The Continuing Future of C++ Concurrency

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The Continuing Future of C++ Concurrency

- C++14
- C++17
- Technical Specifications:
  - Concurrency
  - Parallelism
  - Transactional Memory

Concurrency in C++14

New in C++14

Only one new concurrency feature:

- `std::shared_timed_mutex`
- `std::shared_lock<>`

C++14: `std::shared_timed_mutex`

Multiple threads may hold a shared lock

OR

One thread may hold an exclusive lock

`std::shared_timed_mutex`: shared locks

```
std::map<std::string,std::string> table;
std::shared_timed_mutex m;
std::string find_entry(std::string s){
  std::shared_lock<
    std::shared_timed_mutex> guard(m);
  auto it=table.find(s);
  if(it==table.end())
    throw std::runtime_error("Not found");
  return it->second;
}
```

`std::shared_timed_mutex`: exclusive locks

```
std::map<std::string,std::string> table;
std::shared_timed_mutex m;

void add_entry(
  std::string key,std::string value){
  std::lock_guard<
    std::shared_timed_mutex> guard(m);
  table.insert(std::make_pair(key,value));
}
```

The **timed** part of `std::shared_timed_mutex`

```
std::shared_timed_mutex m;
void foo(){
  std::shared_lock<
    std::shared_timed_mutex> sl(
      m,std::chrono::seconds(1));
  if(!sl.owns_lock())
    return;
  do_foo();
}
```

std::shared_timed_mutex performance

- Not always an optimization:
  profile, profile, profile
- The `std::shared_timed_mutex` itself is a point of contention

Concurrency in C++17

New in C++17

Two new concurrency features:

- `std::shared_mutex` (non-timed)
- Variadic `std::lock_guard<>`

Plus: the Parallelism TS v1 has been merged, so there are parallel versions of most STL algorithms.

std::shared_mutex

std::shared_mutex omits the lock-with-timeout operations form std::shared_timed_mutex. It is simpler and faster on some platforms.

Variadic `std::lock_guard`

In C++11 and C++14, `std::lock_guard` can only be used with a single mutex.

In C++17, you can use `std::lock_guard` to lock multiple mutexes in one go, using the same mechanism as `std::lock()` to avoid deadlock.

```
std::lock_guard<std::mutex,std::mutex>
  guard(m1,m2);
```

Technical Specification for C++ Extensions for Concurrency

Concurrency TS v1

- Continuations for futures
- Waiting for one or all of a set of futures
- Latches and Barriers
- Atomic Smart Pointers

Concurrency TS v2: Proposals Under Consideration

- Executors and Schedulers
- Distributed Counters
- Concurrent Unordered Containers
- Concurrent Queues
- Safe concurrent stream access
- Resumable functions and coroutines
- Pipelines

Concurrency TS namespace

The concurrency TS provides functions and classes in the `std::experimental` namespace.

In the slides I'll use `stdexp` instead, as it's shorter.

```
namespace stdexp=std::experimental;
```

Continuations and `stdexp::future`

- A continuation is a new task to run when a future becomes ready
- Continuations are added with the new `then` member function
- Continuation functions must take a `stdexp::future` as the only parameter
- The source future is no longer `valid()`
- Only one continuation can be added

Continuations and `stdexp::future`

```
int find_the_answer();
std::string process_result(
  stdexp::future<int>);
auto f=stdexp::async(find_the_answer);
auto f2=f.then(process_result);
```

Exceptions and continuations

```
int fail(){
  throw std::runtime_error("failed");
}
void next(stdexp::future<int> f){
  f.get();
}
void foo(){
  auto f=stdexp::async(fail).then(next);
  f.get();
}
```

Using lambdas to wrap plain functions

```
int find_the_answer();
std::string process_result(int);

auto f=stdexp::async(find_the_answer);
auto f2=f.then([](stdexp::future<int> f){
  return process_result(f.get());});
```

Continuations and `stdexp::shared_future`

- Continuations work with `stdexp::shared_future` as well
- The continuation function must take a `stdexp::shared_future`
- The source future remains `valid()`
- Multiple continuations can be added

`stdexp::shared_future` continuations

```
int find_the_answer();
void next1(stdexp::shared_future<int>);
int next2(stdexp::shared_future<int>);

auto fi=stdexp::async(find_the_answer).
  share();
auto f2=fi.then(next1);
auto f2=fi.then(next2);
```

Waiting for the first future to be ready

`when_any` waits for the first future in the supplied set to be ready. It has two overloads:

```
template<typename ... Futures>
stdexp::future<stdexp::when_any_result<
std::tuple<Futures...>>>
when_any(Futures... futures);

template<typename Iterator>
stdexp::future<stdexp::when_any_result<
std::vector<
    std::iterator_traits<Iterator>::
      value_type>>>
when_any(Iterator begin,Iterator end);
```

