codeplay
THE HETEROGENEOUS SYSTEMS EXPERTS

The future of C++ and heterogeneous programming

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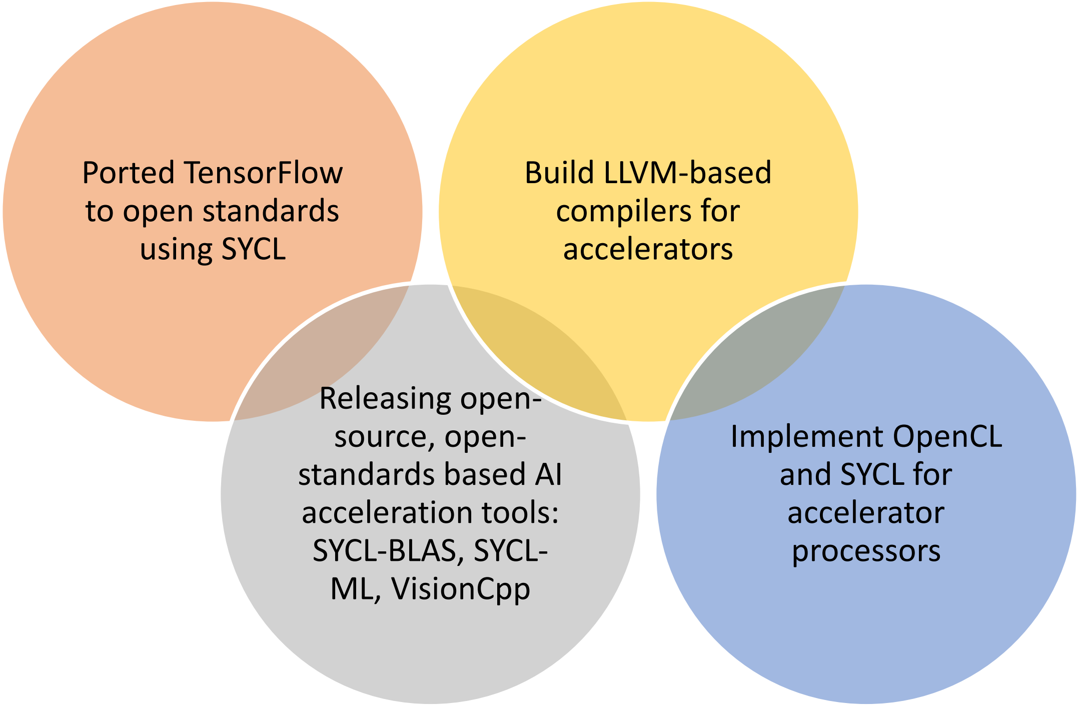
Who am I?

VP of R&D of Codeplay

Chair of SYCL Heterogeneous Programming Language
C++ Directions Group
ISOCPP.org Director, VP
http://isocpp.org/wiki/faq/wg21#michael-wong
Head of Delegation for C++ Standard for Canada
Chair of Programming Languages for Standards Council of Canada
Chair of WG21 SG19 Machine Learning
Chair of WG21 SG14 Games Dev/Low Latency/Financial Trading/Embedded
Editor: C++ SG5 Transactional Memory Technical Specification
Editor: C++ SG1 Concurrency Technical Specification
MISRA C++ and AUTOSAR
wongmichael.com/about

We build GPU compilers for semiconductor companies

- **Now working to make AI acceleration safe for automotive**



Ported TensorFlow to open standards using SYCL

Build LLVM-based compilers for accelerators

Releasing open-source, open-standards based AI acceleration tools: SYCL-BLAS, SYCL-ML, VisionCpp

Implement OpenCL and SYCL for accelerator processors

Acknowledgement Disclaimer

Numerous people internal and external to the original C++/Khronos group, in industry and academia, have made contributions, influenced ideas, written part of this presentations, and offered feedbacks to form part of this talk.

Specifically, Paul Mckenney, Joe Hummel, Bjarne Stroustrup for some of the slides.

I even lifted this acknowledgement and disclaimer from some of them.

But I claim all credit for errors, and stupid mistakes. **These are mine, all mine!**

Legal Disclaimer

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OTHER COMPANY, PRODUCT, AND SERVICE NAMES MAY BE TRADEMARKS OR SERVICE MARKS OF OTHERS.

Codeplay - Connecting AI to Silicon

Products

ComputeCpp™

C++ platform via the SYCL™ open standard, enabling vision & machine learning e.g. TensorFlow™

ComputeAorta™

The heart of Codeplay's compute technology enabling OpenCL™, SPIR™, HSA™ and Vulkan™

Addressable Markets

Automotive (ISO 26262)
IoT, Smartphones & Tablets
High Performance Compute (HPC)
Medical & Industrial

Technologies: Vision Processing
Machine Learning
Artificial Intelligence
Big Data Compute

Company

High-performance software solutions for custom heterogeneous systems

Enabling the toughest processor systems with tools and middleware based on open standards

Established 2002 in Scotland

~70 employees

Customers

BROADCOM.
RENESAS
Imagination
QUALCOMM
Movidius

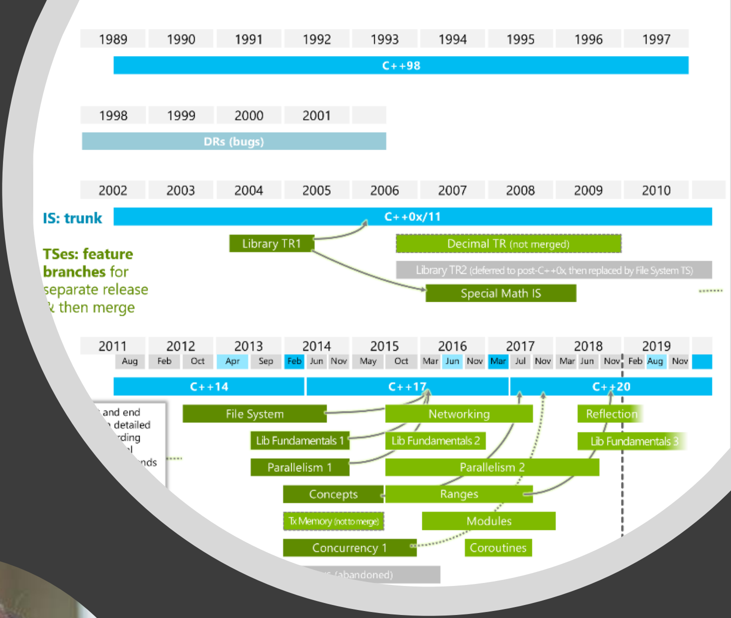
Partners
intel
AMD

3 Act Play

- Where is C++ Standard now?

- What is Parallelism in C++ 11, 14, 17, 20, 23?

- Is there a direction for C++?



- What gets me up every morning?

C++11,14,17“No more Raw Food”

Don’t use	Don’t use raw numbers, do type-rich programming with UDL
Don’t declare	Don’t declare, use auto whenever possible
Don’t use	Don’t use raw NULL or (void *) 0, use nullptr
Don’t use	Don’t use raw new and delete, use unique_ptr/shared_ptr
Don’t use	Don’t use heap-allocated arrays, use std::vector and std::string, or the new VLA, then dynarray<>
Don’t use	Don’t use functors, use lambdas
Don’t use	Don’t use raw loops; use STL algorithms, ranged-based for loops, and lambdas
Rule	Rule of Three? Rule of Zero or Rule of Five.

Parallelism “Use the right abstraction”

Abstraction	How is it supported
Cores	C++11/14/17 threads, async
HW threads	C++11/14/17 threads, async
Vectors	Parallelism TS2
Atomic, Fences, lockfree, futures, counters, transactions	C++11/14/17 atomics, Concurrency TS1, Transactional Memory TS1
Parallel Loops	Async, TBB:parallel_invoke, C++17 parallel algorithms, for_each
Heterogeneous offload, fpga	OpenCL, SYCL, HSA, OpenMP/ACC, Kokkos, Raja
Distributed	HPX, MPI, UPC++
Caches	C++17 false sharing support
Numa	Executors, Execution Context, Affinity
TLS	EALS
Exception handling in concurrent environment	EH reduction properties

Act 1

- Where is C++ Standard now?

- What is Parallelism in C++ 11, 14, 17, 20, 23?

- Is there a direction for C++?

C++ Standard ratification

First X3J16 meeting

Somerset, NJ, USA (1990)

Completed C++11

Madrid, Spain (2011)

Completed C++14

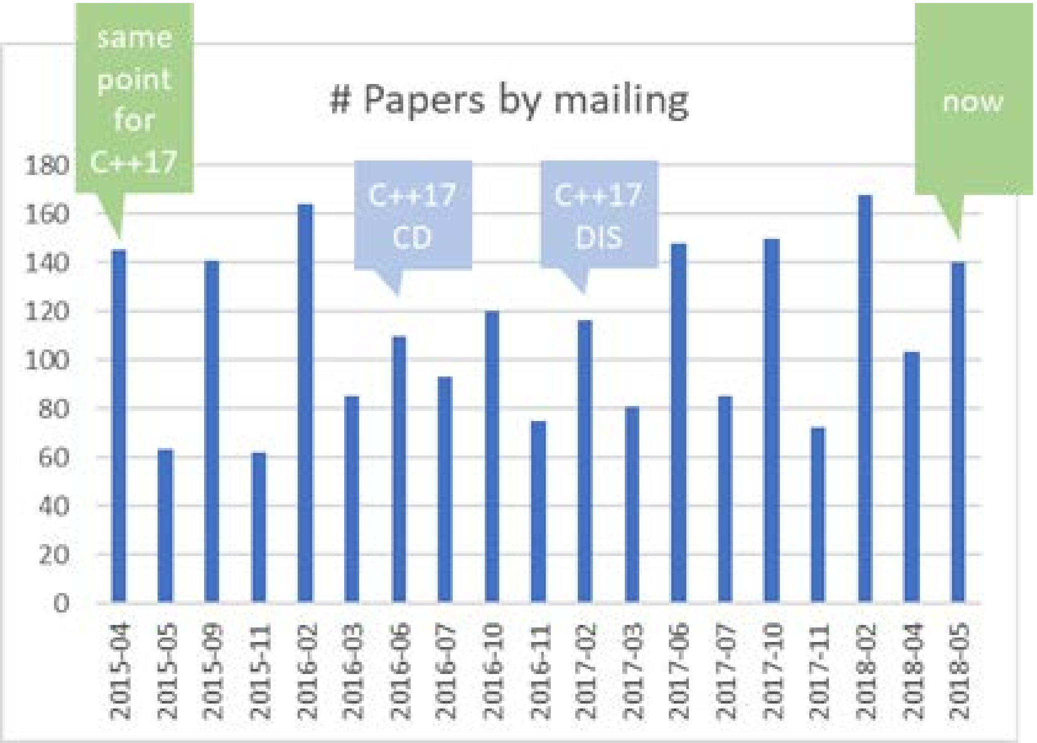
Issaquah, WA, USA (2014)

