Move semantics

Part 1: Value categories, move and (some types of) copy elision

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Basics of move semantics

- Moving an object A to an object B means that B will have the data of A and that A will be in a valid but unspecified state
  - Methods of A can be called (mainly its destructor) but you don’t know which data it contains

```
std::string otherStr{ "bonjour les gens" };
std::string str{ std::move(otherStr) };
```

- Now “str” contains the string “bonjour les gens” and “otherStr” contains something unspecified
  - But most implementations will just change “otherStr” to an empty string

Basics of move semantics

- A call to std::move is just a cast to an rvalue reference, so the two lines below are equivalent

```
std::string something;

std::move(something);
static_cast<std::string&&>(something);
```

Basics of copy elision

- Sometimes compilers can elide copies (and moves) to optimize the code
  - In C++17 some copy-elisions are mandatory

```
std::pair object = std::pair{ 1, '2' };
```

Without copy elision:

- The right object is constructed with “1” and “’2’”
- The left object is move-constructed with the right object

With copy elision:

- The left object is constructed with “1” and “’2’”
- That’s all

What's an expression

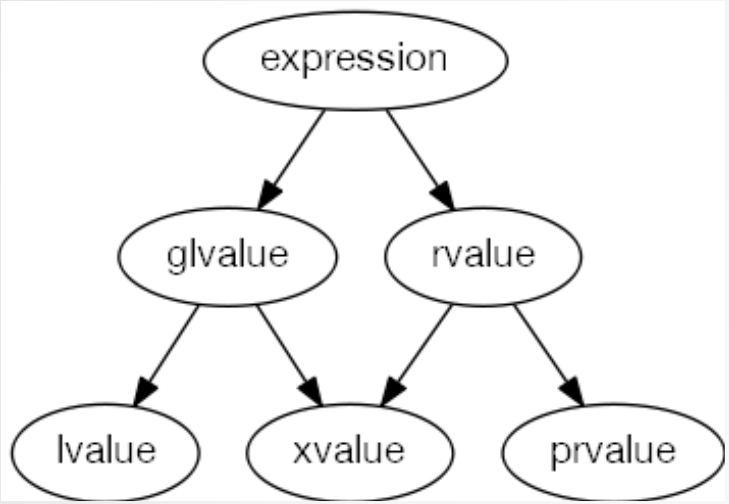
- An expression is a computation that may produce a result
  - If it doesn't return a result, it's called a void expression
- Results of expressions are entities, some of these entities are:
  - Values: data not stored in the memory, used to build objects
  - Objects / subobjects: data stored in the memory
  - References: refer an object (or a function)

```
std::string str1, str2; /* not an expression */
str1; /* expression result is object str1 */
str1 += str2; /* expression result is an unnamed
                 lvalue reference to object str1 */
str1 + str2; /* expression result is an unnamed object */
5; /* expression result is a value */
```

Value categories: disclaimers

- What is described here is what the standard say for C++17
- For C++14, if copy elision is not disabled everything will be mostly the same, some things may be described differently in the standard but at the end the binary generated will be the same
- If copy elision is disabled the things explained here won’t be 100 % accurate, but because it should never be disabled, and because in C++17 it won’t be possible to disable it, i chose to not talk about how it will work in this configuration

Value categories



Historically:

- Lvalue: left value. Because it can be on the left hand side of operator =
- Rvalue: right value. Because it can only be on the right hand side of operator =

Now:

- Glvalue: generalized left value
- Rvalue: right value

- Lvalue: left value, sometimes called locator value because you can call the unary operator & on it. Basically named objects.
- Xvalue: expiring value. Basically temporary objects.
- Prvalue: right value. Basically just a value, not inside an object.

Value categories

- How expressions can by used to initialize objects:
  - Lvalue: Via copy
  - Xvalue: Via copy or move
  - Prvalue: Via copy, move, or by copy elision

Identifying categories

- Has an identity
  - You can compare two entities to know if they are the same
  - Basically you can know their address
- Can be moved from
  - Can be used by a move constructor / assignment
  - Basically can be bound to an rvalue reference

Identifying lvalues

- Has an identity but can’t be moved from
  - You can apply the unary & operator on it
  - You can’t pass it to a move constructor / assignment
- It’s an lvalue if its result is (not exhaustive):
  - An lvalue reference or a named rvalue reference
  - A named object that isn’t a subobject of an rvalue
    - Static data members are complete objects
- The expression of a function that return an lvalue reference is an lvalue

Identifying lvalues

```
std::string obj;
obj;                    // lvalue

std::string& function();
function();             // lvalue

std::string&& rvalRef = std::move(obj);
rvalRef;                // lvalue
```

Identifying xvalues

- Has an identity and can be moved from
  - You can’t apply the unary & operator on it but can have the address of its result by accessing the object from elsewhere
  - You can move construct / assign from it
- Xvalue means eXpiring value, their result is an object that you can move but that can still be accessed from elsewhere, like:
  - Unnamed rvalue references
  - Subobjects of rvalues
    - Static data members are complete objects
- The expression of a function that return an rvalue reference is an xvalue

