Beyond Objects

Understanding The Software We Write

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Polymorphism as Implementation

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Abstract

- Look at existing techniques for handling runtime polymorphism in C++.
  - Associated complex system of "patterns" that complicate the use of libraries.
- Develop an alternative approach to runtime polymorphism.
  - Hide polymorphic implementation inside objects that can be copied, assigned, compared for equality, stored in STL containers and used with STL algorithms.

Background

- Improve code through understanding
- Increasing use of generic programming
  - Prefer the term Concept-based programming
- Struggle with object-oriented vs. generic
- Often choice is runtime vs. compile-time
  - An artificial dichotomy

Promise of Concepts

- Algorithms Determine Type Requirements
- Requirements Cluster as Concepts
  - Most Appropriate Algorithm Selected by Concept Match
- Code is Reusable and Efficient
  - Write Algorithms Once

Combine OO and Generic Code

```
typedef std::pair<int, int> point;

class shape
{
    point center_m;

 public:
    shape(const point& center) : center_m(center) { }

    point where() const { return center_m; }
    void move(const point& to) { center_m = to; }

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

Combine OO and Generic Code

```
class circle : public shape
{
 public:
     int radius;

     circle(const point& center, int r) : shape(center), radius(r) { }

     void draw() const {
             std::cout << "circle(point(" << where().first << ", “
                       << where().second << "), “ << radius << ");“
                       << std::endl;
     }
};
```

Combine OO and Generic Code

```
class rectangle : public shape
{
 public:
    int width, height;

    rectangle(const point& center, int w, int h) :
            shape(center), width(w), height(h) { }

    void draw() const {
            std::cout << "rectangle(point(" << where().first << ", “
                     << where().second << "), “ << width << ", " << height
                     << ");" << std::endl;
    }
};
```

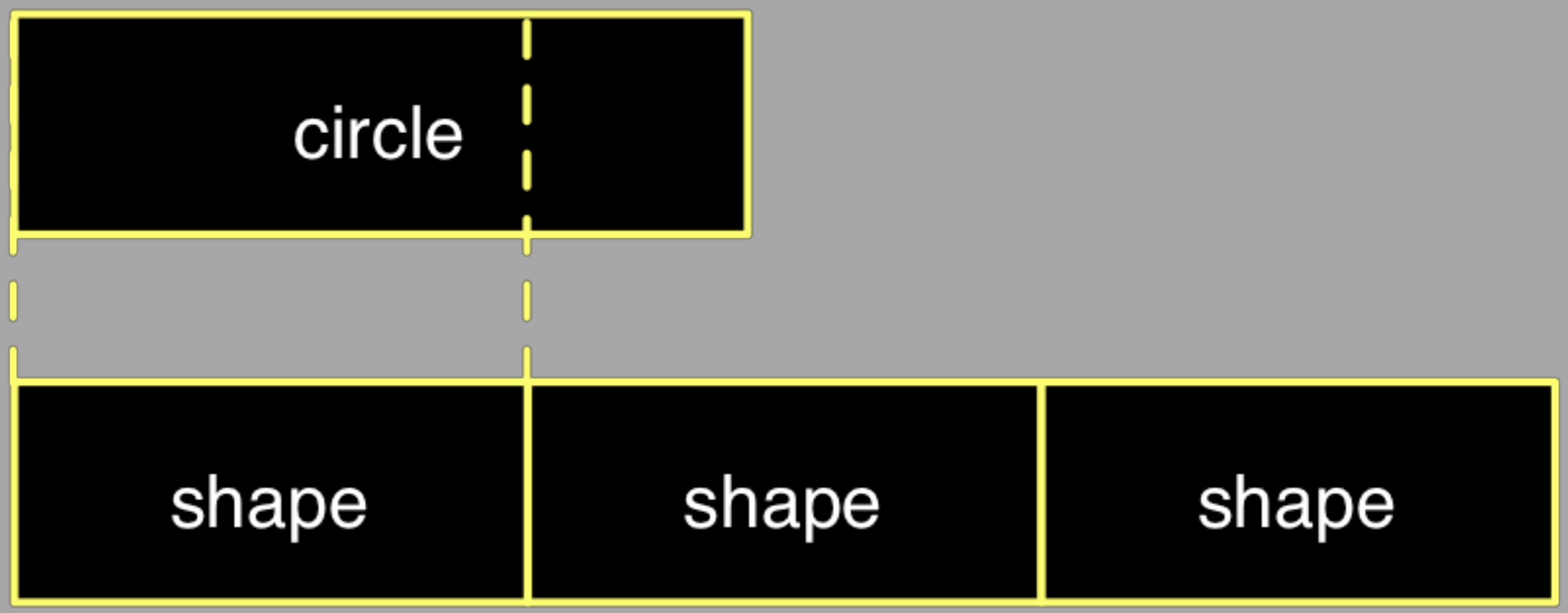
The Goal (Pseudo Code)

