Thread Safety

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Adobe

Outline of Talk

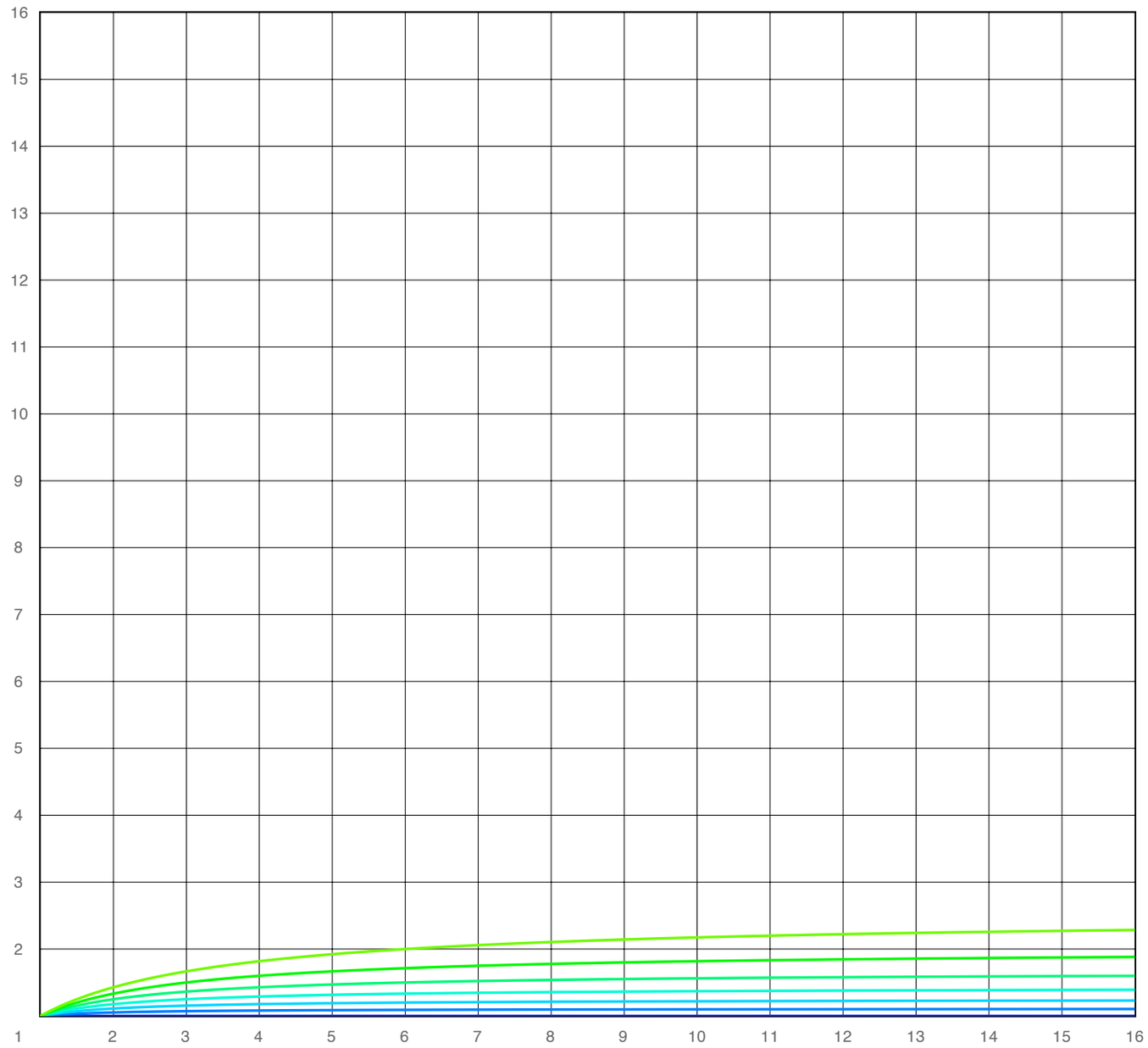
- Why Concurrent Code?
- What is Thread Safe Code?
  - Classes without synchronization
- Synchronization:
  - Memory Hierarchy, Compiler Reordering, Execution Reordering and Memory Barriers
  - Memory, Atomics, and Locks in Multi-Processor World
- Problems with Locks:
  - Deadlocks, Race Conditions, Starvation
- Common Patterns of Sharing:
  - Singletons
  - Reference Counting and Copy-On-Write

Why Concurrent Code?

- Clock speeds getting faster at a slower rate
- Number of transistors continuing to double every 18-24 months
- Result is *rapid* growth in number of cores
- Except:
  - Few applications scale well beyond 2-4 cores (most don't scale beyond 1)
  - Very little system gain beyond 8 cores
  - Amdahl's Law* still hurts
  - Memory has not sped up as fast as cores

* Amdahl's law states that if P is the proportion of a program that can be made parallel (i.e. benefit from parallelization), and (1 – P) is the proportion that cannot be parallelized (remains serial), then the maximum speedup that can be achieved by using N processors is:

$$\frac{1}{(1-P) + \frac{P}{N}}$$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Why Concurrent Code?

- There is no concurrent *silver bullet*
- For Performance:
  - Optimize algorithm complexity
  - Optimize memory access and utilization
  - Optimize I/O (including asynchronous read ahead and write behind)
  - Consider parallel algorithms - the closer P is to 1, the higher the gains
- For Interactivity:
  - Use work queues and execute them on your event loop
  - Consider multiple processes (see Google Chrome)
  - Consider concurrent tasks
- Profile and Measure Response Times
  - Let hard data guide your optimization efforts
  - Concurrency is one tool at your disposal

What is Thread Safe Code?

- Thread safe code is code which remains correct when executed concurrently
  - But that isn't the whole story...
- A function is thread safe if it remains correct when executed concurrently *assuming any modified objects are not shared or access is synchronized*
- A type is thread safe if the basis operations on the type are thread safe functions
  - Thread safety does not imply a single instance can be shared by multiple threads without synchronization
  - int is a thread safe type, std::vector<int> is a thread safe type
  - shared_ptr<int> is not thread safe
  - shared_ptr<const int> is thread safe
- A type is sharable if the basis operations on the type are thread safe functions when operating on a shared instance

Key to Thread Safety

- All code should be written thread safe
  - The once task based threading is introduced to an application, it becomes difficult to control what code is and is not execute on a thread
- Reduce sharing of mutable data to reduce synchronization - *any* synchronization will fall victim to Amdahl's law given enough processors
  - This is why functional programming and Haskell continue to gain ground - eliminating mutable data is one way to eliminate the sharing of mutable data
- There is often a cost to eliminating sharing and a tradeoff in the performance of code when executed linearly against the ability to scale to many processors
  - Look for opportunities to leverage concurrency to offset the costs - typically, just getting to leverage two processors will more than offset these costs

Classes Without Synchronization

- OOP has indirectly led to very thread unsafe code -
- The requirement of a polymorphic type, by definition, comes from it's use -
  - That is, there is no such thing as a polymorphic type, only a polymorphic use of *similar* types
- By using inheritance to capture polymorphic use, we shift the burden of use to the type, tightly coupling components
- Inheritance implies variable size, which implies heap allocation
- Heap allocation forces a further burden on use to manage the object lifetime
- Object lifetime management leads to garbage collection or reference counting
- This encourages *shared* ownership and the proliferation of *incidental data-structures*
- Shared mutable objects are not thread safe without synchronization

Disclaimer

- In the following code, the proper use of header files, inline functions, and namespaces are ignored for clarity

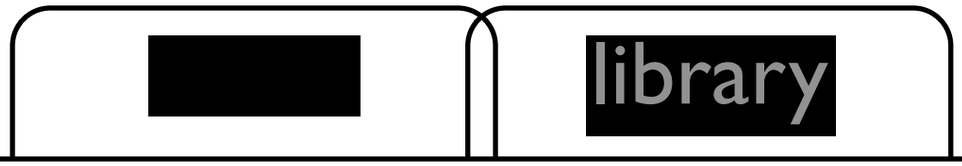
[redacted] library

[redacted] guidelines defects

[redacted] library

```
int main()
{
    cout << "Hello World!" << endl;
    return 0;
}
```

[redacted] guidelines defects

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}
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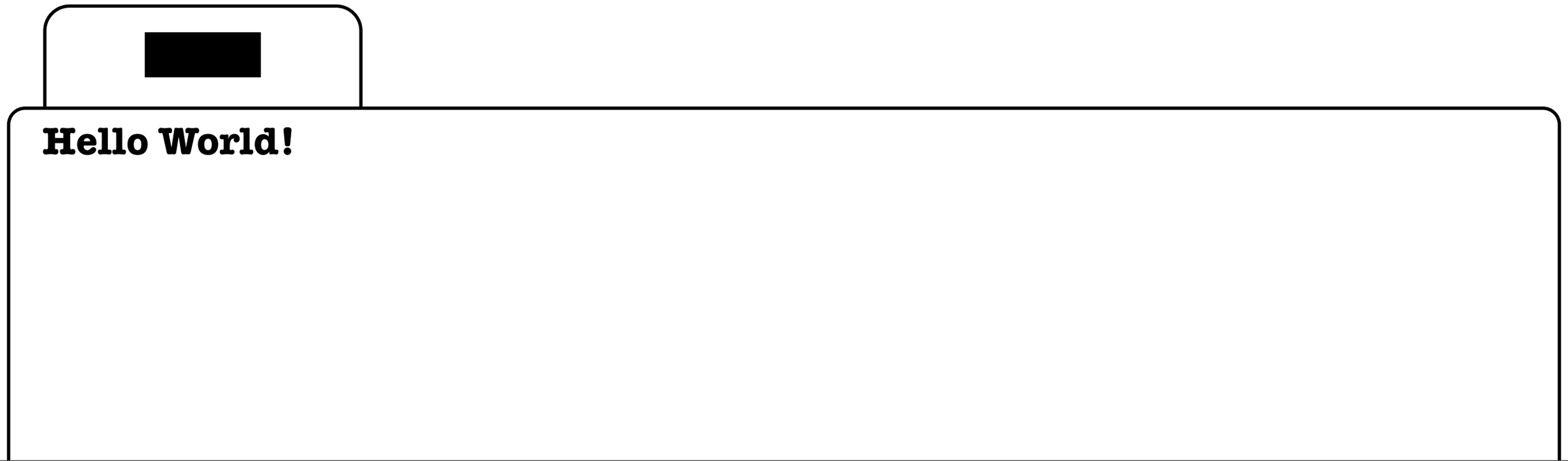

client

cout guidelines defects

client [redacted]

```
typedef int object_t;

void print(ostream& out, const object_t& x) { out << x << endl; }

typedef vector<object_t> document_t;

void print(ostream& out, const document_t& x)
{
  out << "<document>" << endl;
  for (document_t::const_iterator f = x.begin(), l = x.end(); f != l; ++f) {
      print(out, *f);
  }
  out << "</document>" << endl;
}
```