Photo: Chandler Carruth and Olivier Giroux. License: tinyurl.com/9wn439f

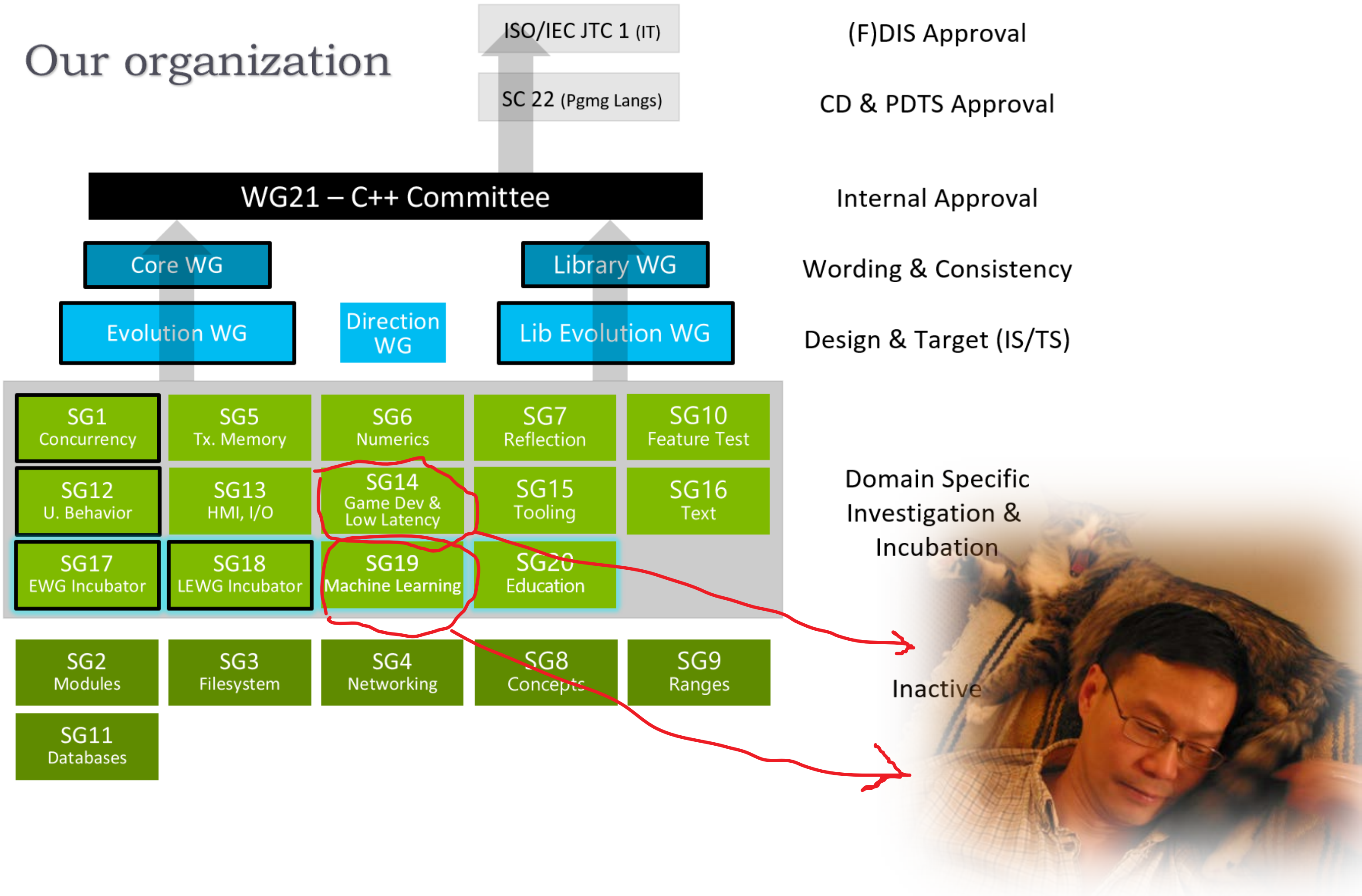
Completed C++17

Kona, HI, USA (2017)

C++ is more popular than ever



ISO C++ Standard



Our organization

ISO/IEC JTC 1 (IT) — (F)DIS Approval

SC 22 (Pgmg Langs) — CD & PDTS Approval

WG21 – C++ Committee — Internal Approval

Core WG, Library WG — Wording & Consistency

Evolution WG, Direction WG, Lib Evolution WG — Design & Target (IS/TS)

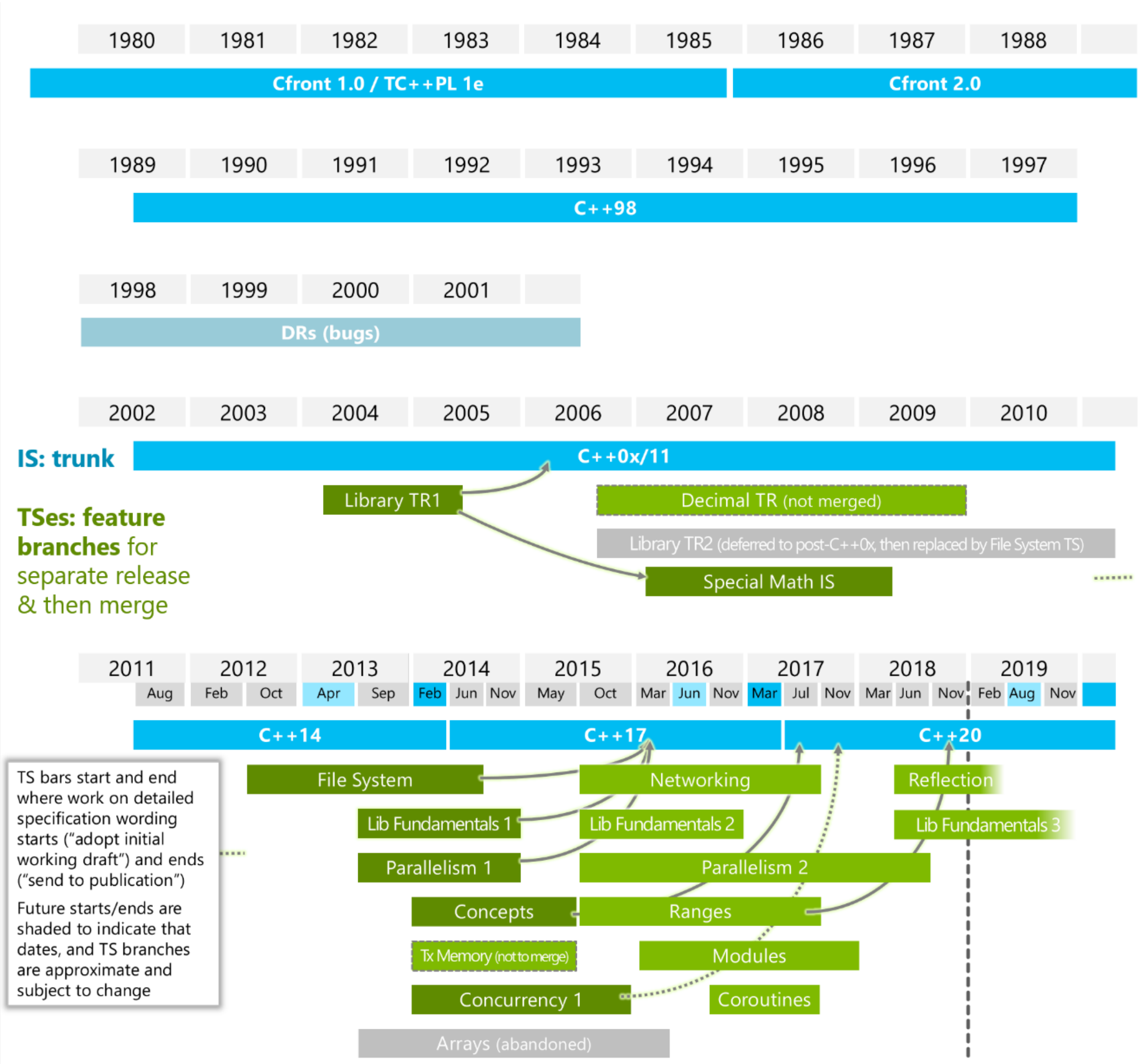
Domain Specific Investigation & Incubation:

- SG1 Concurrency
- SG5 Tx. Memory
- SG6 Numerics
- SG7 Reflection
- SG10 Feature Test
- SG12 U. Behavior
- SG13 HMI, I/O
- SG14 Game Dev & Low Latency
- SG15 Tooling
- SG16 Text
- SG17 EWG Incubator
- SG18 LEWG Incubator
- SG19 Machine Learning
- SG20 Education

Inactive:

- SG2 Modules
- SG3 Filesystem
- SG4 Networking
- SG8 Concepts
- SG9 Ranges
- SG11 Databases

C++ Std Timeline/status
https://isocpp.org/std/status



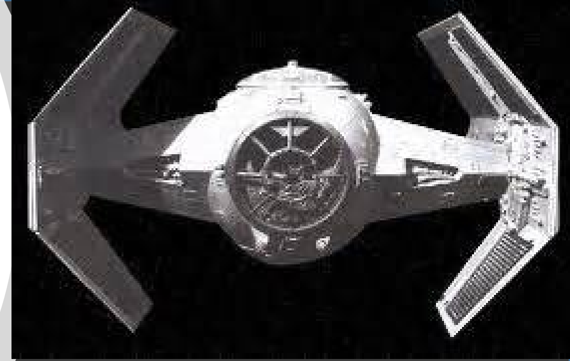
IS: trunk

TSes: feature branches for separate release & then merge

TS bars start and end where work on detailed specification wording starts ("adopt initial working draft") and ends ("send to publication")

Future starts/ends are shaded to indicate that dates, and TS branches are approximate and subject to change

<=>



- No Concepts
- No Unified Call Syntax
- No Default Comparison
- No operator dot
- No Contracts
- No Modules
- No Transactional Memory

So What is the best feature of C++17

- Parallel STL Algorithm
- Execution policy
- Thread of Execution
- Progress Guarantees

Priorities for C++ 20

- Concepts (in the WP)
- Modules (offering proper modularity and dramatic compile-time improvements)
- Ranges (incl., some of the infinite sequence extensions to the TS)
- Networking which means
    - we need Executors in IS20
- Concepts in the standard library

C++20 if time permits

- Contracts as specified in [GDR,2016], [GDR,2017].
- Coroutines [Nishanov,2017].
- Recommendation
    - Additions beyond that should be discouraged as time sinks and distractions.
    - Proposals for minor features should be given priority if and only if they support the priority items

C++ 20 Language Features

- Most notably, the **Concepts Technical Specification has been merged into C++20**!
- Template parameter lists for generic lambdas. T
- Designated initializers.
- Lambda capture [=, *this]
- A __VA_OPT__ macro to make variadic macros easier to use.
- Default member initializers for bitfields
- A tweak to C++17's constructor template argument deduction rules
- Fixing const-qualified pointers to members

- The most significant new feature voted in was **operator<=>**,
- Range-based for statements with initializer.
- Lambdas is unevaluated contexts.
- Default constructible and assignable stateless lambdas.
- Simplifying implicit lambda capture.
- Fixing small functionality gaps in constraints.
- Deprecating the notion of "plain old data" (POD).
- Access checking on specializations.
- const mismatch with defaulted copy constructor.
- ADL and function templates that are not visible.
- Core issue 1581: when are constexpr member functions defined?

More C++20 Language Features

- Language support for empty objects
- Relaxing the structured bindings customization point finding rules.
- Structured bindings in accessible members.
- Allow pack expansion in lambda *init-capture*.
- Symmetry for <=>
- Likely and unlikely attributes
- Down with typename!
- Relaxing range-based for loop’s customization point finding rules
- Support for contract-based programming in C++20
- Class types in non-type template parameters.
- Allowing virtual function calls in constant expressions.
- Prohibit aggregates with user-declared constructors.
- Efficient sized deletion for variable-sized classes.

