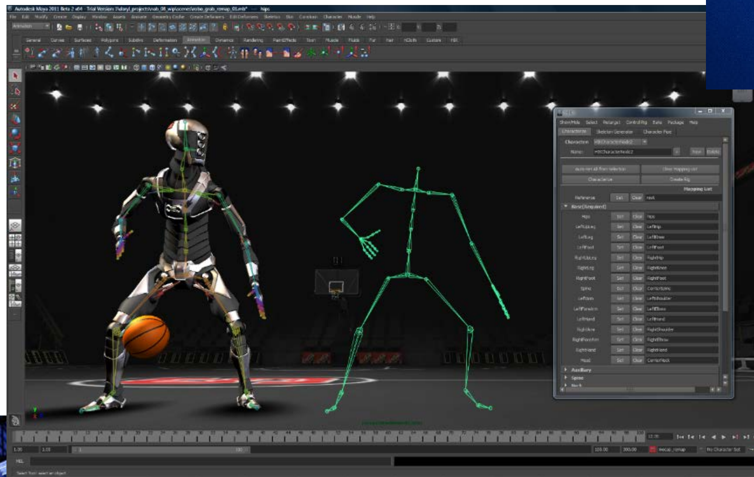
A short introduction to the aims and status of modern C++

Bjarne Stroustrup
Morgan Stanley
Columbia University
www.stroustrup.com

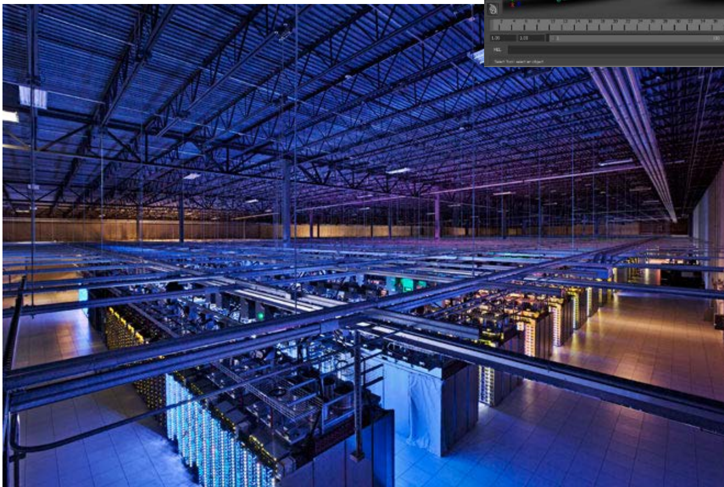
Overview

- C++ aims and means
- C++20
  - Time to celebrate
- Concepts
- Modules
- Span
- Concurrency and parallelism