[redacted] guidelines [redacted]

[redacted] library

[redacted] defects

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(1));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted] defects

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
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    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted]

```
<document>
0
1
2
3
</document>
```

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(1));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted]

- Write all code as a library.
  - Reuse increases your productivity.
  - Writing unit tests is simplified.

client [redacted]

```
typedef int object_t;

void print(ostream& out, const object_t& x) { out << x << endl; }
```

```
typedef vector<object_t> document_t;

void print(ostream& out, const document_t& x)
{
    out << "<document>" << endl;
    for (document_t::const_iterator f = x.begin(), l = x.end(); f != l; ++f) {
        print(out, *f);
    }
    out << "</document>" << endl;
}
```

[redacted] guidelines [redacted]

client [redacted]

```
void print(ostream& out, const int& x) { out << x << endl; }

class object_t {
 public:
    explicit object_t(const int& x) : object_m(x)
    { }

    friend void print(ostream& out, const object_t& x);
 private:
    int object_m;
};

void print(ostream& out, const object_t& x)
{ print(out, x.object_m); }
```

```
typedef vector<object_t> document_t;

void print(ostream& out, const document_t& x)
{
    out << "<document>" << endl;
    for (document_t::const_iterator f = x.begin(), l = x.end(); f != l; ++f) {
        print(out, *f);
    }
```

[redacted] cout [redacted] defects

client [redacted]

```
void print(ostream& out, const int& x) { out << x << endl; }

class object_t {
 public:
    explicit object_t(const int& x) : object_m(x)
    { }

    friend void print(ostream& out, const object_t& x);
 private:
    int object_m;
};

void print(ostream& out, const object_t& x)
{ print(out, x.object_m); }
```

```
typedef vector<object_t> document_t;

void print(ostream& out, const document_t& x)
```

[redacted]

- The compiler will supply member-wise copy and assignment operators.
  - Let the compiler do the work where appropriate.

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(1));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted] defects

[redacted] library

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    print(cout, document);
    return 0;
}
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[redacted]

```
<document>
0
1
2
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</document>
```

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int main()
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    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted]

- Write classes that behave like *regular* objects to increase reuse.

client [redacted]

```
void print(ostream& out, const int& x) { out << x << endl; }

class object_t {
 public:
    explicit object_t(const int& x) : object_m(x)
    { }

    friend void print(ostream& out, const object_t& x);
 private:
    int object_m;
};

void print(ostream& out, const object_t& x)
{ print(out, x.object_m); }

typedef vector<object_t> document_t;

void print(ostream& out, const document_t& x)
{
    out << "<document>" << endl;
    for (document_t::const_iterator f = x.begin(), l = x.end(); f != l; ++f) {
        print(out, *f);
    }
```

[redacted]

cout guidelines defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(x)
    { }

    friend void print(ostream& out, const object_t& x);
 private:
    int object_m;
};

void print(ostream& out, const object_t& x)
{ print(out, x.object_m); }
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typedef vector<object_t> document_t;

void print(ostream& out, const document_t& x)
{
    cout << "<document>" << endl;
    for (document_t::const_iterator f = x.begin(), l = x.end(); f != l; ++f) {
        print(out, *f);
    }
    cout << "</document>" << endl;
```

[redacted] guidelines defects

client [redacted]

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class object_t {
 public:
    explicit object_t(const int& x) : object_m(x)
    { }

    friend void print(ostream& out, const object_t& x);
 private:
    int object_m;
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void print(ostream& out, const object_t& x)
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typedef vector<object_t> document_t;

void print(ostream& out, const document_t& x)
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    cout << "<document>" << endl;
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        print(out, *f);
    }
    cout << "</document>" << endl;
}
```

cout guidelines defects

client [redacted]

```
class object_t {
 public:
```

```
typedef vector<object_t> document_t;

void print(ostream& out, const document_t& x)
```

cout guidelines defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }

    friend void print(ostream& out, const object_t& x);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void print(ostream& out, const object_t& x)
{ x.object_m->print_(out); }

typedef vector<object_t> document_t;

void print(ostream& out, const document_t& x)
```

cout guidelines defects

client

[redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
```

[redacted]

```
    friend void print(ostream& out, const object_t& x);
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[redacted]

cout defects

client

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class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    friend void print(ostream& out, const object_t& x);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

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cout defects

client [redacted]

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        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

[redacted]

- Do your own memory management - don't create garbage for your client to clean-up.

client

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    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    friend void print(ostream& out, const object_t& x);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void print(ostream& out, const object_t& x)
{ x.object_m->print_(out); }
```

cout defects

client [redacted]

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    { }
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    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }

    friend void print(ostream& out, const object_t& x);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

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void print(ostream& out, const object_t& x)
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[redacted] cout [redacted] defects

client [redacted]

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        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };
```

[redacted]

- The semantics of copy are to create a new object which is equal to, and logically disjoint from, the original.
- Copy constructor must copy your object. The compiler is free to elide copies so if your copy constructor does something else you code is incorrect.

- When a type manages *remote parts* it is necessary to supply your own copy constructor.
  - If you can, use an existing class (such as a vector) to manage remote parts.

client

[redacted]

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class object_t {
 public:
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    { }
    ~object_t() { delete object_m; }

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    { }
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[redacted]

```
    friend void print(ostream& out, const object_t& x);
 private:
    struct int_model_t {
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        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
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cout [redacted] defects

client [redacted]

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    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { delete object_m; object_m = new int_model_t(*x.object_m); return *this; }

    friend void print(ostream& out, const object_t& x);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
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        int data_m;
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};
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cout [redacted] defects

client [redacted]

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 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
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    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
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    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
```

[redacted]

- Assignment is consistent with copy. Generally:

  `T x; x = y;` is equivalent to `T x = y;`

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(1));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted] defects

[redacted] library

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int main()
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    document_t document;

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    print(cout, document);
    return 0;
}
```

[redacted]

```
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0
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2
3
</document>
```

[redacted] library

```
int main()
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    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted]

- The Private Implementation (Pimpl), or Handle-Body, idom is good for separating the implementation and reducing compile times.

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { delete object_m; object_m = new int_model_t(*x.object_m); return *this; }

    friend void print(ostream& out, const object_t& x);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout [redacted] guidelines

client [redacted]

```
class object_t {
 public:
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    { }
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    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { delete object_m; object_m = new int_model_t(*x.object_m); return *this; }

    friend void print(ostream& out, const object_t& x);
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    struct int_model_t {
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        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };
```

[redacted]

- If new throws an exception, the object will be left in an invalid state.
- If we assign an object to itself this will crash.

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
```

[redacted]

```
    friend void print(ostream& out, const object_t& x);
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    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
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        int data_m;
    };

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[redacted]

cout [redacted] defects

client [redacted]

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class object_t {
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    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
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cout [redacted] defects

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    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
private:
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        int data_m;
```

[redacted]

- Assignment should satisfy the *strong exception guarantee*.
  - Either complete successfully or throw an exception, leaving the object unchanged.
- Don't optimize for rare cases which impact common cases.
  - Don't test for self-assignment to avoid the copy.

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);

 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout guidelines defects

client [redacted]

```
public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout guidelines defects

client [redacted]

```
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void print(ostream& out, const object_t& x)
```

[redacted]

cout guidelines defects

client [redacted]

```
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void print(ostream& out, const object_t& x)
{ x.object_m->print_(ostream& out); }
```

cout guidelines defects

client [redacted]

```
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void print(ostream& out, const object_t& x)
{ x.object_m->print_(ostream& out); }
```

cout guidelines defects

client [redacted]

```
    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void print(ostream& out, const object_t& x)
{ x.object_m->print_(ostream& out); }

typedef vector<object_t> document_t;
```

cout guidelines defects

client [redacted]

```
    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void print(ostream& out, const object_t& x)
{ x.object_m->print_(ostream& out); }

typedef vector<object_t> document_t;
```

cout guidelines defects

client [redacted]

```
    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout guidelines defects

client [redacted]

```
    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

```
void swap(object_t& x, object_t& y)
{
    swap(x.object_m, y.object_m);
    cout << "swap" << endl;
}
```

cout guidelines defects

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(1));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted] defects

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(1));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

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

    print(cout, document);
    return 0;
}
```

[redacted] defects

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(1));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

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

    print(cout, document);
    return 0;
}
```

[redacted]

```
swap
swap
<document>
3
2
1
0
</document>
```

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(1));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

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

    print(cout, document);
    return 0;
}
```

[redacted]

- Provide a non-throwing swap function in the same namespace as the class.
- Call swap unqualified allowing argument dependent lookup (ADL) to find the best swap.