More C++ 20 Language Features

- Consistency improvements for <=> and other comparison operators.
- Conditionally explicit constructors, a.k.a. explicit(bool).
- · Deprecate implicit capture of this via [=].
- · Integrating feature-test macros into the C++ working draft.
- · A tweak to the rules about when certain errors related to a class being abstract are reported.
- · A tweak to the treatment of padding bits during atomic compare-and-exchange operations.
- · Tweaks to the __VA_OPT__ preprocessor feature.
- · Updating the reference to the Unicode standard.

- **Abbreviated function templates** (AFTs).
- Improvements to *return-type-requirements*.
- Immediate functions.
- std::is_constant_evaluated()
- try / catch blocks in constexpr functions.
- Allowing dynamic_cast and polymorphic typeid in constant expressions.
- Changing the active member of a union inside constexpr
- char8_t: a type for UTF-8 characters and strings.
- Access control in contract conditions.
- Revising the C++ memory model.
- Weakening release sequences.
- Nested inline namespaces
- Signed integers are two’s complement

C++20 Library Features

- Support for detecting endianness programmatically
- Repairing elementary string conversions (also a Defect Report)
- Improvements to the integration of C++17 class template argument deduction into the standard library (also a Defect Report)
- Extending make_shared to support arrays

- Transformation trait remove_cvref
- Treating unnecessary decay
- Using nodiscard in the standard library
- Make std::memory_order a scoped enumeration
- Synchronized buffered ostream
- A utility to convert pointer-like objects to raw pointers
- Add constexpr modifiers to functions in <algorithm> and <utility> headers.
- constexpr for std::complex
- Atomic shared_ptr
- Floating-point atomics
- De-pessimize legacy <numeric> algorithms with std::move
- String prefix and suffix checking, i.e. starts_with() and ends_with()

More C++20 library Features

- **calendar and timezone library**.
- std::span
- <version> header
- Tweak on how unordered containers are compared
- String::reserve() should not shrink
- User specializations of function templates in namespace std
- Manipulators for C++ synchronized buffer ostream
- constexpr iterator requirements

- The most notable addition at this meeting was **standard library Concepts**.
- atomic_ref
- Bit-casting object representations
- Standard library specification in a Concepts and Contracts world
- Checking for the existence of an element in associative containers
- Add shift() to <algorithm>
- Implicit conversion traits and utility functions
- Integral power-of-2 operations
- The identity metafunction
- Improving the return value of erase()-like algorithms
- constexpr comparison operators for std::array
- constexpr for swap and related functions
- fpos requirements
- Eradicating unnecessarily explicit default constructors
- Removing some facilities that were deprecated in C++17 or earlier

More C++20 Library Features

- The most notable addition at this meeting was **merging the Ranges TS into C++20**!
- Fixing operator>>(basic_istream&, CharT*).
- variant and optional should propagate copy/move triviality.
- visit<R>: explicit return type for visit.
- <chrono> zero(), min(), and max() should be noexcept.
- constexpr in std::pointer_traits.
- Miscellaneous constexpr bits.
- unwrap_ref_decay and unwrap_reference
- reference_wrapper for incomplete types
- A sane variant converting constructor
- std::function move constructor should be noexcept

- std::assume_aligned
- Smart pointer creation with default initialization
- Improving completeness requirements for type traits)
- Remove CommonReference requirement from StrictWeakOrdering (a.k.a fixing relations)
- Utility functions to implement uses-allocator construction
- Should span be Regular?
- Make stateful allocator propagation more consistent for operator+(basic_string))
- Simplified partial function application
- Heterogeneous lookup for unordered containers
- Adopt consistent container erasure from Library Fundamentals v2

Pre-C++11 projects

ISO number	Name	Status	What is it?	C++17?
ISO/IEC TR 18015:2006	Technical Report on C++ Performance	Published 2006 (ISO store) Draft: TR18015 (2006-02-15)	C++ Performance report	No
ISO/IEC TR 19768:2007	Technical Report on C++ Library Extensions	Published 2007-11-15 (ISO store) Draft: n1745 (2005-01-17) TR 29124 split off, the rest merged into C++11	Has 14 Boost libraries, 13 of which was added to C++11.	N/A (mostly already included into C++11)
ISO/IEC TR 29124:2010	Extensions to the C++ Library to support mathematical special functions	Published 2010-09-03 (ISO Store) Final draft: n3060 (2010-03-06). Under consideration to merge into C++17 by p0226 (2016-02-10)	Really, ORDINARY math today with a Boost and Dinkumware Implementation	YES
ISO/IEC TR 24733:2011	Extensions for the programming language C++ to support decimal floating-point arithmetic	Published 2011-10-25 (ISO Store) Draft: n2849 (2009-03-06) May be superseded by a future Decimal TS or merged into C++ by n3871	Decimal Floating Point decimal32 decimal64 decimal128	No. Ongoing work in SG6

Status after Nov SAN C++ Meeting

ISO NUMBER	NAME	STATUS	LINKS	C++20?
ISO/IEC TS 19841:2015	Transactional Memory TS	Published 2015-09-16, (ISO Store). Final draft: n4514 (2015-05-08)	Composable lock-free programming that scales	No. Already in GCC 6 release and waiting for subsequent usage experience.
ISO/IEC TS 19217:2015	C++ Extensions for Concepts	Published 2015-11-13. (ISO Store). Final draft: n4553 (2015-10-02) Current draft: p0734r0 (2017-07-14) Merged into C++20 (with modifications).	Constrained templates	Merged into C++20, **including (now) abbreviated function templates!**
	Executors		Abstraction for where/how code runs in a concurrent context	Lite form headed for C++20, rest aiming for C++23
	Coroutines TS		Resumable functions, based on Microsoft's await design	Published! C++20 merge uncertain
	Reflection TS		Static code reflection mechanisms	PDTS ballot underway; publication expected in early 2019

Concepts: compromised design for Abbreviated Function Template

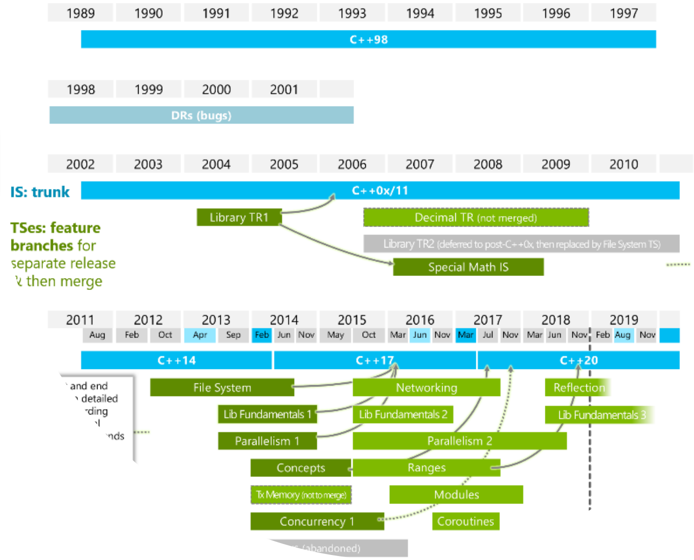
```
void f(Concept auto x);
Concept auto f(Concept auto x);
```

Status after Nov SAN C++ Meeting

ISO number	Name	Status	What is it?	C++20?
ISO/IEC TS 19571:2016	C++ Extensions for Concurrency	Published 2016-01-19. (ISO Store) Final draft: p0159r0 (2015-10-22)	improvements to future, latches and barriers, atomic smart pointers	Latches, atomic<shared_ptr<t>> merged into C++20. Already in Visual Studio release and Anthony Williams Just Threads! and waiting for subsequent usage experience.
ISO/IEC TS 19568:2017	C++ Extensions for Library Fundamentals, Version 2	Published 2017-03-30. (ISO Store) Draft: n4617 (2016-11-28)	source code information capture and various utilities	Published! Parts of it merged into C++17
ISO/IEC DTS 21425:2017	Ranges TS	Published 2017-12-05. (ISO Store) Draft: n4685 (2017-07-31)	Range-based algorithms and views	Merged in C++20
ISO/IEC TS 19216:2018	Networking TS	Published 2018-04-24. (ISO Store) Draft n4734 (2017-04-04). Latest draft: n4771 (2018-10-08)	Sockets library based on Boost.ASIO	Published. But may not be added to C++20.
ISO/IEC TS 21544:2018	Modules V1	Published 2018-05-16. (ISO Store) Final Draft n4720 (2018-01-29)	A component system to supersede the textual header file inclusion model	Published as a TS
	Modules V2		Improvements to Modules v1, including a better transition path	On track to be merged into C++20

Status after Nov SAN C++ Meeting

ISO number	Name	Status	What is it?	C++20?
ISO/IEC DTS 19568:xxxx	Numerics TS	Early development. Draft p0101 (2015-09-27)	Various numerical facilities	Under active development
ISO/IEC DTS 19571:xxxx	Concurrency TS 2	Early development	Exploring , lock-free, hazard pointers, RCU, atomic views, concurrent data structures	Under active development. Possible new clause
ISO/IEC TS 19570:2018	Parallelism TS 2	Published 2018-11-15. (ISO Store). Draft: n4773 (2018-10-08)	task blocks, progress guarantees, SIMD<T>, vec, no_vec loop based execution policy	Published. Headed into C++20
ISO/IEC DTS 19841:xxxx	Transactional Memory TS 2	Early development	Exploring on_commit, in_transaction. Lambda-based executor model.	Under active development.
ISO/IEC DTS 19568:xxxx	Graphics TS	Early development. Draft p0267r8 (2018-06-26)	2D drawing API using Cairo interface, adding stateless interfacec	Restarted after being shutdown.
ISO/IEC DTS 19568:xxxx	Library Fundamental V3	Initial draft, early development	Maybe mdspan and expected<T>	Under development



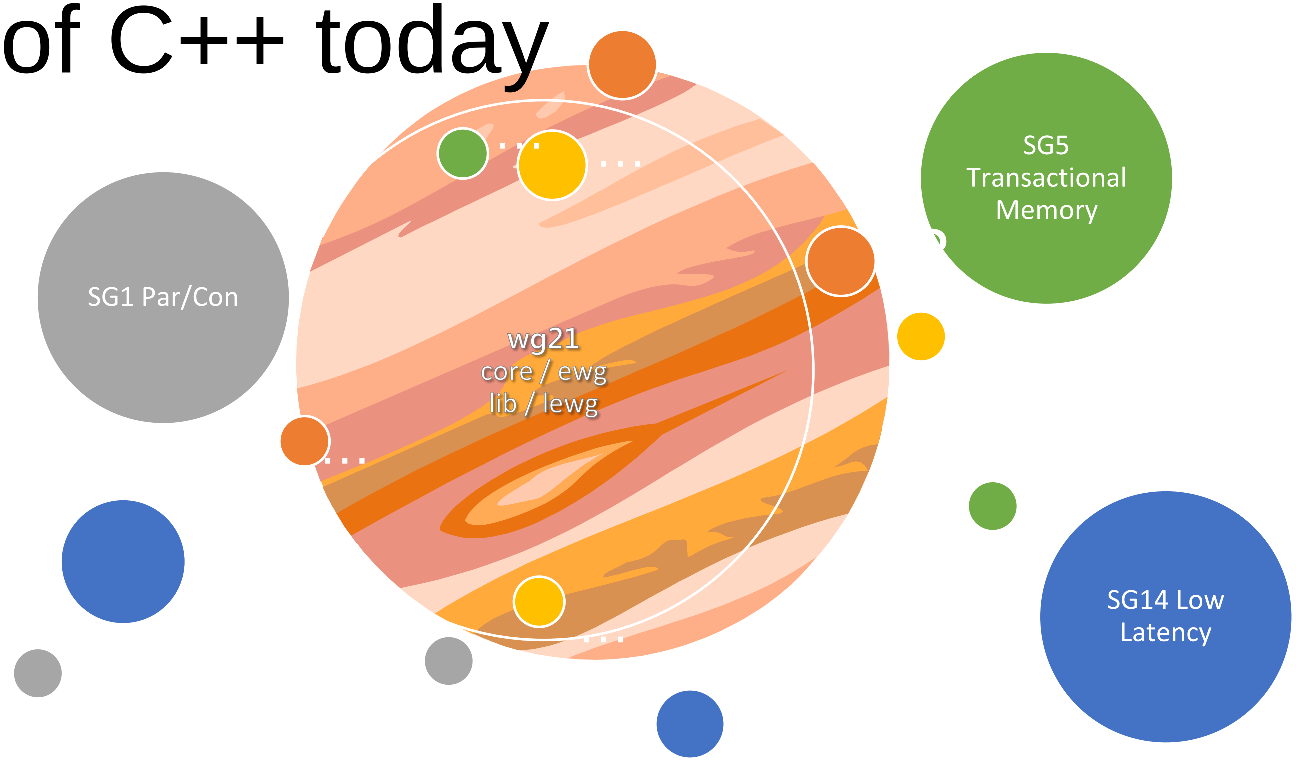
Act 2

- Where is C++ Standard now?

