Classes that Work

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About this Talk

- Interoperability of software components increases productivity as well as quality, security, and performance
- This talk is from Adobe's Software Technology Lab which is responsible for developing better ways to write code

- This talk focuses on two of the basic operations of all types, copy and assignment, it is not the whole story but presents an interesting taste of the techniques being developed
- Proficiency with C++ and STL is assumed
- The proper use of header files, inline functions, and namespaces are ignored for clarity

client | library

cout | guidelines

client | library

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

cout | guidelines | defects

client | library

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

Hello World!

client

library

client | library

```
typedef int object_t;

void print(const object_t& x) { cout << x << endl; }

typedef vector<object_t> document_t;

void print(const document_t& x)
{
    cout << "<document>" << endl;
    for_each(x.begin(), x.end(), (void (*)(const object_t&))(&print));
    cout << "</document>" << endl;
}
```

cout | guidelines

client | library

cout | guidelines | defects

client | library

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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(document);
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cout | guidelines | defects

client | library

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cout

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<document>
0
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client | library

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    document.push_back(object_t(3));

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

guidelines

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

client | library

```
typedef int object_t;

void print(const object_t& x) { cout << x << endl; }

typedef vector<object_t> document_t;

void print(const document_t& x)
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    cout << "<document>" << endl;
    for_each(x.begin(), x.end(), (void (*)(const object_t&))(&print));
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}
```

cout | guidelines

client | library

```
typedef vector<object_t> document_t;

void print(const document_t& x)
{
    cout << "<document>" << endl;
    for_each(x.begin(), x.end(), (void (*)(const object_t&))(&print));
    cout << "</document>" << endl;
}
```

cout | guidelines | defects

client | **library**

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

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

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

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

```
typedef vector<object_t> document_t;

void print(const document_t& x)
{
    cout << "<document>" << endl;
    for_each(x.begin(), x.end(), (void (*)(const object_t&))(&print));
    cout << "</document>" << endl;
}
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cout | **guidelines** | defects

client | library

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

class object_t {
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    { }

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 private:
    int object_m;
};

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

typedef vector<object_t> document_t;

void print(const do
```

guidelines

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

client | 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(document);
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cout | guidelines | defects

client | library

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    print(document);
    return 0;
}
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cout

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client | library

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

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

guidelines

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

client | library

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

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

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

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

typedef vector<object_t> document_t;

void print(const document_t& x)
{
    cout << "<document>" << endl;
    for_each(x.begin(), x.end(), (void (*)(const object_t&))(&print));
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client | library

```
class object_t {
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    { }

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

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

```
typedef vector<object_t> document_t;

void print(const document_t& x)
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    cout << "<document>" << endl;
    for_each(x.begin(), x.end(), (void (*)(const object_t&))(&print));
    cout << "</document>" << endl;
}
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cout | guidelines | defects

client | library

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class object_t {
 public:
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    friend void print(const object_t& x);
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void print(const object_t& x)
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```
typedef vector<object_t> document_t;

void print(const document_t& x)
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cout | guidelines

client | library

```
class object_t {
 public:
```

```
typedef vector<object_t> document_t;

void print(const document_t& x)
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cout | guidelines

client | library

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

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

        int data_m;
    };

    int_model_t* object_m;
};

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

```
typedef vector<object_t> document_t;

void print(const document_t& x)
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cout | guidelines

client | library

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class object_t {
 public:
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cout | guidelines

client | library

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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(const object_t& x);
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cout | guidelines

client | library

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        int data_m;
    };

    int_model_t* object_m;
};
```

guidelines

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

client | library

```
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(const object_t& x);
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        int data_m;
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```

cout | guidelines

client | library

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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; }

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

    friend void print(const object_t& x);
 private:
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cout | guidelines | defects

client | library

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

        int data_m;
    };
```

guidelines

- 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 | library

```
class object_t {
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    friend void print(const object_t& x);
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    struct int_model_t {
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cout | guidelines

client | library

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class object_t {
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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(const object_t& x);
 private:
    struct int_model_t {
        explicit int_model_t(const int& x) : data_m(x) { }
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cout | guidelines

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

        int data_m;
```

guidelines

- Assignment is consistent with copy. Generally:

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

client | library

```
int main()
{
    document_t document;

    document.push_back(object_t(0));
    document.push_back(object_t(1));
    document.push_back(object_t(2));
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    print(document);
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}
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cout | guidelines

client | library

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cout

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<document>
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client | library