- The standard library treats swap as an operator and calls it unqualified.*

**Microsoft Visual C++ does not currently make unqualified calls to swap.*

client [redacted]

```
    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void swap(object_t& x, object_t& y)
{
    swap(x.object_m, y.object_m);
    cout << "swap" << endl;
}
```

[redacted]

```
    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void swap(object_t& x, object_t& y)
{
    swap(x.object_m, y.object_m);
}
```

client [redacted]

```
    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void swap(object_t& x, object_t& y)
{
    swap(x.object_m, y.object_m);
}
```

cout guidelines defects

client

```
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void swap(object_t& x, object_t& y)
{
    swap(x.object_m, y.object_m);
```

cout defects

client

[redacted]

```
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void swap(object_t& x, object_t& y)
{
```

cout defects

client [redacted]

```
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

void swap(object_t& x, object_t& y)
```

[redacted]

cout guidelines defects

client [redacted]

```
public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout guidelines defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout guidelines defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
                                    
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
                                    
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout guidelines defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { cout << "ctor" << endl; }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { cout << "copy" << endl; }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

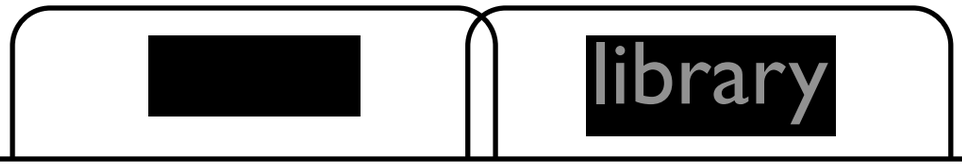
    int_model_t* object_m;
};
```

[redacted]

cout guidelines defects

[redacted] library

[redacted] guidelines defects



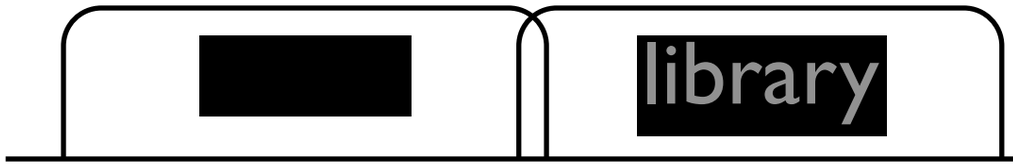

```
object_t function() { return object_t(5); }

int main()
{
    /*
        Quiz: What will this print?
    */

    object_t x = function();

    return 0;
}
```

[redacted] guidelines defects

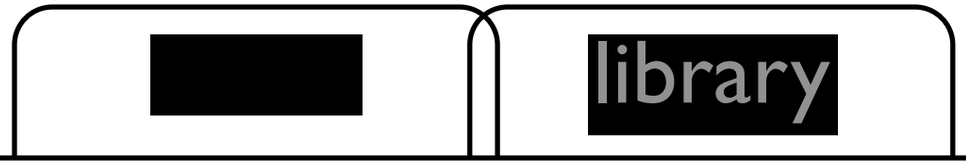



```
object_t function() { return object_t(5); }

int main()
{
    /*
        Quiz: What will this print?
    */

    object_t x = function();

    return 0;
}
```

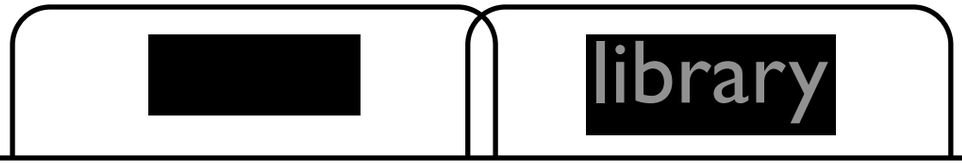



```
object_t function() { return object_t(5); }

int main()
{
    /*
        Quiz: What will this print?
    */
```

```
    return 0;
}
```

cout guidelines defects




```
object_t function() { return object_t(5); }

int main()
{
    /*
        Quiz: What will this print?
    */

    object_t x(0);

    x = function();

    return 0;
}
```

cout guidelines defects

[redacted] library

```
object_t function() { return object_t(5); }

int main()
{
    /*
        Quiz: What will this print?
    */

    object_t x(0);

    x = function();

    return 0;
}
```

[redacted]

ctor
ctor
copy

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { cout << "ctor" << endl; }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { cout << "copy" << endl; }
    object_t& operator=(const object_t& x)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout guidelines defects

client

[redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { cout << "ctor" << endl; }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { cout << "copy" << endl; }
```

[redacted]

```
    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout

defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { cout << "ctor" << endl; }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { cout << "copy" << endl; }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

[redacted] cout [redacted] defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { cout << "ctor" << endl; }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { cout << "copy" << endl; }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(o                    onst { print(out, data_m); }
```

[redacted]

- Pass *sink* arguments by value and swap or move into place.
- A sink argument is any argument consumed or returned by the function.
  - The argument to assignment is a sink argument.

[redacted] library

```
object_t function() { return object_t(5); }

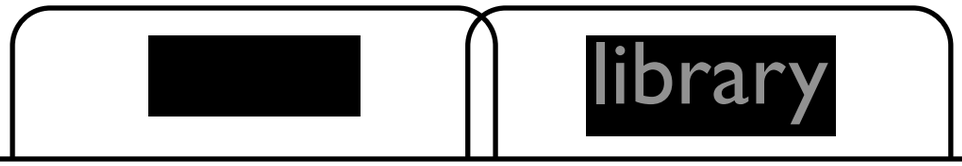
int main()
{
    /*
        Quiz: What will this print?
    */

    object_t x(0);

    x = function();

    return 0;
}
```

[redacted] guidelines defects




```
object_t function() { return object_t(5); }

int main()
{
    /*
        Quiz: What will this print?
    */

    object_t x(0);

    x = function();

    return 0;
}
```

ctor
ctor

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { cout << "ctor" << endl; }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { cout << "copy" << endl; }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

[redacted]

cout guidelines defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
                                    
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
                                    
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout guidelines defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
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    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

[redacted]

cout guidelines defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
```

cout guidelines defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct string_model_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };
```

[redacted] guidelines [redacted]

client [redacted]

```
class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
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private:
    struct string_model_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };
```

cout guidelines defects

client [redacted]

```
public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct string_model_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t {
```

cout guidelines defects

client [redacted]

```
explicit object_t(const string& x) : object_m(new string_model_t(x))
{ }
explicit object_t(const int& x) : object_m(new int_model_t(x))
{ }
~object_t() { delete object_m; }

object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
{ }
object_t& operator=(object_t x)
{ swap(*this, x); return *this; }

   friend void print(ostream& out, const object_t& x);
   friend void swap(object_t& x, object_t& y);
private:
   struct string_model_t {
       explicit string_model_t(const string& x) : data_m(x) { }
       void print_(ostream& out) const { print(out, data_m); }

       string data_m;
   };

   struct int_model_t {
       explicit int_model_t(const int& x) : data_m(x) { }
```

cout guidelines defects

client [redacted]

```
{ }
explicit object_t(const int& x) : object_m(new int_model_t(x))
{ }
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object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
{ }
object_t& operator=(object_t x)
{ swap(*this, x); return *this; }

friend void print(ostream& out, const object_t& x);
friend void swap(object_t& x, object_t& y);
private:
    struct string_model_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }
```

[redacted]

cout guidelines defects

client [redacted]

```
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
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private:
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        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
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    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }
```

[redacted] guidelines [redacted]

client [redacted]

```
    { }
    ~object_t() { delete object_m; }

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    struct string_model_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
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    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
```

cout guidelines defects

client [redacted]

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    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
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    { swap(*this, x); return *this; }

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    struct string_model_t {
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cout guidelines defects

client [redacted]

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    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
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cout guidelines defects

client [redacted]

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    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
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    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct string_model_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    int_model_t* object_m;
```

cout guidelines defects

client [redacted]

```
    { }
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private:
    struct string_model_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
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    };

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[redacted]

cout guidelines defects

client [redacted]

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[redacted]

cout guidelines defects

client [redacted]

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        void print_(ostream& out) const { print(out, data_m); }

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    };

};
```

[redacted]

cout guidelines defects

client [redacted]

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    { }
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        int data_m;
    };

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};
```

[redacted]

cout guidelines defects

client [redacted]

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cout guidelines defects

client

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    void print_(ostream& out) const { print(out, data_m); }

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cout guidelines defects

client [redacted]

```
    friend void print(ostream& out, const object_t& x);
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private:
    struct concept_t {
        virtual ~concept_t() { }
    };

    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
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    struct int_model_t : concept_t {
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        int data_m;
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};
```

[redacted]

cout guidelines defects

client [redacted]

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        friend void print(ostream& out, const object_t& x);
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    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
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    struct int_model_t : concept_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
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cout guidelines defects

client [redacted]

```
    friend void print(ostream& out, const object_t& x);
  friend void swap(object_t& x, object_t& y);
private:
  struct concept_t {
    virtual ~concept_t() { }
    virtual void print_(ostream& out) const = 0;
  };

  struct string_model_t : concept_t {
    explicit string_model_t(const string& x) : data_m(x) { }
    void print_(ostream& out) const { print(out, data_m); }

    string data_m;
  };

  struct int_model_t : concept_t {
    explicit int_model_t(const int& x) : data_m(x) { }
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cout guidelines defects

client [redacted]

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    friend void print(ostream& out, const object_t& x);
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    explicit string_model_t(const string& x) : data_m(x) { }
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  };

  struct int_model_t : concept_t {
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cout guidelines defects

client [redacted]

```
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        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };
```

[redacted] guidelines [redacted]

client [redacted]

```
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
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    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
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    };
```

cout guidelines defects

client [redacted]

```
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
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cout guidelines defects

```
    { }
    object_t& operator=(object_t x)
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struct int_model_t : concept_t {
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```

client [redacted]

```
    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
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```

cout guidelines defects

client [redacted]

```
    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
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    };

    struct int_model_t : concept_t {
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```

[redacted]

cout guidelines defects

client [redacted]

```
    ~object_t() { delete object_m; }

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    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_(ostream& out) const = 0;
    };

    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t : concept_t {
```

cout guidelines defects

client

```
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
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        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };
```

cout defects

client [redacted]

```
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
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        string data_m;
    };
```

cout guidelines defects

client [redacted]

```
{ }
explicit object_t(const int& x) : object_m(new int_model_t(x))
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        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
```

[redacted]

client [redacted]

```
explicit object_t(const string& x) : object_m(new string_model_t(x))
{ }
explicit object_t(const int& x) : object_m(new int_model_t(x))
{ }
~object_t() { delete object_m; }

object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
{ }
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{ swap(*this, x); return *this; }

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   struct concept_t {
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       void print_(ostream& out) const { print(out, data_m); }
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cout guidelines defects

client [redacted]

```
public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
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    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
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```

[redacted] cout guidelines defects

client [redacted]

```
class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
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    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
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    object_t& operator=(object_t x)
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```

cout guidelines defects

client [redacted]

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class object_t {
 public:
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    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
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private:
    struct concept_t {
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    struct string_model_t : concept_t {
```

cout guidelines defects

client [redacted]

```
void print(ostream& out, const int& x) { out << x << endl; }

class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
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    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
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private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_(ostream& out) const = 0;
    };
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cout guidelines defects

client [redacted]

```
void print(ostream& out, const int& x) { out << x << endl; }

class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
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    { }
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    };
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cout guidelines defects

client [redacted]

```
void print(ostream& out, const string& x) { out << x << endl; }
void print(ostream& out, const int& x) { out << x << endl; }

class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
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    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

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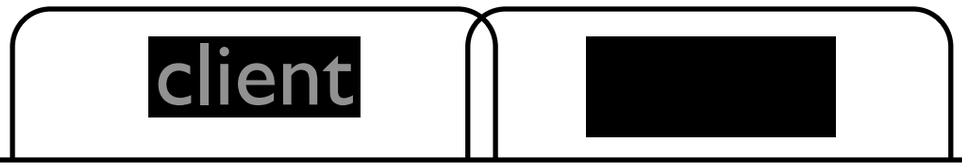
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_(ostream& out) const = 0;
    };
```

cout guidelines defects




```
void print(ostream& out, const string& x) { out << x << endl; }
void print(ostream& out, const int& x) { out << x << endl; }

class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
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    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
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private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_(ostream& out) const = 0;
    };
```

cout guidelines defects

client [redacted]

```
void print(ostream& out, const string& x) { out << x << endl; }
void print(ostream& out, const int& x) { out << x << endl; }

class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
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    { }
    ~object_t() { delete object_m; }
```

```
    { }
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    };
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cout guidelines defects

client [redacted]

