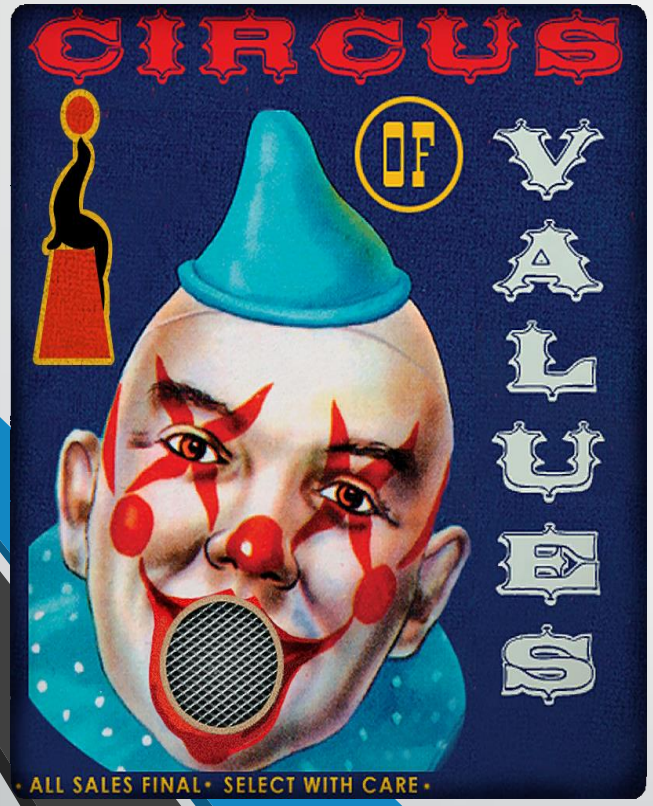


Advanced C++ Programming

Value Semantics

Basics

C++ has **Values**

- What does this mean?
  - Let's look at "01_01_basic_values.cpp"
- All types default to *value semantics*
- This means that they are *copied* when passed to or returned from functions

C++ also has **References**

- What does that mean?
  - Let's look at "01_02_basic_references.cpp"
- References *point to some specific object in memory*
- By modifying the reference, you are modifying that original object

Notes

- You can freely use any C++ type either as a value or as a reference
- This is quite different from many other mainstream languages, which might e.g. only allow value semantics for built-in types
- In C++, behaviour is uniform for all types
- This also means that the programmer needs to define what "*copying*" means for non-trivial cases

References vs. Pointers

- Same concept (reference/point to another object in memory)
- Major differences:
  - Pointers can be **nullptr**
  - References act like the object they are referencing, while pointers need to be dereferenced
  - No “reference arithmetic”

  → References might be optimized slightly better by the compiler

Object Lifecycle

Object Creation and Destruction

- Basics of the lifecycle
- When objects are *created*, their **Constructor** is invoked
- When objects are *destroyed*, their **Destructor** is invoked
  - Note: *The point at which the Destructor is invoked is well-defined*

- Let's look at "01_03_lifecycle_creation_destruction.cpp"

Copy Construction

- Recall: whenever a value is passed to or returned from a function, it is copied
- For objects, this happens by *Copy Construction*

- Let's look at "01_04_lifecycle_copy_construction.cpp"

Implicit Definition of Class Methods

- Why were we able to copy “Cls” in the first code example
  - We did not write a copy constructor
- The compiler implicitly provides a set of functions:
  - Default Constructor
  - Destructor
  - Copy Constructor
  - Move Constructor
  - Copy Assignment
  - Move Assignment

Rules for each on when they are implicitly generated, and when they can not be.

Why is understanding the object lifecycle important?

