Everything You Ever Wanted To Know About Move Semantics

(and then some)

Howard Hinnant
Ripple

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Outline

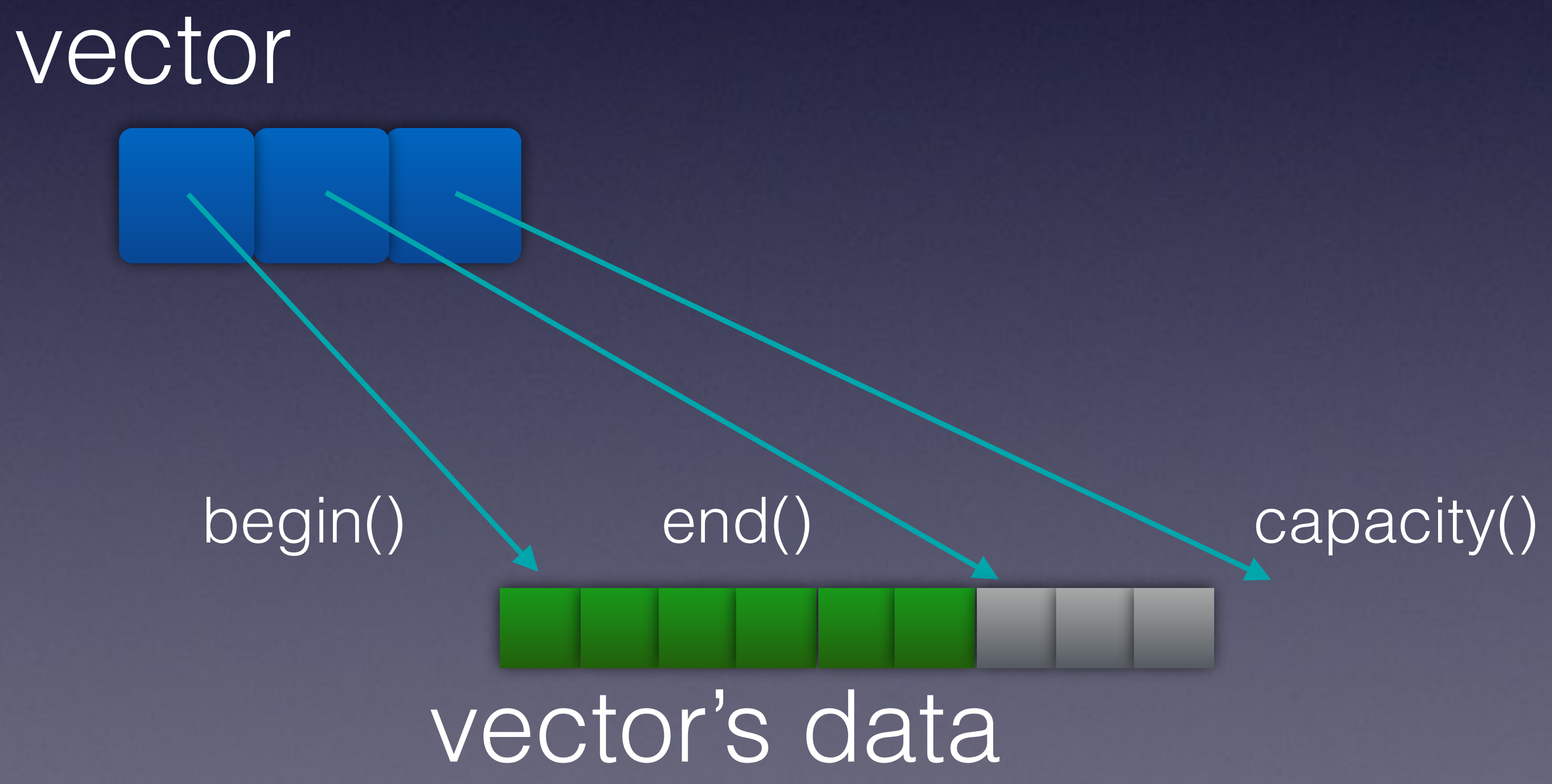
- The genesis of move semantics
- Special member functions
- Introduction to the special move members
- Best practices for the move members
- Details, details…

How Did Move Semantics Get Started?