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guidelines

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

client | **library**

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class object_t {
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    explicit object_t(const int& x) : object_m(new int_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=(const object_t& x)
    { delete object_m; object_m = new int_model_t(*x.object_m); return *this; }

    friend void print(const object_t& x);
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        int data_m;
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    int_model_t* object_m;
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cout | guidelines | **defects**

client | library

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        void print_() const { print(data_m); }

        int data_m;
    };
```

defects

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

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

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    { object_t tmp(x); swap(*this, tmp); return *this; }
    friend void print(const object_t& x);
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cout | guidelines

client | library

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    struct int_model_t {
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        void print_() const { print(data_m); }

        int data_m;
```

guidelines

- 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 | library

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cout | guidelines

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

    friend void print(const object_t& x);
    friend void swap(object_t& x, object_t& y);
 private:
    struct int_model_t {
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cout | guidelines

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        int data_m;
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    int_model_t* object_m;
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void print(const object_t& x)
```

cout | guidelines

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```
    { }
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    struct int_model_t {
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        int data_m;
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void print(const object_t& x)
{ x.object_m->print_(); }
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cout | guidelines | defects

client | library

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    ~object_t() { delete object_m; }

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void print(const object_t& x)
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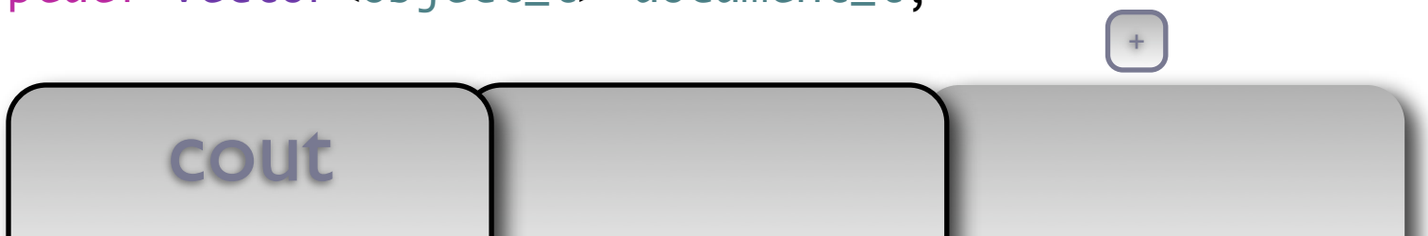
typedef vector<object_t> document_t;
```



client | library

```
    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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

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

typedef vector<object_t> document_t;
```

cout | guidelines | defects

client | library

```
    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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines

client | library

```
    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(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_() const { print(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

client | 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(document);
    return 0;
}
```

cout | guidelines

client | 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(document);
    return 0;
}
```

cout | guidelines

client | 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(document);
    return 0;
}
```

cout

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

client | 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(document);
    return 0;
}
```

guidelines

- 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 | library

```
    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(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_() const { print(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

client | library

```
    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(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_() const { print(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

client | library

```
    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(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_() const { print(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 | library

```
    ~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(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_() const { print(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

```
{ }
~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(const object_t& x);
friend void swap(object_t& x,
```

client | library

```
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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};

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

cout | guidelines

client | library

```
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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines | defects

client | library

```
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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines

client | library

```
class object_t {
 public:
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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)
    { object_t tmp(x); swap(*this, tmp); return *this; }

    friend void print(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines | defects

client | library

```
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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines

client | library

cout | guidelines

client | library

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

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

    object_t x = function();

    return 0;
}
```

cout | guidelines | defects

client | library

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

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

    object_t x = function();

    return 0;
}
```

cout

ctor

client | library

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

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

```
    return 0;
}
```

cout | guidelines

client | library

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

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

    object_t x(0);

    x = function();

    return 0;
}
```

cout | guidelines

client | library

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

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

    object_t x(0);

    x = function();

    return 0;
}
```

cout

```
ctor
ctor
copy
```

client | library

```
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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines

client | library

```
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; }
```

```
    friend void print(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines

client | library

```
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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines | +

client | library

```
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(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_data() const { cout << data_m); }
```

guidelines

- 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.

client | library

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

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

    object_t x(0);

    x = function();

    return 0;
}
```

cout | guidelines

client | library

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

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

    object_t x(0);

    x = function();

    return 0;
}
```

cout

```
ctor
ctor
```

client | library

```
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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines | defects

client | library