- Fundamental to **R**esource **A**cquisition **i**s **I**nitialization (**RAII**)
- The idea is to manage resources (such as memory, files, threads, mutexes, etc.) by leveraging the object lifecycle

- See the basics in “01_05_lifecycle_raii.cpp”

RAII Implementation Principles

- Encapsulate each resource into a class, where
  - the constructor acquires the resource and establishes all class invariants (or throws an exception if that cannot be done),
  - the destructor releases the resource and never throws exceptions
- Always use the resource via an instance of a RAII-class that either
  - has automatic storage duration or temporary lifetime itself, or
  - has lifetime that is bounded by the lifetime of an automatic or temporary object

http://en.cppreference.com/w/cpp/language/raii

Advanced Values

Move Semantics

- C++ is designed to encourage *zero-overhead abstractions*
  - *Then what about all these copies happening all over the place?*
- Let's consider a simple example of a **string** class
  - Note: *you should never actually write your own "string" class*
- We'll look at "01_06_advanced_string.cpp"

Rvalue References

```
i) string c(funReturningString());        ii) string a(x);
```

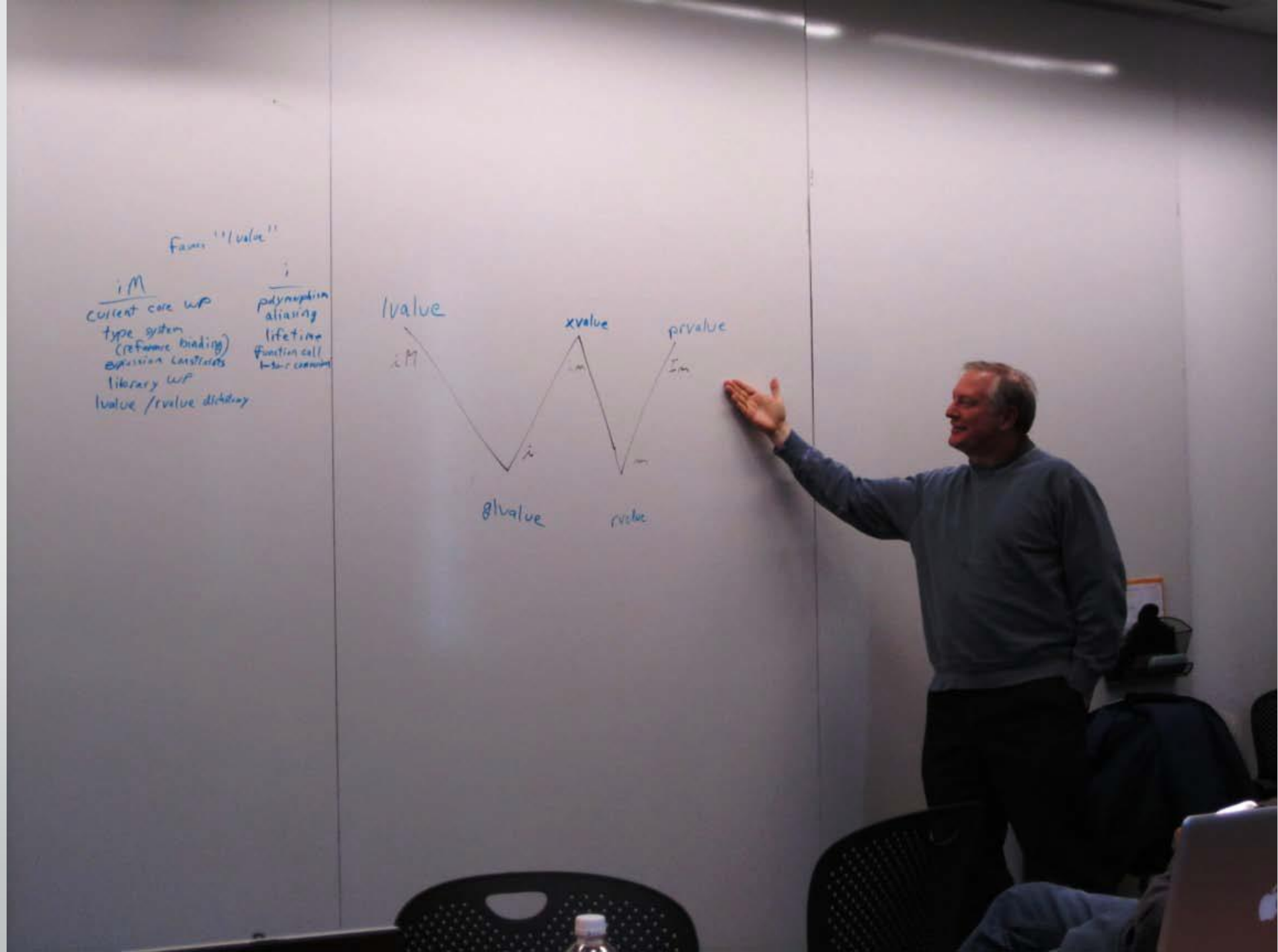
- How can we safely express the idea of reusing existing object state for `i)` but not for `ii)` ?
- `funReturningString()` generates an **rvalue**
  - This is a temporary, unnamed value we cannot assign to and cannot reuse later
- To write functions that only bind to rvalues we use *rvalue references* e.g. **`int&&`**
  - Accordingly, standard reference types like `int&` are also called *lvalue references*

