Rvalues and Move Semantics

Chapter 17

Objectives

- **Describe the difference between LValues and RValues.**
- **Use RValue reference operator.**
- **Compare overload methods based on reference types.**
- **Describe move semantics and its usefulness.**
- **Gain experience through code walk-throughs.**
  - The example programs are in the chapter directory.

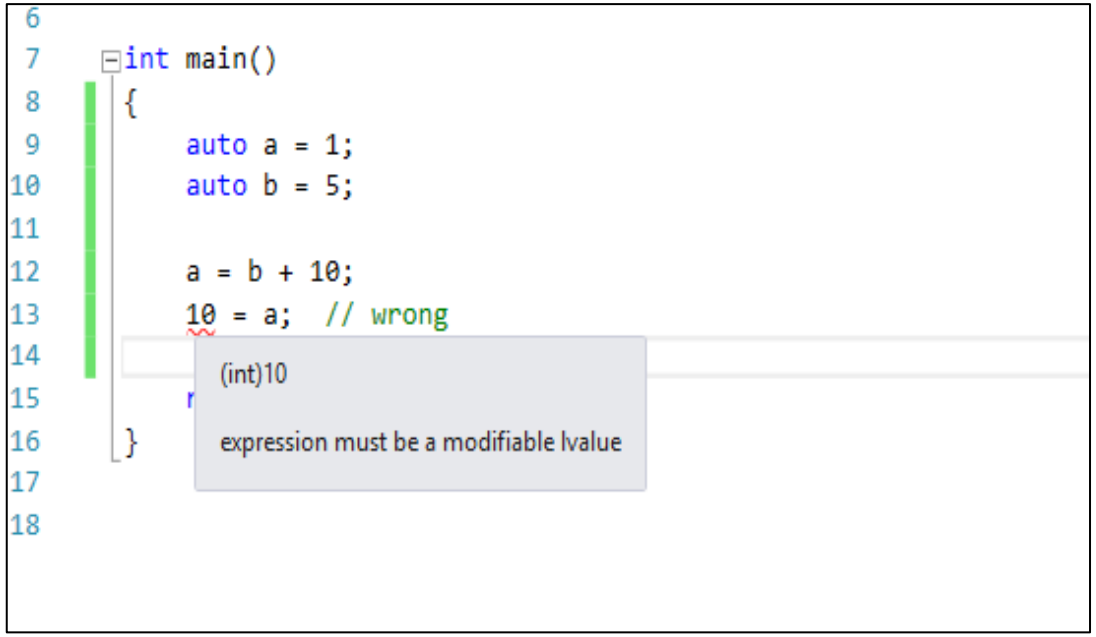
LValue versus RValue

- **Lvalue can appear on the left of an assignment.**
- **Lvalue can evaluate to an addressable value**
- **Rvalue can only appear on the right side of an assignment.**
- **Rvalue cannot be evaluated to an explicit address**

```
int FuncA(){
   return 5;
}
int &FuncB() {
   static int b=10;
   return b;
}
void main() {
   int a = 100;          // a is lvalue
   100 = a;              // 100 is a rvalue
   int c = FuncA();      // FuncA is rvalue
   FuncB() = a;          //  FuncB is an lvalue.
}
```

Literal Constants

- **Literal constants are an example of Rvalue.**
- **They are not addressable.**
- **Any attempt to use a Rvalue as an Lvalue will cause a compiler error.**



Rvalue Reference Operator

- **& indicates an Lvalue reference.**
- **Lvalue reference is a constant pointer to another object. Lvalue reference can only reference a Lvalue.**
- **&& indicates an Rvalue reference for referencing Rvalues.**

- **int a = 5;**
- **int &b = a;**
- **int &&d = 10;**

Overload Reference Type

- **You can overload based on lvalue versus rvalue reference.**
- **Compilers selects appropriate match.**

```
// Which overloaded method is called in the following code?
void Func(int &var) {
   cout << "Lvalue reference" << endl;
}
void Func(int &&var) {
   cout << "Rvalue reference" << endl;
}
int main() {
   int a = 5;

   Func(a);   // Lvalue ref
   Func(10); // Rvalue ref
}
```

Universal Reference Type

- **Reference type within a template can be deduced at compile time.**
- **Compilers selects appropriate match.**
- **Provides support for perfect forwarding (discussed later)**

```
template <typename T> void func(T &&t)
{
   // "T &&" is a UNIVERSAL REFERENCE
   cout << t << endl;
}

int main() {
   int a = 5;
   func(a);     // Lvalue reference
   func(5);     // Rvalue reference
}
```