```
vector<shape> s1;
s1.push_back(circle(point(1, 2), 3));
s1.push_back(circle(point(4, 5), 6));
s1.push_back(rectangle(point(7, 8), 9, 10));

vector<shape> s2(s1);

reverse(s1);

find(s1, circle(point(4, 5), 6))->move(point(10, 20));

for_each(s1, &shape::draw);
for_each(s2, &shape::draw);
```

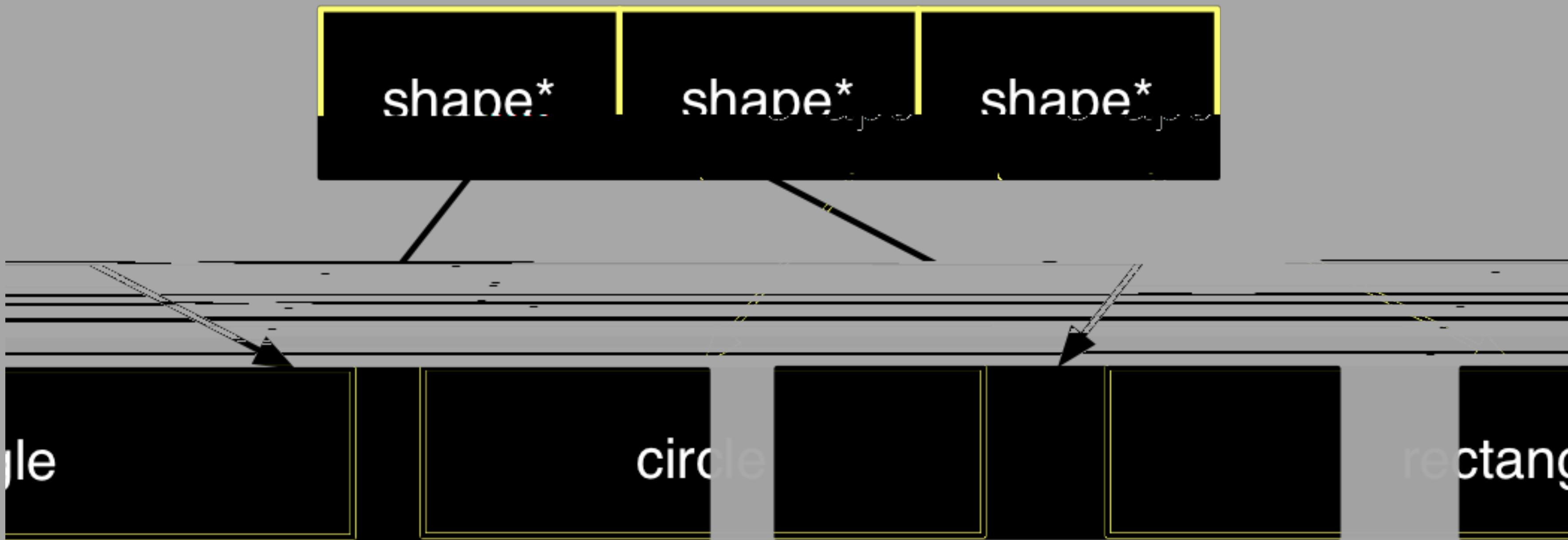
First Attempt

```
int main()
{
    using namespace std;

    vector<shape> s1;
    s1.push_back(circle(point(1, 2), 3)); // Error!
        // Cannot allocate an object of abstract type shape

    return 0;
}
```

Classic Problem: Object Slicing



Classic Solution: Indirection



Second Attempt

```
vector<shape*> s1;
s1.push_back(new circle(point(1, 2), 3));
s1.push_back(new circle(point(4, 5), 6));
s1.push_back(new rectangle(point(7, 8), 9, 10));

vector<shape*> s2(s1);
reverse(s1.begin(), s1.end());

