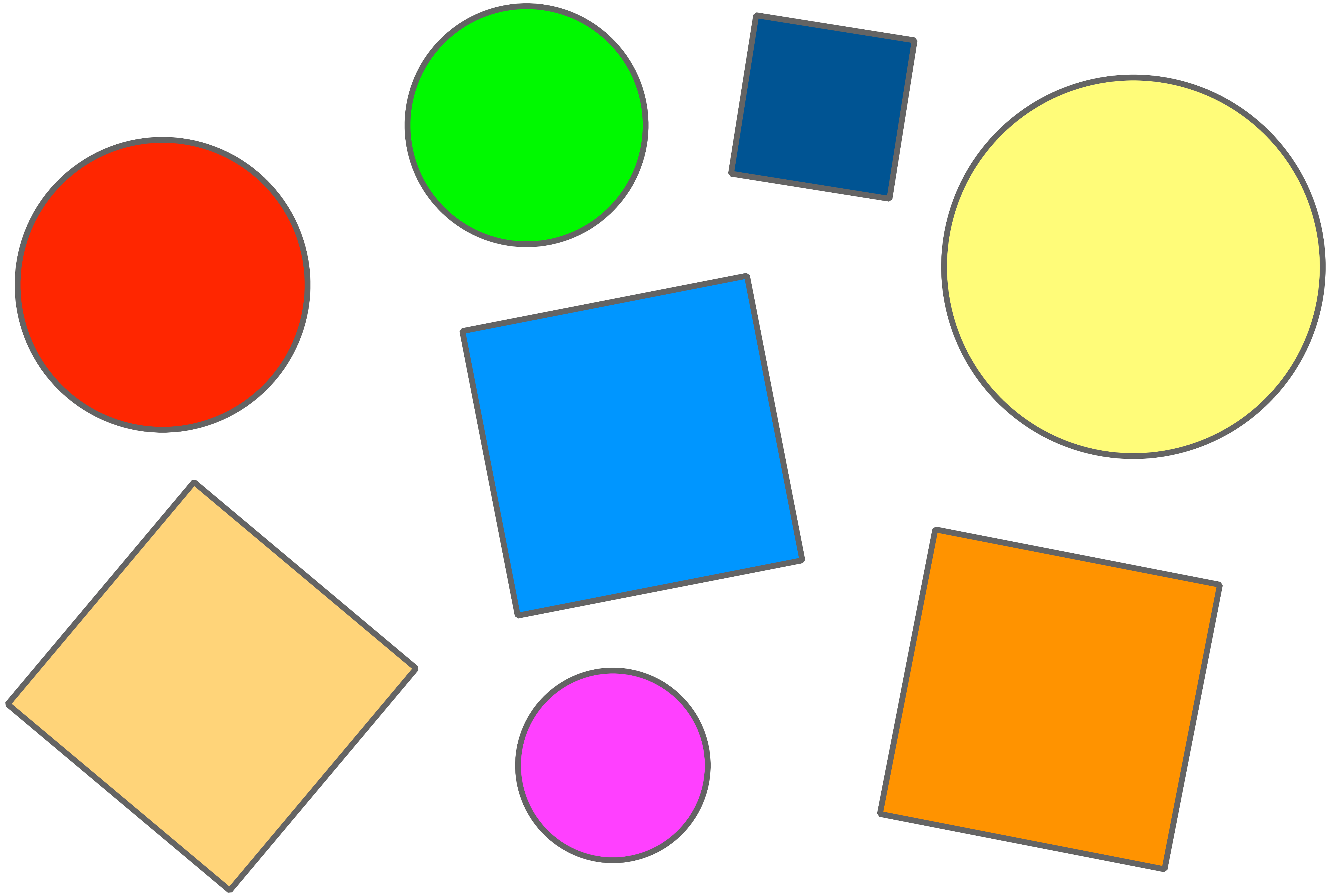
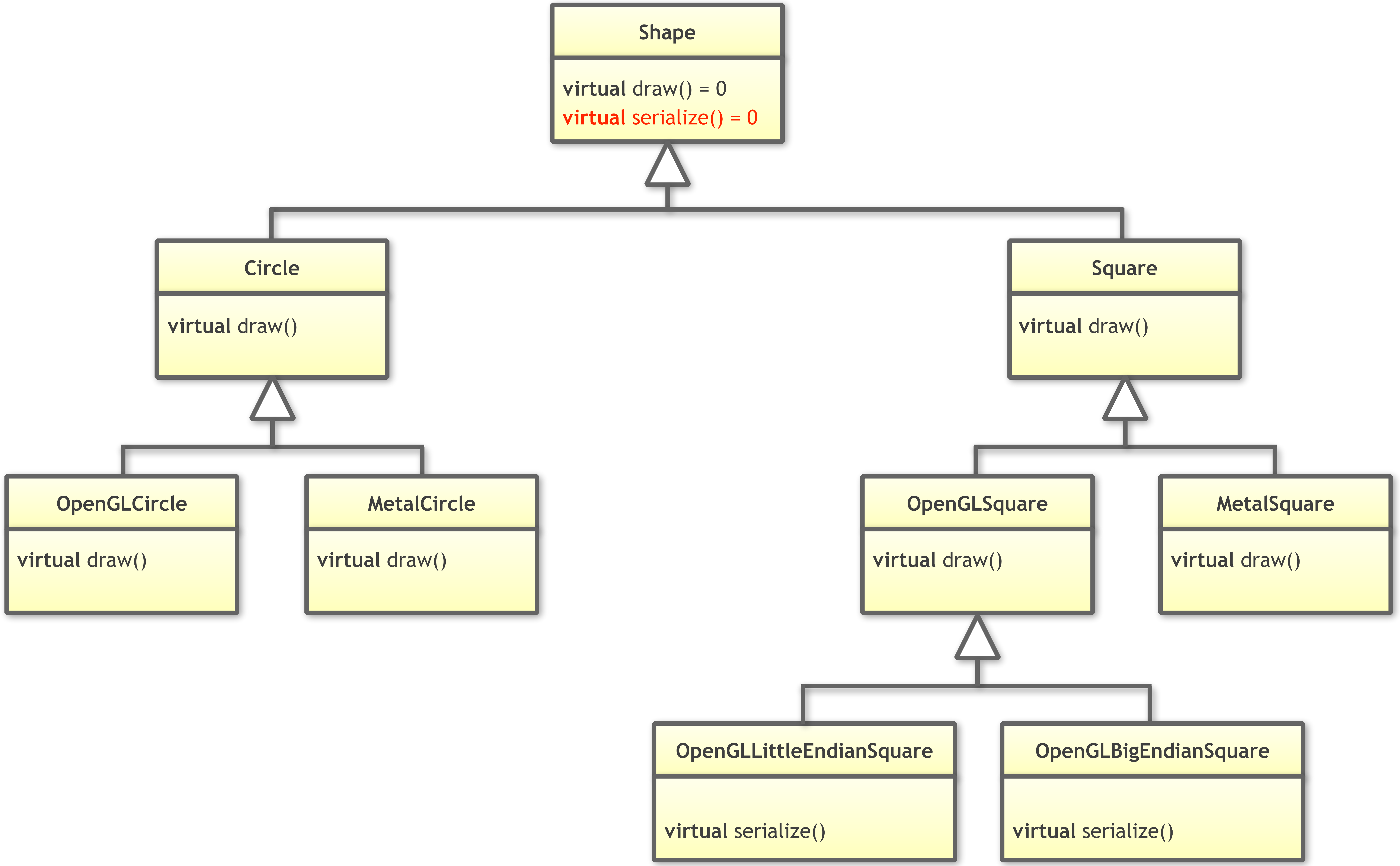
Our Toy Problem: Shapes