`when_any`

`when_any` is ideal for:

- Waiting for speculative tasks
- Waiting for first results before doing further processing

```
auto f1=stdexp::async(foo);
auto f2=stdexp::async(bar);
auto f3=when_any(
  std::move(f1),std::move(f2));
f3.then(baz);
```

Waiting for all futures to be ready

`when_all` waits for all futures in the supplied set to be ready. It has two overloads:

```
template<typename ... Futures>
stdexp::future<std::tuple<Futures...>>
when_all(Futures... futures);

template<typename Iterator>
stdexp::future<std::vector<
    std::iterator_traits<Iterator>::
      value_type>>
when_all(Iterator begin,Iterator end);
```

`when_all`

`when_all` is ideal for waiting for all subtasks before continuing. Better than calling `wait()` on each in turn:

```
auto f1=stdexp::async(subtask1);
auto f2=stdexp::async(subtask2);
auto f3=stdexp::async(subtask3);
auto results=when_all(
  std::move(f1),std::move(f2),
  std::move(f3)).get();
```

Small improvements

The TS also has a couple of small improvements to the `stdexp::future` interface:

- `make_ready_future()` — creates a `stdexp::future` that is **ready**, holding the supplied value
- `make_exceptional_future()` — creates a `stdexp::future` that is **ready**, holding the supplied exception
- `is_ready()` member function — returns whether or not the future is **ready**

Latches and Barriers

- A **Latch** is a single-use count-down synchronization mechanism: once **Count** threads have decremented the latch it is permanently signalled.
- A **Barrier** is a reusable count-down synchronization mechanism: once **Count** threads have decremented the barrier, it is reset.

Atomic Smart Pointers

std::shared_ptr<T> and std::weak_ptr<T> are not bitwise-copyable, so you can't have std::atomic<std::shared_ptr<T> > or std::atomic<std::weak_ptr<T> >.

The TS provides stdexp::atomic_shared_ptr<T> and stdexp::atomic_weak_ptr<T> instead.

Concurrency TS:
Proposals Under Consideration

Executors and Schedulers

- An executor schedules tasks for execution
- Different executors have different scheduling properties
  e.g Thread Pools, Serial executor

Distributed Counters

Distributed counters improve performance by reducing contention on a global counter.

- Counts can be buffered locally to a function or a thread
- Updates of the global count can be via push from each thread or pull from the reader

Concurrent Unordered Containers

The current proposal is for a `concurrent_unordered_value_map`.

- No references can be obtained to the stored elements
- Many functions return `optional<mapped_type>`
- As well as simple queries like `find` there are also member functions `reduce` and `for_each`

Concurrent Queues

A concurrent queue is a vital means of inter-thread communication.

- Queues may or may not be lock-free
- May be fixed-size of unlimited
- May be **closed** to prevent additional elements being pushed
- You can obtain a “push handle” or “pop handle” for writing or reading
- Input and output iterators are supported

Safe concurrent stream access

The standard streams provide limited thread safety — output may be interleaved

```
void thread_1(){
  std::cout<<10<<20<<30;
}
void thread_2(){
  std::cout<<40<<50<<60;
}
```

output may be

```
104050206030
```

Safe concurrent stream access

We need a way to group output from several inserts:

`basic_ostream_buffer<char>`

```
void thread_1(){
  basic_ostream_buffer<char> buf(
    std::cout);
  buf<<10<<20<<30;
} // buf destroyed
  // contents written to std::cout
```

Resumable functions and coroutines

Coroutines expose a “pull” interface for callback-style implementations.

Resumable functions automatically generate async calls from code that waits on futures.

Both provide alternative ways of structuring code that does asynchronous operations.

Pipelines

The pipeline proposal is a way of wrapping concurrent queues and tasks:

```
queue<InputType> source;
queue<OutputType> sink;
pipeline::from(source) |
  pipeline::parallel(foo,num_threads) |
  bar | baz | sink;
```

Further proposals

There are more proposals not covered here.

See the C++ committee website
`http://www.open-std.org/jtc1/sc22/wg21/`
and the ISO C++ Foundation `https://isocpp.org`.