```
void print(ostream& out, const string& x) { out << x << endl; }
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class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
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    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(x.object_m->copy_())
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
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private:
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        virtual ~concept_t() { }
        virtual void print_(ostream& out) const = 0;
    };
```

[redacted]

cout guidelines defects

client [redacted]

```
void print(ostream& out, const string& x) { out << x << endl; }
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class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
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private:
    struct concept_t {
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        virtual void print_(ostream& out) const = 0;
    };
```

cout guidelines defects

client [redacted]

```
void print(ostream& out, const int& x) { out << x << endl; }

class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
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    object_t(const object_t& x) : object_m(x.object_m->copy_())
    { }
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        virtual ~concept_t() { }
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```

[redacted] cout guidelines defects

client [redacted]

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class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
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    object_t& operator=(object_t x)
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    struct concept_t {
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    };

    struct string_model_t : concept_t {
```

cout guidelines defects

client [redacted]

```
class object_t {
 public:
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    { }
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    ~object_t() { delete object_m; }

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    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
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    struct concept_t {
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    };

    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
```

cout guidelines defects

client [redacted]

```
public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
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        explicit string_model_t(const string& x) : data_m(x) { }
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cout guidelines defects

client [redacted]

```
explicit object_t(const string& x) : object_m(new string_model_t(x))
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```

cout guidelines defects

client [redacted]

```
{ }
explicit object_t(const int& x) : object_m(new int_model_t(x))
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        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
```

[redacted]

cout guidelines defects

client [redacted]

```
    explicit object_t(const int& x) : object_m(new int_model_t(x))
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    object_t(const object_t& x) : object_m(x.object_m->copy_())
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        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };
```

[redacted] cout [redacted] defects

client [redacted]

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    { }
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cout guidelines defects

client [redacted]

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    ~object_t() { delete object_m; }

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cout guidelines defects

client [redacted]

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cout guidelines defects

client [redacted]

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    object_t(const object_t& x) : object_m(x.object_m->copy_())
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cout guidelines defects

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client [redacted]

```
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        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t : concept_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
```

cout guidelines defects

client [redacted]

```
    { swap(*this, x); return *this; }

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    friend void swap(object_t& x, object_t& y);
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        string data_m;
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```

cout guidelines defects

client [redacted]

```
    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_(ostream& out) const = 0;
    };

    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t : concept_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };
```

[redacted] guidelines [redacted]

client [redacted]

```
    friend void print(ostream& out, const object_t& x);
  friend void swap(object_t& x, object_t& y);
private:
  struct concept_t {
    virtual ~concept_t() { }
    virtual void print_(ostream& out) const = 0;
  };

  struct string_model_t : concept_t {
    explicit string_model_t(const string& x) : data_m(x) { }
    void print_(ostream& out) const { print(out, data_m); }

    string data_m;
  };

  struct int_model_t : concept_t {
    explicit int_model_t(const int& x) : data_m(x) { }
    void print_(ostream& out) const { print(out, data_m); }

    int data_m;
  };

  concept_t* object_m;
```

cout guidelines defects

client [redacted]

```
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_(ostream& out) const = 0;
    };

    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t : concept_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    concept_t* object_m;
};
```

cout guidelines defects

client [redacted]

```
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_(ostream& out) const = 0;
    };

    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t : concept_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };

    concept_t* object_m;
};
```

cout guidelines defects

client [redacted]

```
private:
    struct concept_t {
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        void print_(ostream& out) const { print(out, data_m); }

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    struct int_model_t : concept_t {
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        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };
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cout guidelines defects

client [redacted]

```
private:
    struct concept_t {
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    };

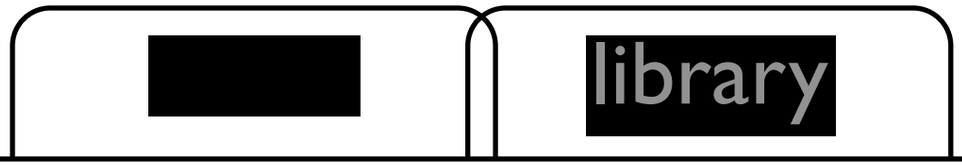
    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        concept_t* copy_() const { return new string_model_t(data_m); }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t : concept_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        concept_t* copy_() const { return new int_model_t(data_m); }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };
```

cout guidelines defects




```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(1));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

cout guidelines defects

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted] defects

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted] defects

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted]

```
<document>
0
Hello
2
3
</document>
```

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(2));
    document.push_back(object_t(3));

    print(cout, document);
    return 0;
}
```

[redacted]

- Don't allow polymorphism to complicate the client code.
  - Polymorphism is an implementation detail.

client [redacted]

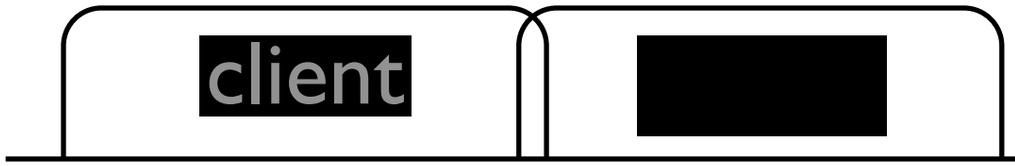
```
void print(ostream& out, const string& x) { out << x << endl; }
void print(ostream& out, const int& x) { out << x << endl; }

class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
    { }
    explicit object_t(const int& x) : object_m(new int_model_t(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(x.object_m->copy_())
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
```

cout guidelines defects




```
class object_t {
 public:
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(x.object_m->copy_())
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
    };
```

cout guidelines defects

client [redacted]

```
template <typename T>
void print(ostream& out, const T& x) { out << x << endl; }

class object_t {
 public:
    template <typename T>
    explicit object_t(const T& x) : object_m(new model<T>(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(x.object_m->copy_())
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
    };
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cout guidelines defects

client [redacted]

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template <typename T>
void print(ostream& out, const T& x) { out << x << endl; }

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    { }
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    friend void print(ostream& out, const object_t& x);
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```

cout guidelines defects

client [redacted]

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void print(ostream& out, const T& x) { out << x << endl; }

class object_t {
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cout guidelines defects

client [redacted]

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 public:
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    friend void print(ostream& out, const object_t& x);
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private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
    };

    struct string_model_t : concept_t {
```

[redacted] guidelines [redacted]

client [redacted]

```
class object_t {
 public:
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    explicit object_t(const T& x) : object_m(new model<T>(x))
    { }
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    object_t(const object_t& x) : object_m(x.object_m->copy_())
    { }
    object_t& operator=(object_t x)
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    friend void print(ostream& out, const object_t& x);
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private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
    };

    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
```

cout guidelines defects

client [redacted]

```
public:
    template <typename T>
    explicit object_t(const T& x) : object_m(new model<T>(x))
    { }
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    object_t(const object_t& x) : object_m(x.object_m->copy_())
    { }
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    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        concept_t* copy_() const { return new string_model_t(data_m); }
```

[redacted] guidelines defects

client [redacted]

```
template <typename T>
explicit object_t(const T& x) : object_m(new model<T>(x))
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    };

    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        concept_t* copy_() const { return new string_model_t(data_m); }
        void print_(ostream& out) const { print(out, data_m); }
```

[redacted] guidelines [redacted]

client [redacted]

```
    explicit object_t(const T& x) : object_m(new model<T>(x))
    { }
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    object_t(const object_t& x) : object_m(x.object_m->copy_())
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        concept_t* copy_() const { return new string_model_t(data_m); }
        void print_(ostream& out) const { print(out, data_m); }
```

[redacted] cout guidelines defects

client [redacted]

```
    { }
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        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
```
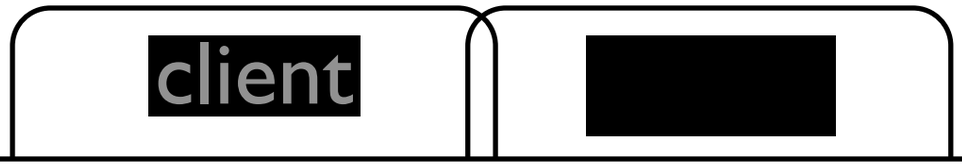

cout guidelines defects

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cout guidelines defects

client [redacted]

```
    object_t(const object_t& x) : object_m(x.object_m->copy_())
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```

cout guidelines defects

client [redacted]

```
    object_t(const object_t& x) : object_m(x.object_m->copy_())
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    concept_t* copy_() const { return new string_model_t(data_m); }
    void print_(ostream& out) const { print(out, data_m); }

    string data_m;
};

struct int_model_t : concept_t {
```

[redacted]

cout guidelines defects

client [redacted]

```
    { }
    object_t& operator=(object_t x)
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    friend void print(ostream& out, const object_t& x);
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```

[redacted]

cout guidelines defects

client [redacted]

```
    object_t& operator=(object_t x)
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        explicit int_model_t(const int& x) : data_m(x) { }
        concept_t* copy_() const { return new int_model_t(data_m); }
```

[redacted]

cout guidelines defects

client [redacted]

```
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
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    struct concept_t {
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        virtual concept_t* copy_() const = 0;
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[redacted]

cout guidelines defects

client [redacted]

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    friend void print(ostream& out, const object_t& x);
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[redacted]

cout guidelines defects

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    string data_m;
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  struct int_model_t : concept_t {
    explicit int_model_t(const int& x) : data_m(x) { }
    concept_t* copy_() const { return new int_model_t(data_m); }
    void print_(ostream& out) const { print(out, data_m); }

    int data_m;
```

client [redacted]