The value of a programming language is in the quality of its applications



AlphaGo



amazon

NVIDIA

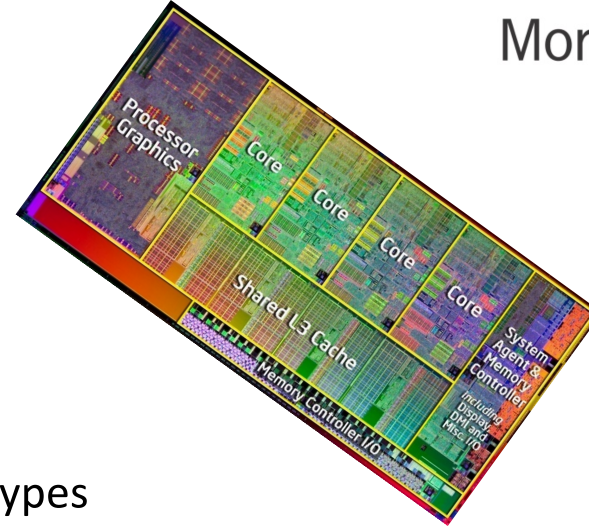
AMADEUS

Google

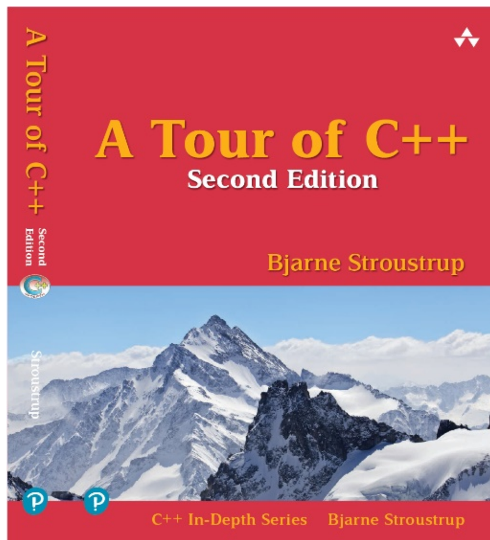
C++ community

- About 4.5 million developers (surveys)
  - Seems to be growing by 100,000++ developers per year
  - Worldwide
    - North America, South America, Western Europe, Eastern Europe, Russia, China, India, Australia, …
  - Most industries
    - Finance, games, Web applications, Web infrastructure, data bases, telecommunications, aerospace, automotive, microelectronics, medical, movies, graphics, imaging, scientific, embedded systems, …

C++ in two lines



- Direct map to hardware
  - of instructions and fundamental data types
  - Future: use novel hardware better (caches, multicores, GPUs, FPGAs, SIMD, …)
- Zero-overhead abstraction
  - Classes, inheritance, templates, concepts, aliases, …
  - Future: Complete type- and resource-safety, concepts, modules, concurrency, …



C++ ideals/aims

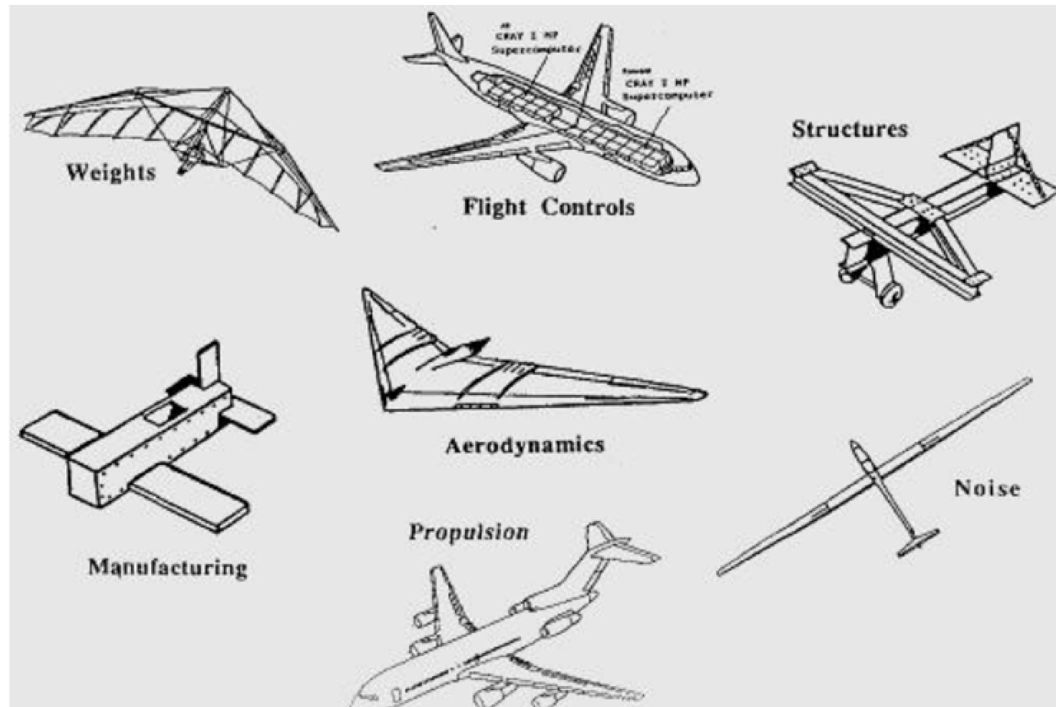
- Write type-safe and resource-safe C++
  - No leaks
  - No memory corruption
  - No garbage collector
  - No limitation of expressibility
  - No performance degradation
  - ISO C++
  - Guaranteed: tool enforced (eventually)
- This cannot be done while allowing arbitrary code
  - C++ Core Guidelines: https://github.com/isocpp/CppCoreGuidelines

