Polymorphism != Virtual

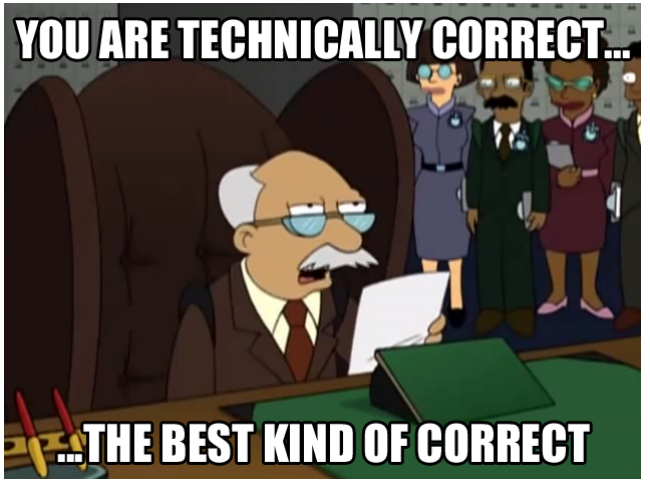
Flexible Runtime Polymorphism Without Inheritance

John R. Bandela, MD

What is polymorphism

What is polymorphism

- "Many Forms"


YOU ARE TECHNICALLY CORRECT...
...THE BEST KIND OF CORRECT

What is polymorphism?

What is polymorphism?

Providing a single interface to entities of different types

What is polymorphism?

Providing a single interface to entities of different types

- Bjarne Stroustrup

Polymorphism predated OOP

Polymorphism predated OOP

A + B

Polymorphism predated OOP

A + B

- Integers

Polymorphism predated OOP

A + B

- Integers
- Reals

Polymorphism predated OOP

A + B

- Integers
- Reals
- Complex numbers

Polymorphism predated OOP

A + B

- Integers
- Reals
- Complex numbers
- Vectors

Polymorphism predated OOP

A + B

- Integers
- Reals
- Complex numbers
- Vectors
- Matrices

Types of polymorphism

Types of polymorphism

- Static polymorphism

Types of polymorphism

- Static polymorphism
- Dynamic polymorphism

Static polymorphism

Static polymorphism

Overloading

Dynamic polymorphism

Dynamic polymorphism

Virtual Functions

What about variant?

What about variant?

Variant

- Types - Closed set
- Operations - Open set

What about variant?

Variant

- Types - Closed set
- Operations - Open set

Polymorphism in this talk

- Types - Open set
- Operations - Closed set

Motivating example

Motivating example

Shape

Motivating example

Shape

- Draw

Motivating example

Shape

- Draw
- Get Bounding Box

Motivating example

Shape

- Draw
- Get Bounding Box
- Translate

Motivating example

Shape

- Draw
- Get Bounding Box
- Translate
- Rotate

Overloading

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- Determines at compile time which function to call based on parameters

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- Many, many rules, but in general it just works

Overloading

- Determines at compile time which function to call based on parameters
- Many, many rules, but in general it just works
- No runtime overhead

Overloading example

```
class circle{
public:
  void draw() const;
  box get_bounding_box() const;
  void translate(double x, double y);
  void rotate(double degrees);

};
```

Overloading example

```
class box{
public:
  point upper_left()const;
  void set_upper_left(point);
  point lower_right()const;
  void set_lower_right(point);
  bool overlaps(const box&)const;

};
```

Overloading example

```
// Draw only if the shape will be visible.
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = s.get_bounding_box();
  if(viewport.overlaps(bounding_box)) s.draw();
}
```

Overloading example

```
// Move and rotate
template<typename Shape>
void spin(const Shape& s){
  s.translate(4,2);
  s.rotate(45);
}
```

How do we use this

```
cirlce c{...};
spin(c);
smart_draw(c,viewport);
```

What about box

```
circle c;
smart_draw(c, viewport);
```

What about box

```
circle c;
smart_draw(c, viewport);
```

What about box

```
box b;
smart_draw(b,viewport);
```

What about box

```
box b;
smart_draw(b,viewport);
```

What to do

Write a facade?

What to do

Write a facade?