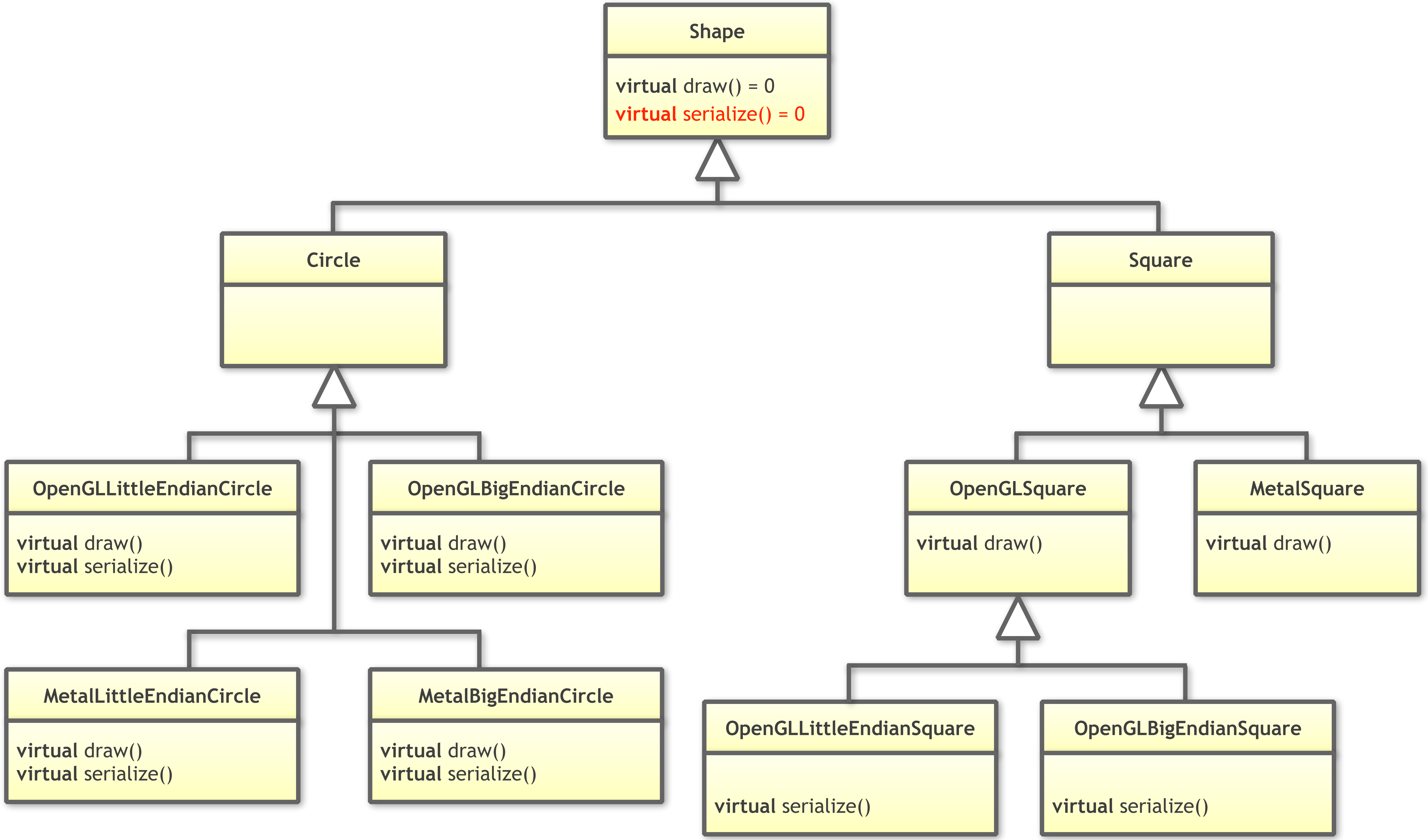
"I'm tired of this example, but I don't know any better one."

(Lukas Bergdoll, MUC++ organizer)

Designing the Shape Hierarchy



Designing the Shape Hierarchy



Designing the Shape Hierarchy

```
class OpenGLLittleEndianCircle : public Circle
{
 public:
   // ...
   virtual void draw( Screen& s, /*...*/ ) const;
   virtual void serialize( ByteStream& bs, /*...*/ ) const;
   // ...
};
```

Using inheritance naively to solve our problem easily leads to …

- … **many derived classes;**
- … **ridiculous class names;**
- … **deep inheritance hierarchies;**
- … **duplication** between similar implementations (DRY);
- … (almost) impossible **extensions** (OCP);
- … impeded **maintenance.**

”Inheritance is Rarely the Answer.
Delegate to Services: Has-A Trumps Is-A.”
(Andrew Hunt, David Thomas, The Pragmatic Programmer)

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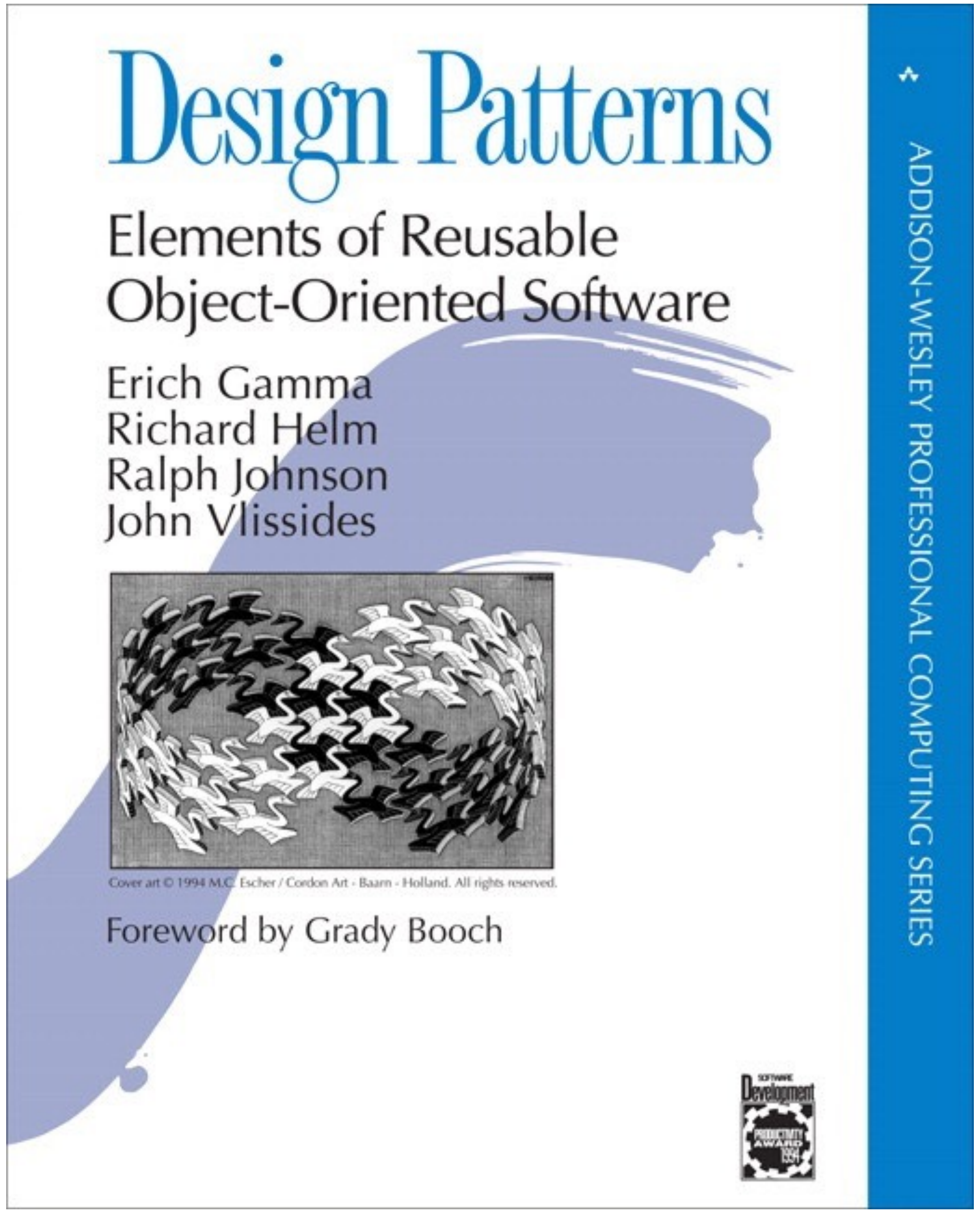
The Solution: Design Patterns

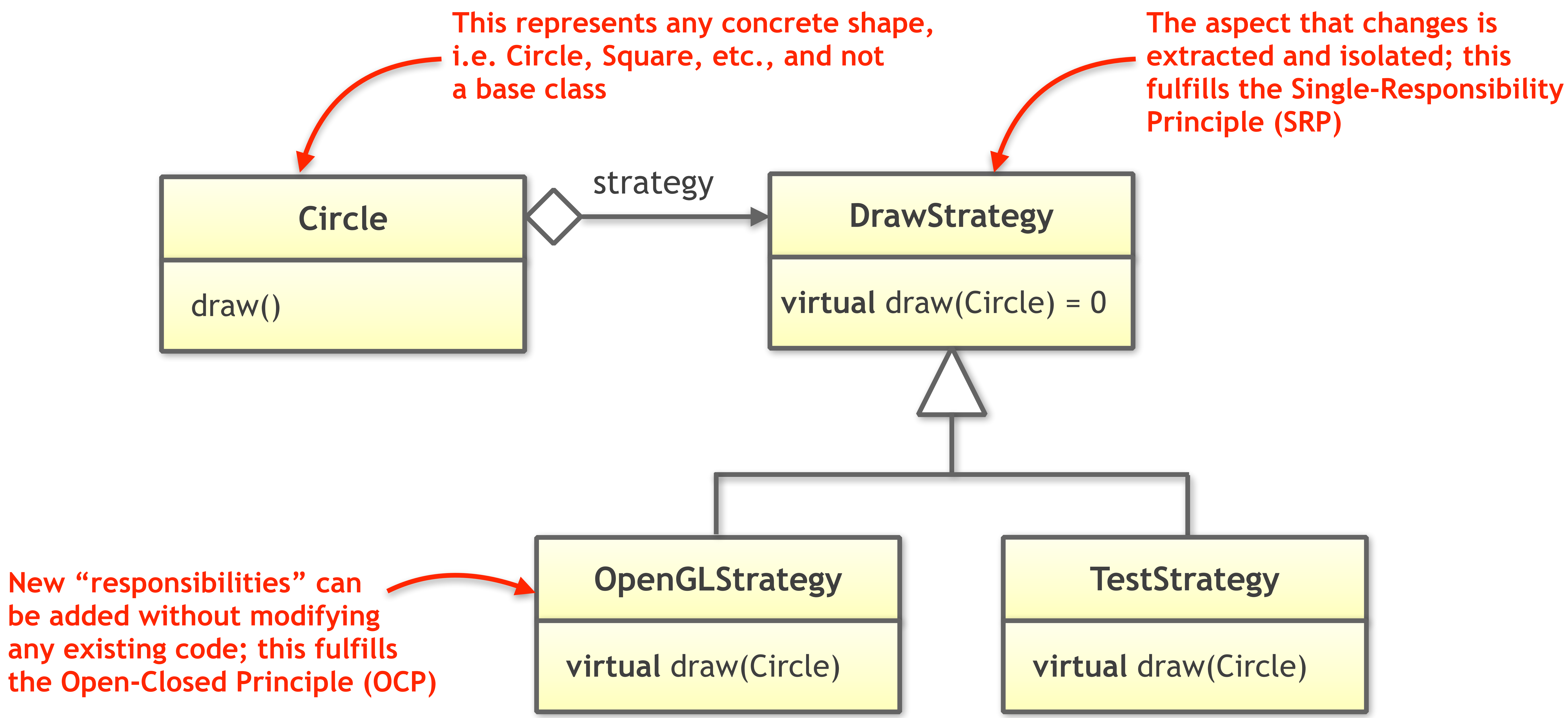


The **Gang-of-Four** (**GoF**) book: Origin of 23 of the most commonly used design patterns.