(*find(s1.begin(), s1.end(), new circle(point(4, 5), 6)))
        ->move(point(10, 20)); // Runtime Error!
```

Identity Is Not Equality

- Comparing Pointer is Checking Identity
- Need to Compare Polymorphic Instances

Borrow (Back) From Java…

```
class object {
 public:
    virtual bool equals(const object&) const = 0;
};
class shape : public object
{ /* … */ };
class circle : public shape {
/* … */
    bool equals(const object& x) const {
            if (typeid(x) != typeid(circle)) return false;
            const circle& c(static_cast<const circle&>(x));
            return (c.where() == where()) && (c.radius == radius);
    }
/* … */
```

Not Done Yet!

```
struct equal_object : std::unary_function<const object*, bool>
{
    const object* object_m;
    equal_object(const object* x) : object_m(x) { }

    bool operator()(const object* x) const
    { return object_m->equals(*x); }
};
```

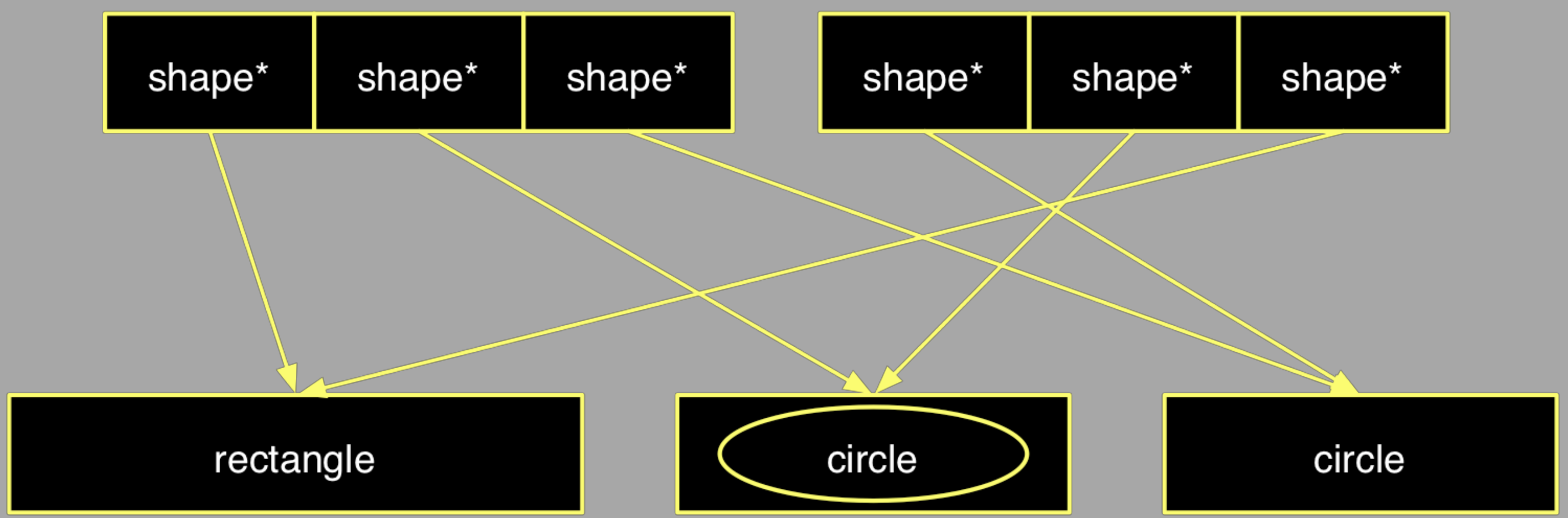
Third Attempt

```
/*…*/
(*find_if(s1.begin(), s1.end(), equal_object(new circle(point(4, 5), 6))))
        ->move(point(10, 20));

for (vector<shape*>::const_iterator first(s1.begin()), last(s1.end());
        first != last; ++first)
    { (*first)->draw(); }

/* … draw each shape in s2 */
```

Output from Third Attempt

```
rectangle(point(7, 8), 9, 10);
circle(point(10, 20
```

Implicit Data Structure



Lesson:

- “A shared pointer is as ‘good’ as a global.”

  - Exclusions:
    - Explicit Container
      - Shared Pointer as Relationship
    - Pointers to Immutable Values.

References as Values:

- A reference can be used as a value if the value is immutable during the lifetime of the reference.
  - There is no need to copy immutable objects.
  - This is why passing parameters as a const & works.

Borrow a Little More From Java…