The onion principle

- Management of complexity
  - Make simple things simple!
- Layers of abstraction
  - The more layers you peel off, the more you cry

Engineering

- Principled and pragmatic
- Progress gradually guided by feedback
- There are always many tradeoffs
  - Choosing is hard

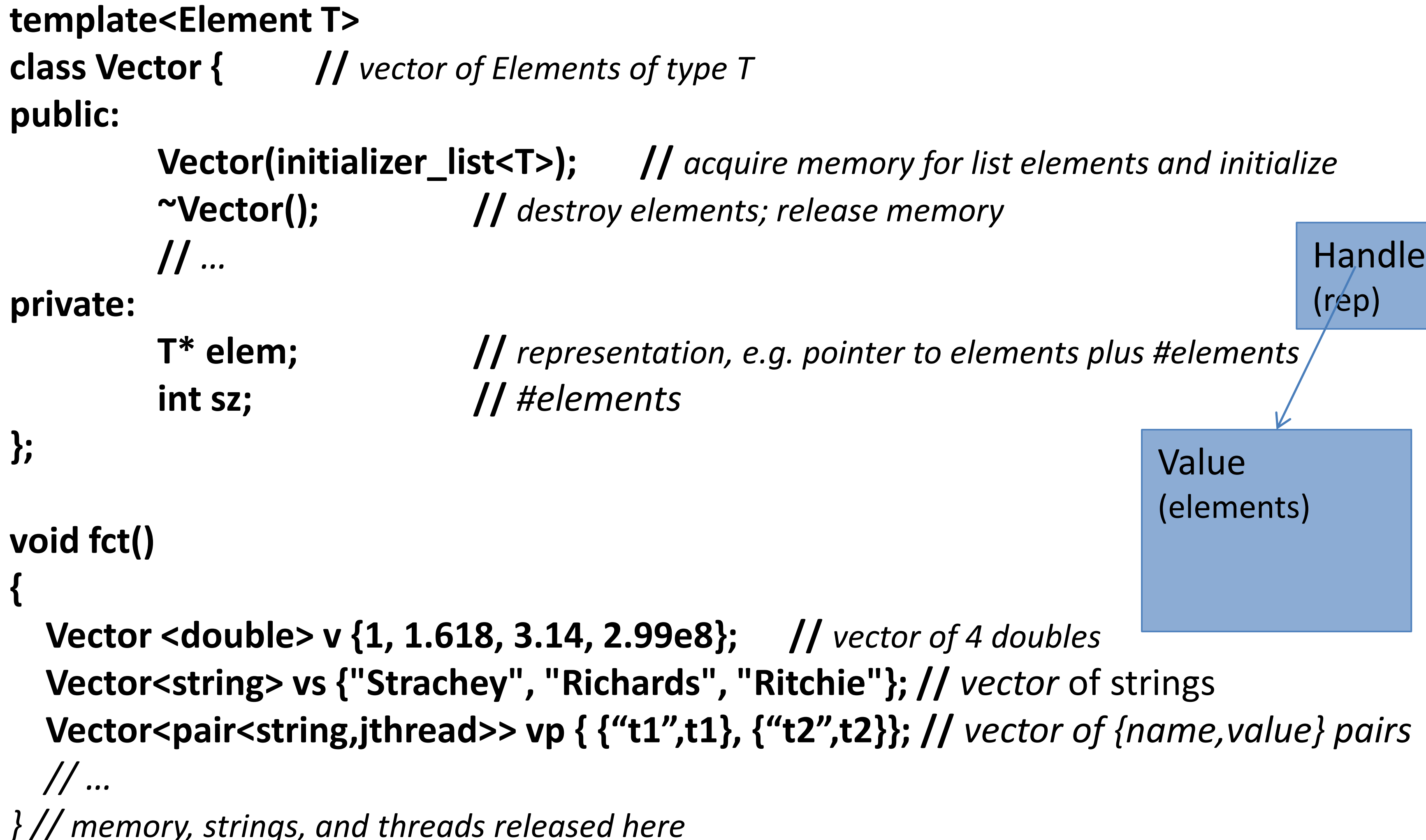


C++: stability and evolution

- Evolution is necessary
  - Newer features and techniques leads to simpler, safer, and faster code
- Stability/compatibility is a feature
  - Old code will run
  - But don't repeat all the old mistakes
- Use C++ as a modern language
  - Type safe
    - Don't mess with casts, raw pointers, void*, etc.
  - Resource safe
    - RAII
  - Modular
    - Avoid macros
    - Avoid #include

This will take time

Resource management: Constructors and destructors



"the committee"

1990

2011

2014

2017

C++20 is here

C++20 trip reports

- "semi-official" on reddit
  - https://www.reddit.com/r/cpp/comments/f47x4o/202002_prague_iso_c_committee_trip_report_c20_is/
- Herb Sutter
  - https://herbsutter.com/
- Focused on the latest developments and features
  - Not on C++20 as a whole
  - Not on general principles

C++20

- Major language features
  - Modules
  - Concepts
  - Coroutines
  - Improved compile-time programming support
- Major standard-library components
  - Ranges
  - Dates
  - Formats
  - Parallel algorithms
  - Span
- Many minor language features and standard-library components
- A dense web of interrelated mutually-supporting features

By “major” I mean “changes how we think”

Generic programming:

The backbone of the C++ standard library

- Containers
  - vector, list, stack, queue, priority_queue, ...
- Ranges
- Algorithms
  - sort(), partial_sort(), is_sorted(), merge(), find(), find_if(),...
  - Most with parallel and vectorized versions