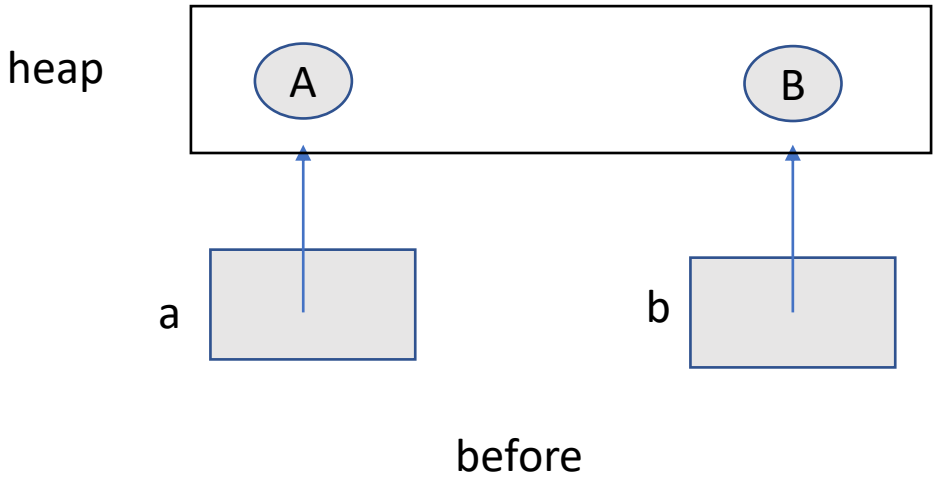
Copy vs Move Semantics

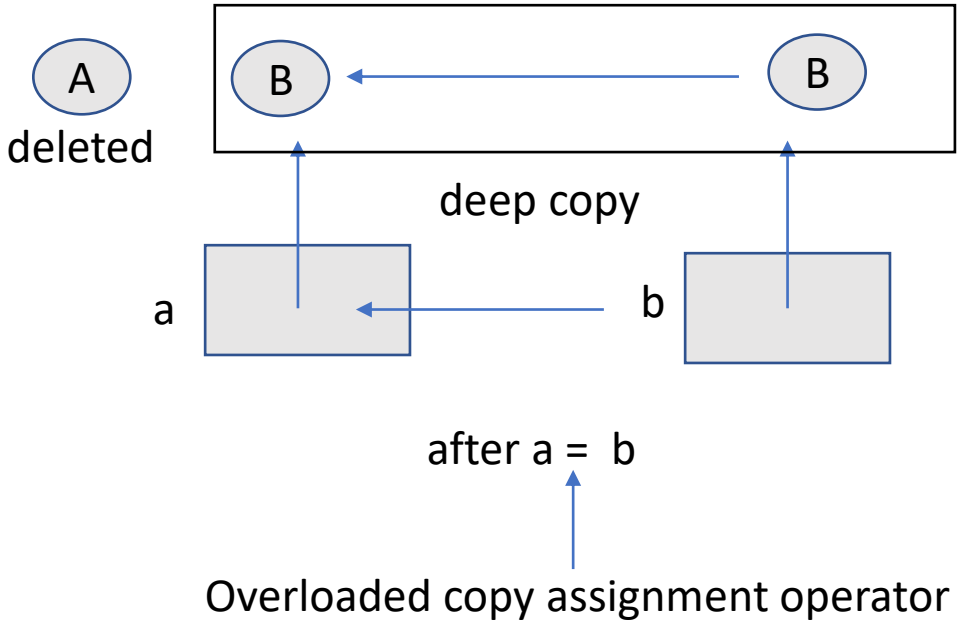
- **Copy and assignment can be expensive – especially temporary objects pointing to a lot of data. This can adversely impact performance and resource utilization.**

```
template <typename T>
swap(T& a, T& b) {
   T tmp(a);       //  copy constructor
   a = b;          // copy assignment
   b = tmp;        // copy assignment
}
```