A design pattern …

- … has a **name;**
- … carries an **intent**;
- … aims at reducing **dependencies**;
- … provides some sort of **abstraction**;
- … has **proven to work** over the years.

The Strategy Design Pattern



The Strategy Design Pattern

The Strategy Design Pattern …

- … is not limited to object-oriented programming;
- … is not limited to dynamic polymorphism;
- … is not a language-specific idiom.

Examples from the Standard Library

```
std::vector<int> numbers{ 1, 2, 3, 4, 5, 6, 7 };

std::accumulate( begin(numbers), end(numbers), 0
               , std::plus<>{} );
```

Strategy

Examples from the Standard Library

```
template<
    class T,
    class Allocator = std::allocator<T>
> class vector;
```

Strategy

Examples from the Standard Library

```
template<
    class Key,
    class Hash = std::hash<Key>,
    class KeyEqual = std::equal_to<Key>,
    class Allocator = std::allocator<Key>
> class unordered_set;
```

Strategy

Examples from the Standard Library

```
template<
    class T,
    class Deleter = std::default_delete<T>
> class unique_ptr;
```

Strategy

A Strategy-Based Solution

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

   virtual void draw( /*...*/ ) const = 0;
   virtual void serialize( /*...*/ ) const = 0;
   // ...
};


class Circle;

class DrawCircleStrategy
{
 public:
   virtual ~DrawCircleStrategy() {}

   virtual void draw( Circle const& circle, /*...*/ ) const = 0;
};


class Circle : public Shape
{
 public:
   Circle( double rad
         , std::unique_ptr<DrawCircleStrategy> strategy )
      : radius{ rad }
      , // ... Remaining data members
```

A Strategy-Based Solution

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

   virtual void draw( /*...*/ ) const = 0;
   virtual void serialize( /*...*/ ) const = 0;
   // ...
};


class Circle;

class DrawCircleStrategy
{
 public:
   virtual ~DrawCircleStrategy() {}

   virtual void draw( Circle const& circle, /*...*/ ) const = 0;
};


class Circle : public Shape
{
 public:
   Circle( double rad
         , std::unique_ptr<DrawCircleStrategy> strategy )
      : radius{ rad }
      , // ... Remaining data members
```

A Strategy-Based Solution

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

   virtual void draw( /*...*/ ) const = 0;
   virtual void serialize( /*...*/ ) const = 0;
   // ...
};


class Circle;

class DrawCircleStrategy
{
 public:
   virtual ~DrawCircleStrategy() {}

   virtual void draw( Circle const& circle, /*...*/ ) const = 0;
};


class Circle : public Shape
{
 public:
   Circle( double rad
         , std::unique_ptr<DrawCircleStrategy> strategy )
      : radius{ rad }
      , // ... Remaining data members
```

A Strategy-Based Solution

```
};


class Circle : public Shape
{
 public:
   Circle( double rad
         , std::unique_ptr<DrawCircleStrategy> strategy )
      : radius{ rad }
      , // ... Remaining data members
      , drawing{ std::move(strategy) }
   {}

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

   void draw( /*...*/ ) const override
   {
      drawing->draw( this, /*...*/ );
   }
   void serialize( /*...*/ ) const override;

   // ...

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



```
class Square:
```

A Strategy-Based Solution

```
   // ...

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



class Square;

class DrawSquareStrategy
{
 public:
   virtual ~DrawSquareStrategy() {}

   virtual void draw( Square const& square, /*...*/ ) const = 0;
};



class Square : public Shape
{
 public:
   Square( double s
         , std::unique_ptr<DrawSquareStrategy> strategy )
      : side{ s }
      , // ... Remaining data members
      , drawing{ std::move(strategy) }
   {}

   double getSide() const noexcept;
```

A Strategy-Based Solution

```
};


class Square : public Shape
{
 public:
   Square( double s
         , std::unique_ptr<DrawSquareStrategy> strategy )
      : side{ s }
      , // ... Remaining data members
      , drawing{ std::move(strategy) }
   {}

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

   void draw( /*...*/ ) const override
   {
      drawing->draw( this, /*...*/ );
   }
   void serialize( /*...*/ ) const override;

   // ...

 private:
   double side;
   // ... Remaining data members
   std::unique_ptr<DrawSquareStrategy> drawing;
};
```



```
class OpenGLCircleStrategy : public DrawCircleStrategy
```

A Strategy-Based Solution

```
 private:
   double side;
   // ... Remaining data members
   std::unique_ptr<DrawSquareStrategy> drawing;
};



class OpenGLCircleStrategy : public DrawCircleStrategy
{
 public:
   virtual ~OpenGLStrategy() {}

   void draw( Circle const& circle ) const override;
};

class OpenGLSquareStrategy : public DrawSquareStrategy
{
 public:
   virtual ~OpenGLStrategy() {}

  void draw( Square const& square ) const override;
};



int main()
{
   using Shapes = std::vector<std::unique_ptr<Shape>>;

   // Creating some shapes
   Shapes shapes;
   shapes.emplace_back( std::make_unique<Circle>( 2.0
```

A Strategy-Based Solution

```
class OpenGLSquareStrategy : public DrawSquareStrategy
{
 public:
   virtual ~OpenGLStrategy() {}

   void draw( Square const& square ) const override;
};



int main()
{
   using Shapes = std::vector<std::unique_ptr<Shape>>;

   // Creating some shapes
   Shapes shapes;
   shapes.emplace_back( std::make_unique<Circle>( 2.0
                      , std::make_unique<OpenGLCircleStrategy>() ) );
   shapes.emplace_back( std::make_unique<Square>( 1.5
                      , std::make_unique<OpenGLSquareStrategy>() ) );
   shapes.emplace_back( std::make_unique<Circle>( 4.2
                      , std::make_unique<OpenGLCircleStrategy>() ) );

   // Drawing all shapes
   drawAllShapes( shapes );
}
```

A Strategy-Based Solution — Design Analysis

High-level
(stable)

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

   // ...
};
```

Architectural Boundary

```cpp
class Circle : public Shape
{
 public:
   Circle( double rad
         , std::unique_ptr<DrawCircleStrategy> strategy );

   // ...
};
```

```cpp
class Circle;

class DrawCircleStrategy
{
 public:
   virtual ~DrawCircleStrategy() {}

   virtual void draw( const Circle& circle ) const = 0;
};
```

Architectural Boundary