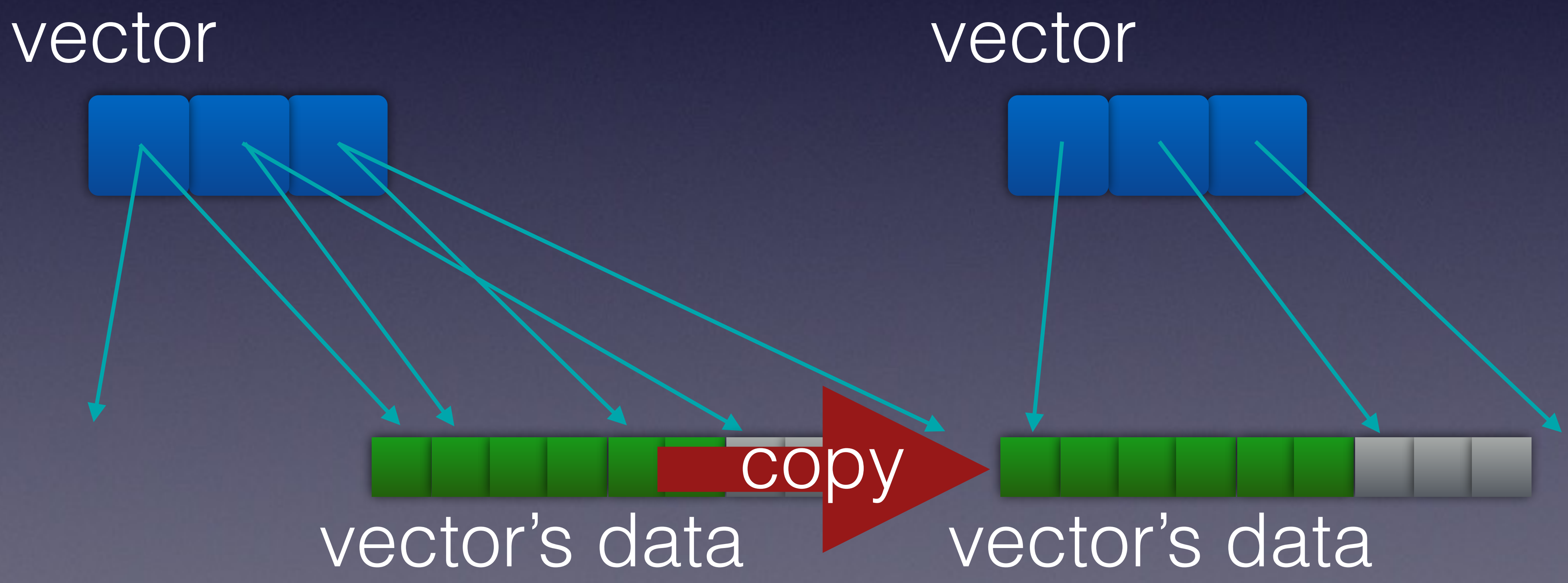
- It was all about optimizing std::vector<T>.
- And everything else just rode along on its coattails.

What is std::vector?