Use overloaded customization points

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```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = s.get_bounding_box();
  if(viewport.overlaps(bounding_box)) s.draw();
}
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Use overloaded customization points

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template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = s.get_bounding_box();
  if(viewport.overlaps(bounding_box)) s.draw();
}
```

Use overloaded customization points

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = get_bounding_box(s);
  if(viewport.overlaps(bounding_box)) draw(s);
}
```

Use overloaded customization points

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = get_bounding_box(s);
  if(viewport.overlaps(bounding_box)) draw(s);
}
```

Provide default implementation

```
template<typename Shape>
void draw(const Shape& s){
 s.draw();
}
```

Use overloaded customization points

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = get_bounding_box(s);
  if(viewport.overlaps(bounding_box)) draw(s);
}
```

Provide default implementation

```
template<typename Shape>
void draw(const Shape& s){
 s.draw();
}
```

Provide box implementation

```
void draw(const box& b){
// Draw box.
}
```

Smart Draw

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = get_bounding_box(s);
  if(viewport.overlaps(bounding_box)) draw(x);
}
```

Spin

```
// Move and rotate
template<typename Shape>
void spin(const Shape& s){
  translate(s,4,2);
  rotate(s,45);
}
```

Use

```
cirlce c{...};
spin(c);
smart_draw(c,viewport);
```

Use

```
cirlce c{...};
spin(c);
smart_draw(c,viewport);
```

```
box b{...};
spin(b);
smart_draw(b,viewport);
```

Value semantics

```
circle c1;
```

Value semantics

```
circle c1;
```

```
circle c2 = c1;
```

Value semantics

```
circle c1;
```

```
circle c2 = c1;
```

```
spin(c1);
```

Value semantics

```
circle c1;
```

```
circle c2 = c1;
```

```
spin(c1);
```

```
smart_draw(c1);
smart_draw(c2);
```

Low Coupling

Low Coupling

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = get_bounding_box(s);
  if(viewport.overlaps(bounding_box)) draw(x);
}
```

Low Coupling

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = get_bounding_box(s);
  if(viewport.overlaps(bounding_box)) draw(x);
}
```

What operations does this depend on?

Low Coupling

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = get_bounding_box(s);
  if(viewport.overlaps(bounding_box)) draw(x);
}
```

What operations does this depend on?

- Get Bounding Box
- Draw

PPP

PPP

Purchasing Power Parity?

PPP

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Parent's Polymorphic Principles (PPP)

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- The requirement of a polymorphic type, by definition, comes from its use

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- The requirement of a polymorphic type, by definition, comes from its use
- There are no polymorphic types, only a polymorphic use of similar types

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- The requirement of a polymorphic type, by definition, comes from its use
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From "Inheritance is the base class of evil" by Sean Parent

PPP

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = get_bounding_box(s);
  if(viewport.overlaps(bounding_box)) draw(x);
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PPP

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = get_bounding_box(s);
  if(viewport.overlaps(bounding_box)) draw(x);
}
```

What has static polymorphism ever done for us?

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- ☑ Low boilerplate

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- ☑ Low coupling
- ☑ PPP
- ☑ Performance

What has static polymorphism ever done for us?

- ✅ Low boilerplate
- ✅ Easy adaptation of existing class
- ✅ Value semantics
- ✅ Low coupling
- ✅ PPP
- ✅ Performance
  - Obviously, performance. I mean, performance goes without saying.

Why don't we just stop now?

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- ✕ Requires everything to be a template and thus live in headers

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
```

Why don't we just stop now?

- ✕ Requires everything to be a template and thus live in headers

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
```

- ✕ Can't store in runtime containers

```
vector<???> shapes;
shapes.push_back(circle{});
shapes.push_back(box{});
```

Dynamic polymorphism - virtual

Dynamic polymorphism - virtual

Interface

Dynamic polymorphism - virtual

Interface

```
struct shape{
```

Dynamic polymorphism - virtual

Interface

```
struct shape{
```

```
  virtual void draw() const = 0;
```

Dynamic polymorphism - virtual

Interface

```
struct shape{

  virtual void draw() const = 0;

  virtual box get_bounding_box() const = 0;
```

Dynamic polymorphism - virtual

Interface

```
struct shape{

  virtual void draw() const = 0;

  virtual box get_bounding_box() const = 0;

  virtual void translate(double x, double y) = 0;
```

Dynamic polymorphism - virtual

Interface

```
struct shape{

  virtual void draw() const = 0;

  virtual box get_bounding_box() const = 0;

  virtual void translate(double x, double y) = 0;

  virtual void rotate(double degrees) = 0;
};
```

Don't forget the virtual destructor!