```cpp
class OpenGLStrategy : public DrawCircleStrategy
{
 public:
    virtual void draw( const Circle& circle ) const;
};
```

Low-level
(malleable, volatile)

A Strategy-Based Solution — Summary

Good job! We have used the Strategy design pattern to …

- … extract implementation details (SRP);
- … create the opportunity for easy extension (OCP);
- … separate interfaces (ISP);
- … reduce duplication (DRY);
- … limit the depth of the inheritance hierarchy;
- … simplify maintainance.

But …

- … performance is reduced due to a second indirection;
- … performance is reduced due to many small, manual allocations;
- … performance is affected due to many pointers;
- … we need one Strategy for every operation (`draw()`, `serialize()`, …);
- … we need to manage lifetimes explicitly;
- … we have a proliferation of inheritance hierarchies;
- … circles, squares, etc. still know about all operations (affordances).

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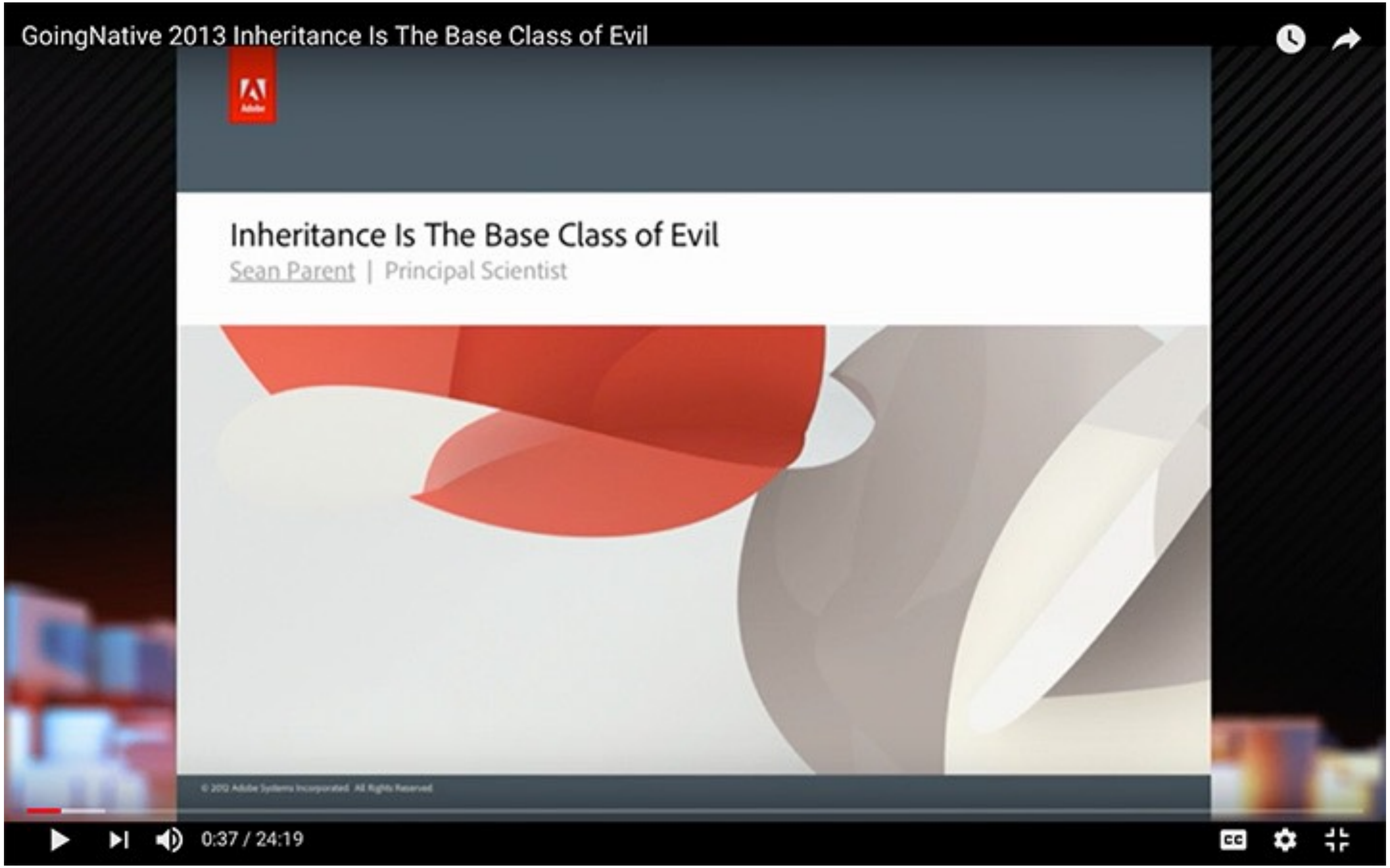
Towards a Value-Based Solution



Type Erasure — The Origin

Valued Conversions (C++ Report 12(7), July–August 2000)

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FROM MECHANISM TO METHOD

Valued Conversions

"HOW WOULD YOU like to pay for that?" Good question. Digging deep into pockets, wallets, and bags uncovered a wealth of possibilities, a handful of different currencies and mechanisms to choose from: credit cards, debit cards, coins, bills, and a couple of IOUs, each form in some way substitutable for another when realizing monetary value.

Cash is the simplest, least troublesome form for small amounts and quick transactions. However, sifting through the metal and

to any concrete form of inheritance. Substitutability here is based on values and conversions between values. Sometimes the use is implicit, at other times it must be made explicit. Conversions can be fully value preserving, widening, or narrowing. Widening conversions are always safe and typically acceptable (e.g., tipping), whereas narrowing conversions may not be (e.g., shortchanging tends to lead to exceptional or even undefined behavior).

Rescuing me from further metaphor stretching, the point-of-

Type Erasure — Terminology

Type Erasure is **not** …

- … a **`void*`**;
- … a **pointer-to-base**;
- … a **`std::variant`**.

Type Erasure is …

- … a **templated constructor** plus …
- … a completely **non-virtual interface;**
- **… External Polymorphism + Bridge + Prototype.**

A Type-Erased Solution

```
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 Type-Erased Solution

```
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 Type-Erased Solution

```
 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
};


struct ShapeConcept
{
   virtual ~ShapeConcept() {}
```

Circles and squares …

- … don’t need a base class;
- … don’t know about each other;
- … don’t know anything about their operations (affordances).

A Type-Erased Solution

```
struct ShapeConcept
{
   virtual ~ShapeConcept() {}



   // ...
};

template< typename T >
struct ShapeModel : ShapeConcept
{
   ShapeModel( T&& value )
      : object{ std::forward<T>(value) }
   {}

   // ...

   T object;
};
```

A Type-Erased Solution

```
struct ShapeConcept
{
   virtual ~ShapeConcept() {}

   virtual void serialize( /*...*/ ) const = 0;
   virtual void draw( /*...*/ ) const = 0;
   // ...
};

template< typename T >
struct ShapeModel : ShapeConcept
{
   ShapeModel( T&& value )
      : object{ std::forward<T>(value) }
   {}

   // ...

   T object;
};
```

A Type-Erased Solution

```
struct ShapeConcept
{
   virtual ~ShapeConcept() {}

   virtual void serialize( /*...*/ ) const = 0;
   virtual void draw( /*...*/ ) const = 0;
   // ...
};

template< typename T >
struct ShapeModel : ShapeConcept
{
   ShapeModel( T&& value )
      : object{ std::forward<T>(value) }
   {}

   // ...

   void serialize( /*...*/ ) const override
   {
      serialize( object, /*...*/ );
   }

   void draw( /*...*/ ) const override
   {
      draw( object, /*...*/ );
   }

   T object;
};
```

The implementation of the virtual functions in the `ShapeModel` class defines the affordances required by the type `T`

A Type-Erased Solution

```
struct ShapeConcept
{
   virtual ~ShapeConcept() {}

   virtual void serialize( /*...*/ ) const = 0;
   virtual void draw( /*...*/ ) const = 0;
   // ...
};

template< typename T >
struct ShapeModel : ShapeConcept
{
   ShapeModel( T&& value )
      : object{ std::forward<T>(value) }
   {}

   // ...

   void serialize( /*...*/ ) const override
   {
      serialize( object, /*...*/ );
   }

   void draw( /*...*/ ) const override
   {
      draw( object, /*...*/ );
   }

   T object;
};
```

The External Polymorphism
Design Pattern

The External Polymorphism Design Pattern

External Polymorphism (3rd Pattern Languages of Programming Conference, September 4-6, 1996)

External Polymorphism

An Object Structural Pattern for Transparently Extending C++ Concrete Data Types

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This paper appeared in the Proceedings of the 3^{rd} Pattern Languages of Programming Conference, Allerton Park, Illinois, September 4–6, 1996.

1 Intent

Allow C++ classes unrelated by inheritance and/or having no virtual methods to be treated polymorphically. These unrelated classes can be treated in a common manner by software that uses them.

2 Motivation

Working with C++ classes from different sources can be difficult. Often an application may wish to "project" common

1. *Space efficiency* – The solution must not constrain the storage layout of existing objects. In particular, classes that have no virtual methods (*i.e.*, concrete data types) must not be forced to add a virtual table pointer.

2. *Polymorphism* – All library objects must be accessed in a uniform, transparent manner. In particular, if new classes are included into the system, we won't want to change existing code.

Consider the following example using classes from the ACE network programming framework [3]:

```
SOCK_Acceptor acceptor; // Global storage

int main (void) {
   SOCK_Stream stream; // Automatic storage
```

The External Polymorphism Design Pattern

The External Polymorphism Design Pattern …

- … allows any object to be treated polymorphically;
- … extracts implementation details (SRP);
- … removes dependencies to operations (affordances);
- … creates the opportunity for easy extension (OCP).

A Type-Erased Solution

```
struct ShapeConcept
{
   virtual ~ShapeConcept() {}

   virtual void serialize( /*...*/ ) const = 0;
   virtual void draw( /*...*/ ) const = 0;
   // ...
};

template< typename T >
struct ShapeModel : ShapeConcept
{
   ShapeModel( T&& value )
      : object{ std::forward<T>(value) }
   {}

   // ...

   void serialize( /*...*/ ) const override
   {
      serialize( object, /*...*/ );
   }

   void draw( /*...*/ ) const override
   {
      draw( object, /*...*/ );
   }

   T object;
};
```

A Type-Erased Solution

```
      serialize( object, /*...*/ );
   }

   void draw( /*...*/ ) const override
   {
      draw( object, /*...*/ );
   }

   T object;
};


void serialize( Circle const&, /*...*/ );
void draw( Circle const&, /*...*/ );

void serialize( Square const&, /*...*/ );
void draw( Square const&, /*...*/ );


void drawAllShapes( std::vector<std::unique_ptr<ShapeConcept>> const& shapes )
{
   for( auto const& shape : shapes )
   {
      shape->draw();
   }
}


int main()
{
   using Shapes = std::vector<std::unique_ptr<ShapeConcept>>;