- Concurrency support (type safe)
  - Threads, locks, futures, ...
- Time
  - time_points, durations, calendars, time_zones
- Random numbers
  - distributions and engines (lots)
- Numeric types and algorithms
  - complex
  - accumulate(), inner_product(), iota(), ...
- Strings and Regular expressions
- Formats

Generic Programming

- Write code that works for all suitable argument types
  - **void sort(R);** // *pseudo declaration*
    - **R** can be any sequence with random access
    - **R**’s elements can be compared using **<**
  - **E* find_if(R,P);** // *pseudo declaration*
    - **R** can be any sequence that you can read from sequentially
    - **P** must be a predicate on **R**’s element type
    - **E*** must point to the found element of **R** if any (or one beyond the end)

- That’s what the standard says
  - “our job” is to tell this to the compiler
  - C++20 enables that

Generic Programming

- Write code that works for all suitable argument types

```
void sort(Sortable_range auto& r);

vector<string> vs;
// … fill vs …
sort(vs);

array<int,128> ai;
// … fill ai …
sort(ai);
```

A concept:
- Specifies what is required r's type

Implicit:
- Type of container
- Type of element
- Number of elements
- Comparison criteria

Generic Programming

- Write code that works for all suitable argument types
  - Many/most algorithms have more than one template argument type
  - We need to express relationships among template arguments

```
template<input_range R, indirect_unary_predicate<iterator_t<R> Pred>
        Iterator_t<R> ranges::find_if(R&& r, Pred p);

list<int> lsti;
// … fill lsti …
auto p = find_if(lsti, greater_than{7});

vector<string> vs;
// … fill vs …
auto q = find_if(vs, [](const string& s) { return has_vowels(s); });
```

Morgan Stanley

Overloading

Design principles:

- Don't force the user to do what a machine does better
- Zero overhead compared to unconstrained templates

- Overloading based on concepts

```
void sort(Forward_sortable_range auto&);
void sort(Sortable_range auto&);

void some_code(vector<int> vec&,list<int> lst)
{
        sort(lst);        // sort(Forward_sortable_range auto&)
        sort(vec)         // sort(Sortable_range auto&)
}
```

- We don't have to say
  - "**Sortable_range** is stricter/better than **Forward_sortable_range**"
  - we compute that from their definitions

Concepts

- A concept is a compile-time predicate
  - A function run at compile time yielding a Boolean
  - Often built from other concepts

There are libraries of concepts
<ranges>: random_access_range and sortable

```
template<typename R>
concept Sortable_range =
        random_access_range<R>          // has begin()/end(), ++, [], +, …
        && sortable<iterator_t<R>>;     // can compare and swap elements

template<typename R>
concept Forward_sortable_range =
        forward_range<R>                // has begin()/end(), ++; no [] or +
        && sortable<iterator_t<R>>;     // can compare and swap elements
```

Concepts

- A concept is a compile-time predicate
  - A function runs at compile time yielding a Boolean
  - One or more arguments
  - Can be built from fundamental language properties: use patterns

```
template<typename T, typename U = T>
concept equality_comparable = requires(T a, U b) {
        {a==b} -> bool;
        {a!=b} -> bool;
        {b==a} -> bool;
        {b!=a} -> bool;
}
```

There are libraries of concepts
<concepts>: equality_comparable

Types and concepts

- A type
  - Specifies the set of operations that can be applied to an object
    - Implicitly and explicitly
    - Relies on function declarations and language rules
  - Specifies how an object is laid out in memory
- A ***single-argument*** concept
  - Specifies the set of operations that can be applied to an object
    - Implicitly and explicitly
    - Relies on use patterns
      - reflecting function declarations and language rules
  - Says nothing about the layout of the object

Ideal:
Use concepts where we now use types,
except for defining layout

Generic Programming is "just" programming

- Why?
  - From 1988 to now "template programming" and "ordinary programming" have been very different
    - Different syntax
    - Different look-up rules
    - Different source code organization
    - "Expert friendly" programming techniques
  - We don't need two different sets of techniques (and notations)
    - Unnecessary complexity
    - Make simple things simple!
  - "ordinary programming" is expressive and familiar

Generic Programming

- will change the way we think about Programming

Modules and transition

- Source organization
- Header file conversion
  - Header and module coexistence
- Build systems
  - Build2
  - Cmake prototype

Richard Smith

Gabriel Dos Reis

Nathan Sidwell

Modules

- Better code hygiene: modularity (especially protection from macros)
- Faster compile times (hopefully factors rather than percent)

```
export module map_printer;                    // we are defining a module

import iostream;
import containers;
using namespace std;

export
template<Sequence S>
        requires Printable<Key_type<S>> && Printable<Value_type<S>>
void print_map(const S& m) {
        for (const auto& [key,val] : m)        // break out key and value
                    cout << key << " -> " << val << '\n';
}
```

Modularity and transition

```
import A;
import B;
```

Is the same as

```
import B;
import A;
```

Import is not transitive

```
module;
#include “xx.h”          // to global module
export module C;
import “a.h”             // “modular headers”
import “b.h”
import A;
export int f() { … }
```

Module partitions

Compile speeds

USE THE MODULE

```
1 #include <libGalil/DmcDevice.h>
2
3 int main() {
4   libGalil::DmcDevice("192.168.55.10");
5 }
```

457440 lines after preprocessing

151268 non-blank lines

1546 milliseconds to compile

becomes

```
1 import libGalil;
2
3 int main() {
4   libGalil::DmcDevice("192.168.55.10");
5 }
```

5 lines after preprocessing

4 non-blank lines

62 milliseconds to compile

The compile time was taken on a Intel Core i7-6700K @ 4 GHz using msvc 19.24.28117, average of 100 compiler invocations after preloading the filesystem caches.