```
class object {
 public:
    virtual bool equals(const object&) const = 0;
    virtual object* clone() const = 0;
};

class circle : public shape {
    /* … */
    object* clone() const { return new circle(*this); }
};
```

Fourth Attempt

```
/* … */

vector<shape*> s2(s1);

for (vector<shape*>::iterator first(s2.begin()), last(s2.end());
        first != last; ++first)
{ *first = static_cast<shape*>((*first)->clone()); }

/* … */
```

Output from Fourth Attempt

```
rectangle(point(7, 8), 9, 10);
circle(point(10, 20), 6);
circle(point(1, 2), 3);

circle(point(1, 2), 3);
circle(point(4, 5), 6);
rectangle(point(7, 8), 9, 10);
```

Fourth Attempt (Complete Code)

```
vector<shape*> s1;
s1.push_back(new circle(point(1, 2), 3));
s1.push_back(new circle(point(4, 5), 6));
s1.push_back(new rectangle(point(7, 8), 9, 10));

vector<shape*> s2(s1);

for (vector<shape*>::iterator first(s2.begin()), last(s2.end()); first != last; ++first)
{ *first = static_cast<shape*>((*first)->clone()); }

reverse(s1.begin(), s1.end());

(*find_if(s1.begin(), s1.end(), equal_object(new circle(point(4, 5), 6))))->move(point(10, 20));

for (vector<shape*>::const_iterator first(s1.begin()), last(s1.end()); first != last; ++first)
{ (*first)->draw(); }

for (vector<shape*>::const_iterator first(s2.begin()), last(s2.end()); first != last; ++first)
{ (*first)->draw(); }
```

The Goal (Pseudo Code)

```
vector<shape> s1;
s1.push_back(circle(point(1, 2), 3));
s1.push_back(circle(point(4, 5), 6));
s1.push_back(rectangle(point(7, 8), 9, 10));

vector<shape> s2(s1);

reverse(s1);

find(s1, circle(point(4, 5), 6))->move(point(10, 20));