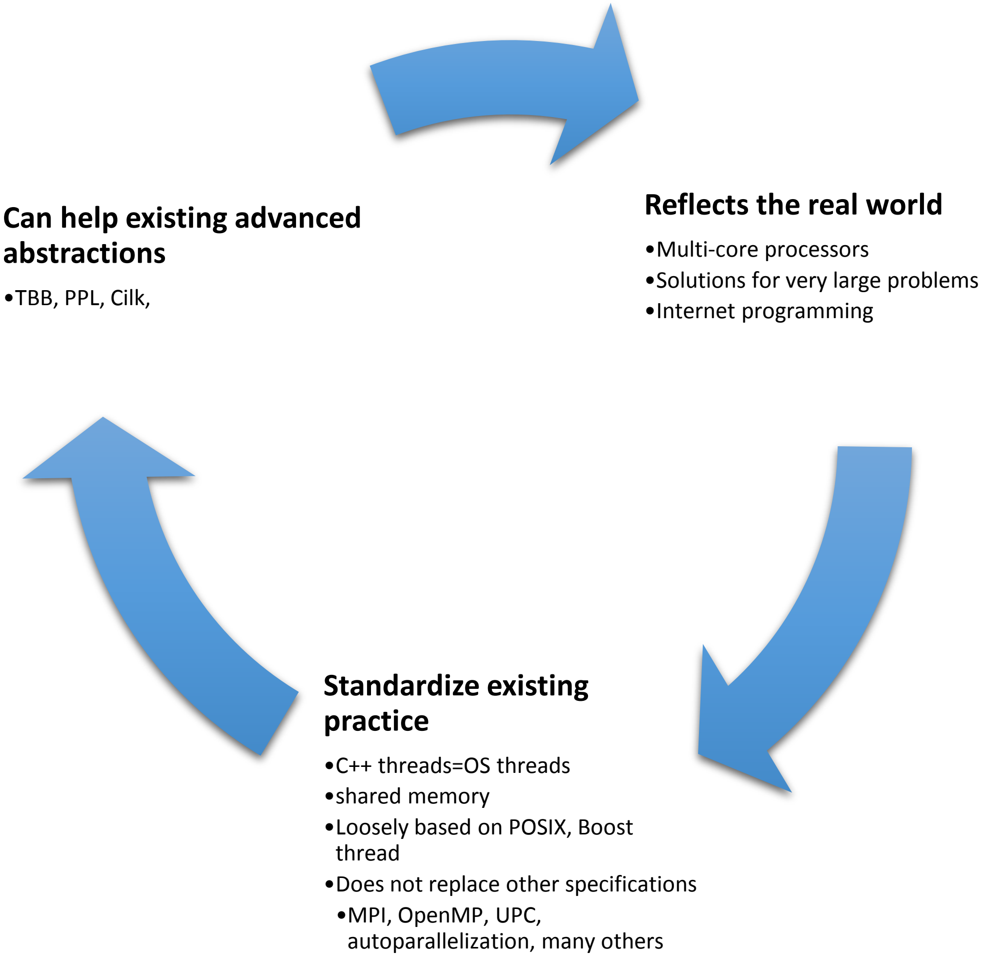
- What is Parallelism in C++ 11, 14, 17, 20, 23?

- Is there a direction for C++?

The Parallel and concurrency planets of C++ today



So Why do we need to standardize concurrency?



Can help existing advanced abstractions

- TBB, PPL, Cilk,

Reflects the real world

- Multi-core processors
- Solutions for very large problems
- Internet programming

Standardize existing practice

- C++ threads=OS threads
- shared memory
- Loosely based on POSIX, Boost thread
- Does not replace other specifications
  - MPI, OpenMP, UPC, autoparallelization, many others

Concurrency Language and Library

Core: what does it mean to share memory and how it affects variables

- TLS
- Static duration variable initialization/destruction
- Memory model
- Atomic types and operations
- Lock-free programing
- Fences
- Dependence based Ordering

•Library: threads and mutexes

- How to create/synchronize/terminate threads,
- Thread , mutex , locks
- RAII for locking, type safe
- propagate exceptions
- A few advanced abstraction
  - Async() , promises and futures
  - parallel STL

What we got in C++

•Low level support to enable higher abstractions	Elementary Thread pools in asynch, eventually replaced with executors
•Ease of programming	Writing correct concurrent code is hard Lots of concurrency in modern HW, more than you imagine
•Portability with the same natural syntax	Not achievable before
•Uncompromising Performance	
•Stable memory model	
•System level interoperability	
•C++ shares threads with other languages	

What we are still trying to get

- All the nifty, higher parallel abstractions
  - TM, atomic<shared<T>>, queues and counters
  - SIMD, Task Blocks, coroutines, networking
  - Distributed and Heterogeneous programming
  - Reactive programming
- Complete Compatibility between C and C++
- Total isolation from programmer mistakes

It`s a Fan!
It`s a Wall!
It`s a Spear!
It`s a Rope!
It`s a Snake!
It`s a Tree!

Coverage before C++11 (C++98)

	Asynchronus Agents	Concurrent collections	Mutable shared state	Heterogeneous (GPUs, accelerators, FPGA, embedded AI processors)
summary	tasks that run independently and communicate via messages	operations on groups of things, exploit parallelism in data and algorithm structures	avoid races and synchronizing objects in shared memory	Dispatch/offload to other nodes (including distributed)
examples	GUI,background printing, disk/net access	trees, quicksorts, compilation	locked data(99%), lock-free libraries (wizards), atomics (experts)	Pipelines, reactive programming, offload,, target, dispatch
key metrics	responsiveness	throughput, many core scalability	race free, lock free	Independent forward progress,, load-shared
requirement	isolation, messages	low overhead	composability	Distributed, heterogeneous
today's abstractions	POSIX threads, win32 threads, OpenCL, vendor intrinsic	openmp, TBB, PPL, OpenCL, vendor intrinsic	locks, lock hierarchies, vendor atomic instructions, vendor intrinsic	OpenCL, CUDA

Coverage after C++11

	Asynchronus Agents	Concurrent collections	Mutable shared state	Heterogeneous (GPUs, accelerators, FPGA, embedded AI processors)
summary	tasks that run independently and communicate via messages	operations on groups of things, exploit parallelism in data and algorithm structures	avoid races and synchronizing objects in shared memory	Dispatch/offload to other nodes (including distributed)
examples	GUI,background printing, disk/net access	trees, quicksorts, compilation	locked data(99%), lock-free libraries (wizards), atomics (experts)	Pipelines, reactive programming, offload,, target, dispatch
key metrics	responsiveness	throughput, many core scalability	race free, lock free	Independent forward progress,, load-shared
requirement	isolation, messages	low overhead	composability	Distributed, heterogeneous
today's abstractions	C++11: thread,lambda function, TLS	C++11: Async, packaged tasks, promises, futures, atomics	C++11: locks, memory model, mutex, condition variable, atomics, static init/term	C++11: lambda

Coverage after C++14

	Asynchronus Agents	Concurrent collections	Mutable shared state	Heterogeneous
summary	tasks that run independently and communicate via messages	operations on groups of things, exploit parallelism in data and algorithm structures	avoid races and synchronizing objects in shared memory	Dispatch/offload to other nodes (including distributed)
examples	GUI,background printing, disk/net access	trees, quicksorts, compilation	locked data(99%), lock-free libraries (wizards), atomics (experts)	Pipelines, reactive programming, offload,, target, dispatch
key metrics	responsiveness	throughput, many core scalability	race free, lock free	Independent forward progress,, load-shared
requirement	isolation, messages	low overhead	composability	Distributed, heterogeneous
today's abstractions	C++11: thread,lambda function, TLS, async C++14: generic lambda	C++11: Async, packaged tasks, promises, futures, atomics,	C++11: locks, memory model, mutex, condition variable, atomics, static init/term, C++ 14: shared_lock/shared_timed_mutex, OOTA, atomic_signal_fence,	C++11: lambda C++14: none

Coverage after C++17

	Asynchronus Agents	Concurrent collections	Mutable shared state	Heterogeneous (GPUs, accelerators, FPGA, embedded AI processors)
summary	tasks that run independently and communicate via messages	operations on groups of things, exploit parallelism in data and algorithm structures	avoid races and synchronizing objects in shared memory	Dispatch/offload to other nodes (including distributed)
today's abstractions	C++11: thread,lambda function, TLS, async C++14: generic lambda	C++11: Async, packaged tasks, promises, futures, atomics, C++ 17: ParallelSTL, control false sharing	C++11: locks, memory model, mutex, condition variable, atomics, static init/term, C++ 14: shared_lock/shared_timed_mutex, OOTA, atomic_signal_fence, C++ 17: scoped _lock, shared_mutex, ordering of memory models, progress guarantees, TOE, execution policies	C++17: , progress guarantees, TOE, execution policies