```
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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines

client | library

```
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(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_() const { print(data_m); }

        int data_m;
    };

    int_model_t* object_m;
};
```

cout | guidelines

client | library

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

cout | guidelines | defects

client | library

```
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(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_() const { print(data_m); }

        string data_m;
    };
```

cout | guidelines | defects

client | library

```
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(
```

cout | guidelines

client | library

```
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(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_() const { print(data_m); }

        string data_m;
    };

    struct int_model_t {
```

cout | guidelines

client | library

```
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(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_() const { print(data_m); }

        string data_m;
    };

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

cout | guidelines

client | library

```
{ }
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(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_() const { print(data_m); }

        string data_m;
    };

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

cout | guidelines

client | library

```
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(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_() const { print(data_m); }

        string data_m;
    };

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

cout | guidelines

client | library

```
    { }
    ~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(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_() const { print(data_m); }

        string data_m;
    };

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

        int data_m;
```

cout | guidelines | defects

client | library

```
    ~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(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_() const { print(data_m); }

        string data_m;
    };

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

        int data_m;
    };
```

cout | guidelines | defects

client | library

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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

client | **library**

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

        int data_m;
    };

    int_model_t* object_m;
```

cout | guidelines | **defects**

client | library

```
    { }
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cout | guidelines

client | library

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        string data_m;
};

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

cout | guidelines

client | library

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    { }
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cout | guidelines

client | library

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        int data_m;
    };

    concept_t* object_m;
};
```

cout | guidelines

client | library

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cout | guidelines | defects

client | library

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client | library

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client | library

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cout | guidelines

client | library

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client | library

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cout | guidelines

client | library

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client | library

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

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cout | guidelines

client | library

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client | library

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client | library

```
    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
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client | library

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client | library

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

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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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client | library

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```

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cout | guidelines

client | library

```
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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    friend void print(const object_t& x);
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    struct concept_t {
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```

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client | library

```
class object_t {
 public:
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    { }
    object_t& operator=(object_t x)
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private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_() const = 0;
    };

    struct string_model_t : concept_t {
```

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client | library

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

class object_t {
 public:
    explicit object_t(const string& x) : object_m(new string_model_t(x))
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client | library

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void print(const string& x) { cout << x << endl; }
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    object_t(const object_t& x) : object_m(new int_model_t(*x.object_m))
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void print(const string& x) { cout << x << endl; }
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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(const object_t& x);
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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(const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_() const = 0;
    };
```

cout | guidelines | defects

client | library

```
void print(const int& x) { cout << 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_())
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client | library

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class object_t {
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    object_t& operator=(object_t x)
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    friend void print(const object_t& x);
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private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_() const = 0;
    };

    struct string_model_t : concept_t {
```

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class object_t {
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private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual void print_() const = 0;
    };

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

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client | library

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

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

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client | library

```
explicit object_t(const string& x) : object_m(new string_model_t(x))
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{ }
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object_t(const object_t& x) : object_m(x.object_m->copy_())
{ }
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```

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    friend void print(const object_t& x);
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```

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

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

        string data_m;
```

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client | library

```
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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    struct string_model_t : concept_t {
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        void print_() const { print(data_m); }

        string data_m;
    };
```

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    { }
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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) { }
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    string data_m;
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```

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client | library

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

    object_t(const object_t& x) : object_m(x.object_m->copy_())
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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) { }
        void print_() const { print(data_m); }

        string data_m;
};

struct int_model_t : concept_t {
```

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client | library

```
    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_() const { print(data_m); }

        string data_m;
    };

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

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    object_t(const object_t& x) : object_m(x.object_m->copy_())
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struct int_model_t : concept_t {
    explicit int_model_t(const int& x) : data_m(x) { }
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```

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client | library

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client | library

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

    string data_m;
};

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

    int data_m;
```

cout | guidelines | defects

client | library

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

    friend void print(const object_t& x);
    friend void swap(object_t& x, object_t& y);
private:
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client | library

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cout | guidelines | defects

client | library

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

        string data_m;
    };

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

        int data_m;
    };

    concept_t* object_m;
```

cout | guidelines | defects

client | library

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

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

        string data_m;
    };

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

        int data_m;
    };

    concept_t* object_m;
};
```

cout

client | library

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

        string data_m;
    };