```
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
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```

cout guidelines defects

client [redacted]

```
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
    };

    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        concept_t* copy_() const { return new string_model_t(data_m); }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t : concept_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        concept_t* copy_() const { return new int_model_t(data_m); }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };
```

cout guidelines defects

client [redacted]

```
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
    };

    struct string_model_t : concept_t {
        explicit string_model_t(const string& x) : data_m(x) { }
        concept_t* copy_() const { return new string_model_t(data_m); }
        void print_(ostream& out) const { print(out, data_m); }

        string data_m;
    };

    struct int_model_t : concept_t {
        explicit int_model_t(const int& x) : data_m(x) { }
        concept_t* copy_() const { return new int_model_t(data_m); }
        void print_(ostream& out) const { print(out, data_m); }

        int data_m;
    };
```

cout guidelines defects

client [redacted]

```
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
    };
```

```
    concept_t* object_m;
};

void swap(object_t& x, object_t& y)
{
    swap(x.object_m, y.object_m);
}
```

cout guidelines defects

client [redacted]

```
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
    };

    template <typename T>
    struct model : concept_t {
        explicit model(const T& x) : data_m(x) { }
        concept_t* copy_() const { return new model(data_m); }
        void print_(ostream& out) const { print(out, data_m); }

        T data_m;
    };

    concept_t* object_m;
};

void swap(object_t& x, object_t& y)
{
    swap(x.object_m, y.object_m);
}
```

cout guidelines defects

[redacted] library

[redacted]

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(2));
```

[redacted]

```
    print(cout, document);
    return 0;
}
```

[redacted] defects

[redacted] library

```
class my_class_t {
    /* ... */
};

void print(ostream& out, const my_class_t& x)
{ out << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(2));
    document.push_back(object_t(my_class_t()));

    print(cout, document);
    return 0;
}
```

[redacted] defects

[redacted] | library

```
class my_class_t {
    /* ... */
};

void print(ostream& out, const my_class_t& x)
{ out << "my_class_t" << endl; }
```

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(2));
    document.push_back(object_t(my_class_t()));

    prin[redacted], document);
    return 0;
```

```
<document>
0
Hello
2
my_class_t
</document>
```

[redacted]

[redacted] library

```
class my_class_t {
    /* ... */
};

void print(ostream& out, const my_class_t& x)
{ out << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(2));
    document.push_back(object_t(my_class_t()));

    print(cout, docum[redacted]
    return 0;
```

- The runtime-concept idiom allows polymorphism when needed without inheritance.
  - Client isn't burdened with inheritance, factories, class registration, and memory management.
  - Penalty of runtime polymorphism is only payed when needed.
  - Polymorphic types are used like any other types, including built-in types.

[redacted] library

```
class my_class_t {
    /* ... */
};

void print(ostream& out, const my_class_t& x)
{ out << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));

    document.push_back(object_t(my_class_t()));

    print(cout, document);
    return 0;
}
```

[redacted] guidelines defects

[redacted] library

```
class my_class_t {
    /* ... */
};

void print(ostream& out, const my_class_t& x)
{ out << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(document));
    document.push_back(object_t(my_class_t()));

    print(cout, document);
    return 0;
}
```

[redacted] guidelines defects

[redacted] library

```
class my_class_t {
    /* ... */
};

void print(ostream& out, const my_class_t& x)
{ out << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(document));
```

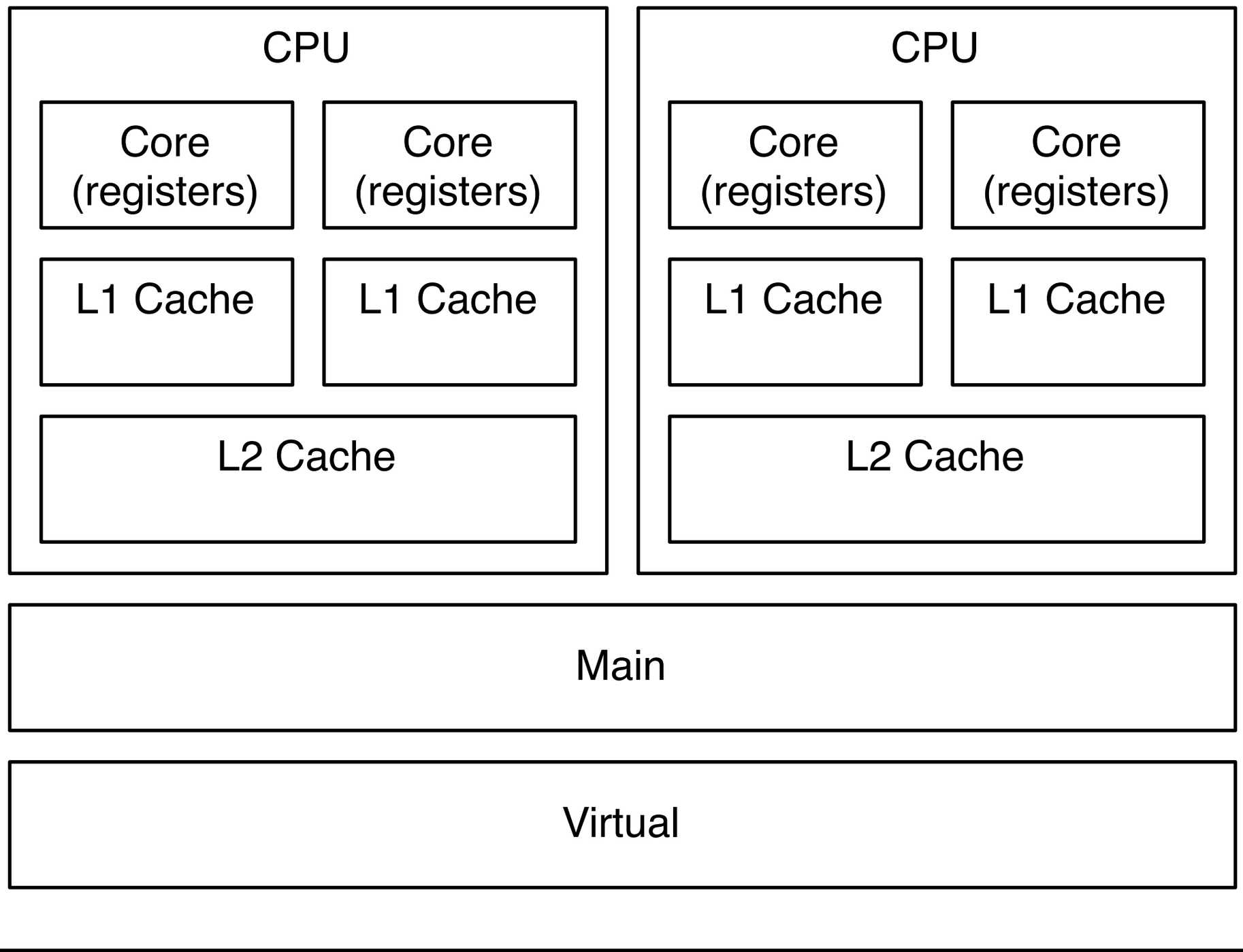
```
<document>
0
Hello
<document>
0
Hello
</document>
my_class_t
</document>
```

Classes Without Synchronization

- Using regular semantics for the common basis operations *copy, assignment,,* and *move*, help to reduce shared objects and improve thread safety
- Regular types promote interoperability of software components, increases productivity as well as quality, security, and performance
- There is no necessary performance penalty to using regular semantics, and often times there are performance benefits from a decreased use of the heap (currently a synchronization point on Mac and Windows).
- When constructs such as shared_ptr are used, or already in place, great care must be taken

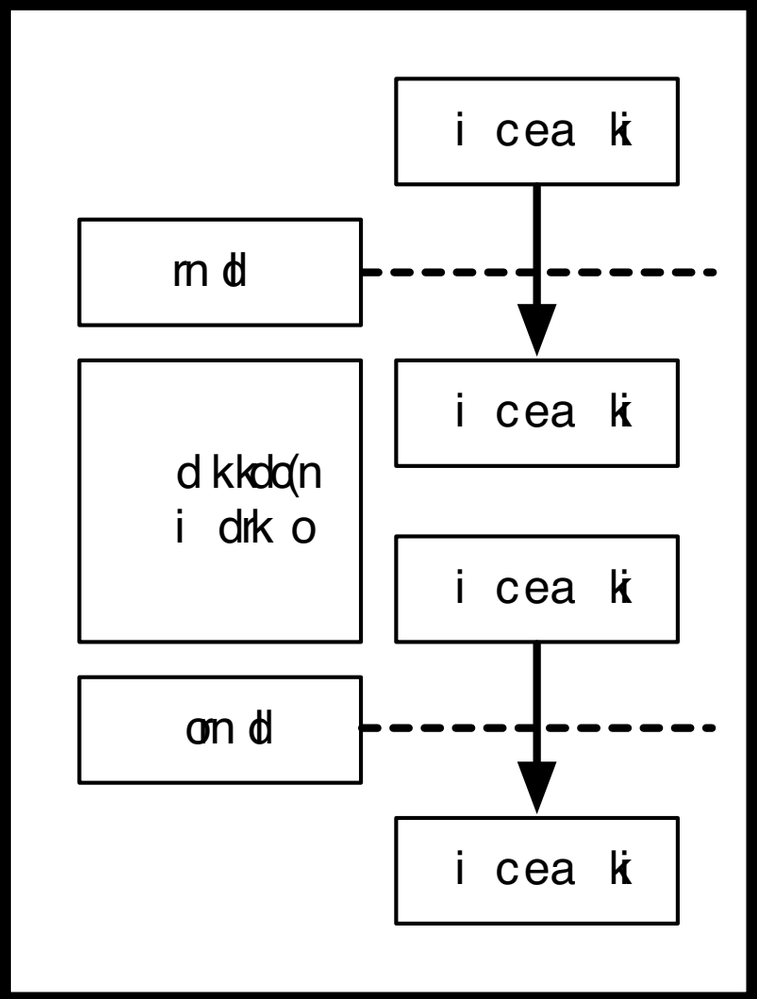
Synchronization

- Sometimes sharing is unavoidable, or the cost of avoidance is unacceptable
  - The cost of avoidance is sometimes amortized across the tasks
  - It may be better to write code that takes many times longer on one processor but scales linearly
- There are two basic synchronization primitives:
  - Locks
  - Atomics
- For modifying a single word of memory on a Core 2 Duo:
  - An Atomic takes 5x as long as direct memory access
  - A lock/unlock takes 10x as long as a direct memory access


CPU
Core (registers)
Core (registers)
L1 Cache
L1 Cache
L2 Cache
CPU
Core (registers)
Core (registers)
L1 Cache
L1 Cache
L2 Cache
Main
Virtual