for_each(s1, &shape::draw);
for_each(s2, &shape::draw);
```

Did It Work?

Let's Try Again…

A Quick Look At Concepts

expression	return type	post-condition
T(t)		t is equal to T(t)
T(u)		u is equal to T(u)
t.~T()		
&t	T*	denotes address of t
&u	const T*	denotes address of u

Table 1 - CopyConstructable

t = u	T&	t is equal to u

Table 2 - Assignable

a==b	convertible to bool	== is the equality relation

Table 3 – EqualityComparable

Value Semantics

For all a, a == a.

If a == b, then b == a.

If a == b, and b == c, then a == c.

T a(b) implies a == b.

T a; a = b ⇔ T a(b).

T a(c); T b(c); a = d; then b == c.

T a(c); T b(c); modify(a) then b == c && a != b.

If a == b then for any *regular* function f, f(a) == f(b).

!(a == b) ⇔ a != b.

Why Polymorphism?

- Apply an algorithm to heterogeneous objects as if they were homogeneous

- In this example – I need a “Drawable” type that can contain any Drawable object and is also a *Regular** type.

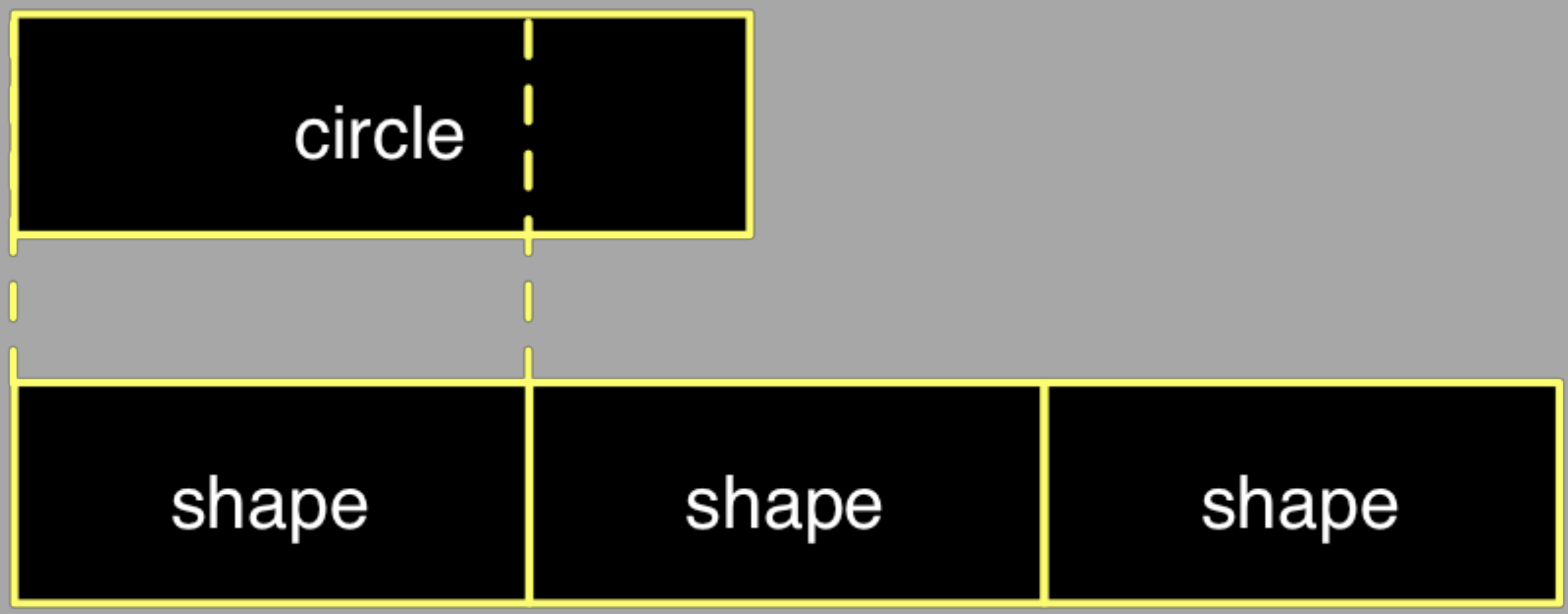
  - *CopyConstructible, Assignable, and EqualityComparable.

Why Polymorphism?

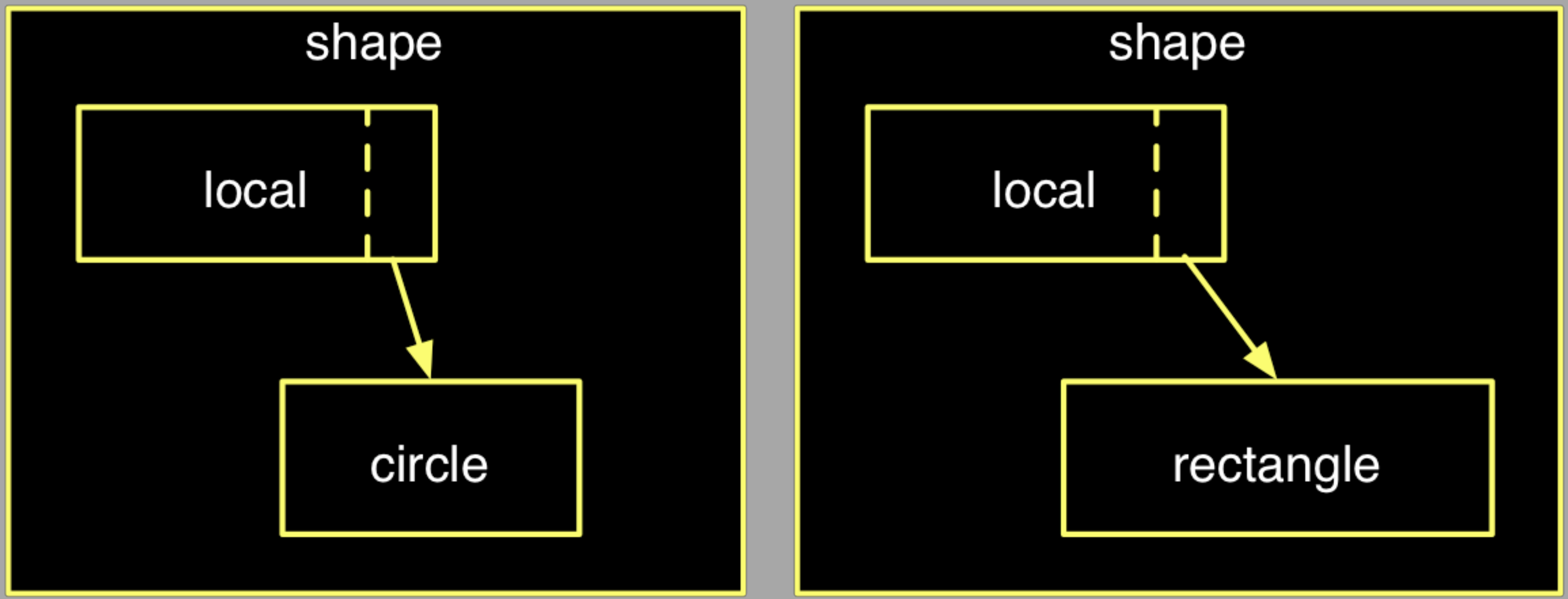
- Apply an algorithm to heterogeneous *typed* objects as if they were homogeneous

- Part of a continuum between “static and dynamic”
  - We use *variables* for heterogeneous values.
  - We use *Concepts* for heterogeneous types.

Root Cause



Another Solution – Remote Parts



Bottom-Up Rewrite