Identifying xvalues

```
std::string obj;
std::move(obj);                          // xvalue

std::pair<int, int>{}.first;             // xvalue

std::pair<int, int> pair;
std::move(pair).first;                   // xvalue
```

Identifying prvalues

- Don’t have an identity but can be moved from
  - You can’t get the address of its result or deduce it from another entity
  - You can move construct / assign from it
- If it’s neither an lvalue or an xvalue, it’s a prvalue
  - That means the result of a prvalue isn’t an object or a reference, it’s a value (and some others entities)
- The expression of a function that don’t return a reference is a prvalue

Identifying prvalues

```
std::string{};      // prvalue

std::string otherFunction();
otherFunction();    // prvalue
```

Identifying value categories: one slide

```
std::string obj;
obj;                                // lvalue

std::string& function();
function();                         // lvalue

std::string&& rvalRef = std::move(obj);
rvalRef;                            // lvalue

std::string obj;
std::move(obj);                     // xvalue

std::pair<int, int>{}.first;        // xvalue

std::pair<int, int> pair;
std::move(pair).first;              // xvalue

std::string{};                      // prvalue

std::string otherFunction();
otherFunction();                    // prvalue
```

Summarizing value categories

- Lvalues result in objects that can still be used after the expression, they exist “physically” in the memory and must kept their “data” until they are destroyed
- Xvalues result in objects that are expiring, they exist “physically” in the memory but they won’t be used anymore so their “data” can be moved to another object
- Prvalues don’t result in objects, they don’t exist “physically” in the memory, they don’t have an address, their result is accessible only in the expression that created them, so their “data” can safely be moved somewhere else
  - In fact most prvalues are in the memory but it’s “as-if” they weren’t there because you can’t know were they are exactly and they are free to move (copy elision)

Guaranteed copy elision (C++17)

- Copy elision is linked to prvalues
- Prvalues can be seen as values, and not objects, like if they weren't in the memory
- When an object is needed for computation, a temporary object can be materialized from a prvalue
  - That means an xvalue is produced from the prvalue
- All of this means that passing prvalues is free because there is no object to move
  - But in fact the object is still constructed when the prvalue is created, it's just not constructed where the prvalue was created

Guaranteed copy elision (RVO)

```
VerboseClass iBuildStuff()
{
    return VerboseClass{};
}

void basicExemple()
{
    VerboseClass imStuff = iBuildStuff();
}
```

-fno-elide-constructors --std=c++14

```
VerboseClass default constructor.
VerboseClass move constructor.
VerboseClass move constructor.
```

--std=c++14

```
VerboseClass default constructor.
```

https://godbolt.org/z/jwWFoj

Guaranteed copy elision (RVO)

```
VerboseClass iBuildMoreStuff()
{
    VerboseClass notStuff{ 21 };
    return VerboseClass{ 25 };
}

void advancedExemple()
{
    VerboseClass alsoNotStuff{ 11 };
    VerboseClass imStuff = iBuildMoreStuff();
    VerboseClass stillNotStuff{ 12 };
}
```

-fno-elide-constructors --std=c++14

```
VerboseClass arg constructor. (11: 0x7fff1b0f1168)
VerboseClass arg constructor. (21: 0x7fff1b0f1130)
VerboseClass arg constructor. (25: 0x7fff1b0f1128)
VerboseClass move constructor. (25: 0x7fff1b0f1158)
VerboseClass move constructor. (25: 0x7fff1b0f1160)
VerboseClass arg constructor. (12: 0x7fff1b0f1150)
```

--std=c++14

```
VerboseClass arg constructor. (11: 0x7ffc39e3d878)
VerboseClass arg constructor. (21: 0x7ffc39e3d840)
VerboseClass arg constructor. (25: 0x7ffc39e3d870)
VerboseClass arg constructor. (12: 0x7ffc39e3d868)
```

https://godbolt.org/z/jwWFoj

When to use std::move

- Lvalues:
  - Move them whenever you can, it will prevent some copies to be made, making the software faster
  - Moving const objects is useless because for the move constructor / assignment to work the object need to be non-const
- Xvalues:
  - It’s useless to move them because it will just convert them into xvalues, what they already are
- Prvalues:
  - Don’t move them because it will prevent copy elision, forcing objects to be moved so making the software slower

Questions

```
std::ranges::for_each(
    training.getAttendees() | std::views::filter([](const auto& attendee) { return attendee.haveQuestions(); }),
    [&training](const auto& attendee) { training.getTrainer().answer(attendee.getQuestions(); }
);
```

What's next

- In the second part we will see:
  - Forwarding references
  - std::forward
  - More about copy elision, how to benefit the most of it
  - Why this code is bad:

```
std::vector<int> badFunction()
{
    std::vector<int> bigVector(816);
    return std::move(bigVector);
}
```

References

- https://en.cppreference.com/w/cpp/language/value_category
- https://stackoverflow.com/questions/3601602/what-are-rvalues-lvalues-xvalues-glvalues-and-prvalues
- https://en.cppreference.com/w/cpp/language/implicit_conversion#Temporary_materialization
- https://en.cppreference.com/w/cpp/language/copy_elision
- https://en.cppreference.com/w/cpp/language/return#Notes
- https://stackoverflow.com/questions/3106110/what-is-move-semantics