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

        int data_m;
    };

    concept_t* object_m;
};
```

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client | library

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        string data_m;
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        void print_() const { print(data_m); }

        int data_m;
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```

cout | guidelines

client | library

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        virtual concept_t* copy_() const = 0;
        virtual void print_() 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_() const { print(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_() const { print(data_m); }

        int data_m;
    };
```

cout | guidelines | defects

client | 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(document);
    return 0;
}
```

cout | guidelines

client | 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(document);
    return 0;
}
```

cout | guidelines

client | library

```
int main()
{                                                    ("Hello"
    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(document);
    return
```

```
                                                    op]ɐcf¯f(
```

cout | guidelines | defects

client | 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(document);
    return 0;
}
```

cout

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

client | 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(document);
    return 0;
}
```

guidelines

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

client | library

```
void print(const string& x) { cout << x << endl; }
void print(const int& x) { cout << 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(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_() const = 0;
```

cout | guidelines

client | library

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

    object_t(const object_t& x) : object_m(x.object_m->copy_())
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private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_() const = 0;
    };
```

cout | guidelines

client | library

```
template <typename T>
void print(const T& x) { cout << 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(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_() const = 0;
    };
```

cout | guidelines

client | library

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template <typename T>
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class object_t {
 public:
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    object_t(const object_t& x) : object_m(x.object_m->copy_())
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    };
```

cout | guidelines | defects

client | library

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void print(const T& x) { cout << x << endl; }

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    template <typename T>
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    object_t(const object_t& x) : object_m(x.object_m->copy_())
    { }
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    { swap(*this, x); return *this; }

    friend void print(const object_t& x);
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private:
    struct concept_t {
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        virtual concept_t* copy_() const = 0;
        virtual void print_() const = 0;
    };
```

cout | guidelines

client | library

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

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

    struct string_model_t : concept_t {
```

cout | guidelines | defects

client | library

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

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

cout | guidelines

client | library

```
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_())
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private:
    struct concept_t {
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        virtual concept_t* copy_() const = 0;
        virtual void print_() 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); }
```

cout | guidelines | defects

client | library

```
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_())
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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_() const { print(data_m); }
```

cout

client | library

```
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(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_() 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_() const { print(data_m); }
```

cout | guidelines

client | library

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        string data_m;
```

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client | library

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client | library

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        void print_() const { print(data_m); }

        string data_m;
    };

    struct int_model_t : concept_t {
```

cout | guidelines | defects

client | library

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    { }
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        concept_t* copy_() const { return new string_model_t(data_m); }
        void print_() const { print(data_m); }

        string data_m;
    };

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

cout | guidelines | defects

client | library

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

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client | library

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client | library

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        concept_t* copy_() const { return new int_model_t(data_m); }
        void print_() const { print(data_m); }

        int data_m;
```

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client | library

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client | library

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client | library

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        concept_t* copy_() const { return new string_model_t(data_m); }
        void print_() const { print(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_() const { print(data_m); }

        int data_m;
    };
```

cout | guidelines

client | library

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

```
    concept_t* object_m;
};

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

cout | guidelines

client | library

```
private:
    struct concept_t {
        virtual ~concept_t() { }
        virtual concept_t* copy_() const = 0;
        virtual void print_() 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_() const { print(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

client | 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));

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

cout | guidelines | defects

client | library

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

void print(const my_class_t& x)
{ cout << "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(document);
    return 0;
}
```

cout | guidelines | defects

client | library

```
class my_class_t {
    /* ... */
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void print(const my_class_t& x)
{ cout << "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()));
```

cout

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

guidelines

client | library

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

void print(const my_class_t& x)
{ cout << "my_class_t" << endl; }

int main()
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    document.push_back(object_t(0));
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    document.push_back(object_t(my_class_t()));

    print(document);
    return 0;
```

guidelines

- 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.

client | library

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

void print(const my_class_t& x)
{ cout << "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(document);
    return 0;
}
```

cout | guidelines

client | library

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

void print(const my_class_t& x)
{ cout << "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(document);
    return 0;
}
```

cout | guidelines

client | library

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

void print(const my_class_t& x)
{ cout << "my_class_t" << endl; }

int main()
{
    document_t document;
    document.push_back(object_t(0));
    ck(object_t(string("Hello")));
    ck(object_t(document));
```

cout

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

Concluding Remarks

- Interoperability of software components increases productivity as well as quality, security, and performance
- Focusing on the properties of the types instead of the types themselves allows us to create interoperable components with less work than specialized components - with no loss (and often a gain) in performance and code size
- There is even more to say about copy and assignment - which are just two of many properties of *regular* types
- See http://stlab.corp.adobe.com/ for links and contact information for the Software Technology Lab

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