Advanced C++ Programming

Libraries

Preliminaries

Overview & Goals

- *The best code is the code you don’t have to write*
- This chapter provides an overview of **available high-quality C++ libraries**
- We won’t go into as much detail as for the language-specific chapters
  - Too many libraries, too little time
  - It’s more important to get an overview of what is out there – if you decide to use some of these libraries, you’ll have to study them in more detail

Libraries Already Covered

We already mentioned/used some parts of the standard library:

Containers and **Iterators**	`<iterator>, <vector>, <unordered_map>, …`
Algorithms	`<algorithm>`
Utilities (e.g. tuple, move)	`<limits>, <typeinfo>, <tuple>, …`
Memory	`<memory>, <new>, …`
Strings	`<string>`
I/O Streams	`<iostream>, <fstream>, …`

Standard Library

Regular Expressions

- Part of the standard library since C++11
  - **Note**: compiler language compliance is sometimes achieved more quickly than *full* standard library support for a given language version
- Supports well-known regex operations – e.g. match, search, replace
- Regex syntax defaults to ECMAScript grammar

http://en.cppreference.com/w/cpp/regex/ecmascript

http://en.cppreference.com/w/cpp/regex

Example in **07_01_regex.cpp**

Filesystem

- Allows you to operate on **paths** and **navigate/iterate** in the filesystem
- Also has operations to query and **modify meta-information** on files (e.g. permissions)
- Developed as a boost library, only recently standardized in **C++17**

➡ You should be familiar with this from earlier in the lab, we will use it later in another example

http://en.cppreference.com/w/cpp/filesystem

Thread Support Library

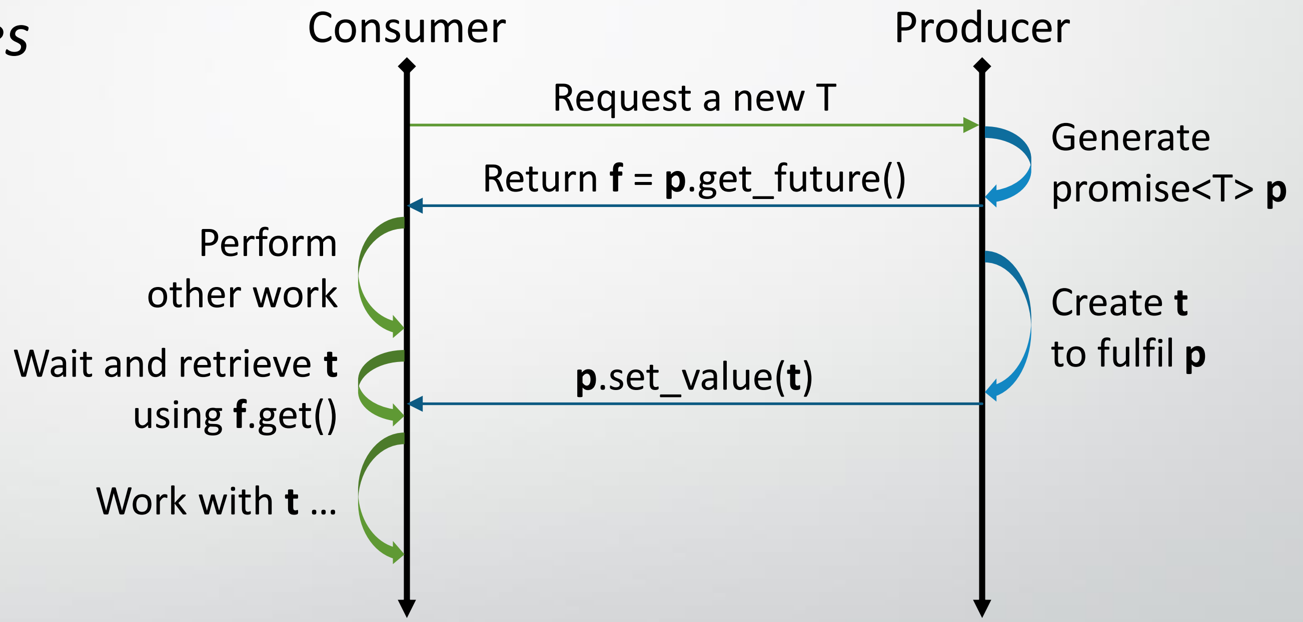
- Provides various features to deal with **concurrency**
  - Threads, mutexes, condition variables, locks, …
  - How to actually use these to build a *correct* parallel program is the subject of several other lectures
  - Simple example in **07_02_threads.cpp**
- Also a few non-functional values provided:
  - `std::thread::hardware_concurrency()`
  - `std::`*`hardware_destructive_interference_size`*
    `std::`*`hardware_constructive_interference_size`*

http://en.cppreference.com/w/cpp/thread

Futures and Promises

Mechanism for *returning values from asynchronous tasks*

- `std::future<T>`
  proxy for a value of type T that *will become available*
- `std::promise<T>`
  means of setting the value associated with a future