- **Move semantics allows an object, under certain conditions, to take ownership of some other object's external resources.**
- **If an object does not manage at least one external resource (either directly, or indirectly through its member objects), move semantics will not offer any advantages over copy.**

copy semantics review



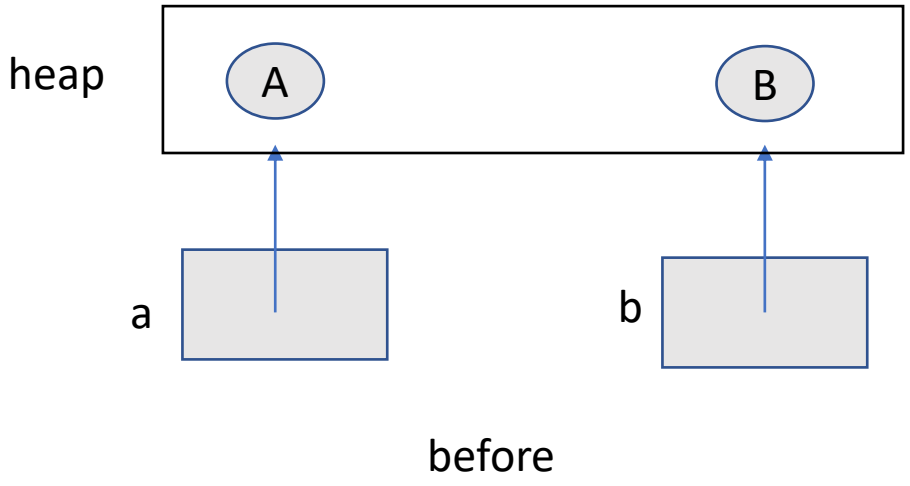


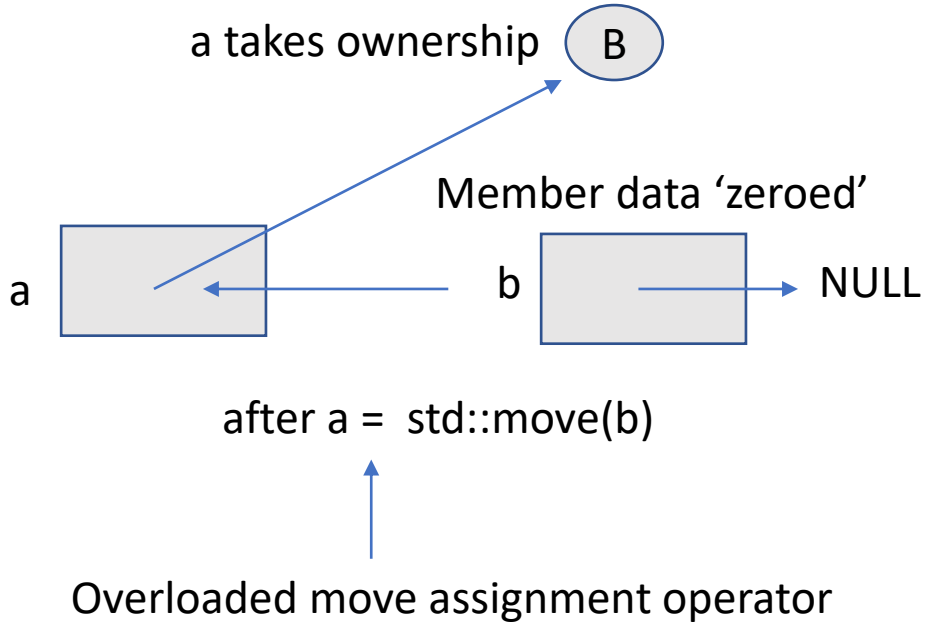
std::move

- std::move() is a cast that produces an rvalue-reference to an object.
- Using std::move allows you to swap the resources instead of copying them.

```
template <typename T>
swap(T& a, T& b) {
   T tmp(std::move(a));    //  move constructor
   a = std::move(b);       //  move assignment
   b = std::move(tmp);     // move assignment
}
```