   // Creating some shapes
```

These functions resolve the requirements posed by the External Polymorphism design pattern.

There can be many implementation, spread over many header/source files (e.g. for OpenGL, Metal, Vulcan, …).

A Type-Erased Solution

```
   T object;
};


void serialize( Circle const&, /*...*/ );
void draw( Circle const&, /*...*/ );

void serialize( Square const&, /*...*/ );
void draw( Square const&, /*...*/ );


void drawAllShapes( std::vector<std::unique_ptr<ShapeConcept>> const& shapes )
{
   for( auto const& shape : shapes )
   {
      shape->draw();
   }
}


int main()
{
   using Shapes = std::vector<std::unique_ptr<ShapeConcept>>;

   // Creating some shapes
   Shapes shapes;
   shapes.emplace_back( std::make_unique<ShapeModel<Circle>>{ 2.0 } );
   shapes.emplace_back( std::make_unique<ShapeModel<Square>>{ 1.5 } );
   shapes.emplace_back( std::make_unique<ShapeModel<Circle>>{ 4.2 } );

   // Drawing all shapes
   drawAllShapes( shapes );
}
```

A Type-Erased Solution

```
void translate( Square const&, /*...*/ );
void draw( Square const&, /*...*/ );


void drawAllShapes( std::vector<std::unique_ptr<ShapeConcept>> const& shapes )
{
   for( auto const& shape : shapes )
   {
      shape->draw();
   }
}


int main()
{
   using Shapes = std::vector<std::unique_ptr<ShapeConcept>>;

   // Creating some shapes
   Shapes shapes;
   shapes.emplace_back( std::make_unique<ShapeModel<Circle>>{ 2.0 } );
   shapes.emplace_back( std::make_unique<ShapeModel<Square>>{ 1.5 } );
   shapes.emplace_back( std::make_unique<ShapeModel<Circle>>{ 4.2 } );

   // Drawing all shapes
   drawAllShapes( shapes );
}
```

A Type-Erased Solution

```cpp
struct ShapeConcept
{
   virtual ~ShapeConcept() {}

   virtual void serialize( /*...*/ ) const = 0;
   virtual void draw( /*...*/ ) const = 0;
   // ...
};

template< typename T >
struct ShapeModel : ShapeConcept
{
   ShapeModel( T&& value )
      : object{ std::forward<T>(value) }
   {}

   // ...

   void serialize( /*...*/ ) const override
   {
      serialize( object, /*...*/ );
   }

   void draw( /*...*/ ) const override
   {
      draw( object, /*...*/ );
   }

   T object;
};
```

A Type-Erased Solution

```
class Shape
{
 private:
   struct ShapeConcept
   {
      virtual ~ShapeConcept() {}

      virtual void serialize( /*...*/ ) const = 0;
      virtual void draw( /*...*/ ) const = 0;
      // ...
   };

   template< typename T >
   struct ShapeModel : ShapeConcept
   {
      ShapeModel( T&& value )
         : object{ std::forward<T>(value) }
      {}

      // ...

      void serialize( /*...*/ ) const override
      {
         serialize( object, /*...*/ );
      }

      void draw( /*...*/ ) const override
      {
         draw( object, /*...*/ );
      }

      T object;
   };
```

A Type-Erased Solution

```
      }

      T object;
   };

   std::unique_ptr<ShapeConcept> pimpl;

 public:
   template< typename T >
   Shape( T const& x )
      : pimpl{ new ShapeModel<T>( x ) }
   {}

   // Special member functions
   Shape( Shape const& s );
   Shape( Shape&& s );
   Shape& operator=( Shape const& s );
   Shape& operator=( Shape&& s );

   // ...
};
```

The Bridge Design Pattern

A templated constructor, creating a bridge

A Type-Erased Solution

```
      }

      T object;
   };

   friend void serialize( Shape const& shape, /*...*/ )
   {
      shape.pimpl->serialize( /*...*/ );
   }

   friend void draw( Shape const& shape, /*...*/ )
   {
      shape.pimpl->draw( /*...*/ );
   }

   std::unique_ptr<ShapeConcept> pimpl;

 public:
   template< typename T >
   Shape( T const& x )
      : pimpl{ new ShapeModel<T>( x ) }
   {}

   // Special member functions
   Shape( Shape const& s );
   Shape& operator=( Shape const& s );
   Shape( Shape&& s ) = default;
   Shape& operator=( Shape&& s ) = default;

   // ...
};
```

Despite being defined inside the class definition, these `friend` functions are free functions and injected into the surrounding namespace.

A Type-Erased Solution

```
      }

      T object;
   };

   friend void serialize( Shape const& shape, /*...*/ )
   {
      shape.pimpl->serialize( /*...*/ );
   }

   friend void draw( Shape const& shape, /*...*/ )
   {
      shape.pimpl->draw( /*...*/ );
   }

   std::unique_ptr<ShapeConcept> pimpl;

 public:
   template< typename T >
   Shape( T const& x )
      : pimpl{ new ShapeModel<T>( x ) }
   {}

   // Special member functions
   Shape( Shape const& s );
   Shape& operator=( Shape const& s );
   Shape( Shape&& s ) = default;
   Shape& operator=( Shape&& s ) = default;

   // ...
};
```

A Type-Erased Solution

```
class Shape
{
 private:
   struct ShapeConcept
   {
      virtual ~ShapeConcept() {}

      virtual void serialize( /*...*/ ) const = 0;
      virtual void draw( /*...*/ ) const = 0;
      // ...
   };

   template< typename T >
   struct ShapeModel : ShapeConcept
   {
      ShapeModel( T&& value )
         : object{ std::forward<T>(value) }
      {}

      // ...

      void serialize( /*...*/ ) const override
      {
         serialize( object, /*...*/ );
      }

      void draw( /*...*/ ) const override
      {
         draw( object, /*...*/ );
      }

      T object;
```

A Type-Erased Solution

```
class Shape
{
 private:
   struct ShapeConcept
   {
      virtual ~ShapeConcept() {}

      virtual void serialize( /*...*/ ) const = 0;
      virtual void draw( /*...*/ ) const = 0;
      virtual std::unique_ptr<ShapeConcept> clone() const = 0;
   };

   template< typename T >
   struct ShapeModel : ShapeConcept
   {
      ShapeModel( T&& value )
         : object{ std::forward<T>(value) }
      {}

      std::unique_ptr<ShapeConcept> clone() const override
      {
         return std::make_unique<ShapeModel>(*this);
      }

      void serialize( /*...*/ ) const override
      {
         serialize( object, /*...*/ );
      }

      void draw( /*...*/ ) const override
      {
         draw( object, /*...*/ );
```

The Prototype Design Pattern

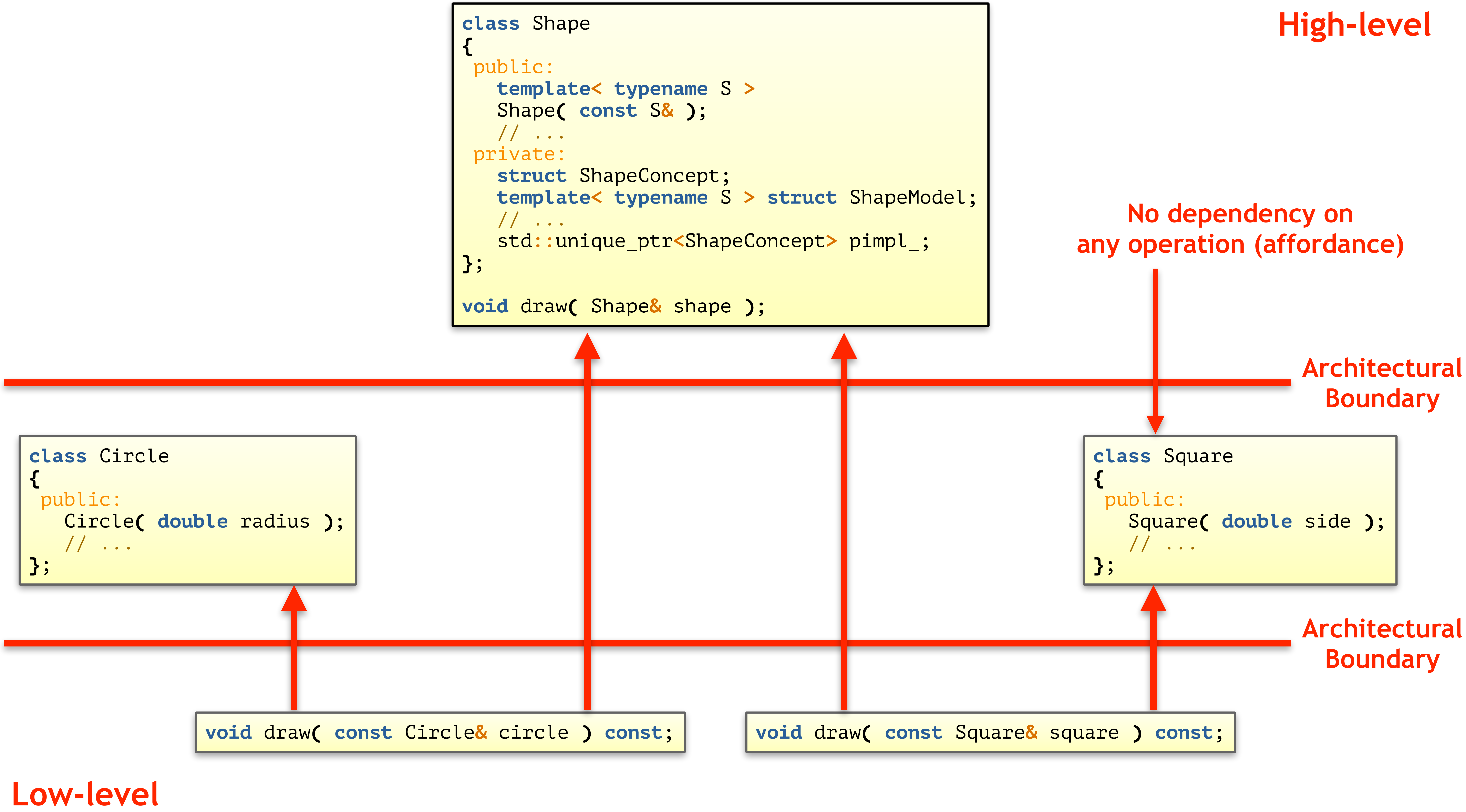
A Type-Erased Solution