```
struct shape{
  virtual void draw() const = 0;
  virtual box get_bounding_box() const = 0;
  virtual void translate(double x, double y) = 0;
  virtual void rotate(double degrees) = 0;
  virtual ~shape(){}
};
```

Circle

```
class circle:public shape{
public:
  void draw() const override;
  box get_bounding_box() const override;
  void translate(double x, double y) override;
  void rotate(double degrees) override;
};
```

Smart Draw

```
void smart_draw(const shape& s, const box& viewport){
  auto bounding_box = s.get_bounding_box();
  if(viewport.overlaps(bounding_box)) s.draw();
}
```

Smart Draw

```
void smart_draw(const shape& s, const box& viewport){
  auto bounding_box = s.get_bounding_box();
  if(viewport.overlaps(bounding_box)) s.draw();
}
```

☑ No longer a template

Smart Draw

```
void smart_draw(const shape& s, const box& viewport){
  auto bounding_box = s.get_bounding_box();
  if(viewport.overlaps(bounding_box)) s.draw();
}
```

Smart Draw

```
void smart_draw(const shape& s, const box& viewport){
  auto bounding_box = s.get_bounding_box();
  if(viewport.overlaps(bounding_box)) s.draw();
}
```

❌ Increased coupling

Splitting Shape

```
struct shape{
  virtual void draw() const = 0;
  virtual box get_bounding_box() const = 0;
  virtual void translate(double x, double y) = 0;
  virtual void rotate(double degrees) = 0;
  virtual ~shape(){}
};
```

Splitting Shape

```
struct shape{
   virtual void draw() const = 0;
   virtual box get_bounding_box() const = 0;
  virtual void translate(double x, double y) = 0;
  virtual void rotate(double degrees) = 0;
  virtual ~shape(){}
};
```

Splitting Shape

```
struct drawing_interface{
  virtual void draw() const = 0;
  virtual box get_bounding_box() const = 0;
  virtual ~drawing_interface(){}
};
```

Splitting Shape

```
struct drawing_interface{
  virtual void draw() const = 0;
  virtual box get_bounding_box() const = 0;
  virtual ~drawing_interface(){}
};
```

```
struct transforming_interface{
  virtual void translate(double x, double y) = 0;
  virtual void rotate(double degrees) = 0;
  virtual ~transforming_interface(){}
};
```

Splitting Shape

```
struct drawing_interface{
  virtual void draw() const = 0;
  virtual box get_bounding_box() const = 0;
  virtual ~drawing_interface(){}
};
```

```
struct transforming_interface{
  virtual void translate(double x, double y) = 0;
  virtual void rotate(double degrees) = 0;
  virtual ~transforming_interface(){}
};
```

```
struct shape: drawing_interface, transforming_interface{};
```

Smart Draw

```
void smart_draw(const drawing_interface& s, const box& viewport){
  auto bounding_box = s.get_bounding_box();
  if(viewport.overlaps(bounding_box)) s.draw();
}
```

Spin

```
void spin(const transforming_interface& s){
  s.translate(4,2);
  s.rotate(45);
}
```

Use

```
std::vector<std::unique_ptr<shape>> shapes;

for(auto& s:shapes){
  spin(*s);
  smart_draw(*s,viewport);

}
```

Use

```
  std::vector<std::unique_ptr<shape>> shapes;

for(auto& s:shapes){
  spin(*s);
  smart_draw(*s,viewport);

}
```

Use

```
  std::vector<std::unique_ptr<shape>> shapes;

for(auto& s:shapes){
  spin(*s);
  smart_draw(*s,viewport);