Technical Specification for C++ Extensions for Parallelism

Parallelism TS

Parallelism TS v1 (merged to C++17):

- Parallel algorithms
- Mapreduce
- Lightweight Execution Agents
- SIMD and Vector algorithms

Parallelism TS v2:

- Task Blocks

Parallel Algorithms

The v1 TS (and thus C++17) provides a new set of overloads of the standard library algorithms with an **execution policy** parameter:

```
template<typename ExecutionPolicy,
  typename Iterator,
  typename Function>
void for_each(
  ExecutionPolicy&& policy,
  Iterator begin,Iterator end,
  Function f);
```

Execution Policies

The **execution policy** may be:

- **std::sequential** — sequential execution on the calling thread
- **std::par** — indeterminately sequenced execution on unspecified threads
- **std::par_vec** — unsequenced execution on unspecified threads

`execution_policy` objects

`execution_policy` objects may be used to pass the desired sequencing as a parameter:

```
void outer(execution_policy policy){
  sort(policy,data.begin(),data.end());
}
void foo(){
  outer(std::par);
}
```

Supported algorithms

The vast majority of the C++ standard algorithms are parallelized, and a few more besides:

`adjacent_difference` `adjacent_find` `all_of` `any_of` **`copy`** `copy_if` `copy_n` **`count`** `count_if` `equal` `exclusive_scan` `fill` `fill_n` **`find`** `find_end` `find_first_of` `find_if` `find_if_not` **`for_each`** `for_each_n` `generate` `generate_n` `includes` `inclusive_scan` `inner_product` `inplace_merge` `is_heap` `is_heap_until` `is_partitioned` `is_sorted` `is_sorted_until` `lexicographical_compare` `max_element` **`merge`** `min_element` `minmax_element` `mismatch` `move` `none_of` `nth_element` `partial_sort` `partial_sort_copy` `partition` `partition_copy` **`reduce`** `remove` `remove_copy` `remove_copy_if` `remove_if` `replace` `replace_copy` `replace_copy_if` `replace_if` `reverse` `reverse_copy` `rotate` `rotate_copy` `search` `search_n` `set_difference` `set_intersection` `set_symmetric_difference` `set_union` **`sort`** `stable_partition` `stable_sort` `swap_ranges` **`transform`** `transform_exclusive_scan` `transform_inclusive_scan` **`transform_reduce`** `uninitialized_copy` `uninitialized_copy_n` `uninitialized_fill` `uninitialized_fill_n` `unique` `unique_copy`

Parallelism TS v2: Task Blocks

Task blocks allow for managing hierarchies of tasks:

- Nested task blocks within an outer task block can run in parallel
- All nested task blocks created within a task region are complete when the region exits
- Task blocks can be nested

Transactional Memory for C++

Transactional Memory

Two basic types of “transaction” blocks: **synchronized** blocks and **atomic** blocks

- **Synchronized** blocks introduced with the `synchronized` keyword
- **Atomic** blocks introduced with one of `atomic_noexcept`, `atomic_commit` or `atomic_cancel`

Synchronized blocks

Synchronized blocks behave as if they lock a global mutex.

```
int i;
void foo(){
  synchronized {
    ++i;
  }
}
```

Atomic blocks

Atomic execute atomically and not concurrently with any `synchronized` blocks.

```
int i;
void bar(){
  atomic_noexcept {
    ++i;
  }
}
```

Atomic blocks may be concurrent

Atomic may execute concurrently if no conflicts

```
int i,j;
void bar(){
  atomic_noexcept { ++i; }
}
void baz(){
  atomic_noexcept { ++j; }
}
```

Atomic blocks and exceptions

The **atomic** blocks differ in their behaviour with exceptions:

- `atomic_noexcept` — escaping exceptions cause undefined behaviour
- `atomic_commit` — escaping exceptions commit the transaction
- `atomic_cancel` — escaping exceptions roll back the transaction, but must be **transaction safe**

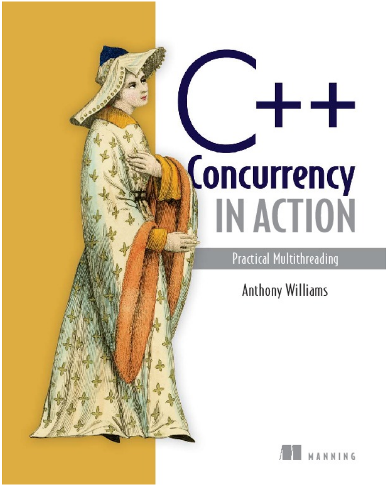
Questions?

Just::Thread

`just::thread` provides a complete implementation of the C++14 thread library and the C++ Concurrency TS.

`Just::Thread` Pro gives you actors, concurrent hash maps, concurrent queues and synchronized values.

My Book



C++ Concurrency in Action:
Practical Multithreading

`http://stdthread.com/book`