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 **08_01_regex.cpp**

std::regex Caution

- Most implementations of std::regex are comparatively slow and may require many memory allocations
  - And this is unlikely to improve due to ABI compatibility constrains
  - Also missing full Unicode support
- If regex performance is important for you then look at other choices

Boost.Regex
Similar interface to std, usually faster.
Documentation

Google RE2
"Fast, safe, thread-friendly"
Github

CTRE
Compile-time regular expressions
Github

Some Benchmarks – std::regex can be *many times* slower.

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, 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

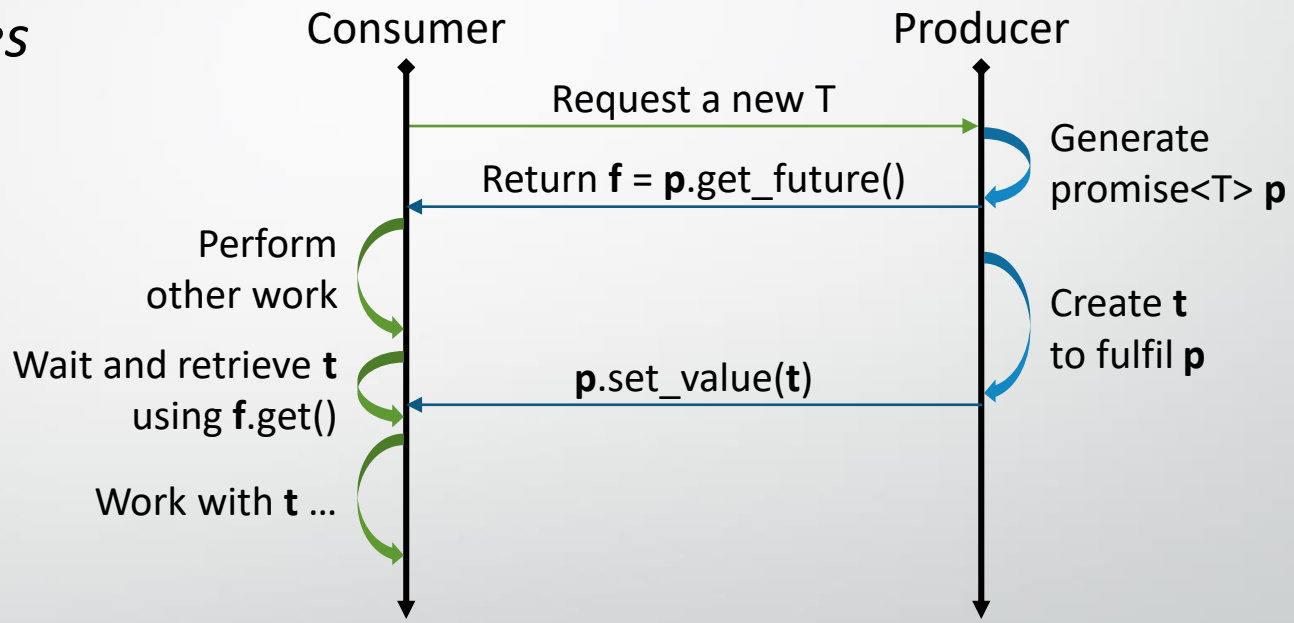
- Provides various features to deal with **concurrency**
  - Threads, mutexes, condition variables, locks, …
  - How to actually use these to build a *correct* parallel program is the subject of several other lectures
  - Simple example in **08_02_threads.cpp**
- Also a few non-functional values provided:
  - `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



Futures are also returned from `std::async`

- ➲ Promise handling automated

Example in **08_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(…)

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

- Atomics

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**
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- c
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-

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 **08_04_boost_format.cpp**

Examples

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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 **08_05_boost_bimap.cpp**

Examples

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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 **08_06_boost_operators.cpp**

Examples

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

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

- Generic Programming
- **Template Metaprogramming**
- Concurrent Programming
- Math and numeric
- Correctness and testing
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Example in **08_07_boost_hana.cpp**

Examples

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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 **08_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

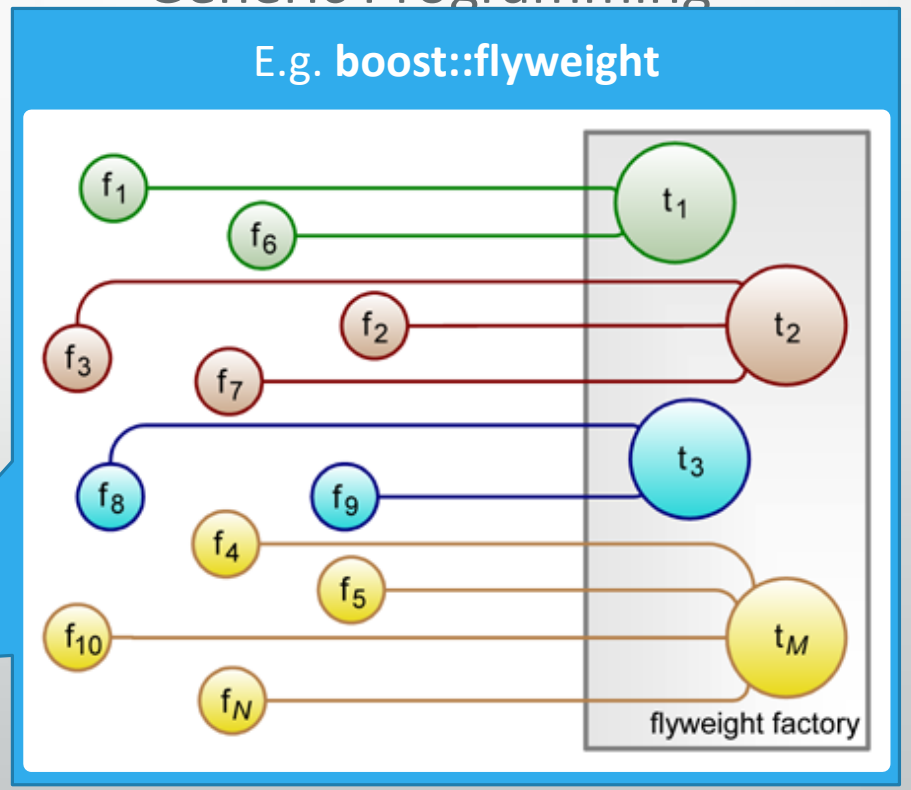

Illustration taken from boost flyweight documentation

Examples

- String and text processing
- Containers
- Iterators
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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

Example in **08_09_boost_log.cpp**

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

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 **08_10_eigen.cpp**

GUI

- **First**: think if you actually want to implement your UI in C++
- If so, one of the most common choices 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

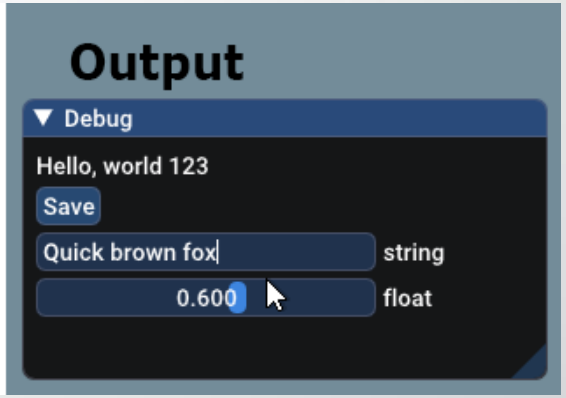
C++ code

```
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);
```



- 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