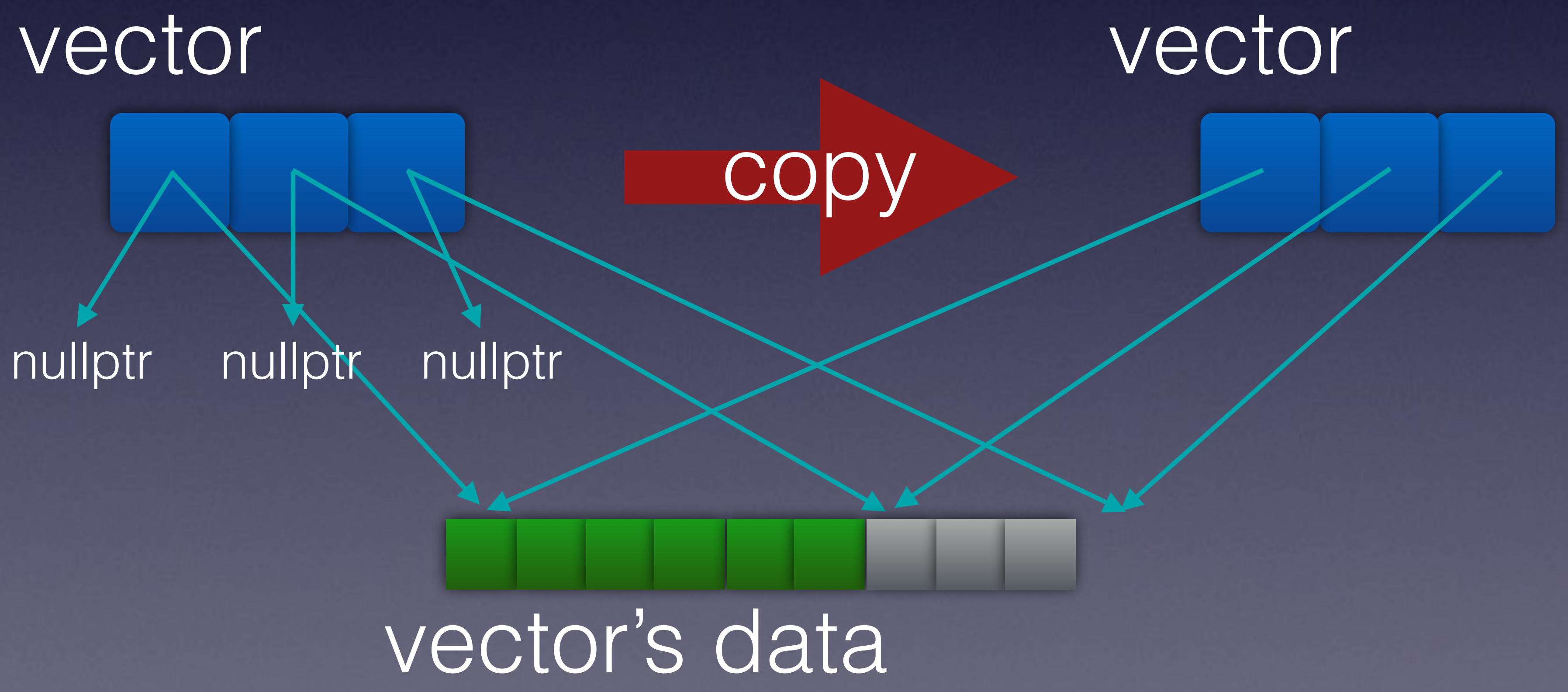
- Anatomy of a vector (simplified)



How does a vector copy?



How does a vector move?



How Did Move Semantics Get Started?

- Remember these fundamentals about move semantics and vector, and you will have a basic understanding of all of move semantics.
- The rest is just details…

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Special Members

- What are they?

Special Members

- Special members are those member functions that the compiler can be asked to automatically generate code for.

Special Members

- How many special members are there?