Coverage aiming for C++20

	Asynchronus Agents	Concurrent collections	Mutable shared state	Heterogeneous/Distributed
today's abstractions	C++11: thread,lambda function, TLS, async C++ 20: Executors Lite Jthreads +interrupt _token	C++11: Async, packaged tasks, promises, futures, atomics, C++ 17: ParallelSTL, control false sharing C++ 20: Is_ready(), make_ready_future() Task blocks simd<T>, Vec execution policy, Algorithm unsequenced policy Executors Lite, mdspan	C++11: locks, memory model, mutex, condition variable, atomics, static init/term, C++ 14: shared_lock/shared_timed_mutex, OOTA, atomic_signal_fence, C++ 17: scoped _lock, shared_mutex, ordering of memory models, progress guarantees, TOE, execution policies C++20: atomic_ref, Latches and barriers atomic<shared_ptr> Atomics & padding bits Simplified atomic init Atomic C/C++ compatibility Semaphores and waiting Fixed gaps in memory model , Improved atomic flags, Repair memory model	C++17: , progress guarantees, TOE, execution policies C++20: atomic_ref, mdspan, executors Lite

invoke async parallel algorithms future::the
n
post

defer define_task_block dispatch asynchronous operations strand<>

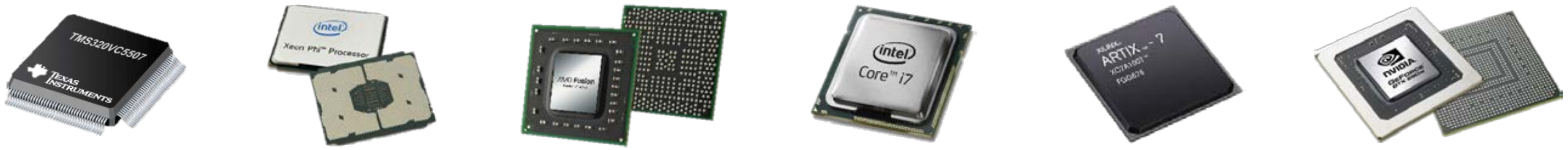
Unified interface for execution

SYCL / OpenCL / CUDA / HCC

OpenMP / MPI

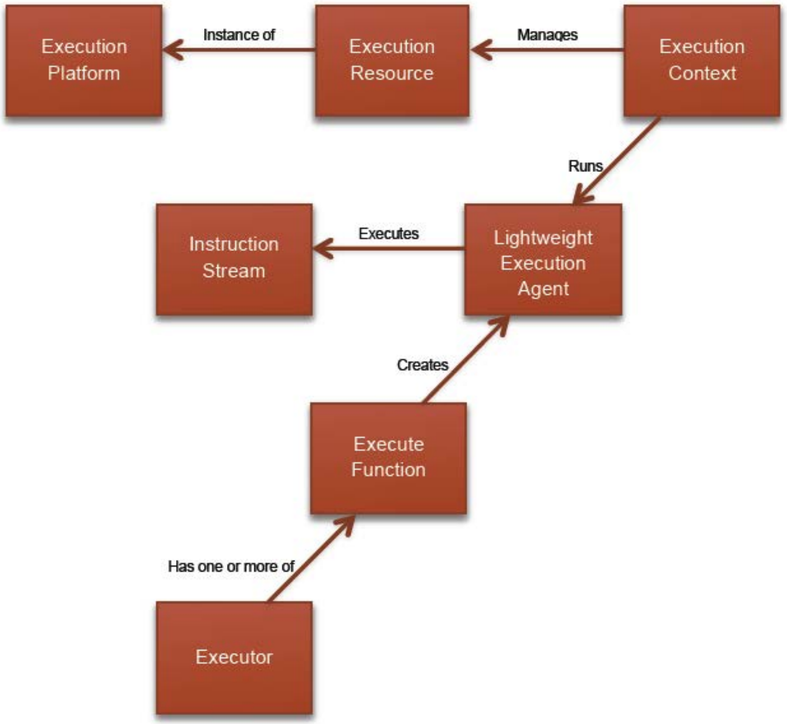
C++ Thread Pool

Boost.Asio / Networking TS



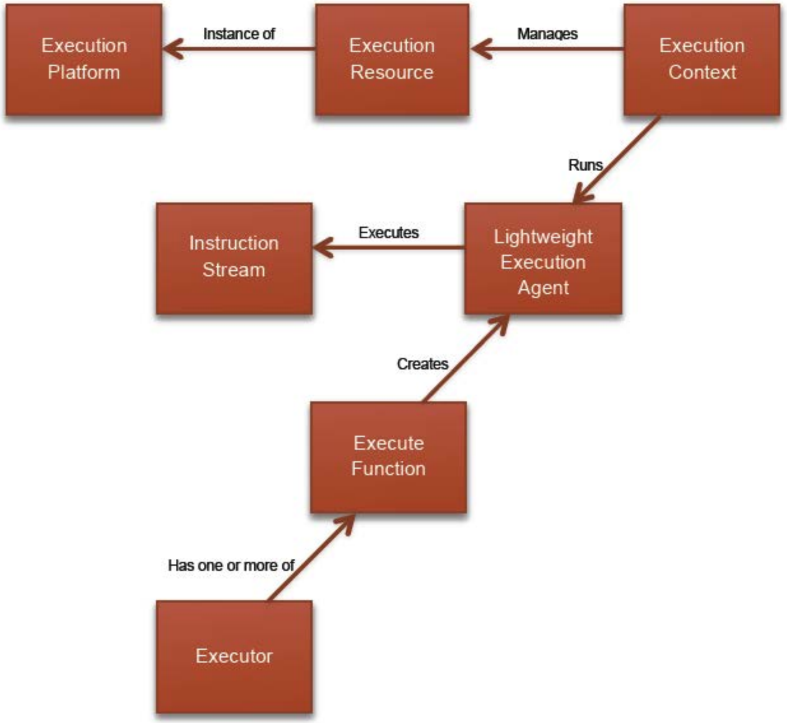
Current Progress of Executors

- An ***instruction stream*** is the function you want to execute
- An ***executor*** is an interface that describes where and when to run an ***instruction stream***
- An ***executor*** has one or more ***execute functions***
- An ***execute function*** executes an ***instruction stream*** on light weight ***execution agents*** such as threads, SIMD units or GPU threads



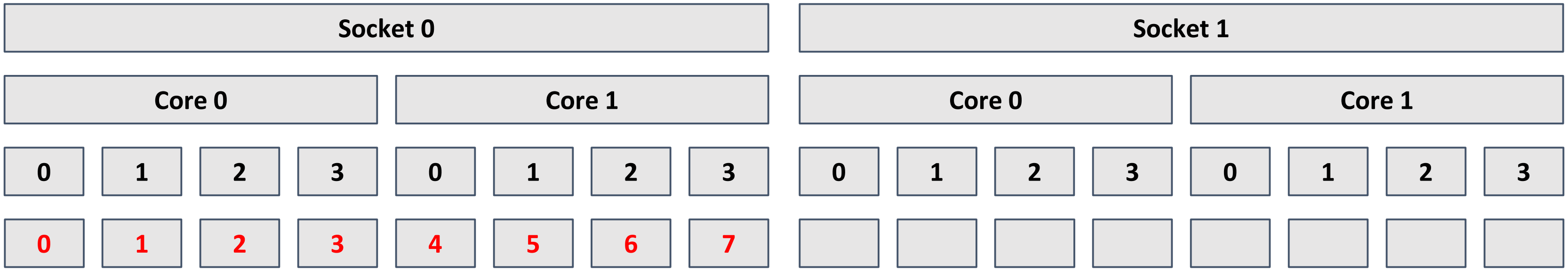
Current Progress of Executors

- An ***execution platform*** is a target architecture such as linux x86
- An ***execution resource*** is the hardware abstraction that is executing the work such as a thread pool
- An ***execution context*** manages the light weight ***execution agents*** of an ***execution resource*** during the execution



Coverage beyond C++20: C++23

	Asynchronus Agents	Concurrent collections	Mutable shared state	Heterogeneous/DIstributed
today's abstractions	C++11: thread,lambda function, TLS, async C++14: generic lambda C++ 20: Executors Lite Jthreads +interrupt _token C++23: coroutines, networking, asynchronous algorithm, reactive programming, EALS, async2	C++11: Async, packaged tasks, promises, futures, atomics, C++ 17: ParallelSTL, control false sharing C++ 20: Is_ready(), make_ready_future() Task blocks simd<T>, Vec execution policy, Algorithm un-sequenced policy Executors Lite, mdspan C++23: new futures, concurrent vector, unordered associative containers, two-way executors with lazy sender-receiver models, concurrent exception handling,	C++11: … C++ 14: … C++ 17: … C++20: atomic_ref, Latches and barriers atomic<shared_ptr> Atomics & padding bits Simplified atomic init Atomic C/C++ compatibility Semaphores and waiting Fixed gaps in memory model , Improved atomic flags , Repair memory model C++23: hazard_pointers, rcu/snapshot, concurrent queues, counters, upgrade lock, TM lite, more lock-free data structures, asymmetric fences	C++17: , progress guarantees, TOE, execution policies C++20: atomic_ref, mdspan, executors Lite C++23: affinity, pipelines, EALS, freestanding/embedded support well specified, mapreduce, ML/AI, reactive programming



Socket 0 Socket 1

Core 0 Core 1 Core 0 Core 1

0 1 2 3 0 1 2 3 0 1 2 3 0 1 2 3

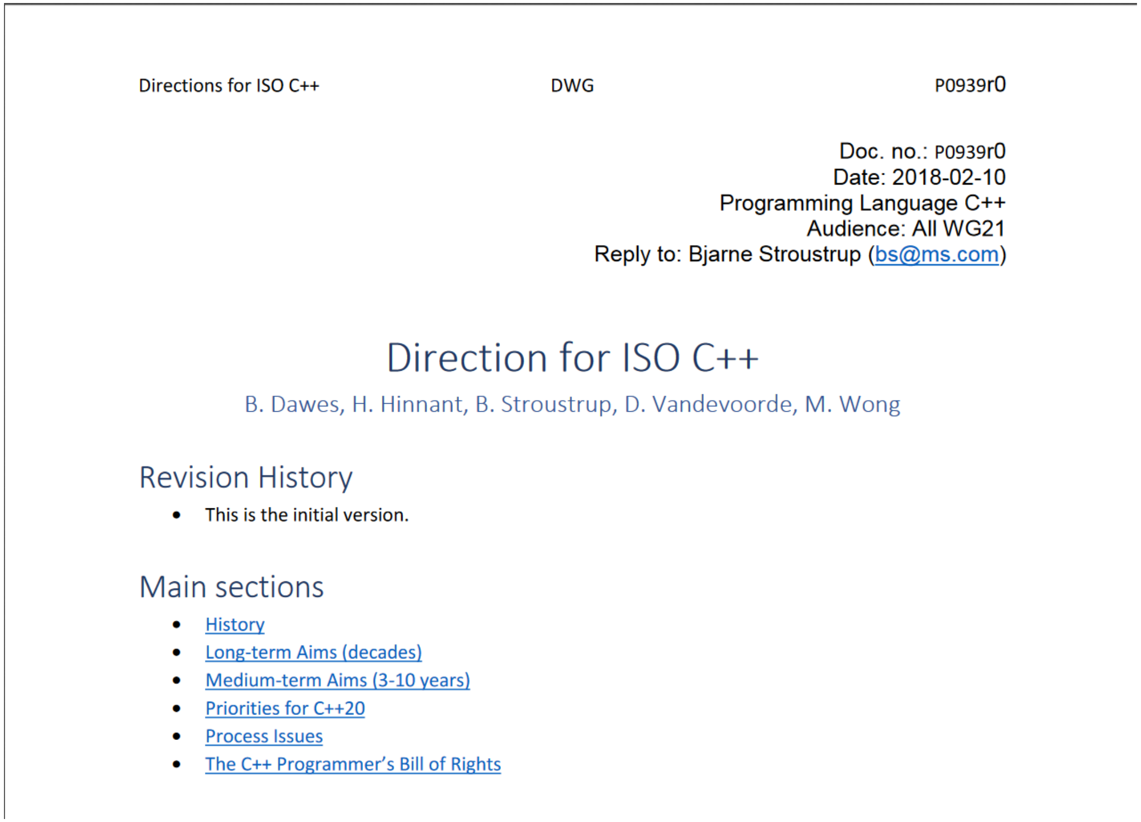
0 1 2 3 4 5 6 7

```
{
  auto exec = execution::execution_context{execRes}.executor();

  auto affExec = execution::require(exec, execution::bulk,
    execution::bulk_execution_affinity.compact);

  affExec.bulk_execute([](std::size_t i, shared s) {
    func(i);
  }, 8, sharedFactory);
}
```

Act 3

- Where is C++ Standard now?
- What is Parallelism in C++ 11, 14, 17, 20, 23?
- Is there a direction for C++?