```
struct circle {
    int radius;

    circle(int r) : radius(r) { }

    void draw(const point&) const {
        std::cout << "shape(point(" << center_m.first << ", "
                << center_m.second << "), circle("
                << radius << ") ); " << std::endl;
    }
};

Inline bool operator == (const circle& x, const circle& y)
{ return x.radius == y.radius; }
```

Same for rectangle

```
struct rectangle {
    int width, height;

    rectangle(int w, int h) : width(w), height(h) { }

    void draw(const point&) const {
        std::cout << "shape(point(" << center_m.first << ", "
                  << center_m.second << "), rectangle("
                  << width << height << ") ); " << std::endl;
    }
};

inline bool operator == (const rectangle& x, const rectangle& y)
{ return x.width == y.width && x.height == y.height; }
```

Shape (Pseudo Code)

```
class shape {
    point center_m;
    Drawable object_m;
 public:
    shape(const point& center, const Drawable& s) :
            center_m(center), object_m(s) { }

    void draw() const { object_m.draw(center_m); }

    point where() const { return center_m; }
    void move(const point& to) { center_m = to; }
};
inline bool operator==(const shape& x, const shape& y)
{ return (x.center_m == y.center_m) && (x.object_m == y.object_m); }
```

Shape

```
class shape {
    /* …MAGIC STUFF HERE… */
    point center_m;
    regular_object<drawable_interface, drawable_instance> object_m;
 public:
    template <typename T> // T models Drawable
    shape(const point& center, const T& s) : center_m(center), object_m(s) { }