}
```

- [x] Able to be stored in runtime containers

Did we do it?

Did we do it?

- [x] Able to be used in non-template functions.

Did we do it?

- [x] Able to be used in non-template functions.
- [x] Able to be stored in runtime containers


What did it cost?
Everything.

Costs

Costs

- ✕ Low boilerplate - Need inheritance hierarchy

Costs

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- ✕ Easy adaptation of existing class - Have to inherit from base

Costs

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- ✕ Value semantics - Pointer semantics

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- ☑ ✕ Low coupling - Only if we are careful/lucky

Costs

- ✕ Low boilerplate - Need inheritance hierarchy
- ✕ Easy adaptation of existing class - Have to inherit from base
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- ✕ PPP - Polymorphic types have to inherit from base

Costs

- ✕ Low boilerplate - Need inheritance hierarchy
- ✕ Easy adaptation of existing class - Have to inherit from base
- ✕ Value semantics - Pointer semantics
- ☑ ✕ Low coupling - Only if we are careful/lucky
- ✕ PPP - Polymorphic types have to inherit from base
- ☑ ✕ Performance - Inherent overhead in runtime dispatch

What would we like

What would we like

- ☑ Low boilerplate

What would we like

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What would we like

- ✅ Low boilerplate
- ✅ Easy adaptation of existing class
- ✅ Value semantics

What would we like

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- ☑ Easy adaptation of existing class
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What would we like

- ☑ Low boilerplate
- ☑ Easy adaptation of existing class
- ☑ Value semantics
- ☑ Low coupling
- ☑ PPP
- ☑ ✕ Performance - Inherent overhead in runtime dispatch
- ☑ Able to be used in non-template functions.

What would we like

- ☑ Low boilerplate
- ☑ Easy adaptation of existing class
- ☑ Value semantics
- ☑ Low coupling
- ☑ PPP
- ☑ ✕ Performance - Inherent overhead in runtime dispatch
- ☑ Able to be used in non-template functions.
- ☑ Able to be stored in runtime containers

Constraints

Constraints

- No MACROS

Constraints

- No MACROS
- Standard C++17

There is already a solution in the C++11 stdlib

History lesson

History lesson

1998

History lesson

1998

```
struct CommandInterface{virtual void execute() = 0;}
```

History lesson

1998

```
struct CommandInterface{virtual void execute() = 0;}
```

```
std::vector<CommandInterface*> commands;
```

History lesson

1998

```
struct CommandInterface{virtual void execute() = 0;}
```

```
std::vector<CommandInterface*> commands;
```

```
for(int i = 0; i < commands.size(); ++i)commands[i]->execute();
```

History lesson

1998

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struct CommandInterface{virtual void execute() = 0;}
```

```
std::vector<CommandInterface*> commands;
```

```
for(int i = 0; i < commands.size(); ++i)commands[i]->execute();
```

2011

History lesson

1998

```
struct CommandInterface{virtual void execute() = 0;}
```

```
std::vector<CommandInterface*> commands;
```

```
for(int i = 0; i < commands.size(); ++i)commands[i]->execute();
```

2011

```
std::vector<std::function<void()>> commands;
```

History lesson

1998

```
struct CommandInterface{virtual void execute() = 0;}
```

```
std::vector<CommandInterface*> commands;
```

```
for(int i = 0; i < commands.size(); ++i)commands[i]->execute();
```

2011

```
std::vector<std::function<void()>> commands;
```

```
for(auto& command:commands)command();
```

std::function

std::function

- ☑ Low boilerplate

std::function

- ✅ Low boilerplate
- ✅ Easy adaptation of existing class

std::function

- ✅ Low boilerplate
- ✅ Easy adaptation of existing class
- ✅ Value semantics

std::function

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std::function

- ✅ Low boilerplate
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- ✅ Low coupling
- ✅ PPP
- ✅ ❌ Performance - Inherent overhead in runtime dispatch
- ✅ Able to be used in non-template functions.
- ✅ Able to be stored in runtime containers

std::function

```
std::function<void()> f;
```

std::function

```
std::function<void()> f;
```

Function type

- Has the information on the parameters and return type of the function

std::function

```
std::function<void()> f;
```

Function type

- Has the information on the parameters and return type of the function
- We, can examine the parameters and return type, using partial template specialization.

function_ref

function_ref

- For passing to functions, sometimes you just need a reference type, instead of an owning type

function_ref

- For passing to functions, sometimes you just need a reference type, instead of an owning type
- Ongoing work on standardizing, but you can find open source implementations

Are we done?

Are we done?

- ✕ Only supports a single operation - function call operator

How to name operations

How to name operations

Function name

```
void rotate(double degrees);
```

How to name operations

Function name

```
void rotate(double degrees);
```

✕ C++17 cannot metaprogram names, except for macros

How to name operations

Function name

```
void rotate(double degrees);
```

✕ C++17 cannot metaprogram names, except for macros

Type

How to name operations

Function name

```
void rotate(double degrees);
```

✕ C++17 cannot metaprogram names, except for macros

Type

```
struct rotate{};
using rotate_signature = void(rotate,double);
```

How to name operations

Function name

```
void rotate(double degrees);
```

✕ C++17 cannot metaprogram names, except for macros

Type

```
struct rotate{};
using rotate_signature = void(rotate,double);
```

☑ C++17 metaprograms types like a boss

Polymorphic

Polymorphic

https://github.com/google/cpp-from-the-sky-down/blob/master/metaprogrammed_polymorphism/polymorphic.hpp

Three important things to say about polymorphic

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This is not an officially supported Google product.