Consumer
Producer
Request a new T
Generate promise<T> **p**
Return **f** = **p**.get_future()
Perform other work
Create **t** to fulfil **p**
Wait and retrieve **t** using **f**.get()
p.set_value(**t**)
Work with **t** …

Futures are also returned from `std::async`

➡ Promise handling automated

Example in **07_03_future_fs.cpp**

More Concurrency/Parallelism in C++

- Parallel Algorithms (*see chapter 3*)
- Concurrency Technical Specification
  - Extends future, promise etc.
  - e.g. future.then(…), when_all(…)
- Atomics

http://en.cppreference.com/w/cpp/experimental/concurrency

http://en.cppreference.com/w/cpp/atomic

➲ Important to note when implementing parallel code: **C++ memory model**
Especially when writing low-level primitives

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

Boost Libraries

Overview

- Set of **peer-reviewed C++ libraries** with some common design/build/distribution standards
- **Note:** you don't use "boost", you use a specific set of boost libraries
- Many libraries are **header-only**, some require compilation
- Usually aim for wide compiler and C++ version compatibility

http://www.boost.org/

Standardization

- Boost libraries commonly get picked up for standardization (often with minor changes)
- Examples:
  - `boost::regex` → `std::regex`
  - `boost::ref` → `std::ref`
  - Type Traits
  - Unordered Containers
  - `boost::filesystem` → `std::filesystem`

Nice side effect: if you are forced to use an older compiler/standard library implementation, you can use the “precursor” boost library to get a similar interface until you can upgrade.

Categories

- String and text processing
- Containers
- Iterators
- Algorithms
- Higher-order programming
- Image processing
- Input/Output
- Memory
- Patterns and Idioms
- System
- Generic Programming
- Template Metaprogramming
- Concurrent Programming
- Math and numeric
- Correctness and testing
- Data structures
- Domain Specific
- Parsing
- State Machines
- Miscellaneous

http://www.boost.org/doc/libs/?view=categorized

Examples

- **String and text processing**
- Containers
- Iterators
- Algorithms
- Higher-order
- Image proces
- Input/Outpu
- Memory
- Patterns and Idioms
- System

- Generic Programming
- Template Metaprogramming
- gramming
- eric
- d testing
- s
- c
- State Machines
-

E.g. **boost::format** for string formatting

- Supports formatting options similar to C-style printf
- **Type safe** and supports user types (!)
- Also supports reordering and additional format options

Example in **07_04_boost_format.cpp**

Examples

- String and text processing
- **Containers**
- Iterators
- Algorithms
- Higher-order
- Image proces
- Input/Outpu
- Memory
- Patterns and Idioms
- System

- Generic Programming
- Template Metaprogramming
- gramming
- eric
- d testing
- s
- c
- State Machines
-

E.g. **boost::bimap** for bidirectional maps

- Works like having 2 maps which are automatically kept in sync
- Other useful container libs:
  - Circular buffer
  - Intrusive
  - ICL (interval sets)

Example in **07_05_boost_bimap.cpp**

Examples

- String and text processing
- Containers
- Iterators
- Algorithms
- Higher-order
- Image proces
- Input/Outpu
- Memory
- Patterns and Idioms
- System

- **Generic Programming**
- T te Metaprogramming
- gramming
- eric
- d testing
- s
- c
- State Machines

E.g. **boost::operators**

- Allows you to define some derived operators without lots of boilerplate code
- Provides fine-grained interface to define either a small set of operations or larger clusters

Example in **07_06_boost_operators.cpp**

Examples

- String and text processing
- Containers
- Patterns and Idioms
- System

- Generic Programming
- **Template Metaprogramming**
- Concurrent Programming
- Math and numeric
- Correctness and testing
- Data structures
- Domain Specific
- Parsing
- State Machines

E.g. **boost::hana**

- A template metaprogramming library
- Can work on values and types transparently
- Utility functions as well as compile-time algorithms and containers

Example in **07_07_boost_hana.cpp**

Examples

- String and text processing
- Containers
- Iterators
- Algorithms
- Higher-order progra
- Image processing
- **Input/Output**
- Memory
- Patterns and Idioms
- System

- Generic Programming
- mming
- ing
- g
- Parsing
- State Machines

E.g. **boost::program_options**

- Provides convenient interface for parsing and storing command line options
- Many features, e.g. automatic vector aggregation
- Good error handling, automatic help/description generation

Example in **07_08_boost_program_options.cpp**

Examples

- String and text processing
- Containers
- Iterators
- Algorithms
- Higher-order programming
- Image processing
- Input/Output
- Memory
- **Patterns and Idioms**
- System