    void draw() const { object_m->draw(center_m); }

    point where() const { return center_m; }
    void move(const point& to) { center_m = to; }
};
inline bool operator==(const shape& x, const shape& y)
{ return (x.center_m == y.center_m) && (x.object_m == y.object_m); }
```

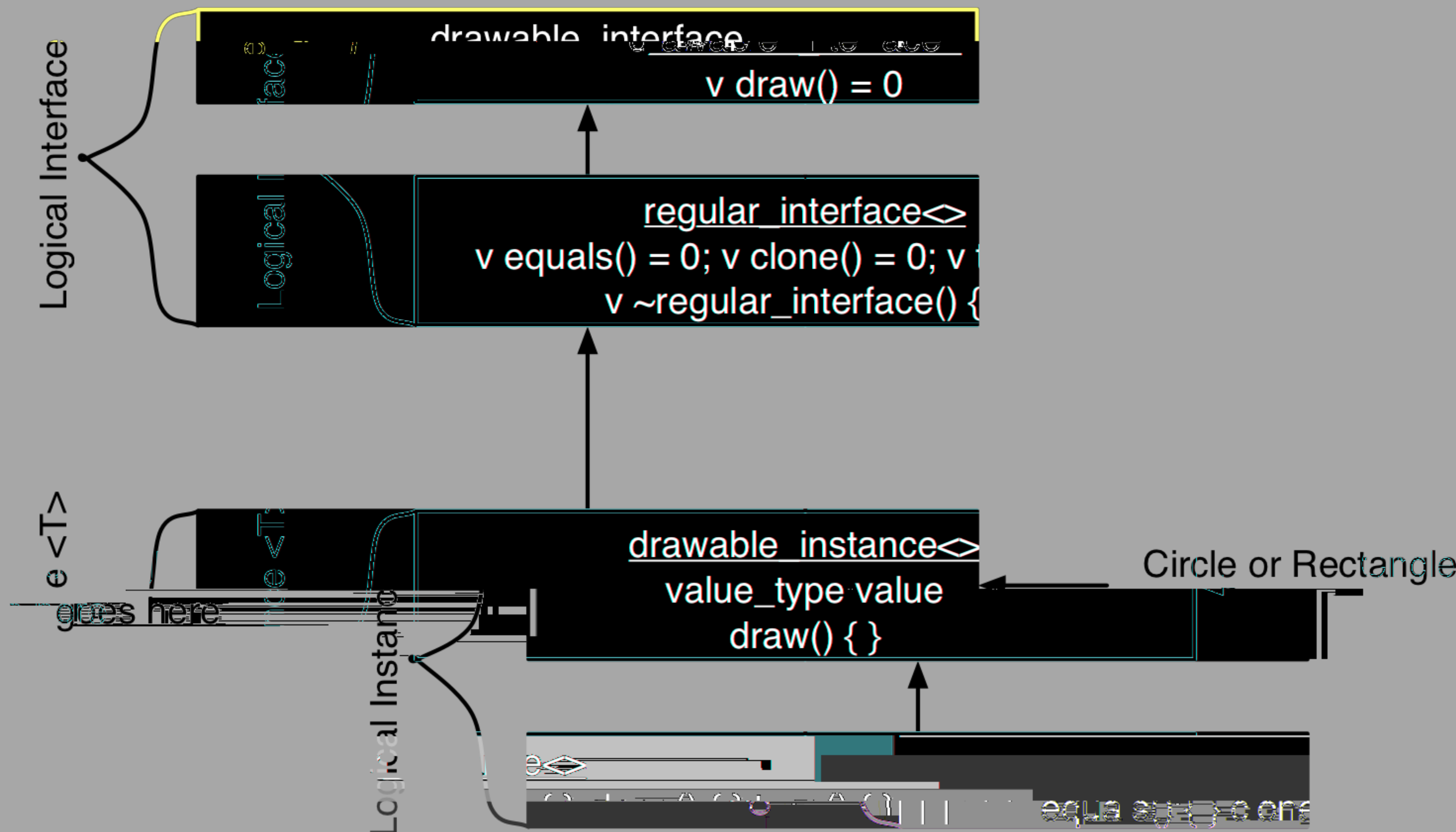
Look What We Can Do!

```
vector<shape> s1;
s1.push_back(shape(point(1, 2), circle(3)));
s1.push_back(shape(point(4, 5), circle(6)));
s1.push_back(shape(point(7, 8), rectangle(9, 10)));

vector<shape> s2(s1);

reverse(s1.begin(), s1.end());

find(s1.begin(), s1.end(), shape(point(4, 5), circle(6)))
            ->move(point(10, 20));

for_each(s1.begin(), s1.end(), mem_fun_ref(&shape::draw));
for_each(s2.begin(), s2.end(), mem_fun_ref(&shape::draw));
```

Final Output

```
shape(point(7, 8), rectangle(9, 10));
shape(point(10, 20), circle(6));
shape(point(1, 2), circle(3));

shape(point(1, 2), circle(3));
shape(point(4, 5), circle(6));
shape(point(7, 8), rectangle(9, 10));
```

Inheritance



The Magic Stuff

```
class shape {
    struct drawable_interface {
        virtual void draw(const point&) const = 0;
    };

    template <typename T> // T models Drawable
    struct drawable_instance : regular_interface<drawable_interface> {
        typedef T value_type;
        value_type value; // ← circle or rectangle goes here
        drawable_instance(const value_type& x) : value(x) { }
        void draw(const point& where) const { value.draw(where); }
    };
    point center_m;
    regular_object<drawable_interface, drawable_instance> object_m;
    /* … */
```

regular_interface<>