C++ Directions Group: P0939



Directions for ISO C++ DWG P0939r0

Doc. no.: P0939r0
Date: 2018-02-10
Programming Language C++
Audience: All WG21
Reply to: Bjarne Stroustrup (bs@ms.com)

Direction for ISO C++

B. Dawes, H. Hinnant, B. Stroustrup, D. Vandevoorde, M. Wong

Revision History

- This is the initial version.

Main sections

- History
- Long-term Aims (decades)
- Medium-term Aims (3-10 years)
- Priorities for C++20
- Process Issues
- The C++ Programmer's Bill of Rights

I have a big idea for a big change

- Change gradually building on previous work
- OR
- Provide better alternative to existing feature

Many cooks (photos by Bjarne Stroustrup)

I have a secret to tell you

Direction Group created as response to Call to Action of

Operating Principles for C++ by Heads of Delegation

C++ in danger of losing coherency due to proposals with differ and contradictory design philosophies

The Direction Group
direction@lists.isocpp.org

We try to represent USERS: the Interest of the larger C++ community

WG 21 Direction Group

What is C++

C++ is a language for defining and using lightweight abstractions

C++ supports building resource constrained applications and software infrastructure

C++ support large-scale software development

How do we want C++ to develop?

- *Improve support for large -scale dependable software*
- ***Improve support for high-level concurrency models***
- ***Simplify language use***
- *Address major sources of dissatisfaction*
- *Address major sources of error*

C++ rests on two pillars

- **A direct map to hardware (initially from C)**
- Zero-overhead abstraction in production code (initially from Simula, where it wasn’t zero-overhead)

Strengthen two pillars

Better support for modern hardware (e.g., concurrency, GPUs, FPGAs, NUMA architectures, distributed systems, new memory systems)

More expressive, simpler, and safer abstraction mechanisms (without added overhead)

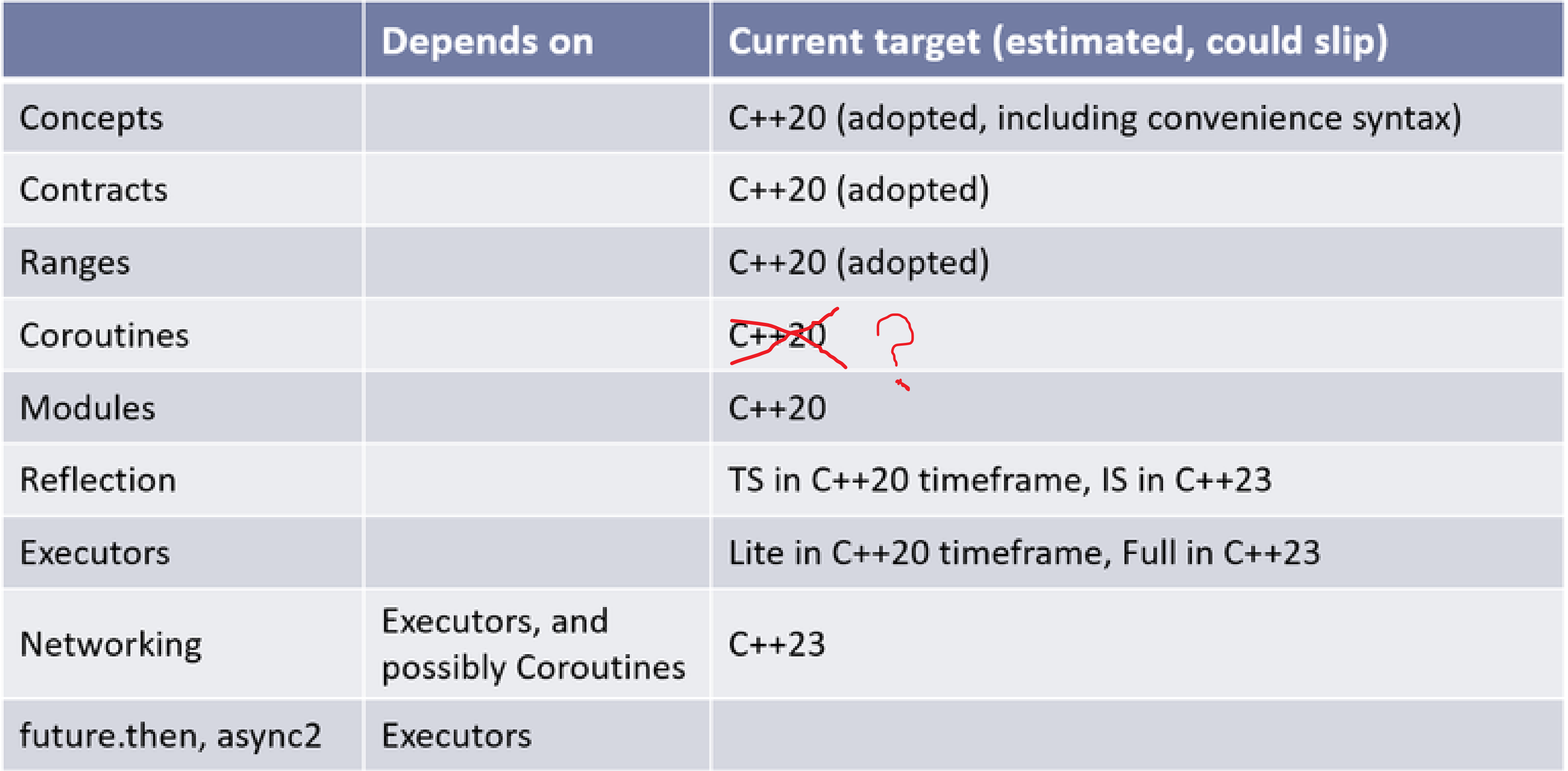
4.3 Concrete Suggestions

- **Pattern matching**
- **Exception and error returns**
- **Static reflection**
- **Modern networking**
- **Modern hardware:**
- *We need better support for modern hardware, such as executors/execution*
- *context, affinity support in C++ leading to **heterogeneous/distributed** computing support,*
- *SIMD/task blocks, more concurrency data structures, improved atomics/memory model/lock-*
- *free data structures support. The challenge is to turn this (incomplete) laundry list into a*
- *coherent set of facilities and to introduce them in a manner that leaves each new standard with*
- *a coherent subset of our ideal.*
- **Simple graphics and interaction**
- **Anything from the Priorities for C++20 that didn't make C++20**

Modern hardware

- We need better support for modern hardware, such as executors/execution context, affinity support in C++ leading to heterogeneous/distributed computing support, ...

What have we achieved so far?



	Depends on	Current target (estimated, could slip)
Concepts		C++20 (adopted, including convenience syntax)
Contracts		C++20 (adopted)
Ranges		C++20 (adopted)
Coroutines		~~C++20~~ ?
Modules		C++20
Reflection		TS in C++20 timeframe, IS in C++23
Executors		Lite in C++20 timeframe, Full in C++23
Networking	Executors, and possibly Coroutines	C++23
future.then, async2	Executors	

Use the Proper Abstraction with C++

Abstraction	How is it supported
Cores	C++11/14/17 threads, async
HW threads	C++11/14/17 threads, async
Vectors	Parallelism TS2->C++20
Atomic, Fences, lockfree, futures, counters, transactions	C++11/14/17 atomics, Concurrency TS1->C++20, Transactional Memory TS1
Parallel Loops	Async, TBB:parallel_invoke, C++17 parallel algorithms, for_each
Heterogeneous offload, fpga	OpenCL, SYCL, HSA, OpenMP/ACC, Kokkos, Raja P0796 on affinity
Distributed	HPX, MPI, UPC++ P0796 on affinity
Caches	C++17 false sharing support
Numa	Executors, Execution Context, Affinity, P0443->Executor TS or IS20
TLS	EALS, P0772
Exception handling in concurrent environment	EH reduction properties P0797

If you have to remember 3 things

1

Expose more parallelism

2

Increase Locality of reference

3

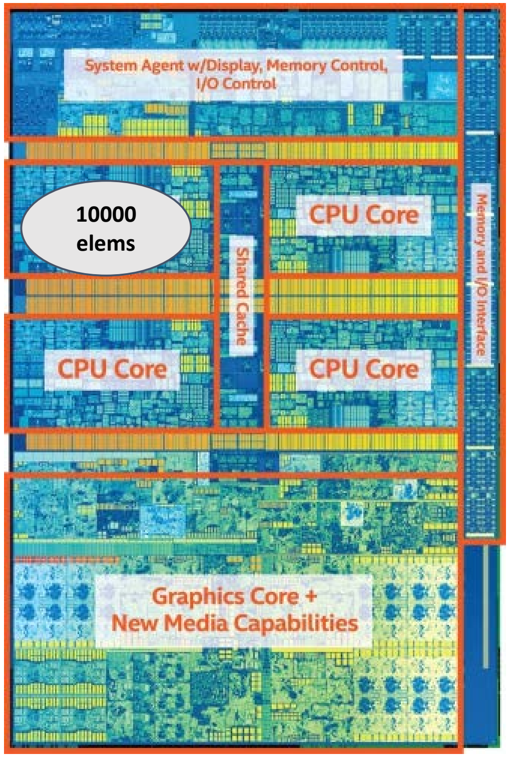
Use Heterogeneous C++ today

- Oh, and one more thing

C++23: Heterogeneous

	Asynchronus Agents	Concurrent collections	Mutable shared state	Heterogeneous/DIstributed
today's abstractions	C++11: thread,lambda function, TLS, async C++14: generic lambda C++ 20: Executors Lite Jthreads +interrupt_token C++23: coroutines, networking, asynchronous algorithm, reactive programming, EALS, async2	C++11: Async, packaged tasks, promises, futures, atomics, C++ 17: ParallelSTL, control false sharing C++ 20: Is_ready(), make_ready_future() Task blocks simd<T>, Vec execution policy, Algorithm un-sequenced policy Executors Lite, mdspan C++23: new futures, concurrent vector, unordered associative containers, two-way executors with lazy sender-receiver models, concurrent exception handling,	C++11: … C++ 14: … C++ 17: … C++20: atomic_ref, Latches and barriers atomic<shared_ptr> Atomics & padding bits Simplified atomic init Atomic C/C++ compatibility Semaphores and waiting Fixed gaps in memory model , Improved atomic flags , Repair memory model C++23: hazard_pointers, rcu/snapshot, concurrent queues, counters, upgrade lock, TM lite, more lock-free data structures, asymmetric fences	C++17: , progress guarantees, TOE, execution policies C++20: atomic_ref, mdspan, executors Lite C++23: affinity, pipelines, EALS, freestanding/embedded support well specified, mapreduce, ML/AI, reactive programming

What can I do with a Parallel For Each?