Locks

- Lock state is aquired / released atomically
- Compiler barrier prevents load / stores from moving out of critical section
  - But they can move into the critical section
- Memory barrier provides partial ordering of read / writes to main memory with respect to corresponding locks
- Double-Check-Locking fails because there is no guarantee that the memory written by the critical section occurs before the write to the checked value - a *race condition*



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Atomics

- Atomic operations only guarantee atomicity regarding the value being operated on
- Atomics do not provide a compiler or memory barrier

- You cannot build a lock from an atomic

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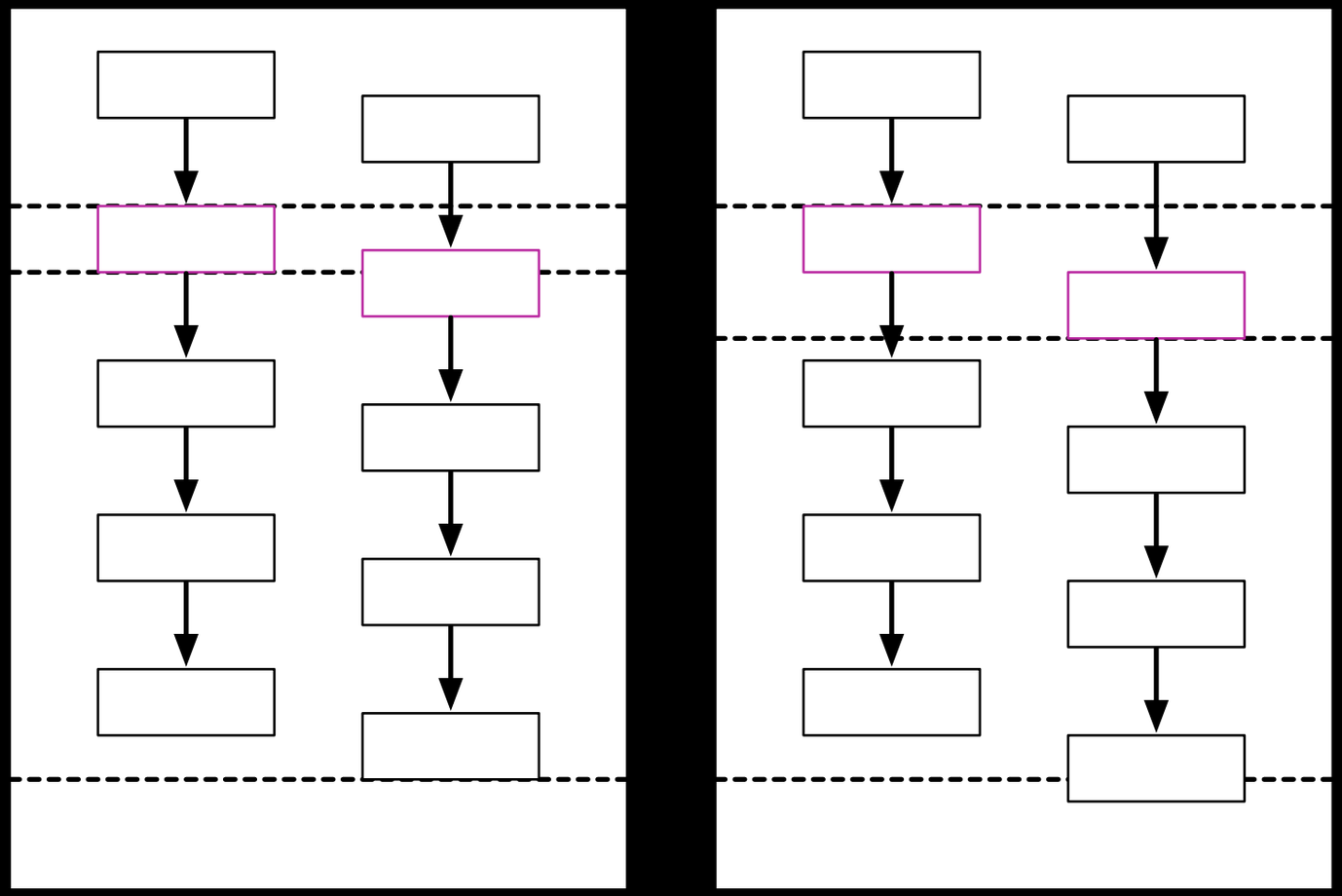
Problems with Locks

- Deadlock: Multiple tasks wait for each other and will not resume until the other task proceeds
  - Avoid using locks, especially multiple locks at the same time. If you must use multiple locks, then always aquire/release them in a strictly scoped manner
- Race Condition: Multiple tasks read from and write to the same memory location without proper synchronization
  - Avoid shared data. Manage shared data in a disciplined manner

Problems with Locks

- Starvation: More threads are executing than allowed by the proportion of the critical sections leading to high lock contention (see Amdahl's Law)
  - Avoid using locks. Hold locks as briefly as possible. Use *shared* locks when possible.
- Livelock: A result of starvation when some tasks cannot acquire a resource and forward progress is halted
  - Avoid using locks. Use *fair* locks unless you can be certain of light contention even with many processors under heavy load. Use shared locks when possible.
- Convoying: When a task is interrupted while holding or waiting for a lock causing other task to reach the lock and wait
  - Avoid using locks. Use *spin* locks if you are certain of light contention. Use shared locks when possible.

Locks and Performance



Adobe

Common Use Cases for Sharing

- Singletons: Singletons (or any global) within an application must be sharable or all code accessing the shared instance must be synchronized
  - Do not force client code to directly manage sharing, treat object consistency in the presence of concurrency as any other invariant and protect it behind an API

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Disclaimer

- Some classes in the following code do not provide implementations of that standard basis operations for regular types and for brevity, the compiler supplied operations are not suppressed even if incorrect

- Complete implementations are left as an exercise

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[redacted] library

[redacted] defects

[redacted] library

```
/*
    Question: Is singleton thread safe?
*/

const string singleton("Hello World!");

void print_singleton(ostream& out) { out << singleton << endl; }

int main()
{
    thread t1(bind(&print_singleton, ref(cout)));
    thread t2(bind(&print_singleton, ref(cerr)));

    return 0;
}
```

[redacted] defects

[redacted] library

```
/*
    Question: Is singleton thread safe?
*/

const string singleton("Hello World!");

void print_singleton(ostream& out) { out << singleton << endl; }

int main()
{
    thread t1(bind(&print_singleton, ref(cout)));
    thread t2(bind(&print_singleton, ref(cerr)));
    [redacted]
    return 0;
```

----- cout -----

Hello World!

----- cerr -----

Hello World!

[redacted] library

```
/*
    Question: Is singleton thread safe?
*/

const string singleton("Hello World!");

void print_singleton(ostream& out) { out << singleton << endl; }

int main()
{
    thread t1(bind(&print_singleton, ref(cout)));
    thread t2(bind(&print_singleton, ref(cerr)));

    return 0;
}
```

[redacted]

- Globals are initialized in a thread safe manner prior to any call in the unit.
- But globals slow application launch and should be avoided.

[redacted] library

[redacted] defects

[redacted] library

```
struct aggregate_string
{
    char* data_m;
    operator string () const { return data_m; }
};

const aggregate_string singleton = { "Hello World!" };

void print_singleton(ostream& out) { out << string(singleton) << endl; }

int main()
{
    thread(bind(&print_singleton, ref(cout)));
    thread(bind(&print_singleton, ref(cerr)));

    return 0;
}
```

[redacted] defects

[redacted] library

```
struct aggregate_string
{
    char* data_m;
    operator string () const { return data_m; }
};

const aggregate_string singleton = { "Hello World!" };

void print_singleton(ostream& out) { out << string(singleton) << endl; }

int main()
{
    [redacted]
    thread(bind(&print_singleton, ref(cout)));
```

```
----- cout -----
Hello World!
----- cerr -----
Hello World!
```

```
struct aggregate_string
{
    char* data_m;
    operator string () const { return data_m; }
};

const aggregate_string singleton = { "Hello World!" };

void print_singleton(ostream& out) { out << string(singleton) << endl; }

int main()
{
    thread(bind(&print_singleton, ref(cout)));
    thread(bind(&print_singleton, ref(cerr)));

    return 0;
}
```

[redacted]

- Types with no-user defined constructors (including for members) can be used to reduce startup time
- Sometimes this causes a tradeoff with cost of use vs. initialization

[redacted] library

[redacted] defects

[redacted] library

```
struct cons
{
    const char* name_m;
    const cons* next_m;
};

const cons x = { "x" };
const cons y = { "y", &x };
const cons z = { "z", &y };
const cons w = { "w", &y };

int main()
{
    for (const cons* f = &z; f != 0; f = f->next_m) cout << f->name_m << "->";
    cout << endl;

    for (const cons* f = &w; f != 0; f = f->next_m) cout << f->name_m << "->";
    cout << endl;

    return 0;
}
```

[redacted] defects

```
struct cons
{
    const char* name_m;
    const cons* next_m;
};

const cons x = { "x" };
const cons y = { "y", &x };
const cons z = { "z", &y };
const cons w = { "w", &y };
```

```
int main()
{
    [redacted]
    for (const cons* f = &z; f != 0; f = f->next_m) cout << f->name_m << "->";
```

z->y->x->

w->y->x->

[redacted] library

```
struct cons
{
    const char* name_m;
    const cons* next_m;
};

const cons x = { "x" };
const cons y = { "y", &x };
const cons z = { "z", &y };
const cons w = { "w", &y };
```

```
int main()
{
    for (const cons* f = &z; f != 0; f = f->next_m) cout << f->name_m << "->";
    cout << endl;

    for (const cons* [redacted]; f = f->next_m) cout << f->name_m << "->";
```

- It's possible to create compile time structures
- Combining templates with static class members allows for fairly complex structures

[redacted] library

[redacted] defects

[redacted] library

```
int main()
{
    typedef adobe::vector<double[2]> complex_set_t;

    cout << adobe::type_info<complex_set_t>() << endl;

    return 0;
}
```

[redacted] defects

[redacted] library

```
int main()
{
    typedef adobe::vector<double[2]> complex_set_t;

    cout << adobe::type_info<complex_set_t>() << endl;

    return 0;
}
```

[redacted]

vector:version_1:adobe<array[0000000002]<double>>

[redacted] library

```
int main()
{
    typedef adobe::vector<double[2]> complex_set_t;

    cout << adobe::type_info<complex_set_t>() << endl;

    return 0;
}
```

[redacted]

- ASL uses const aggregates to simulate RTTI in a form which is ABI safe
- ASL uses similar techniques to simulate v-tables and inheritance

[redacted] library

[redacted] defects

[redacted] library

```
/*
    Question: Is singleton thread safe?
*/

const string& singleton()
{
    static const string result("Hello World!");
    return result;
}

void print_singleton(ostream& out) { out << singleton() << endl; }

int main()
{
    thread t1(bind(&print_singleton, ref(cout)));
    thread t2(bind(&print_singleton, ref(cerr)));

    return 0;
}
```

[redacted] defects

[redacted] library

```
/*
    Question: Is singleton thread safe?
*/

const string& singleton()
{
    static const string result("Hello World!");
    return result;
}

void print_singleton(ostream& out) { out << singleton() << endl; }

int main[redacted]
{
```

?????