Move Construction

- The *move constructor* is a constructor which takes an rvalue reference type of the object
- It is called automatically **instead of the copy constructor** for the implicit construction of applicable values
- We can observe this in “01_06_advanced_string.cpp”

std::move

- Sometimes, we might want to move from an lvalue
  - E.g. when we know it won't be used, but the compiler does not
- `std::move` allows for that
  - Functions as a cast to an rvalue reference type
- Problem: what is the return value?
  - It has an identity, but can also be moved (that is the whole point)


lvalue
xvalue
prvalue
glvalue
rvalue

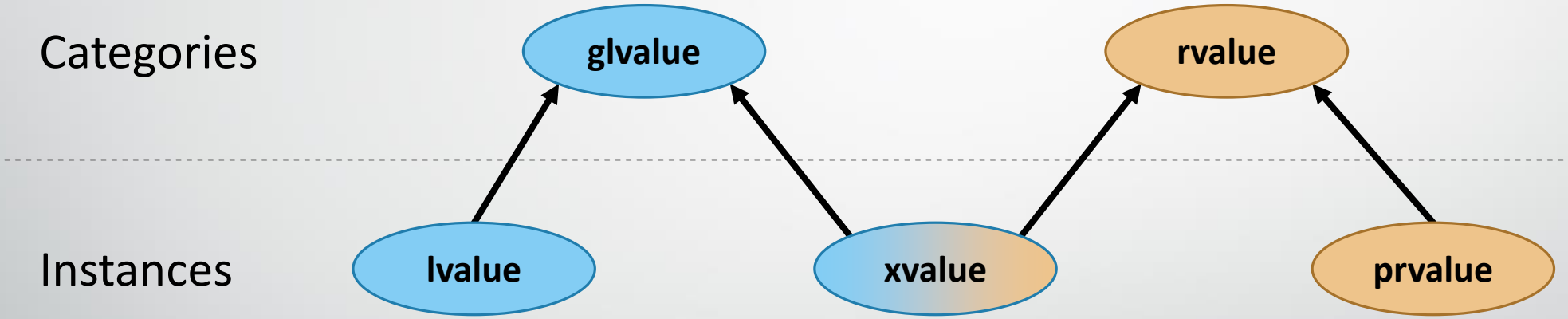
Xvalues

[…] This leaves the top middle of the W: "im"; that is, values that have identity and can be moved. We really don't have anything that guides us to a good name for those esoteric beasts. They are important to people working with the (draft) standard text, but are unlikely to become a household name.

We didn't find any real constraints on the naming to guide us, so we picked 'x' for the center, the unknown, the strange, the xpert only, or even x-rated.

"New" Value Terminology
Bjarne Stroustrup

Value Types – Overview



Properties

- Has an identity
- Can not be moved from

- Has an identity
- Can be moved from

- Has no identity
- Can be moved from

https://stackoverflow.com/a/11540204

Conclusion & Summary

Example Real-World Use Cases

- **RAII**:
  - STL `lock_guard`: http://en.cppreference.com/w/cpp/thread/lock_guard
  - The simple timer I just wrote for the Parallel Systems lab (https://github.com/PeterTh/uibk_ps_parsys/blob/master/exercise02/chrono_timer.h)
- **Move semantics**:
  - `std::basic_string` constructors: http://en.cppreference.com/w/cpp/string/basic_string/basic_string

Summary

- Object lifecycle:
  - Creation, destruction
  - Copy and move semantics, implicitly created functions
  - RAII
- Value categories
- References and rvalue references