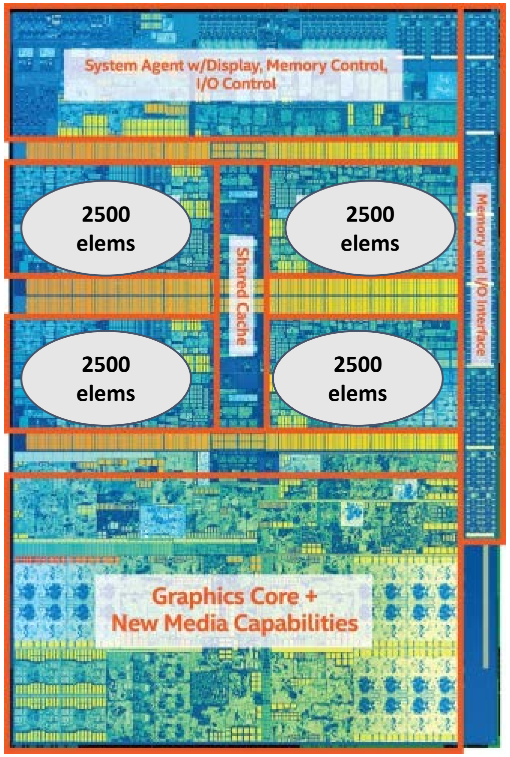

System Agent w/Display, Memory Control, I/O Control
10000 elems
CPU Core
Shared Cache
CPU Core
CPU Core
Memory and I/O Interface
Graphics Core + New Media Capabilities

Intel Core i7 7th generation

```
size_t nElems = 1000u;
std::vector<float> nums(nElems);

std::fill_n(std::begin(v1), nElems, 1);

std::for_each(std::begin(v), std::end(v),
                [=](float f) { f * f + f });
```

Traditional for each uses only one core, rest of the die is unutilized!

What can I do with a Parallel For Each?


System Agent w/Display, Memory Control, I/O Control
2500 elems
2500 elems
Shared Cache
Memory and I/O Interface
2500 elems
2500 elems
Graphics Core + New Media Capabilities

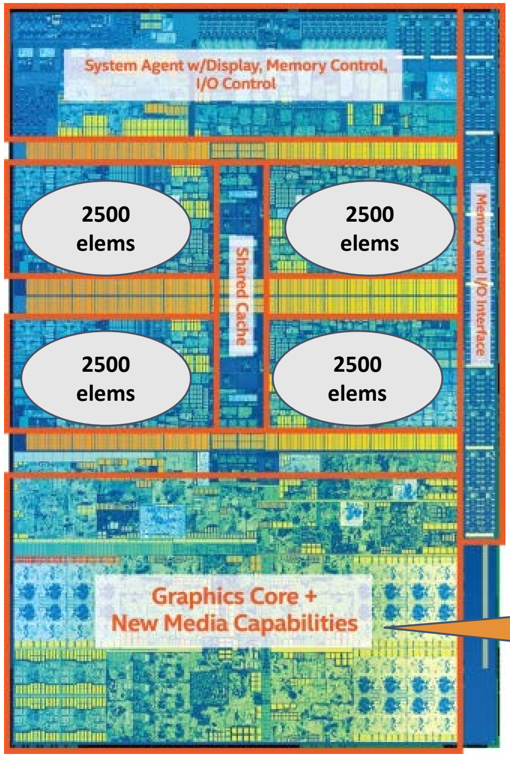
Intel Core i7 7th generation

```
size_t nElems = 1000u;
std::vector<float> nums(nElems);

std::fill_n(std::execution_policy::par,
            std::begin(v1), nElems, 1);

std::for_each(std::execution_policy::par,
              std::begin(v), std::end(v),
              [=](float f) { f * f + f });
```

Workload is distributed across cores!

(mileage may vary, implementation-specific behaviour)

What can I do with a Parallel For Each?


System Agent w/Display, Memory Control, I/O Control
2500 elems
2500 elems
2500 elems
2500 elems
Shared Cache
Memory and I/O Interface
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Intel Core i7 7th generation

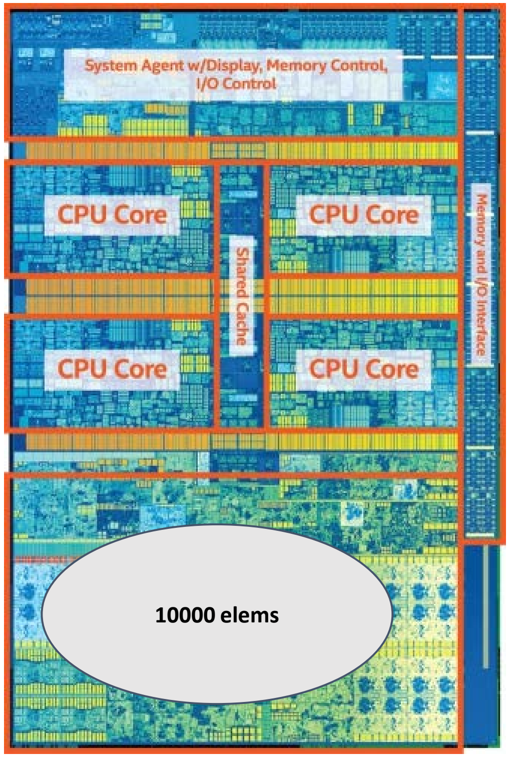
```
size_t nElems = 1000u;
std::vector<float> nums(nElems);

std::fill_n(std::execution_policy::par,
            std::begin(v1), nElems, 1);

std::for_each(std::execution_policy::par,
              std::begin(v), std::end(v),
               [=](float f) { f * f + f });
```

What about this part?

Workload is distributed across cores!

(mileage may vary, implementation-specific behaviour)

What can I do with a Parallel For Each?



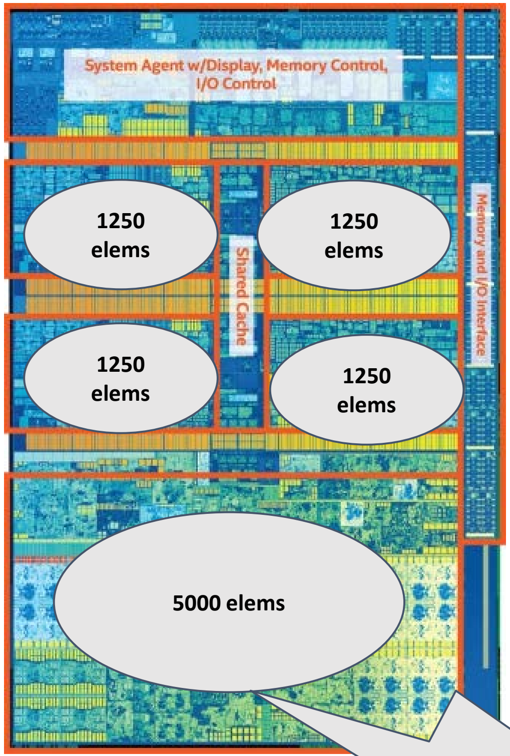
Intel Core i7 7th generation

```
size_t nElems = 1000u;
std::vector<float> nums(nElems);

std::fill_n(sycl_policy,
            std::begin(v1), nElems, 1);

std::for_each(sycl_named_policy
                <class KernelName>,
               std::begin(v), std::end(v),
                [=](float f) { f * f + f });
```

Workload is distributed on the GPU cores

(mileage may vary, implementation-specific behaviour)

What can I do with a Parallel For Each?



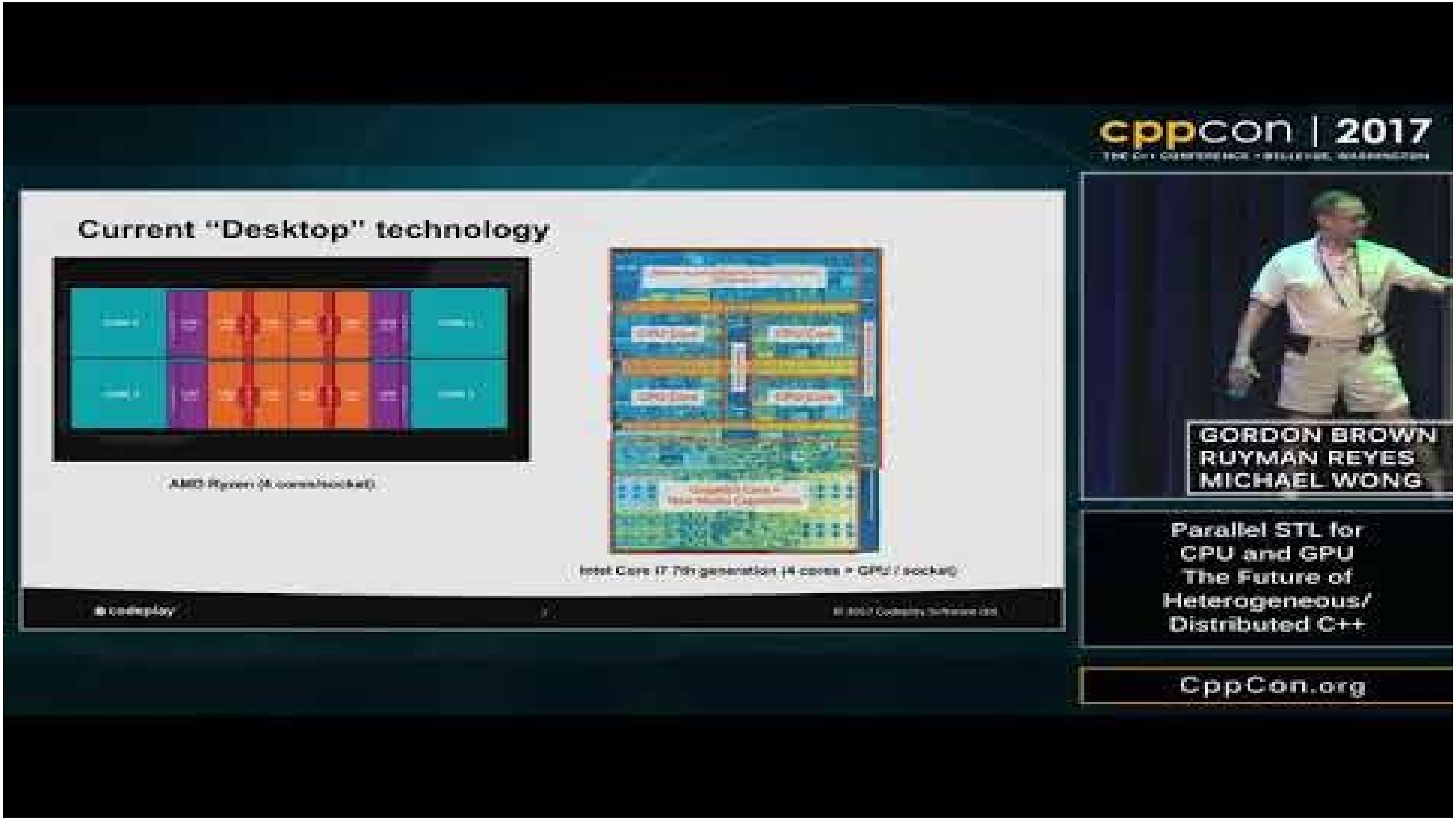
Intel Core i7 7th g

Experimental!

```
size_t nElems = 1000u;
std::vector<float> nums(nElems);

std::fill_n(sycl_heter_policy(cpu, gpu, 0.5),
                std::begin(v1), nElems, 1);

std::for_each(sycl_heter_policy<class kName>
                    (cpu, gpu, 0.5),
                    std::begin(v), std::end(v),
                     [=](float f) { f * f + f });
```

Workload is distributed on all cores!