move assignment



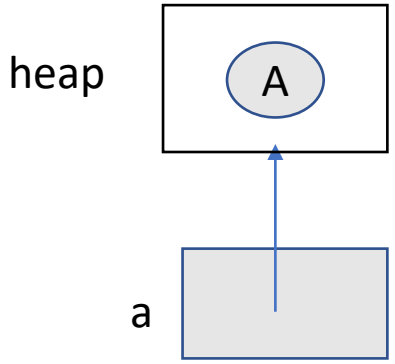


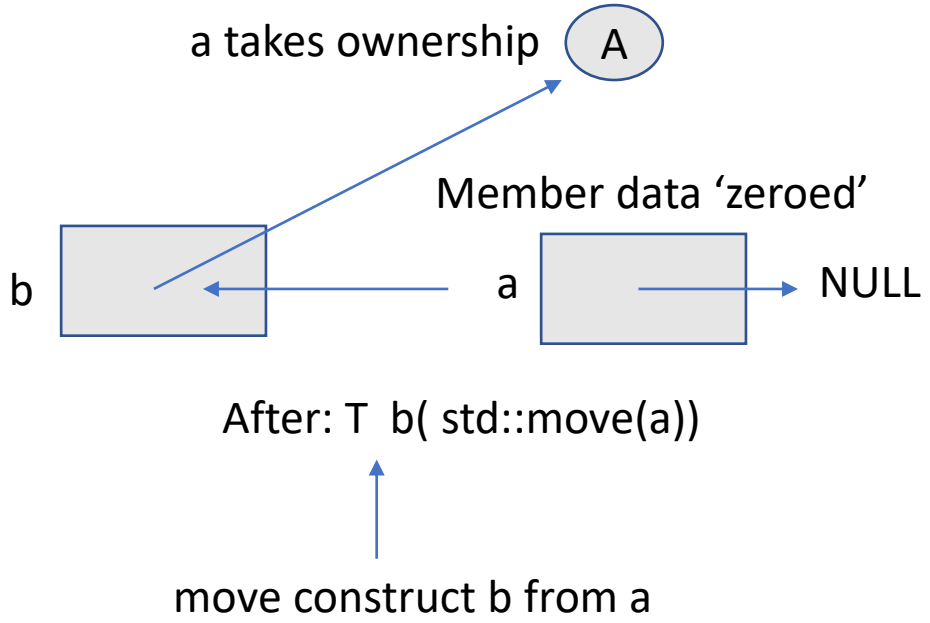
Move assignment operator

- **Move assignment operators typically "steal" the resources held by the argument (e.g. pointers to dynamically-allocated objects)**
- **The compiler will implicitly declare a move assignment operator if all the following are true:**
  - **there are no user-declared copy constructors**
  - **there are no user-declared move constructors**
  - **there are no user-declared copy assignment operators**
  - **there is no user-declared destructor**

```
Data& operator=(Data&& rhs) {     // argument is not const
    if (this == &rhs)  return *this;    // don't destroy yourself!
    delete _data;                       // release what we hold
    // scavenge rhs
    _data = rhs._data;
    rhs._data = nullptr;
    return *this;                       // return this insatnce by ref
}
```

Move construction





Move constructor

- **The purpose of a move constructor purpose is to transfer ownership of the managed resource from the source into the current object.**
- **The move constructor is typically called when an object is initialized (by direct-initialization or copy-initialization) from an rvalue**
- **The compiler will implicitly declare a move constructor if all of the following are true:**
  - **there are no user-declared copy constructors;**
  - **there are no user-declared copy assignment operators;**
  - **there are no user-declared move assignment operators;**
  - **there is no user-declared destructor.**

```
/*
You can eliminate redundant code by writing the move constructor to call the move assignment operator as shown in the example.
*/
Data(Data&& rhs) {
   *this = std::move(rhs);
}
```

The Rule of Five

- **The rule of three specifies that if a class implements any of the following functions, it should implement all of them:**
  - **copy constructor**
  - **copy assignment operator**
  - **destructor**
- **The rule of five identifies that it usually appropriate to also provide the following functions to allow for optimized copies from temporary objects:**
  - **move constructor**
  - **move assignment operator**

Perfect Forwarding

- Like move semantics, perfect forwarding reduces overhead associated with a function call. Often, a function call is essentially a delegate to another function.
- Calling FuncB is essentially a call to FuncA. However, there is additional overhead of two pass by value calls instead of one pass by value call. If obj is a heavy object, the additional overhead could be considerable.
- Here three copy by value constructors are called.

```
class ClassA {
public:
   ClassA() { cout << "Regular ctor" << endl; }
   ClassA(const ClassA & obj)  { cout << "Regular copy ctor" << endl; }
};

void FuncA(ClassA obj) { }
void FuncB(ClassA obj) { FuncA(obj); }

int main() {
   ClassA obj;
   FuncB(obj);

   return 0;
}
```

std::forward()

- Perfect forwarding removes the potential additional overhead of functions that are thin wrappers for delegating to another function.
- Perfect forwarding is accomplished with a combination of move semantics and std::forward to forward parameters through a thin wrapper.

```
template<typename T>
void Func(T b) {
   std::cout << "Func " << b.data() << std::endl;
}

template<typename T>
void Wrapper(T&& b) {
   Func<T>(std::forward<T>(b));  // Forward as lvalue or as rvalue, depending on T
}
```

Summary

- In C++11, in addition to copy constructors, objects can have move constructors.
- And in addition to copy assignment operators, they have move assignment operators.
- The move constructor is used instead of the copy constructor, if the object has type "rvalue-reference" (Type &&).
- std::move() is a cast that produces an rvalue-reference to an object, to enable moving from it.