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Polymorphic combines aspects of virtual and overloading

Polymorphic combines aspects of virtual and overloading

- Specify interface
  - Virtual

Polymorphic combines aspects of virtual and overloading

- Specify interface
  - Virtual
- Use overloading to connect a type to an operation
  - `poly_extend` is used as the overloaded extension point

Specify Interface

Specify Interface

Virtual

```
struct transforming_interface{
  virtual void translate(double x, double y) = 0;
  virtual void rotate(double degrees) = 0;
};

void spin(transforming_interface& s);
```

Specify Interface

Virtual

```
struct transforming_interface{
  virtual void translate(double x, double y) = 0;
  virtual void rotate(double degrees) = 0;
};

void spin(transforming_interface& s);
```

Polymorphic

Specify Interface

Virtual

```
struct transforming_interface{
  virtual void translate(double x, double y) = 0;
  virtual void rotate(double degrees) = 0;
};

void spin(transforming_interface& s);
```

Polymorphic

```
struct translate{};
struct rotate{};

void spin(polymorphic::ref<void(translate,double x,double y),
                           void(rotate,double degrees)> s);
```

Use overloading to connect an interface to an operation

Overloading

```
template<typename Shape>
void translate(Shape& s, double x, double y){
 s.translate(x,y);
}

void translate(box& b, double x, double y){
// Translate box.
}
```

Use overloading to connect an interface to an operation

Overloading

```
template<typename Shape>
void translate(Shape& s, double x, double y){
 s.translate(x,y);
}

void translate(box& b, double x, double y){
// Translate box.
}
```

Polymorphic

Use overloading to connect an interface to an operation

Overloading

```
template<typename Shape>
void translate(Shape& s, double x, double y){
 s.translate(x,y);
}

void translate(box& b, double x, double y){
// Translate box.
}
```

Polymorphic

```
template<typename Shape>
void poly_extend(translate,Shape& s, double x, double y){
 s.translate(x,y);
}

void poly_extend(translate,box& b, double x, double y){
// Translate box.
}
```

Spin implementation

Spin implementation

Virtual

Spin implementation

Virtual

```
void spin(transforming_interface& s){
  s.translate(4,2);
  s.rotate(45);
}
```

Spin implementation

Virtual

```
void spin(transforming_interface& s){
  s.translate(4,2);
  s.rotate(45);
}
```

Polymorphic

Spin implementation

Virtual

```
void spin(transforming_interface& s){
  s.translate(4,2);
  s.rotate(45);
}
```

Polymorphic

```
void spin(polymorphic::ref<void(translate,double x,double y),
                           void(rotate,double degrees)> s){
  s.call<translate>(4,2);
  s.call<rotate>(45);
}
```

Using spin

```
class box{
public:
  point upper_left()const;
  void set_upper_left(point);
  point lower_right()const;
  void set_lower_right(point);
  bool overlaps(const box&)const;
};

class circle{
public:
  void draw() const;
  box get_bounding_box() const;
  void translate(double x, double y);
  void rotate(double degrees);
};
```

Using spin

```
class box{
public:
  point upper_left()const;
  void set_upper_left(point);
  point lower_right()const;
  void set_lower_right(point);
  bool overlaps(const box&)const;
};

class circle{
public:
  void draw() const;
  box get_bounding_box() const;
  void translate(double x, double y);
  void rotate(double degrees);
};
```

Same definitions we used with overload example

Using spin

```
class box{
public:
  point upper_left()const;
  void set_upper_left(point);
  point lower_right()const;
  void set_lower_right(point);
  bool overlaps(const box&)const;
};

class circle{
public:
  void draw() const;
  box get_bounding_box() const;
  void translate(double x, double y);
  void rotate(double degrees);
};
```

Same definitions we used with overload example

```
circle c;
box b;
spin(c);
spin(b);
```

Using spin

```
class box{
public:
  point upper_left()const;
  void set_upper_left(point);
  point lower_right()const;
  void set_lower_right(point);
  bool overlaps(const box&)const;
};

class circle{
public:
  void draw() const;
  box get_bounding_box() const;
  void translate(double x, double y);
  void rotate(double degrees);
};
```

Same definitions we used with overload example

```
circle c;
box b;
spin(c);
spin(b);
```

✅ There are no polymorphic types, only a polymorphic use of similar types

What about const?