[redacted] library

```
/*
    Question: Is singleton thread safe?
*/

const string& singleton()
{
    static const string result("Hello World!");
    return result;
}

void print_singleton(ostream& out) { out << singleton() << endl; }

int main()
{
    thread t1(bind(&print_singleton, ref(cout)));
    thread t2(bind(&p[redacted], ref(cerr)));
```

- With GCC, this code is correct
- With VC, this code is a potential race and may crash

- With C++0x, this code will be correct

[redacted] library

```
/*
    Question: Is singleton thread safe?
*/
```

```
void once_singleton(const string*& x)
{
    static const string result("Hello World!");
    x = &result;
}

const string& singleton()
{
    static const string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}
```

```
void print_singleton(ostream& out) { out << singleton() << endl; }

int main()
{
```

[redacted] defects

[redacted] library

```
/*
    Question: Is singleton thread safe?
*/

void once_singleton(const string*& x)
{
    static const string result("Hello World!");
    x = &result;
}

const string& singleton()
{
    stat[redacted]st string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;
```

```
----- cout -----
Hello World!
----- cerr -----
Hello World!
```

[redacted] library

```
/*
    Question: Is singleton thread safe?
*/
```

```
void once_singleton(const string*& x)
{
    static const string result("Hello World!");
    x = &result;
}

const string& singleton()
{
    static const string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, b[redacted]leton, ref(result)));
    return *result;
}
```

- Use call_once to assure that singletons are correctly initialized
- call_once does have cost on *every* invocation (check of once_flag is atomic)

- I've made a couple of attempts at writing a useful template that will do the correct initialization depending on the compiler - I don't have anything simpler than this yet

```
/*
    Question: Is singleton thread safe?
*/
```

```
void once_singleton(string*& x)
{
    static string result("Hello World!");
    x = &result;
}

string& singleton()
{
    static string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}
```

```
void print_singleton(ostream& out) { out << singleton() << endl; }

int main()
{
```

[redacted] library

```
void once_singleton(string*& x)
{
    static string result("Hello World!");
    x = &result;
}

string& singleton()
{
    static string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}

void print_singleton(ostream& out) { out << singleton() << endl; }

int main()
{
    thread t1(bind(&print_singleton, ref(cout)));
    thread t2(bind(&print_singleton, ref(cerr)));

    return 0;
```

cout guidelines defects

[redacted] library

```
void once_singleton(string*& x)
{
    static string result("Hello World!");
    x = &result;
}

string& singleton()
{
    static string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}

void print_singleton(ostream& out) { out << singleton() << endl; }
void modify_singleton() { singleton() = "Goodbye Cruel World!"; }

int main()
{
    thread t1(bind(&print_singleton, ref(cout)));
    thread t2(bind(&print_singleton, ref(cerr)));
```

cout guidelines defects

[redacted] library

```
void once_singleton(string*& x)
{
    static string result("Hello World!");
    x = &result;
}

string& singleton()
{
    static string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}

void print_singleton(ostream& out) { out << singleton() << endl; }
void modify_singleton() { singleton() = "Goodbye Cruel World!"; }

int main()
{
    thread t1(bind(&print_singleton, ref(cout)));
    thread t2(bind(&print_singleton, ref(cerr)));
```

cout guidelines defects

[redacted] library

```
void once_singleton(const string*& x)
{
    static string result("Hello World!");
    x = &result;
}

string& singleton()
{
    static string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}

void print_singleton(ostream& out) { out << singleton() << endl; }
void modify_singleton() { singleton() = "Goodbye Cruel World!"; }

int main()
{
    thread t1(bind(&modify_singleton));
    thread t2(bind(&print_singleton, ref(cerr)));
```

[redacted] cout

[redacted] library

```
void once_singleton(const string*& x)
{
    static string result("Hello World!");
    x = &result;
}

string& singleton()
{
    static string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}

void print_singleton(ostream& out) { out << singleton() << endl; }
void modify_singleton() { singleton() = "Goodbye Cruel World!"; }

int main()
{
    thread t1(bind(&modify_singleton));
    thread t2(bind(&print_singleton, ref(cerr)));
```

cout

[redacted] library

```
void once_singleton(const string*& x)
{
    static string result("Hello World!");
    x = &result;
}

string& singleton()
{
    static string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}

void print_singleton(ostream& out) { out << singleton() << endl; }
void modify_singleton() { singleton() = [redacted]ruel World!"; }
```

- This will create a race condition and could cause a crash

[redacted] library

```
void once_singleton(const string*& x)
{
    static string result("Hello World!");
    x = &result;
}

string& singleton()
{
    static string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}

void print_singleton([redacted]{ out << singleton() << endl; }
void modify_singleton[redacted]() = "Goodbye Cruel World!"; }
```

- There is no simple fix for allowing direct read/write access to the client
- We need to figure out how we can allow access to the basis operations and protect the invariants

[redacted] library

```
class shared_string
{
    mutable shared_mutex    mutex_m;
    string                  data_m;
 public:
    explicit shared_string(const char* x) : data_m(x) { }
    shared_string& operator=(const char* x) {
        lock_guard<shared_mutex> lock(mutex_m);
        data_m = x;
        return *this;
    }
    operator string () const {
        shared_lock<shared_mutex> lock(mutex_m);
        return data_m;
    }
};
```

```
void once_singleton(const string*& x)
{
    static string result("Hello World!");
    x = &result;
}
```

cout guidelines defects

```
void once_singleton(const string*& x)
{
    static string result("Hello World!");
    x = &result;
}

string& singleton()
{
    static string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}

void print_singleton(ostream& out) { out << singleton() << endl; }
void modify_singleton() { singleton() = "Goodbye Cruel World!"; }

int main()
{
    thread t1(bind(&modify_singleton));
    thread t2(bind(&print_singleton, ref(cerr)));
```

[redacted] library

```
void once_singleton(shared_string*& x)
{
    static shared_string result("Hello World!");
    x = &result;
}

shared_string& singleton()
{
    static shared_string* result = 0;
    static once_flag flag = BOOST_ONCE_INIT;

    call_once(flag, bind(&once_singleton, ref(result)));
    return *result;
}

void print_singleton(ostream& out) { out << string(singleton()) << endl; }
void modify_singleton() { singleton() = "Goodbye Cruel World!"; }

int main()
{
    thread t1(bind(&modify_singleton));
    thread t2(bind(&print_singleton, ref(cerr)));
```

cout guidelines defects

[redacted] library

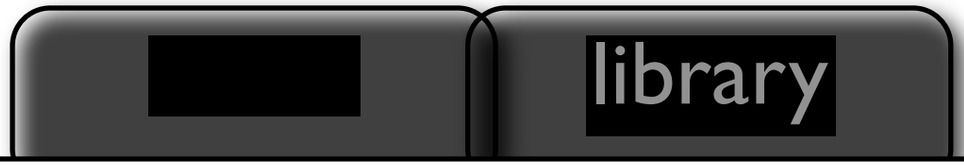
cout guidelines defects

[redacted] library

```
const char* table[] = {
    "width",
    "height",
    "orientation"
};

const char* lookup(const char* x)
{
    static bool init;
    if (!init) { sort(table, str_less_t()); init = true; }
    return *lower_bound(table, x, str_less_t());
}
```

cout guidelines defects


library


cout
defects

[redacted] library

```
const char* const table[] = {
    "height",
    "orientation",
    "width"
};

const char* lookup(const char* x)
{
    #ifndef NDEBUG
    static bool init;
    if (!init) { init = true; assert(is_sorted(table, str_less_t()) && "FATAL: Table
must be sorted");
    #endif
    return *lower_bound(table, x, str_less_t());
}
```

cout defects

Common Use Cases for Sharing

- Reference Counting: A common use case for atomics is reference counts
- An atomic count only protects the count - not the rest of the object
- shared_ptr to a mutable object has all of the same issues as singletons
  - "A shared_ptr is as good as a global variable."
- If you have a shared_ptr to an immutable object, you can optimize the case where the pointer isn't shared and allow modification - this is copy-on-write
- Since we can implement polymorphism without inheritance, our copy-on-write can operate on values instead of pointers
  - Programming is much less error prone when you eliminate the use of pointers

[redacted] library

cout guidelines

[redacted] library

```
template <typename T>
class bad_cow {
    struct object_t {
        explicit object_t(const T& x) : data_m(x) { ++count_m; }
        atomic<int> count_m;
        T           data_m; };
    object_t* object_m;
 public:
    explicit bad_cow(const T& x) : object_m(new object_t(x)) { }
    ~bad_cow() { if (0 == --object_m->count_m) delete object_m; }
    bad_cow(const bad_cow& x) : object_m(x.object_m) { ++object_m->count_m; }

    bad_cow& operator=(const T& x) {
        if (object_m->count_m == 1) object_m->data_m = x;
        else {
            object_t* tmp = new object_t(x);
            --object_m->count_m;
            object_m = tmp;
        }
        return *this;
    }
};
```

cout guidelines

```
template <typename T>
class bad_cow {
    struct object_t {
        explicit object_t(const T& x) : data_m(x) { ++count_m; }
        atomic<int> count_m;
        T           data_m; };
    object_t* object_m;
 public:
    explicit bad_cow(const T& x) : object_m(new object_t(x)) { }
    ~bad_cow() { if (0 == --object_m->count_m) delete object_m; }
    bad_cow(const bad_cow& x) : object_m(x.object_m) { ++object_m->count_m; }

    bad_cow& operator=(const T& x) {
        if (object_m->count_m == 1) object_m->data_m = x;
        else {
            object_t* tmp = new object_t(x);
            --object_m->count_m;
            object_m = tmp;
        }
        return *this;
    }
};
```