6

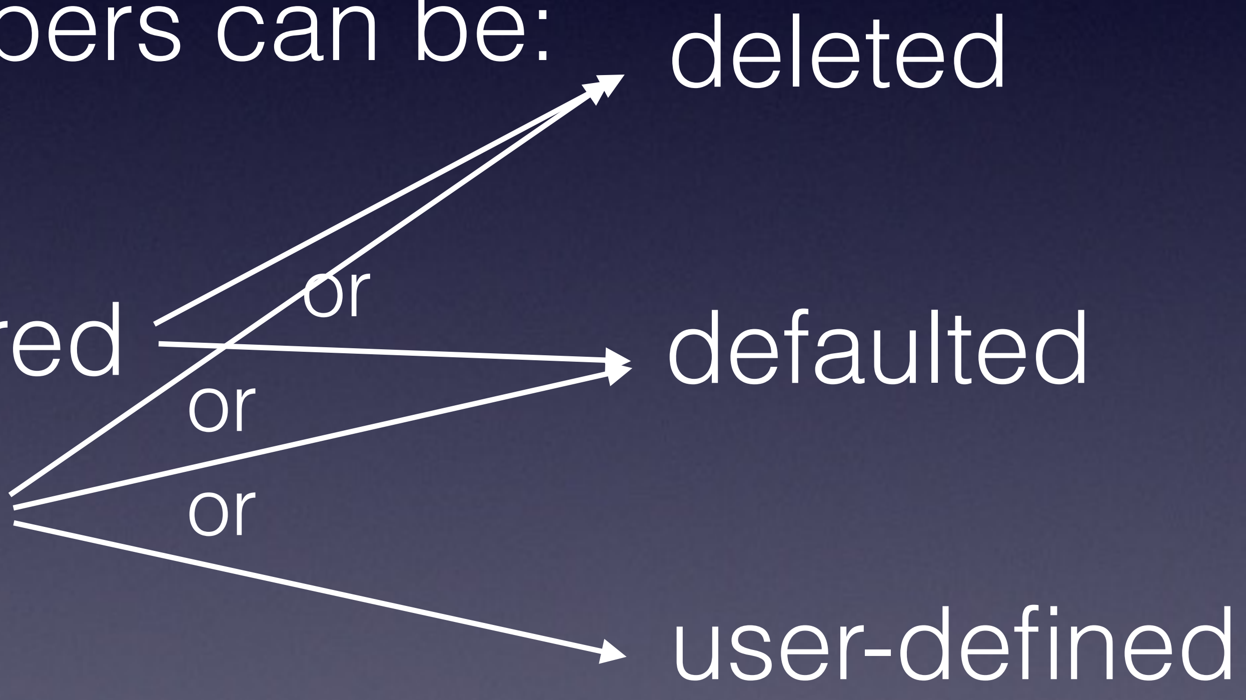
Special Members

- They are:

• default constructor	`X();`
• destructor	`~X();`
• copy constructor	`X(X const&);`
• copy assignment	`X& operator=(X const&);`
• move constructor	`X(X&&);`
• move assignment	`X& operator=(X&&);`

Special Members

- The special members can be:
  - not declared
  - implicitly declared
  - user declared



deleted

or

defaulted

or

or

user-defined

Special Members

- What counts as user-declared?

```
struct X
{
    X() {}            // user-declared
    X();              // user-declared
    X() = default;    // user-declared
    X() = delete;     // user-declared
};
```

Special Members

- What is the difference between not-declared and deleted?

Consider:

```
struct X
{
    template <class ...Args>
        X(Args&& ...args);
    // The default constructor
    // is not declared
};
```

Special Members

```
struct X
{
    template <class ...Args>
        X(Args&& ...args);
    // The default constructor
    // is not declared
};
```

- X can be default constructed by using the variadic constructor.

Special Members

```
struct X
{
    template <class ...Args>
        X(Args&& ...args);

    X() = default;
};
```

- Now X() binds to the defaulted default constructor instead of the variadic constructor.

Special Members

```
struct X
{
    template <class ...Args>
        X(Args&& ...args);

    X() = delete;

};
```

- Now X() binds to the deleted default constructor instead of the variadic constructor.
- X is no longer default constructible.

Special Members

```
struct X
{
    template <class ...Args>
        X(Args&& ...args);

    X() = delete;
};
```

- Deleted members participate in overload resolution.
- Members not-declared do not participate in overload resolution.

Special Members

- Under what circumstances are special members implicitly provided?

Special Members

compiler implicitly declares

	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted

user declares

- If the user declares no special members or constructors, all 6 special members will be defaulted.
- This part is no different from C++98/03

Special Members

compiler implicitly declares

user declares

	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
Any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted

- If the user declares any constructor, this will inhibit the implicit declaration of the default constructor.

Special Members

compiler implicitly declares

	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
Any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted
default constructor	user declared	defaulted	defaulted	defaulted	defaulted	defaulted

user declares

- A user-declared default constructor will not inhibit any other special member.

Special Members

compiler implicitly declares

user declares

	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
Any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted
default constructor	user declared	defaulted	defaulted	defaulted	defaulted	defaulted
destructor	defaulted	user declared	defaulted	defaulted	not declared	not declared

- A user-declared destructor will inhibit the implicit declaration of the move members.
- The implicitly defaulted copy members are deprecated.
    - If you declare a destructor, declare your copy members too, even though not necessary.