- Generic Programming

E.g. **boost::flyweight**

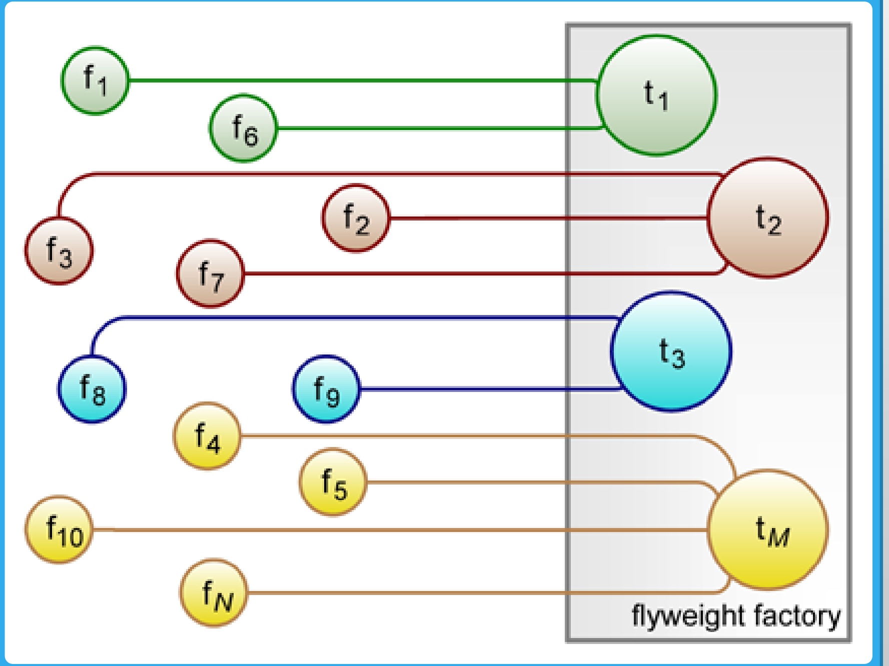


Illustration taken from boost flyweight documentation

Examples

- String and text processing
- Containers
- Iterators
- A
- H
- In
- In
- M
- Pa
- Sy

Example in 07_09_boost_log.cpp

- Concurrent Programming
- Math and numeric
- Correctness and testing
- Data structures
- Domain Specific
- Parsing
- State Machines
- **Miscellaneous**

E.g. **boost::log**

- Provides logging facilities
- Very configurable, from simple logging to console to file-based logging with custom scoped attributes
- **Note**: not header-only, needs to be built and linked

Other Libraries

Eigen

- *“Eigen is a C++ template library for linear algebra: matrices, vectors, numerical solvers, and related algorithms”*
- Versatile and elegant
- Easy to integrate (header only)
- Other options: Blaze, Armadillo, …

Example in **07_07_boost_hana.cpp**

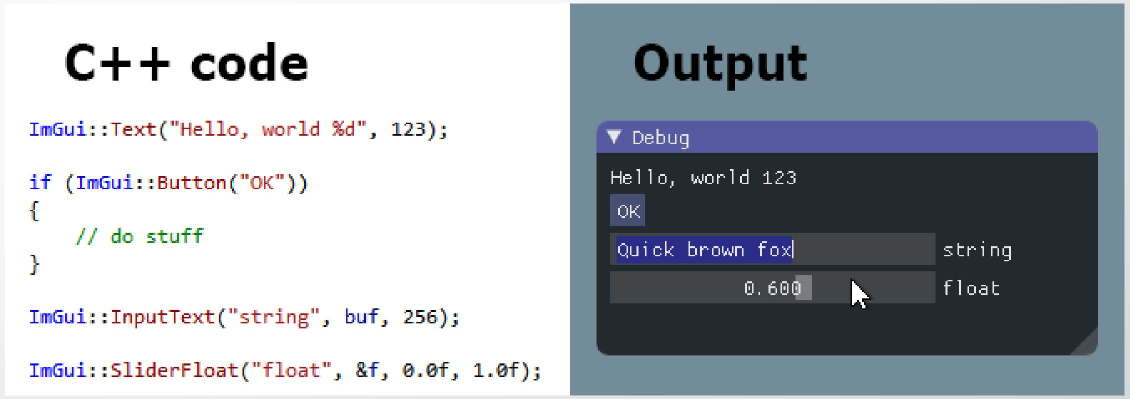
GUI

- **First**: think if you actually want to implement your UI in C++
- If so, the most classical choice is **Qt**
  - **Well supported and documented**, feature-rich
  - Somewhat outdated design by modern C++ standards

- *However*, if you have a good reason to write your UI in C++ you might also have a good reason to use an immediate mode GUI design

Immediate Mode UI

- Don’t store another copy of data in UI toolkit
- Widgets are built by functions calls rather than objects



```
ImGui::Text("Hello, world %d", 123);

if (ImGui::Button("OK"))
{
    // do stuff
}

ImGui::InputText("string", buf, 256);

ImGui::SliderFloat("float", &f, 0.0f, 1.0f);
```

```
▼ Debug
Hello, world 123
OK
Quick brown fox        string
          0.600        float
```

- Advantages and disadvantages compared to traditional retained mode UI
- Very suitable for custom data visualization of changing data sets
- Or for integration in existing real-time applications

→ Examples: https://github.com/ocornut/imgui/issues/973

https://github.com/ocornut/imgui

Conclusion

Summary

- C++, as a language, is designed to allow the implementation of fast, elegant and versatile libraries
- There are a large number of those out there, of varying quality and support
- Study the available technology before making an implementation decision
    - The more impactful / long-lasting the decision, the more effort you should spend on this search and selection process