What about const?

```
template<typename Shape>
void smart_draw(const Shape& s, const box& viewport){
  auto bounding_box = get_bounding_box(s);
  if(viewport.overlaps(bounding_box)) draw(x);
}
```

Smart Draw

Smart Draw

Virtual

Smart Draw

Virtual

```
struct drawing_interface{
  virtual void draw() const = 0;
  virtual box get_bounding_box() const = 0;
};

void smart_draw(const drawing_interface& s, const box& viewport){
  auto bounding_box = s.get_bounding_box();
  if(viewport.overlaps(bounding_box)) s.draw();
}
```

Smart Draw

Virtual

```
struct drawing_interface{
  virtual void draw() const = 0;
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};

void smart_draw(const drawing_interface& s, const box& viewport){
  auto bounding_box = s.get_bounding_box();
  if(viewport.overlaps(bounding_box)) s.draw();
}
```

Polymorphic

```
struct draw{};
struct get_bounding_box{};

void smart_draw(polymorphic::ref<void(draw)const,
                                 box(get_bounding_box)const>, const box& viewport){
  auto bounding_box = s.call<get_bounding_box>();
  if(viewport.overlaps(bounding_box)) s.call<draw>();
}
```

Const polymorphic::ref

```
polymorphic::ref<void(draw)const,
                 box(get_bounding_box)const>
```

Const polymorphic::ref

```
polymorphic::ref<void(draw)const,
                 box(get_bounding_box)const>
```

As long as all the function types in a polymorphic::ref are `const` qualified, it will bind to a const object.

Using smart_draw

```
circle c;
smart_draw(std::as_const(c),viewport);
```

Polymorphic object

Polymorphic object

```
using shape = polymorphic::object<
                void(draw)const,
                box(get_bounding_box)const,
                void(translate,double x,double y),
                void(rotate,double degrees)>;
```

Value Semantics

Value Semantics

```
shape s1{circle{}};
shape s2 = s1;
spin(s1);
smart_draw(s1,viewport);
smart_draw(s2,viewport);
```

Store in collection

```
std::vector<shape> shapes;
shapes.push_back(circle{});
shapes.push_back(box{});

for(auto& s:shapes) smart_draw(s,viewport);
```

Low coupling

With virtual, we had to carefully group our member functions to avoid coupling

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```
struct drawing_interface{
  virtual void draw() const = 0;
  virtual box get_bounding_box() const = 0;
  virtual ~drawing_interface(){}
};
struct transforming_interface{
  virtual void translate(double x, double y) = 0;
  virtual void rotate(double degrees) = 0;
  virtual ~transforming_interface(){}
};
struct shape: drawing_interface, transforming_interface{};
```

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  virtual void translate(double x, double y) = 0;
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  virtual ~transforming_interface(){}
};
struct shape: drawing_interface, transforming_interface{};
```

Polymorphic

- Does not matter how you group the function types.

Polymorphic conversions

Polymorphic conversions

```
void smart_draw(polymorphic::ref<void(draw)const,
                                 box(get_bounding_box)const> s, const box& viewport);
  auto bounding_box = s.call<get_bounding_box>();
  if(viewport.overlaps(bounding_box)) s.call<draw>();
}
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Polymorphic conversions

```
void smart_draw(polymorphic::ref<void(draw)const,
                                 box(get_bounding_box)const> s, const box& viewport);
  auto bounding_box = s.call<get_bounding_box>();
  if(viewport.overlaps(bounding_box)) s.call<draw>();
}
```

```
using shape1 = polymorphic::object<
                 void(draw)const,
                 box(get_bounding_box)const,
                 void(translate,double x,double y),
                 void(rotate,double degrees)>;
shape1 s1{circle{}};
smart_draw(s1,viewport);
```

Polymorphic conversions

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void smart_draw(polymorphic::ref<void(draw)const,
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```

```
using shape1 = polymorphic::object<
                 void(draw)const,
                 box(get_bounding_box)const,
                 void(translate,double x,double y),
                 void(rotate,double degrees)>;
shape1 s1{circle{}};
smart_draw(s1,viewport);
```