```
};


void serialize( Circle const&, /*...*/ );
void draw( Circle const&, /*...*/ );

void translate( Square const&, /*...*/ );
void draw( Square const&, /*...*/ );


void drawAllShapes( std::vector<Shape> const& shapes )
{
   for( auto const& shape : shapes )
   {
      draw( shape );
   }
}


int main()
{
   using Shapes = std::vector<Shape>;

   // Creating some shapes
   Shapes shapes;
   shapes.emplace_back( Circle{ 2.0 } );
   shapes.emplace_back( Square{ 1.5 } );
   shapes.emplace_back( Circle{ 4.2 } );

   // Drawing all shapes
   drawAllShapes( shapes );
```

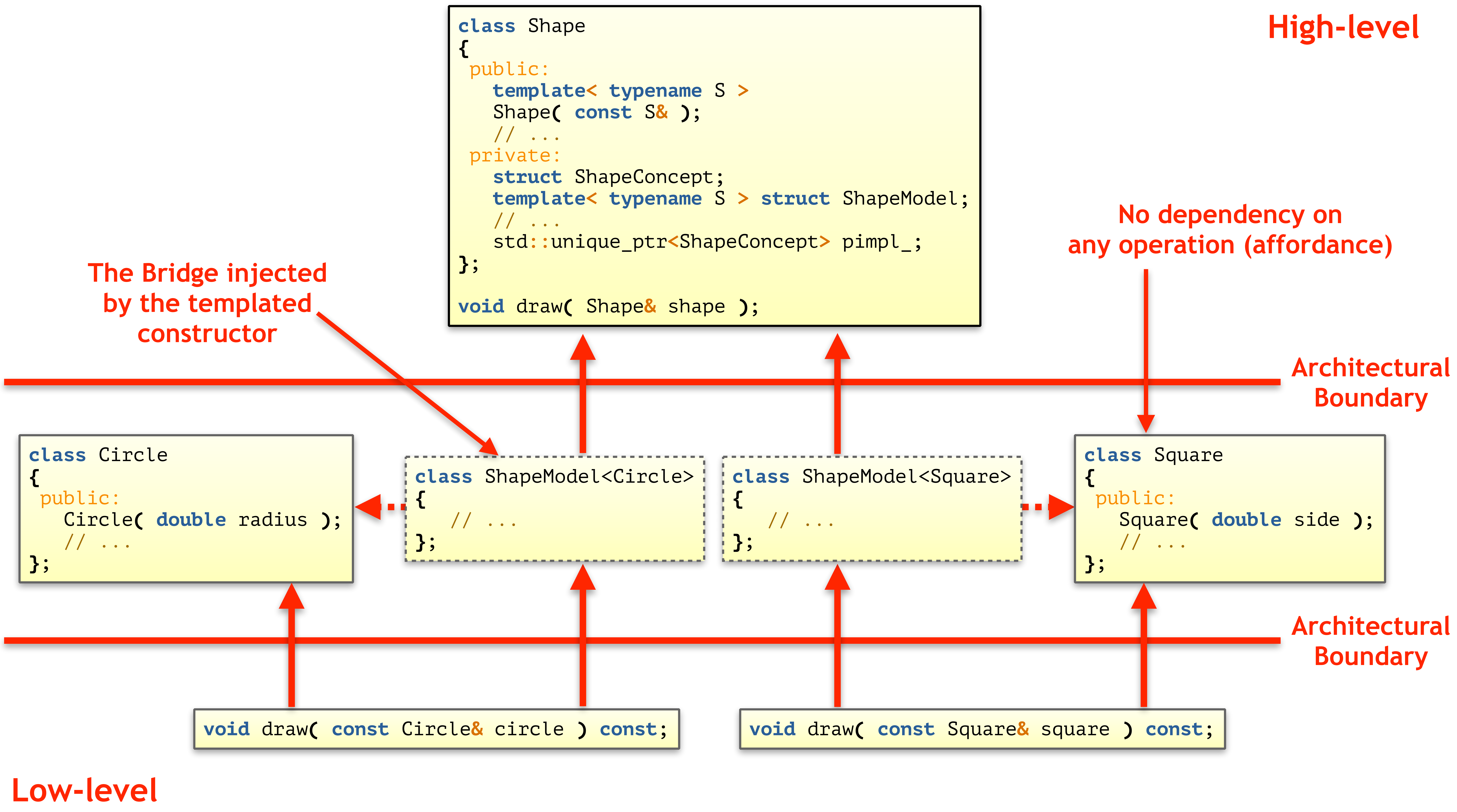
A Type-Erased Solution

```
void draw( Circle const&, /*...*/ );

void translate( Square const&, /*...*/ );
void draw( Square const&, /*...*/ );


void drawAllShapes( std::vector<Shape> const& shapes )
{
   for( auto const& shape : shapes )
   {
      draw( shape );
   }
}


int main()
{
   using Shapes = std::vector<Shape>;

   // Creating some shapes
   Shapes shapes;
   shapes.emplace_back( Circle{ 2.0 } );
   shapes.emplace_back( Square{ 1.5 } );
   shapes.emplace_back( Circle{ 4.2 } );