(mileage may vary, implementation-specific behaviour)



cppcon | 2017

THE C++ CONFERENCE • BELLEVUE, WASHINGTON

Current "Desktop" technology

AMD Ryzen (4 cores/socket)

Intel Core i7 7th generation (4 cores + GPU / socket)

codeplay

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GORDON BROWN
RUYMAN REYES
MICHAEL WONG

Parallel STL for
CPU and GPU
The Future of
Heterogeneous/
Distributed C++

CppCon.org

Demo Results - Running std::sort
(Running on Intel i7 6600 CPU & Intel HD Graphics 520)

size	2^16	2^17	2^18	2^19
std::seq	0.27031s	0.620068s	0.669628s	1.48918s
std::par	0.259486s	0.478032s	0.444422s	1.83599s
std::unseq	0.24258s	0.413909s	0.456224s	1.01958s
sycl_execution_policy	0.273724s	0.269804s	0.277747s	0.399634s

SYCL Ecosystem

- ComputeCpp - https://codeplay.com/products/computesuite/computecpp
- triSYCL - https://github.com/triSYCL/triSYCL
- SYCL - http://sycl.tech
- SYCL ParallelSTL - https://github.com/KhronosGroup/SyclParallelSTL
- VisionCpp - https://github.com/codeplaysoftware/visioncpp
- SYCL-BLAS - https://github.com/codeplaysoftware/sycl-blas
- TensorFlow-SYCL - https://github.com/codeplaysoftware/tensorflow
- Eigen http://eigen.tuxfamily.org

Eigen Linear Algebra Library

SYCL backend in mainline

Focused on Tensor support, providing support for machine learning/CNNs

Equivalent coverage to CUDA

Working on optimization for various hardware architectures (CPU, desktop and mobile GPUs)

https://bitbucket.org/eigen/eigen/

TensorFlow

- **SYCL backend support for all major CNN operations**
- **Complete coverage for major image recognition networks**
  - GoogLeNet, Inception-v2, Inception-v3, ResNet, ….
- **Ongoing work to reach 100% operator coverage and optimization for various hardware architectures (CPU, desktop and mobile GPUs)**
- **https://github.com/tensorflow/tensorflow**

TensorFlow, the TensorFlow logo and any related marks are trademarks of Google Inc.

SYCL Ecosystem

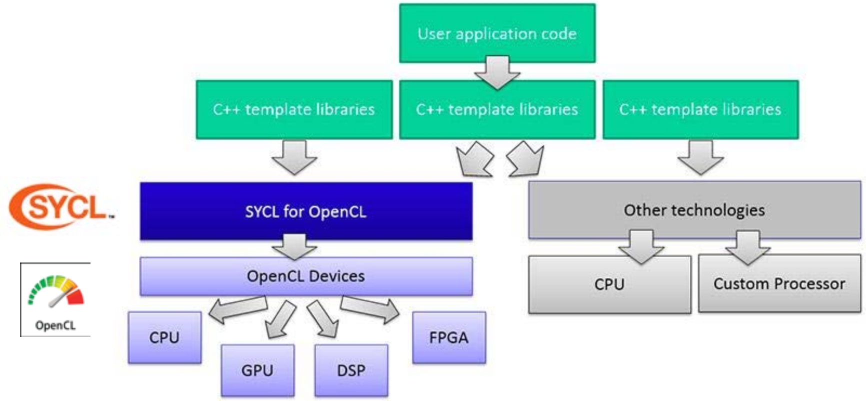
- **Single-source heterogeneous programming using STANDARD C++**
  - Use C++ templates and lambda functions for host & device code
  - Layered over OpenCL
- **Fast and powerful path for bring C++ apps and libraries to OpenCL**
  - C++ Kernel Fusion - better performance on complex software than hand-coding
  - Halide, Eigen, Boost.Compute, SYCLBLAS, SYCL Eigen, SYCL TensorFlow, SYCL GTX
  - triSYCL, ComputeCpp, VisionCpp, ComputeCpp SDK …
- **More information at http://sycl.tech**

Developer Choice

The development of the two specifications are aligned so code can be easily shared between the two approaches

C++ Kernel Language
Low Level Control
'GPGPU'-style separation of device-side kernel source code and host code

Single-source C++
Programmer Familiarity
Approach also taken by C++ AMP and OpenMP



Codeplay

Standards bodies

- HSA Foundation: Chair of software group, spec editor of runtime and debugging
- Khronos: chair & spec editor of SYCL. Contributors to OpenCL, Safety Critical, Vulkan
- ISO C++: Chair of Low Latency, Embedded WG; Editor of SG1 Concurrency TS
- EEMBC: members

Research

- Members of EU research consortiums: PEPPHER, LPGPU, LPGPU2, CARP
- Sponsorship of PhDs and EngDs for heterogeneous programming: HSA, FPGAs, ray-tracing
- Collaborations with academics
- Members of HiPEAC

Open source

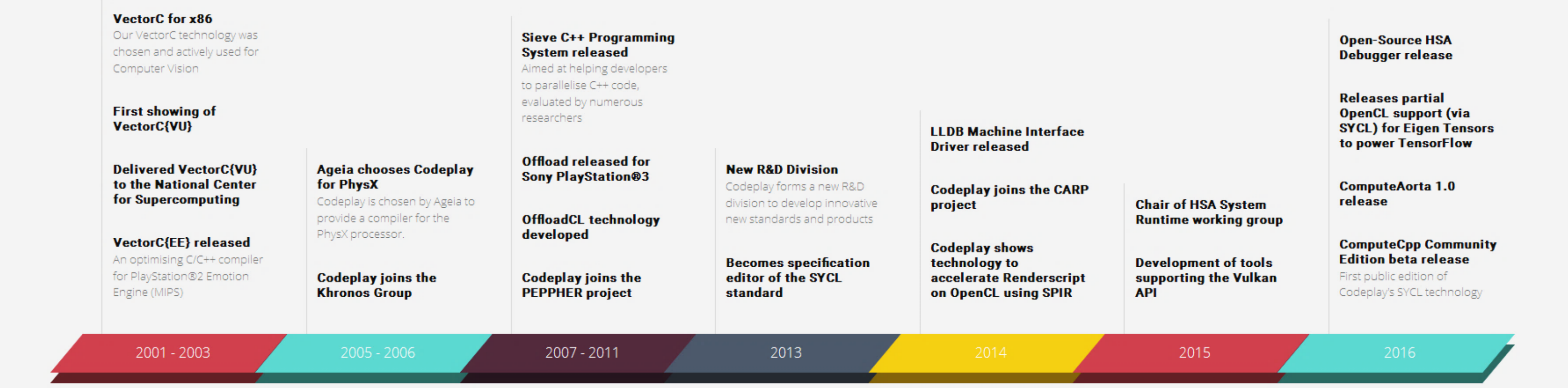
- HSA LLDB Debugger
- SPIR-V tools
- RenderScript debugger in AOSP
- LLDB for Qualcomm Hexagon
- TensorFlow for OpenCL
- C++ 17 Parallel STL for SYCL
- VisionCpp: C++ performance-portable programming model for vision

Presentations

- Building an LLVM back-end
- Creating an SPMD Vectorizer for OpenCL with LLVM
- Challenges of Mixed-Width Vector Code Gen & Scheduling in LLVM
- C++ on Accelerators: Supporting Single-Source SYCL and HSA
- LLDB Tutorial: Adding debugger support for your target

Company

- Based in Edinburgh, Scotland
- 57 staff, mostly engineering
- License and customize technologies for semiconductor companies
- ComputeAorta and ComputeCpp: implementations of OpenCL, Vulkan and SYCL
- 15+ years of experience in heterogeneous systems tools



2001 - 2003

VectorC for x86
Our VectorC technology was chosen and actively used for Computer Vision

First showing of VectorC{VU}

Delivered VectorC{VU} to the National Center for Supercomputing

VectorC{EE} released
An optimising C/C++ compiler for PlayStation®2 Emotion Engine (MIPS)

2005 - 2006

Ageia chooses Codeplay for PhysX
Codeplay is chosen by Ageia to provide a compiler for the PhysX processor.

Codeplay joins the Khronos Group

2007 - 2011

Sieve C++ Programming System released
Aimed at helping developers to parallelise C++ code, evaluated by numerous researchers

Offload released for Sony PlayStation®3

OffloadCL technology developed

Codeplay joins the PEPPHER project

2013

New R&D Division
Codeplay forms a new R&D division to develop innovative new standards and products

Becomes specification editor of the SYCL standard

2014

LLDB Machine Interface Driver released

Codeplay joins the CARP project

Codeplay shows technology to accelerate Renderscript on OpenCL using SPIR

2015

Chair of HSA System Runtime working group

Development of tools supporting the Vulkan API

2016

Open-Source HSA Debugger release

Releases partial OpenCL support (via SYCL) for Eigen Tensors to power TensorFlow

ComputeAorta 1.0 release

ComputeCpp Community Edition beta release
First public edition of Codeplay's SYCL technology

Codeplay build the software platforms that deliver massive performance

What our ComputeCpp users say about us

Benoit Steiner – Google TensorFlow engineer

TensorFlow

“We at Google have been working closely with Luke and his Codeplay colleagues on this project for almost 12 months now. Codeplay's contribution to this effort has been tremendous, so we felt that we should let them take the lead when it comes down to communicating updates related to OpenCL. … we are planning to merge the work that has been done so far… we want to put together a comprehensive test infrastructure”

ONERA

ONERA
THE FRENCH AEROSPACE LAB

“We work with royalty-free SYCL because it is hardware vendor agnostic, single-source C++ programming model without platform specific keywords. This will allow us to easily work with any heterogeneous processor solutions using OpenCL to develop our complex algorithms and ensure future compatibility”

Hartmut Kaiser -HPX

STE||AR
Systems Technology, Emergent Parallelism, and Algorithm Research Group

“My team and I are working with Codeplay's ComputeCpp for almost a year now and they have resolved every issue in a timely manner, while demonstrating that this technology can work with the most complex C++ template code. I am happy to say that the combination of Codeplay's SYCL implementation with our HPX runtime system has turned out to be a very capable basis for Building a Heterogeneous Computing Model for the C++ Standard using high-level abstractions.”

WIGNER Research Centre for Physics

It was a great pleasure this week for us, that Codeplay released the ComputeCpp project for the wider audience. We've been waiting for this moment and keeping our colleagues and students in constant rally and excitement. We'd like to build on this opportunity to increase the awareness of this technology by providing sample codes and talks to potential users. We're going to give a lecture series on modern scientific programming providing field specific examples.“

Further information

• OpenCL	https://www.khronos.org/opencl/
• OpenVX	https://www.khronos.org/openvx/
• HSA	http://www.hsafoundation.com/
• SYCL	http://sycl.tech
• OpenCV	http://opencv.org/
• Halide	http://halide-lang.org/
• VisionCpp	https://github.com/codeplaysoftware/visioncpp

SYCL™

ComputeCpp™

Community Edition

Available now for free!

Visit:

computecpp.codeplay.com

SYCL™

ComputeCpp™

- Open source SYCL projects:
  - ComputeCpp SDK - Collection of sample code and integration tools
  - SYCL ParallelSTL – SYCL based implementation of the parallel algorithms
  - VisionCpp – Compile-time embedded DSL for image processing
  - Eigen C++ Template Library – Compile-time library for machine learning

All of this and more at: http://sycl.tech codeplay®

THE HETEROGENEOUS SYSTEMS EXPERTS

Questions ?

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codeplay.com