```
using shape2 = polymorphic::object<
                 box(get_bounding_box)const,
                 void(translate,double x,double y),
                 void(draw)const,
                 void(rotate,double degrees)>;
shape2 s2{circle{}};
smart_draw(s2,viewport);
```

Benchmarks

- Windows Laptop - i7-8550U
- Fill a vector with different types of polymorphic objects, and then time how long it takes to iterate and call a method on each item.

Type	Median Time (ns)
Non-Virtual	121
Virtual	532
std::function	539
Polymorphic Ref	515
Polymorphic Object	483

Size

- `sizeof(ref)` typically `3*sizeof(void*)`
- `sizeof(object)` typically `4*sizeof(void*)`

Final Assessment

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- ☑ Low boilerplate

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- ✅ Easy adaptation of existing class

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Show me the code?

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https://github.com/google/cpp-from-the-sky-down/blob/master/metaprogrammed_polymorphism/polymorphic.hpp

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247 lines, including comments and whitespace

VTable

- Use an array of function pointer
- Each position of the array, corresponds to a function type that is passed in
- There is a unique array for each type, and each sequence of polymorphic operations
- Each entry in the vtable, contains a trampoline function to jump to the appropriate overload

Trampoline Function

Trampoline Function

```
template <typename T, typename Signature> struct trampoline;
```

Trampoline Function

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    template <typename T, typename Signature> struct trampoline;
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```
template <typename T, typename Return, typename Method, typename... Parameters>
struct trampoline<T, Return(Method, Parameters...)> {
    static auto jump(void* t, Parameters... parameters) -> Return {
        return poly_extend(Method{}, *static_cast<T*>(t), parameters...);
    }
};
```

Trampoline Function

```
    template <typename T, typename Signature> struct trampoline;

template <typename T, typename Return, typename Method, typename... Parameters>
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};
```

Build vtable from trampoline functions

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```
template <typename T, typename... Signatures>
inline const vtable_fun vtable[] = {    reinterpret_cast<vtable_fun>(trampoline<T, Signatures>::jump)... };
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```

Calling the vtable

Calling the vtable

```
template <size_t I, typename Signature> struct vtable_caller;

template <size_t I, typename Method, typename Return, typename... Parameters>
struct vtable_caller<I, Return(Method, Parameters...)> {
    decltype(auto) operator()(const vtable_fun* vt, const std::uint8_t* permutation, Method, void* t,
        Parameters... parameters) const {
        return reinterpret_cast<ptr<Return(void*, Parameters...)>>(vt[permutation[I]])(
            t, parameters...);
    }
};
```

Calling the vtable

```
template <size_t I, typename Signature> struct vtable_caller;

template <size_t I, typename Method, typename Return, typename... Parameters>
struct vtable_caller<I, Return(Method, Parameters...)> {
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        Parameters... parameters) const {
        return reinterpret_cast<ptr<Return(void*, Parameters...)>>(vt[permutation[I]])(
            t, parameters...);
    }
};
```

Permutations

```
void smart_draw(polymorphic::ref<void(draw)const,
                                 box(get_bounding_box)const> s, const box& viewport);
  auto bounding_box = s.call<get_bounding_box>();
  if(viewport.overlaps(bounding_box)) s.call<draw>();
}
```

Permutations

```
void smart_draw(polymorphic::ref<void(draw)const,
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  auto bounding_box = s.call<get_bounding_box>();
  if(viewport.overlaps(bounding_box)) s.call<draw>();
}
```

```
using shape2 = polymorphic::object<
                 box(get_bounding_box)const,
                 void(translate,double x,double y),
                 void(draw)const,
                 void(rotate,double degrees)>;
```

Permutations

```
void smart_draw(polymorphic::ref<void(draw)const,
                                 box(get_bounding_box)const> s, const box& viewport);
  auto bounding_box = s.call<get_bounding_box>();
  if(viewport.overlaps(bounding_box)) s.call<draw>();
}
```

```
using shape2 = polymorphic::object<
                 box(get_bounding_box)const,
                 void(translate,double x,double y),
                 void(draw)const,
                 void(rotate,double degrees)>;
```

```
s.permutation_ = {2,0}
```

Ref Impl

```
template <typename Holder, typename Sequence, typename... Signatures>
    class ref_impl;

template <typename Holder, size_t... I, typename... Signatures>
    class ref_impl<Holder, std::index_sequence<I...>, Signatures...> {
```