```
template <typename I> // I is a pure virtual interface
struct regular_interface : I
{
    virtual bool equals(const regular_interface&) const = 0;
    virtual regular_interface* clone() const = 0;
    virtual const std::type_info& type() const = 0;
    virtual ~regular_interface();
};

template <typename I> regular_interface<I>::~regular_interface() { }
```

regular_instance<>

```
template <typename F> // F is an instance of regular_interface
struct regular_instance : F {
     typedef typename F::value_type value_type;

     regular_instance(const value_type& x): F(x){ }

     bool equals(const interface_type& x) const {
             return (x.type() == typeid(value_type))
             &&  (static_cast<const regular_instance&>(x).value == this->value);
     }

     interface_type* clone() const { return new regular_instance(this->value); }

     const std::type_info& type() const { return typeid(value_type); }
};
```

regular_object<> (Part 1)

```
template <         typename I,       // I is a pure virtual interface class
                   template<class> class D > // D is instance template
class regular_object {
    typedef regular_interface<I> interface_type;
    interface_type* interface_m;
 public:
    template <typename T> explicit regular_object(const T& x) :
            interface_m(new regular_instance<D<T> >(x)) { }

    regular_object(const object& x) :
            interface_m(x.interface_m->clone()) { }

/* … */
```

regular_object<> (Part 2)

```
/* … */

    regular_object& operator=(const regular_object& x) {
        interface_type* tmp = x.interface_m->clone();
        std::swap(tmp, interface_m);
        delete tmp;
        return *this;
    }
    ~regular_object() { delete interface_m; }

    const interface_type* operator->() const { return interface_m; }
    interface_type* operator->() { return interface_m; }

    friend inline
    bool operator==(const regular_object& x, const regular_object& y)
    { return x.interface_m->equals(*y.interface_m); }
};
```

Tradeoffs

- Pros (of value semantics):
  - Simpler Client Interface
    - Writing a new Drawable class is trivial
    - Using Shapes is simple
  - Cleanly Extensible
    - Not Intrusive - works for Integer
  - Types Model RegularType
    - (usable with STL/Boost/ASL…)
  - No External Dependencies
    - Easier to Reuse

Tradeoffs

- Cons (of value semantics):
  - Lost Fast Move
    - reverse() is slower
      - Fixed this by specializing std::swap()
  - Heavy Meta-Machinery
    - The Magic Stuff
  - No Language Concept Support
    - Fail to satisfy Drawable requirements and stare in awe at the error message!
  - No Large Scale Examples
    - But I’m working on it!

What’s Next?

- Language Concept Support
  - How do we define and enforce the semantics of Concepts.
- Move Support
  - More importantly, we need to develop the underlying axioms and incorporate into our regular Concept.
- Semantic Spaces
  - How do I state “when I say swap, I mean a swap for this type with the same semantics as std::swap”.

One More Bit…

Look What We Can Do!

```
vector<shape> s1;
s1.push_back(shape(point(1, 2), circle(3)));
s1.push_back(shape(point(4, 5), circle(6)));
s1.push_back(shape(point(7, 8), rectangle(9, 10)));

vector<shape> s2(s1);

reverse(s1.begin(), s1.83 1768.8518 1493.665 83 0 0 83 990.49835 1097 Tm
```

The Goal (Pseudo Code)

```
vector<shape> s1;
s1.push_back(circle(point(1, 2), 3));
s1.push_back(circle(point(4, 5), 6));
s1.push_back(rectangle(point(7, 8), 9, 10));

vector<shape> s2(s1);

reverse(s1);

find(s1, circle(point(4, 5), 6))->move(point(10, 20));

for_each(s1, &shape::draw);
for_each(s2, &shape::draw);
```

Showing Off (<adobe/algorithms.hpp>)

```
vector<shape> s1;
s1.push_back(shape(point(1, 2), circle(3)));
s1.push_back(shape(point(4, 5), circle(6)));
s1.push_back(shape(point(7, 8), rectangle(9, 10)));

vector<shape> s2(s1);

reverse(s1);

find(s1, shape(point(4, 5), circle(6)))->move(point(10, 20));

for_each(s1, &shape::draw);
for_each(s2, &shape::draw);
```

Links

- Alex Stepanov's Collected Works
  - http://www.stepanovpapers.com/
- Fundamentals of Generic Programming
  - http://www.stepanovpapers.com/DeSt98.pdf

Polymorphism as Implementation

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