   // Drawing all shapes
   drawAllShapes( shapes );
}
```

A Type-Erased Solution — Design Analysis



A Type-Erased Solution — Design Analysis



Type Erasure — Motivation

https://twitter.com/ericniebler/status/1274031123522220033

Eric Niebler #BLM
@ericniebler

If I could go back in time and had the power to change C++, rather than adding virtual functions, I would add language support for type erasure and concepts. Define a single-type concept, automatically generate a type-erasing wrapper for it.

7:27 PM · Jun 19, 2020 · Twitter for Android

6 Retweets **2** Quote Tweets **125** Likes

Eric Niebler #BLM @ericniebler · Jun 20
Replying to @ericniebler
This got more likes than I expected, and not one person saying "but but but my elaborate class hierarchies...." Huh.

4 15

A Type-Erased Solution — Summary

Amazing job! We have used Type Erasure to …

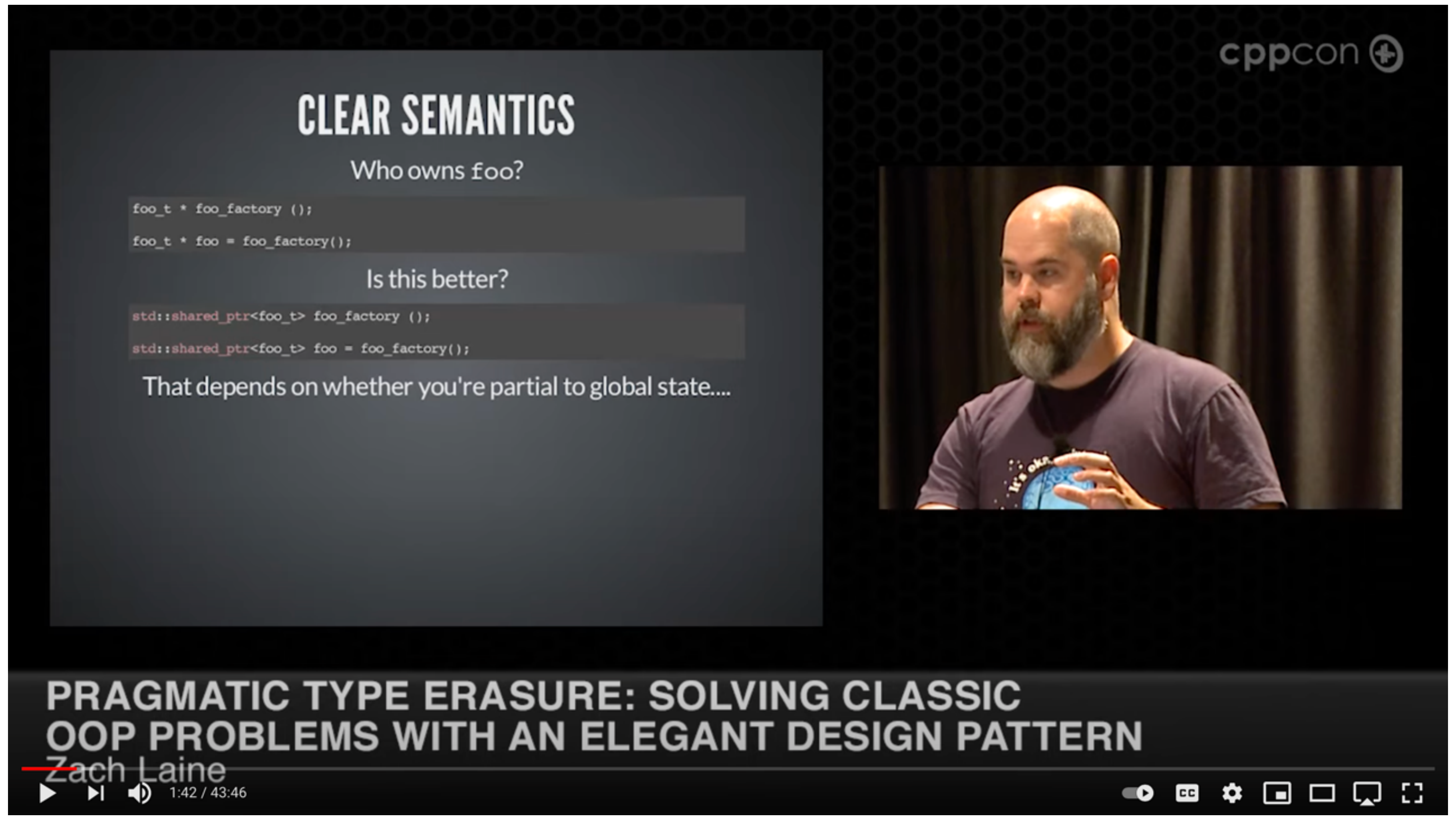
- … extract implementation details (SRP);
- … create the opportunity for easy extension (OCP);
- … separate interfaces (ISP);
- … reduce duplication (DRY);
- … remove all dependencies to operations (affordances);
- … remove all inheritance hierarchies;
- … remove all pointers;
- … remove all manual dynamic allocations;
- … remove all manual lifetime management;
- … improve performance.

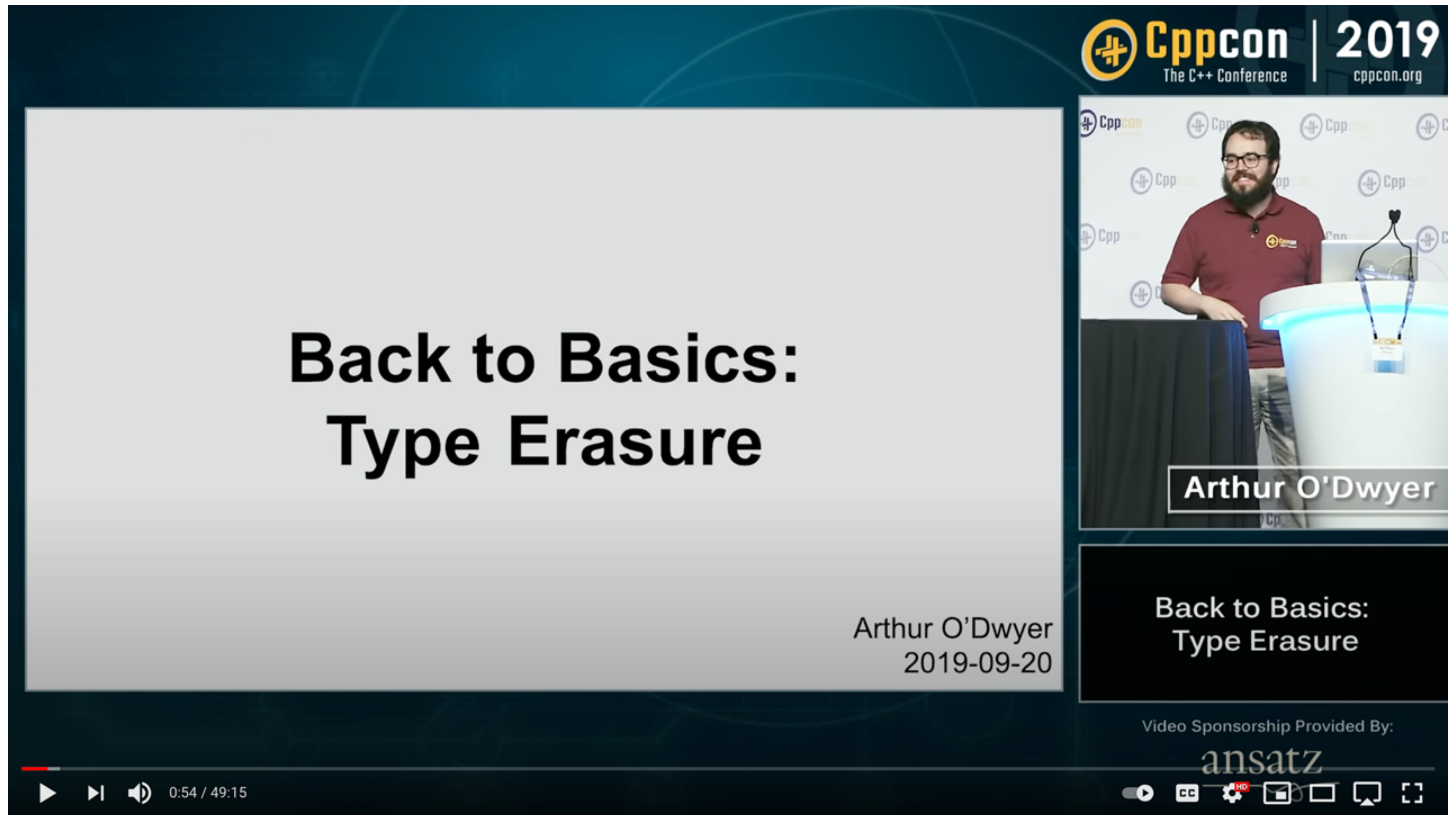
Type Erasure — Performance Optimization

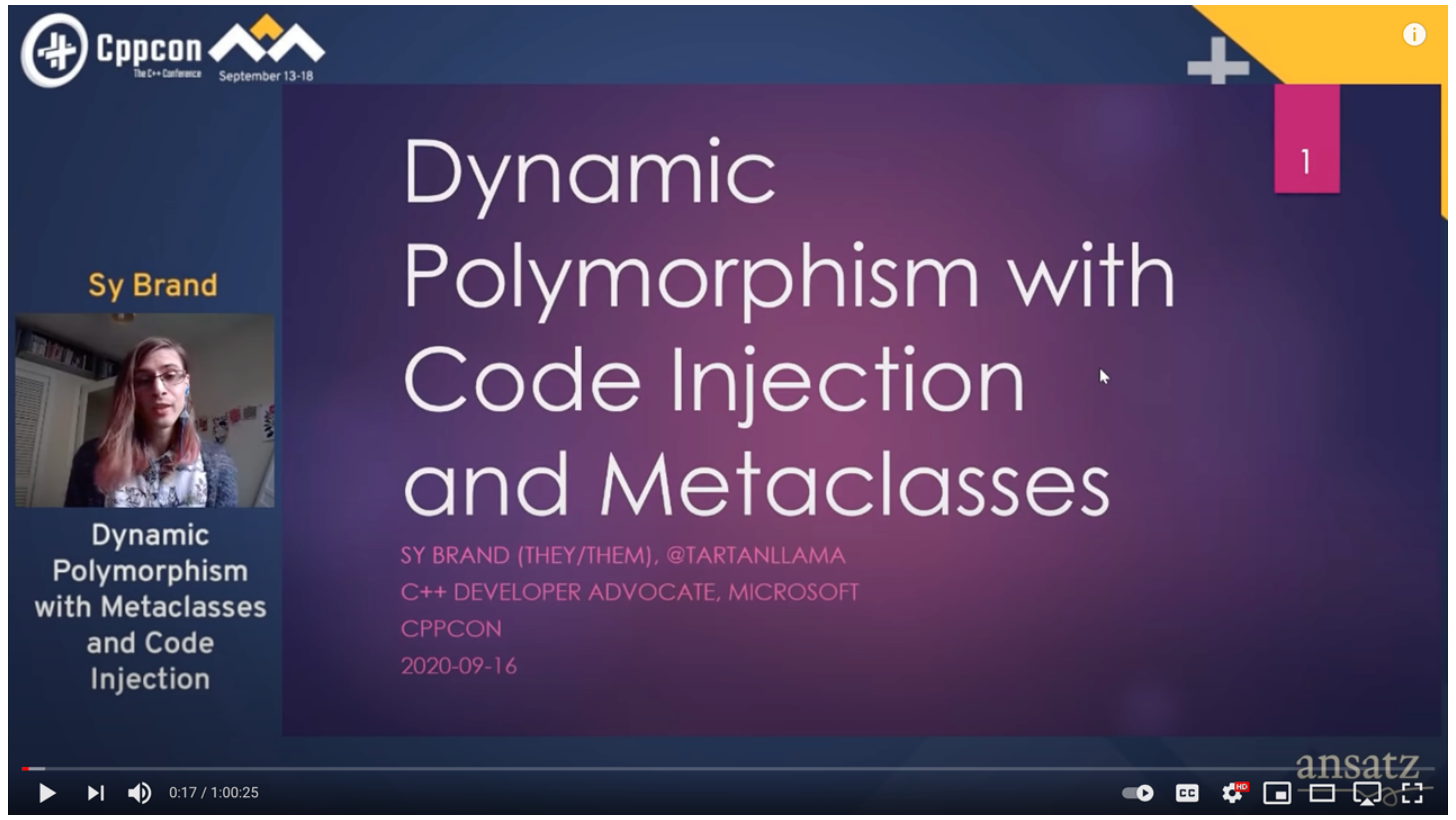
Strategy

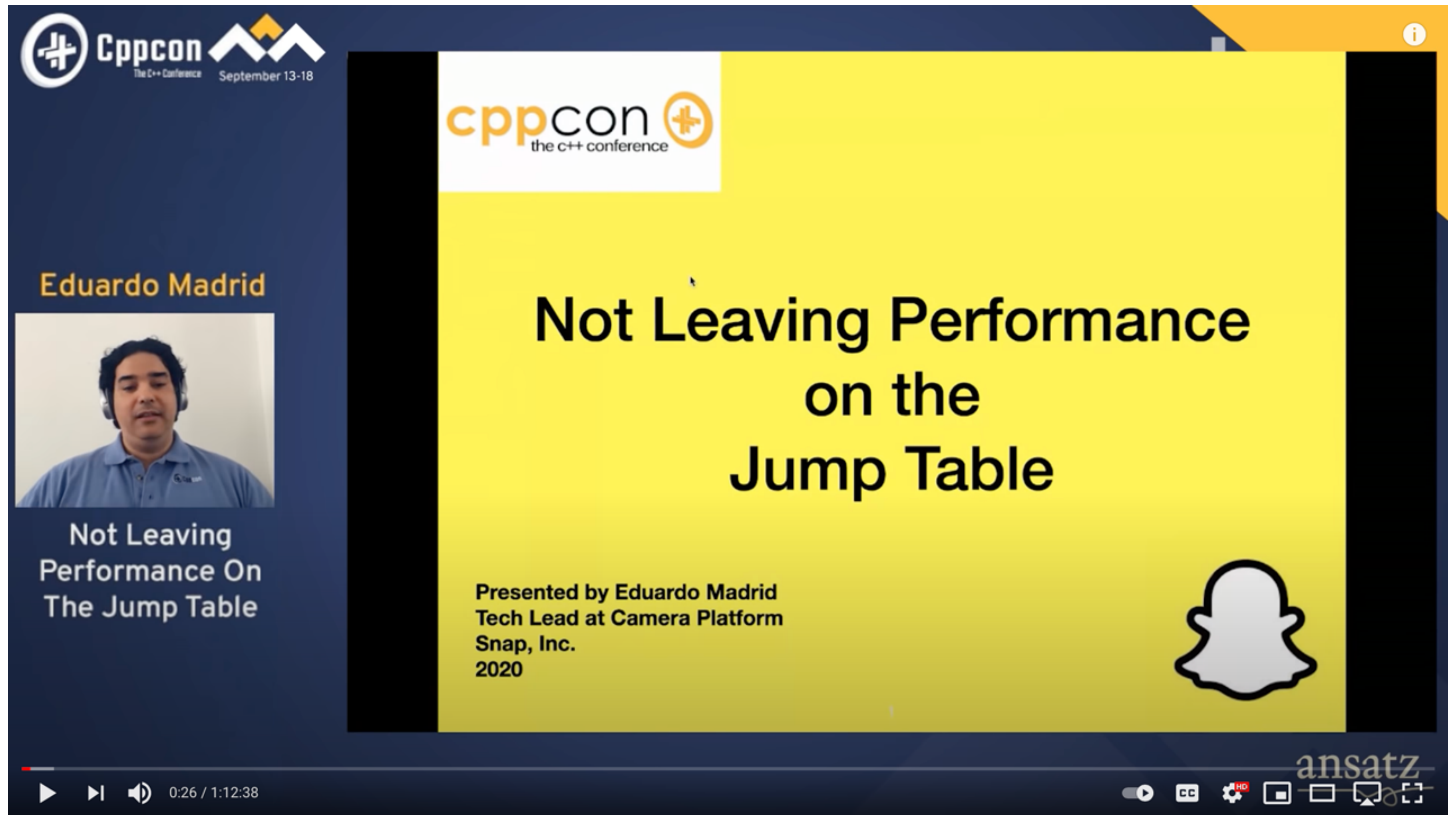
```
template< typename StoragePolicy >
class Shape
{
 private:
   struct ShapeConcept;
   template< typename S > struct ShapeModel;
   // ...