[redacted] library

```
template <typename T>
class bad_cow {
    struct object_t {
        explicit object_t(const T& x) : data_m(x) { ++count_m; }
        atomic<int> count_m;
        T           data_m; };
    object_t* object_m;
 public:
    explicit bad_cow(const T& x) : object_m(new object_t(x)) { }
    ~bad_cow() { if (0 == --object_m->count_m) delete object_m; }
    bad_cow(const bad_cow& x) : object_m(x.object_m) { ++object_m->count_m; }

    bad_cow& operator=(const T& x) {
        if (object_m->count_m == 1) object_m->data_m = x;
        else {
            object_t* tmp = new object_t(x);
            --object_m->count_m;
            object_m = tmp;
```

- There is a subtle race condition here:
  - if count != 1 then the bad_cow could also is owned by another thread(s)
  - if the other thread(s) releases the bad_cow between these two atomic operations
  - then our count will fall to zero and we will leak the object

```
template <typename T>
class bad_cow {
    struct object_t {
        explicit object_t(const T& x) : data_m(x) { ++count_m; }
        atomic<int> count_m;
        T           data_m; };
    object_t* object_m;
 public:
    explicit bad_cow(const T& x) : object_m(new object_t(x)) { }
    ~bad_cow() { if (0 == --object_m->count_m) delete object_m; }
    bad_cow(const bad_cow& x) : object_m(x.object_m) { ++object_m->count_m; }

    bad_cow& operator=(const T& x) {
        if (object_m->count_m == 1) object_m->data_m = x;
        else {
            object_t* tmp = new object_t(x);
            if (0 == --object_m->count_m) delete object_m;
            object_m = tmp;
        }
        return *this;
    }
};
```

cout guidelines defects

Common Use Cases for Sharing

- One common concern with using regular types vs. shared pointers is that you end up with too many copies
- By leveraging RVO with the ASL move library, and copy_on_write, all unnessary copies can be eliminated

Adobe

client [redacted]

```
}

void print(ostream& out, const object_t& x)
{ x.object_m->print_(out); }

typedef vector<object_t> document_t;

void print(ostream& out, const document_t& x)
{
    out << "<document>" << endl;
    for (document_t::const_iterator f = x.begin(), l = x.end(); f != l; ++f) {
        print(out, *f);
    }
    out << "</document>" << endl;
}
```

```
typedef adobe::vector<document_t> history_t;

void commit(history_t& x) { assert(x.size()); x.push_back(x.back()); }
void undo(history_t& x) { assert(x.size() > 1); x.pop_back(); }
document_t& current(history_t& x) { assert(x.size()); return x.back(); }
```

[redacted] cout guidelines defects

client [redacted]

```
}

void print(ostream& out, const object_t& x)
{ x.object_m->print_(out); }

typedef adobe::vector<copy_on_write<object_t> > document_t;

void print(ostream& out, const document_t& x)
{
    out << "<document>" << endl;
    for (document_t::const_iterator f = x.begin(), l = x.end(); f != l; ++f) {
        print(out, **f);
    }
    out << "</document>" << endl;
}

typedef adobe::vector<document_t> history_t;

void commit(history_t& x) { assert(x.size()); x.push_back(x.back()); }
void undo(history_t& x) { assert(x.size() > 1); x.pop_back(); }
document_t& current(history_t& x) { assert(x.size()); return x.back(); }
```

cout guidelines defects

client [redacted]

```
class object_t {
 public:
    template <typename T>
    explicit object_t(const T& x) : object_m(new model<T>(x))
    { }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(x.object_m->copy_())
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
    };

    template <typename T>
    struct model : concept_t {
```

cout guidelines defects

```
class object_t {
 public:
    template <typename T>
    explicit object_t(const T& x) : object_m(new model<T>(x))
    { cout << "copy-ctor" << endl; }
    ~object_t() { delete object_m; }

    object_t(const object_t& x) : object_m(x.object_m->copy_())
    { }
    object_t& operator=(object_t x)
    { swap(*this, x); return *this; }

    object_t(move_from<object_t> x) : object_m(x.source.object_m)
    { x.source.object_m = 0; }

    friend void print(ostream& out, const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_(ostream& out) const = 0;
    };
```

```
class my_class_t
{
    /* ... */
};

void print(ostream& out, const my_class_t& x)
{ out << "my_class_t" << endl; }

int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(document));
    document.push_back(object_t(my_class_t()));

    print(cout, document);
    return 0;
}
```

cout guidelines defects

[redacted] library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(string("Hello")));
    document.push_back(object_t(document));
    document.push_back(object_t(my_class_t()));

    print(cout, document);
    return 0;
}
```

cout guidelines defects

Concluding Remarks

- Q & A

- References:
- Memory Barriers:
  - http://lxr.linux.no/linux/Documentation/memory-barriers.txt
- C++ Memory Model:
  - http://www.hpl.hp.com/personal/Hans_Boehm/
- Regular Types:
  - http://stepanovpapers.com/

client [redacted]

```
struct shape_t
{
    virtual ~shape_t() { }
    virtual void draw() = 0;
};

typedef vector<shared_ptr<shape_t> > document_t;

struct circle_t : shape_t
{
    void draw() { cout << "circle_t" << endl; }
};
```

cout guidelines defects

[redacted] library

```
int main()
{
    document_t document;
    document.push_back(shared_ptr<shape_t>(new circle_t));

    for (document_t::const_iterator f = document.begin(), l = document.end();
          f != l; ++f) {
        (**f).draw();
    }

    return 0;
}
```

[redacted] guidelines defects

[redacted] | library

```
int main()
{
    document_t document;
    document.push_back(shared_ptr<shape_t>(new circle_t));

    for (document_t::const_iterator f = document.begin(), l = document.end();
         [redacted] l; ++f) {
        (**f).draw();
```

circle_t

client [redacted]

```
struct shape_t
{
    virtual ~shape_t() { }
    virtual void draw_() const = 0;
};

typedef std::vector<shared_ptr<shape_t> > document_t;

struct circle_t : shape_t
{
    void draw_() const { cout << "circle_t" << endl; }
};

template <typename T>
void draw(const T& x) { x.draw(); }

template <typename T>
struct poly_shape_t : shape_t
{
    explicit poly_shape_t(T x) : data_m(move(x)) { }
    void draw_() const { draw(data_m); }

    T data_m;
```

[redacted] cout guidelines defects

client [redacted]

```
};

template <typename T>
void draw(const T& x) { x.draw(); }

template <typename T>
struct poly_shape_t : shape_t
{
    explicit poly_shape_t(T x) : data_m(move(x)) { }
    void draw_() const { draw(data_m); }

    T data_m;
};

template <typename T>
shared_ptr<shape_t> make_poly_shape(T x)
{ return shared_ptr<shape_t>(new poly_shape_t<T>(move(x))); }
```

cout guidelines defects

[redacted] library

```
struct square_t
{
    void draw() const { cout << "square_t" << endl; }
};

void draw(const int& x) { cout << x << endl; }

int main()
{
    document_t document;
    document.push_back(shared_ptr<shape_t>(new circle_t));
    document.push_back(make_poly_shape(square_t()));
    document.push_back(make_poly_shape(int(10)));

    for (document_t::const_iterator f = document.begin(), l = document.end();
            f != l; ++f) {
        (**f).draw_();
    }

    return 0;
}
```

[redacted] guidelines defects

[redacted] library

```
struct square_t
{
    void draw() const { cout << "square_t" << endl; }
};

void draw(const int& x) { cout << x << endl; }

int main()
```

circle_t
square_t
10

client [redacted]

```
struct shape_t
{
    virtual ~shape_t() { }
    virtual void draw_() const = 0;
};

template <typename T>
struct disable_if_is_shape_t_pointer :
    disable_if<is_base_and_derived<shape_t, typename remove_pointer<T>::type> >
{ };
```

```
struct poly_shape_t
{
    template <typename T>
    explicit poly_shape_t(T x, typename disable_if_is_shape_t_pointer<T>::type* = 0)
        : object_m(new model_t<T>(move(x))) { }
    explicit poly_shape_t(shape_t* p) : object_m(p) { }
    ~poly_shape_t() { delete object_m; }
    poly_shape_t(const poly_shape_t& x)
        : object_m(dynamic_cast<concept_t&>(*x.object_m).copy_()) { }
    poly_shape_t(move_from<poly_shape_t> x)
        : object_m(x.source.object_m) { x.source.object_m = 0; }
    poly_shape_t& operator=(poly_shape_t x) { swap(*this, x); return *this; }
```

cout guidelines defects

client [redacted]

```
poly_shape_t& operator=(poly_shape_t x) { swap(*this, x); return *this; }
friend inline void swap(poly_shape_t& x, poly_shape_t& y)
   { swap(x.object_m, y.object_m); }
friend inline void draw(const poly_shape_t& x) { x.object_m->draw_(); }

struct concept_t : shape_t
{
    virtual concept_t* copy_() = 0;
};

template <typename T>
struct model_t : concept_t
{
    explicit model_t(T x) : data_m(move(x)) { }
    void draw_() const { draw(data_m); }
    concept_t* copy_() { return new model_t(data_m); }

    T data_m;
};

shape_t* object_m;
};
```

[redacted] guidelines [redacted]

client [redacted]

```
poly_shape_t& operator=(poly_shape_t x) { swap(*this, x); return *this; }
friend inline void swap(poly_shape_t& x, poly_shape_t& y)
   { swap(x.object_m, y.object_m); }
friend inline void draw(const poly_shape_t& x) { x.object_m->draw_(); }

struct concept_t : shape_t
{
    virtual concept_t* copy_() = 0;
};

template <typename T>
struct model_t : concept_t
{
    explicit model_t(T x) : data_m(move(x)) { }
    void draw_() const { draw(data_m); }
    concept_t* copy_() { return new model_t(data_m); }

    T data_m;
};

shape_t* object_m;
};
```

[redacted] guidelines defects

client [redacted]

```
typedef vector<poly_shape_t> document_t;

struct circle_t : shape_t
{
    void draw_() const { cout << "circle_t" << endl; }
};

template <typename T>
void draw(const T& x) { x.draw(); }
```

cout guidelines defects

[redacted] library

```
struct square_t
{
    void draw() const { cout << "square_t" << endl; }
};

void draw(const int& x) { cout << x << endl; }

int main()
{
    document_t document;
    document.push_back(poly_shape_t(new circle_t));
    document.push_back(poly_shape_t(square_t()));
    document.push_back(poly_shape_t(int(10)));

    for_each(document, bind((void(*)(const poly_shape_t&))(&draw), _1));

    return 0;
}
```

[redacted] guidelines defects

[redacted] library

```
struct square_t
{
    void draw() const { cout << "square_t" << endl; }
};

void draw(const int& x) { cout << x << endl; }

int main()
```

circle_t
square_t
10