Special Members

compiler implicitly declares

user declares

	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
Any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted
default constructor	user declared	defaulted	defaulted	defaulted	defaulted	defaulted
destructor	defaulted	user declared	defaulted	defaulted	not declared	not declared
copy constructor	not declared	defaulted	user declared	defaulted	not declared	not declared

- A user-declared copy constructor will inhibit the default constructor and move members.

Special Members

compiler implicitly declares

user declares

	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
Any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted
default constructor	user declared	defaulted	defaulted	defaulted	defaulted	defaulted
destructor	defaulted	user declared	defaulted	defaulted	not declared	not declared
copy constructor	not declared	defaulted	user declared	defaulted	not declared	not declared
copy assignment	defaulted	defaulted	defaulted	user declared	not declared	not declared

- A user-declared copy assignment will inhibit the move members.

Special Members

compiler implicitly declares

user declares

	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
Any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted
default constructor	user declared	defaulted	defaulted	defaulted	defaulted	defaulted
destructor	defaulted	user declared	defaulted	defaulted	not declared	not declared
copy constructor	not declared	defaulted	user declared	defaulted	not declared	not declared
copy assignment	defaulted	defaulted	defaulted	user declared	not declared	not declared
move constructor	not declared	defaulted	deleted	deleted	user declared	not declared

- A user-declared move member will implicitly delete the copy members.

Special Members

compiler implicitly declares

user declares

	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
Any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted
default constructor	user declared	defaulted	defaulted	defaulted	defaulted	defaulted
destructor	defaulted	user declared	defaulted	defaulted	not declared	not declared
copy constructor	not declared	defaulted	user declared	defaulted	not declared	not declared
copy assignment	defaulted	defaulted	defaulted	user declared	not declared	not declared
move constructor	not declared	defaulted	deleted	deleted	user declared	not declared
move assignment	defaulted	defaulted	deleted	deleted	not declared	user declared

Special Members

compiler implicitly declares

user declares

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copy assignment	defaulted	defaulted	defaulted	user declared

This is C++98/03

Special Members

compiler implicitly declares

user declares

	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
Any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted
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destructor	defaulted	user declared	defaulted	defaulted	not declared	not declared
copy constructor	not declared	defaulted	user declared	defaulted	not declared	not declared
copy assignment	defaulted	defaulted	defaulted	user declared	not declared	not declared
move constructor	not declared	defaulted	deleted	deleted	user declared	not declared
move assignment	defaulted	defaulted	deleted	deleted	not declared	user declared

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- Details, details…

What does a defaulted move constructor do?

```
class X
  : public Base
{
  Member m_;

  X(X&& x)
    : Base(static_cast<Base&&>(x))
    , m_(static_cast<Member&&>(x.m_))
  {}
};
```

What does a typical user-defined move constructor do?

```
class X
  : public Base
{
  Member m_;

  X(X&& x)
    : Base(std::move(x))
    , m_(std::move(x.m_))
  {
    x.set_to_resourceless_state();
  }
```

What does a defaulted move assignment do?

```
class X
  : public Base
{
  Member m_;

  X& operator=(X&& x) {
    Base::operator=
            (static_cast<Base&&>(x));
    m_ = static_cast<Member&&>(x.m_);
    return *this;
  }
```

What does a typical user-defined move assignment do?

```
class X
  : public Base
{
  Member m_;

  X& operator=(X&& x) {
    Base::operator=(std::move(x));
    m_ = std::move(x.m_);
    x.set_to_resourceless_state();
    return *this;
  }
```

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Can I define one special member in terms of another?

Yes.

Should I define one special member in terms of another?

No!

Should I define one special member in terms of another?

No!

- Give each special member the tender loving care it deserves.
- The entire point of move semantics is to boost performance.

Should I define one special member in terms of another?

Case study: the copy/swap idiom

```
class X
{
  std::vector<int> v_;
public:
  X& operator=(X x) { // Implements
    v_.swap(x.v_);    // both copy and
    return *this;     // move assignment
  }
};
```

What’s not to love?