 public:
   template< typename T >
   Shape( T const& shape );
   // ...
};
```

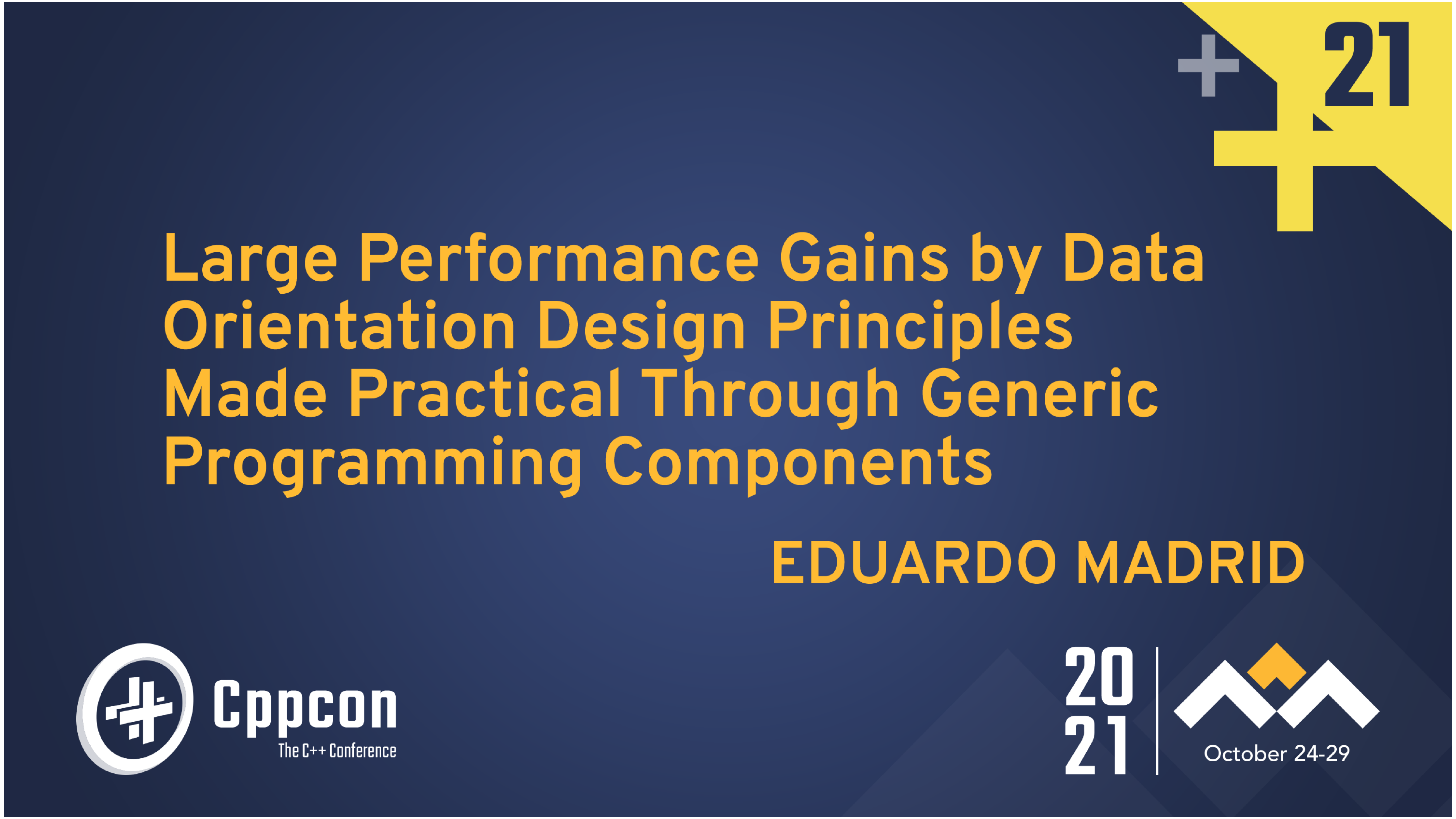
Type Erasure — Performance Optimization











Friday, October 29th, 1:30pm MDT

Libraries

- Zoo (https://github.com/thecppzoo/zoo)
- Dyno (https://github.com/ldionne/dyno)
- Boost Type Erasure (https://www.boost.org)
- …

Summary

Type Erasure is …

- … a **templated constructor** plus …
- … a completely **non-virtual interface;**
- … **External Polymorphism + Bridge + Prototype;**
- … one of the most interesting **design patterns** today.

Type Erasure …

- … significantly reduces **dependencies**;
- … enables **value semantics**;
- … improves **performance**;
- … improves **readability** and **comprehensibility**;
- … eases **maintenance;**
- … is for good reason the default choice for dynamic polymorphism in many other languages.

Breaking Dependencies:

Type Erasure - A Design Analysis

KLAUS IGLBERGER

Cppcon
The C++ Conference

2021
October 24-29