The time shown is the **additional** time on top of compiling an empty main function.

45

Coroutines

```
generator<int> fibonacci() // generate 0,1,1,2,3,5,8,13 …
{
        int a = 0; // initial values
        int b = 1;
        while (true) {
                int next = a+b;
                co_yield a; // return next Fibonacci number
                a = b; // update values
                b = next;
        }
}
f
int main()
{
        for (auto v: fibonacci())
                cout << v << '\n';
}
```

Fast pipelines and generators

Simple asynchronous programming

Ranges library

- Think “STL 2.0 using concepts”
- Simplify use

```
vector<string> v;
// …
sort(v);
```

- Infinite sequences and pipes

```
std::vector<int> v(42);
std::span foo = v | view::take(3);
```

- And much more
- On GitHub

Eric Niebler

Casey Carter

Span

- Non-owning potentially run-time checked reference to a continuous sequence

```
int a[100];
span s {a};     // note: template argument deduction
for (auto x : s) cout << x << '\n';
```

- From the GSL
- On GitHub

Neil Macintosh

Concurrency and parallelism

- C++20
  - Atomics
  - Lock-free programming
  - Fences and barriers
  - Type-safe Posix/windows tread, mutex, etc.
  - Future and promise
  - Parallel algorithms
  - Coroutines (synchronous and asynchronous)
- C++23?
  - Executor model (readers and writers, push and pull)
    - We have consensus, but not in time for C++20
  - Networking (now a TS)
    - Depends on executors
  - Standard library support for coroutines
    - Implementation likely to depend on executors

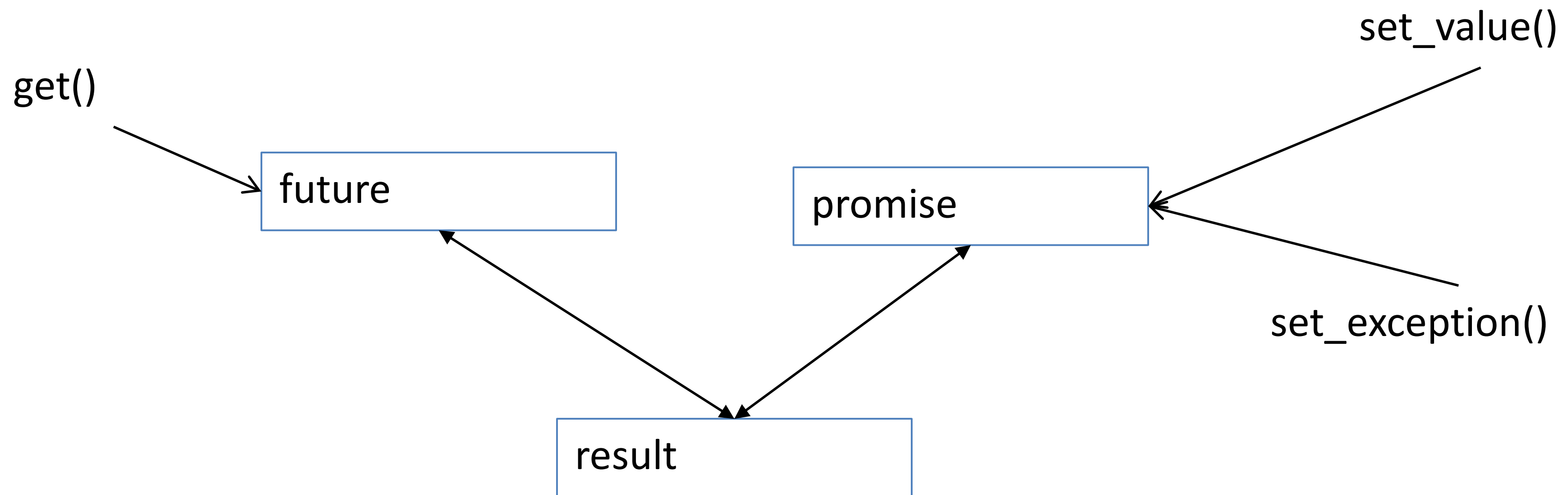
What we want

- Ease of programming
  - Writing correct concurrent code is hard
  - Modern hardware is concurrent in more ways than you imagine
- Uncompromising performance
  - But for what?
- Portability
  - Preferably portable performance
- System level interoperability
  - C++ shares threads with other languages and with the OSs