Should I define one special member in terms of another?

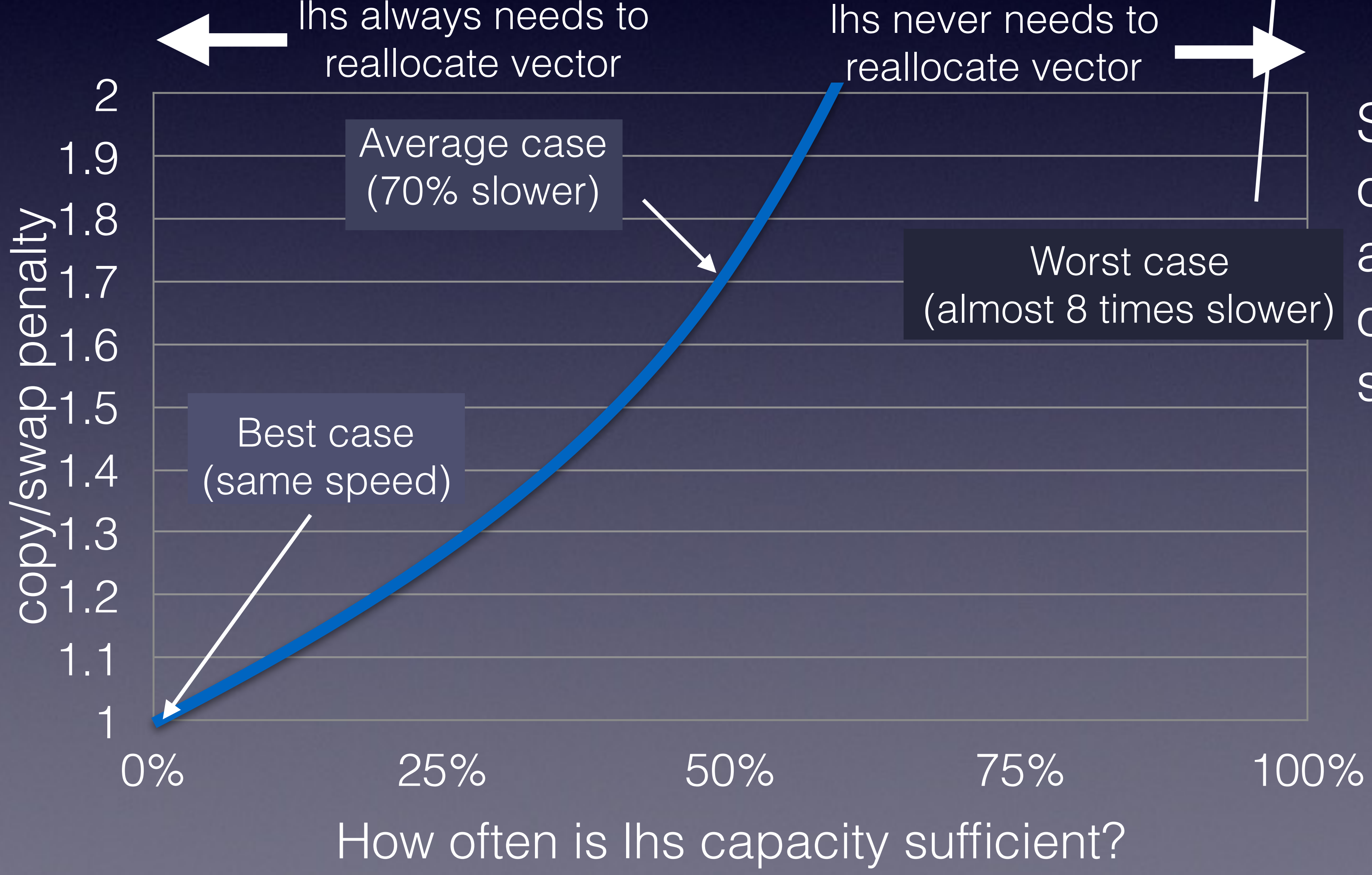
Case study: the copy/swap idiom

```
class X
{
  std::vector<int> v_;
public:
  X& operator=(X const& x);
  X& operator=(X&& x);
};
```

I’ve written highly optimized versions of the copy and move assignment operators.