Ref Impl

```
template <typename Holder, typename Sequence, typename... Signatures>
    class ref_impl;

template <typename Holder, size_t... I, typename... Signatures>
    class ref_impl<Holder, std::index_sequence<I...>, Signatures...> {
            const detail::vtable_fun* vptr_;
```

Ref Impl

```
template <typename Holder, typename Sequence, typename... Signatures>
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template <typename Holder, size_t... I, typename... Signatures>
    class ref_impl<Holder, std::index_sequence<I...>, Signatures...> {
            const detail::vtable_fun* vptr_;
             std::array<std::uint8_t, sizeof...(Signatures)> permutation_;
            Holder t_;
```

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    class ref_impl;

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    class ref_impl<Holder, std::index_sequence<I...>, Signatures...> {
            const detail::vtable_fun* vptr_;
            std::array<std::uint8_t, sizeof...(Signatures)> permutation_;
            Holder t_;
             static constexpr overload<vtable_caller<I, Signatures>...> call_vtable{};
```

Ref Impl

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    class ref_impl<Holder, std::index_sequence<I...>, Signatures...> {
            const detail::vtable_fun* vptr_;
            std::array<std::uint8_t, sizeof...(Signatures)> permutation_;
            Holder t_;
            static constexpr overload<vtable_caller<I, Signatures>...> call_vtable{};

            template <typename Method, typename... Parameters>
             decltype(auto) call(Parameters&&... parameters) const {
                return call_vtable(vptr_, permutation_.data(), Method{}, t_.get_ptr(),
                    std::forward<Parameters>(parameters)...);
            }
```

Ref Impl

```
template <typename Holder, typename Sequence, typename... Signatures>
    class ref_impl;

template <typename Holder, size_t... I, typename... Signatures>
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                    std::forward<Parameters>(parameters)...);
            }
```

Ref alias

```
template <typename... Signatures>
using ref = detail::ref_impl<
    detail::ptr_holder<std::conditional_t<
    std::conjunction_v<detail::is_const_signature<Signatures>...>,
    const void, void>>,
    std::make_index_sequence<sizeof...(Signatures)>, Signatures...>;
```

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template <typename... Signatures>
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    const void, void>>,
    std::make_index_sequence<sizeof...(Signatures)>, Signatures...>;
```

Object alias

```
template <typename... Signatures>
using object = detail::ref_impl<
    std::conditional_t<
    std::conjunction_v<detail::is_const_signature<Signatures>...>,
    detail::shared_ptr_holder, detail::value_holder >,
    std::make_index_sequence<sizeof...(Signatures)>, Signatures...>;
```

Object alias

```
template <typename... Signatures>
using object = detail::ref_impl<
    std::conditional_t<
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```

Polymorphic

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References

- Sean Parent - Inheritance is the base class of evil - https://www.youtube.com/watch?v=bIhUE5uUFOA
- Louis Dionne - CppCon 2017 - Runtime polymorphism: Back to basics - https://www.youtube.com/watch?v=gVGtNFg4ay0

https://github.com/google/cpp-from-the-sky-down/blob/master/metaprogrammed_polymorphism/polymorphic.hpp

P1521

Types as function names

- A proposal I am working on to allow types as function names

P1521

Types as function names

- A proposal I am working on to allow types as function names
- Universal function call syntax
- Extension methods
- Extension points
- Overload sets
- Forwarding proxies proxies
- Adding monadic bind to pre-existing monad types
- Making a monadic type automatically map/bind

P1521

```
template<typename Shape>
void poly_extend(translate,Shape& s, double x, double y){
 s.translate(x,y);
}
```

P1521

```
template<typename Shape>
void poly_extend(translate,Shape& s, double x, double y){
 s.translate(x,y);
}
```

```
template<typename Shape>
void translate.(Shape& s, double x, double y){
 s.translate(x,y);
}
```

P1521

```
void spin(polymorphic::ref<void(translate,double x,double y),
                           void(rotate,double degrees)> s){
  s.call<translate>(4,2);
  s.call<rotate>(45);
}
```

P1521

```
void spin(polymorphic::ref<void(translate,double x,double y),
                           void(rotate,double degrees)> s){
  s.call<translate>(4,2);
  s.call<rotate>(45);
}
```

```
void spin(polymorphic::ref<void(translate,double x,double y),
                           void(rotate,double degrees)> s){
  s.translate.(4,2);
  s.rotate.(45);
}
```