Threading

- A thread represents a system's notion of executing a task concurrently with other tasks
- You can
  - start a task on a tread
  - wait for a thread for a **specified time**
  - control access to some data by **mutual exclusion**
  - control access to some data using **locks**
  - wait for an action of another task using a **condition variable**
  - return a value from a thread through a **future**

Future and promise



- future+promise provides a simple way of passing a value from one thread to another
  - No explicit synchronization
  - Exceptions can be transmitted between threads

Parallel algorithms

- algorithms giving the option of parallel and/or vectorised execution of standard-library algorithms
  - e.g, **sort(par,b,e)** and **sort(unseq,b,e)**
- All the traditional STL algorithms, e.g., **find(seq,b,e,x)**,
  - but no **find_all(par,b,e,x)** or **find_any(unseq,b,e,x)**
- parallel algorithms:
  - For_each
  - Reduce // parallel accumulate
  - Exclusive scan
  - Inclusive scan
  - Transform reduce
  - Transform exclusive scan
  - Transform inclusive scan
  - …

SIMD vector (in parallelism TS)

- **simd** is a data-parallel type. The width of a given **simd** is a constant expression

```
template<class T, class Abi>        // Abi is size, simd is single dimentional
class simd {
public:
        simd() noexcept = default
        template<class U> simd(U&& value) noexcept;
        template<class U> simd(const simd<U, simd_abi::fixed_size<size()>>&) noexcept;
        // no copy constructor or copy assignment
        template<class G> explicit simd(G&& gen) noexcept;
        template<class U, class Flags> simd(const U* mem, Flags f);
        template<class U, class Flags> copy_from(const U* mem, Flags f);
        template<class U, class Flags> copy_to(U* mem, Flags f);
        reference operator[](size_t);value_type operator[](size_t) const;
        // unary @, binary @, and @= for all @ where it makes sense
};
```

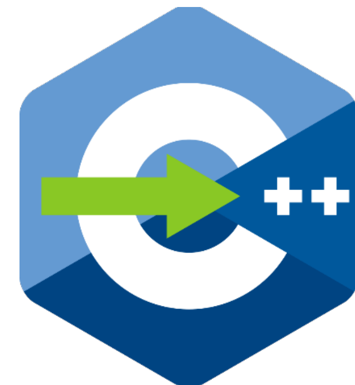
http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2019/n4796.pdf

C++23 – we have a plan

- Top priorities:
  - Library support for coroutines
  - A modular standard library
  - Executors
  - Networking
- Also make progress on
  - Reflection
  - Pattern matching
  - Contracts
- After that
  - Everything else

C++

- C++20
  - Competed February 15, 2020
  - Most features shipping somewhere
  - Expected: essentially all features shipping by all major vendors in 2020
  - Is going to make a major difference to the way we think and program
  - Compatible / stable
- Use C++ as a modern language
  - Aim for complete type-safety and resource-safety
  - Enforce coding guidelines



Notable features in C++20

- **Modules**.
- **Coroutines**.
- **Concepts**.
- **Ranges**.
- Compile-time programming support:
  - constinit, consteval
  - is_constant_evaluated
  - constexpr allocation, vector, string, union, try and catch, dynamic_cast and typeid
- format("For C++{}", 20).
- operator<=>.
- Feature test macros.
- std::span.
- Synchronized output.
- source_location.
- atomic_ref.
- atomic::wait, atomic::notify, latch, barrier, counting_semaphore, etc.
- jthread and stop_*.