Should I define one special member in terms of another?

Case study: the copy/swap idiom



Speed of optimized copy assignment operator vs “copy/ swap” assignment

Should I define one special member in terms of another?

Case study: the copy/swap idiom

How hard is it to make separate optimized copy and move assignment operators for this case?

Should I define one special member in terms of another?

Case study: the copy/swap idiom

```
class X
{
  std::vector<int> v_;
public:
  // Just keep your grubby fingers
  //  off of the keyboard.
  // The defaults are optimal!

};
```

What's not to love?

Should I define one special member in terms of another?

Case study: the copy/swap idiom

But the copy/swap idiom gives me strong exception safety!

Good point. Are all of your clients willing to pay a giant performance penalty for strong exception safety on assignment?

Should I define one special member in terms of another?

Case study: the copy/swap idiom

Perhaps you could interest the portion of your clients that do need strong exception safety in this generic function:

```
template <class C>
C& strong_assign(C& dest, C src) {
    using std::swap;
    swap(dest, src);
    return dest;
}
```

Should I define one special member in terms of another?

Case study: the copy/swap idiom

Now clients who need speed can:

```
x = y;
```

And clients who need strong exception safety can:

```
strong_assign(x, y);
```

In A Hurry?

- If you don’t have time to carefully consider all 6 special members, then just delete the copy members:

```
class X
{
public:
  X(X const&) = delete;
  X& operator=(X const&) = delete;
};
```

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What can I do with a moved-from object?

- The following is a myth:
  - All you can do with a moved-from object is destruct it or assign it a new value.
- That *might* be true for a type which has such documented preconditions.

What is the state of a moved-from object?

- The state of a moved-from object is generally unspecified.

What can I do with a moved-from object?

- You can do anything with a moved-from object that does not require a precondition.

What is a precondition?

- A requirement in the function specification which restricts the state of the object prior to the call.
- For example:
- vector<T>::pop_back();
  - Requires: empty() shall be false.

Precondition!

What can I do with a moved-from object?

- Anything that does not require a precondition.
- For example, vector<T>:
  - destruct it. ← **No precondition**
  - assign it a new value. ← **No precondition**
  - get its size(). ← **No precondition**
  - clear() it. ← **No precondition**
  - Do not pop_back() it! ← **Precondition!**

Guideline:
Never delete the move members

- Deleted move members are at best redundant, and at worst, a bug…

Guideline:
Never delete the move members

```
class X
{
public:
   X(X const&) = default;
   X& operator=(X const&) = default;
   X(X&&) = delete;
   X& operator=(X&&) = delete;
};
```

- Incorrect way to make a copyable type with no move members:

Guideline:
Never delete the move members

```
class X
{           X x = get_X();  // error!
public:
  X(X const&) = default;
  X& operator=(X const&) = default;
  X(X&&) = delete;
  X& operator=(X&&) = delete;
};
```

- This type can not be copied from an rvalue. Is that intended?!

Guideline:
Never delete the move members

```
class X
{
public:
  X(X const&) = default;
  X& operator=(X const&) = default;



};
```

- Correct way to make a copyable type with no move members:

Guideline:
Never delete the move members

```
class X
{
public:
  X(X const&) = delete;
  X& operator=(X const&) = delete;
  X(X&&) = delete;
  X& operator=(X&&) = delete;
};
```

- Correct but unadvised way to make class non-copyable and non-movable.

Guideline:
Never delete the move members

```
class X
{
public:
  X(X const&) = delete;
  X& operator=(X const&) = delete;
  X(X&&) = delete;
  X& operator=(X&&) = delete;
};
```

- Deleted move members are redundant.

Guideline:
Never delete the move members

```
class X
{
public:
  X(X const&) = delete;
  X& operator=(X const&) = delete;



};
```

- Better way to make class non-copyable and non-movable.

Summary

- Know when the compiler is defaulting or deleting special members for you, and what defaulted members will do.
- Always define or delete a special member when the compiler’s implicit action is not correct.
- Give tender loving care to each of the 6 special members, even if the result is to let the compiler handle it.