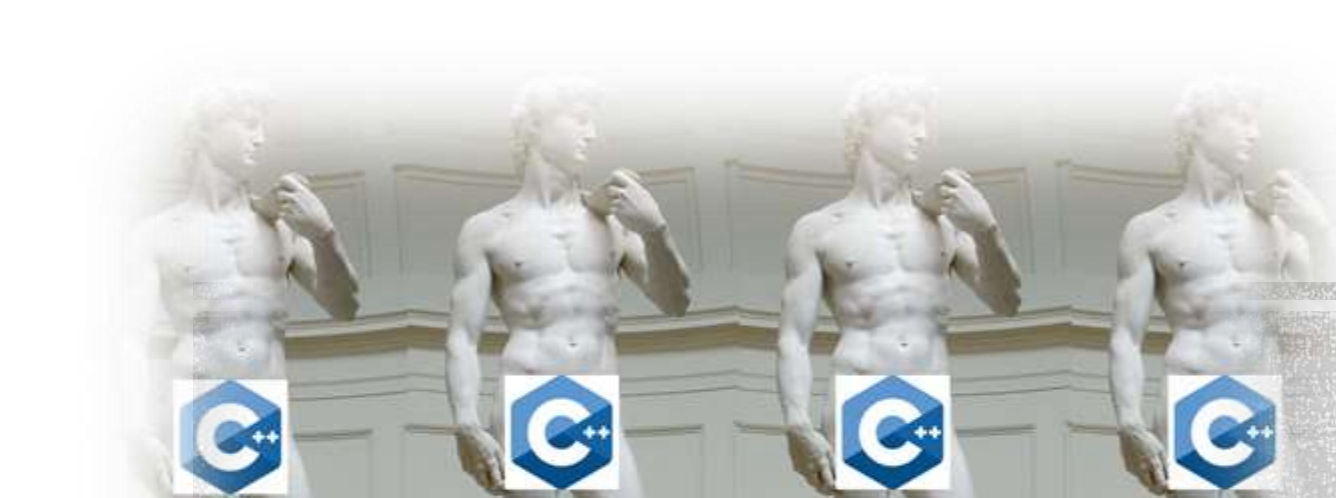
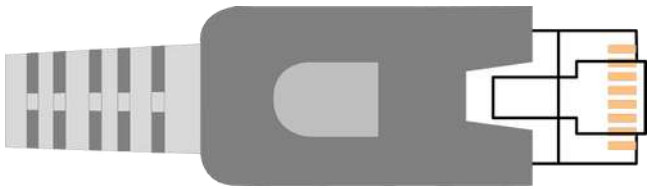


NAKED COROUTINES

LIVE
CppCon 2017

live with Networking

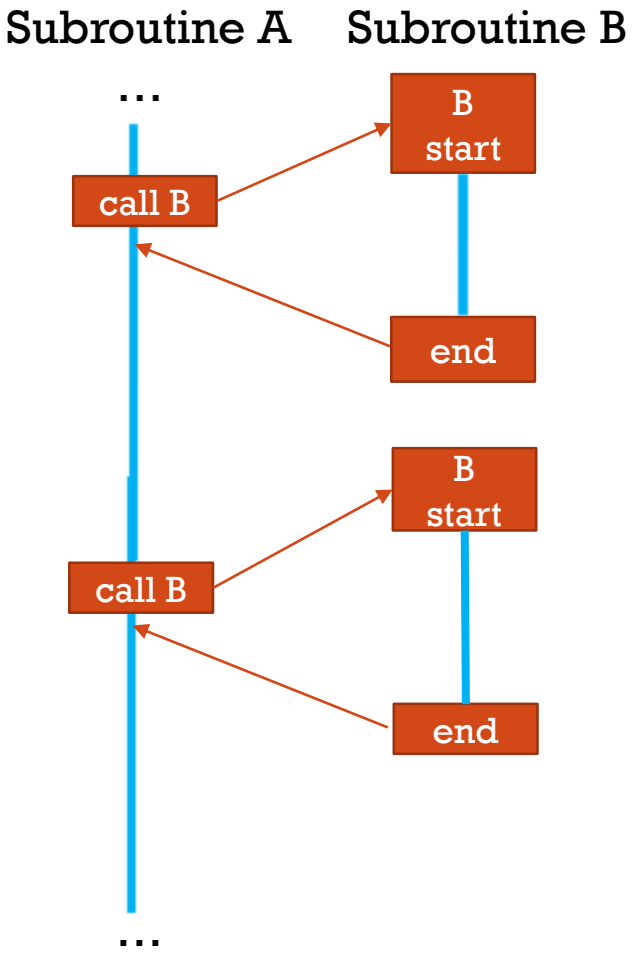
Gor Nishanov • Visual C++ Team • Microsoft



DESIGN PRINCIPLES

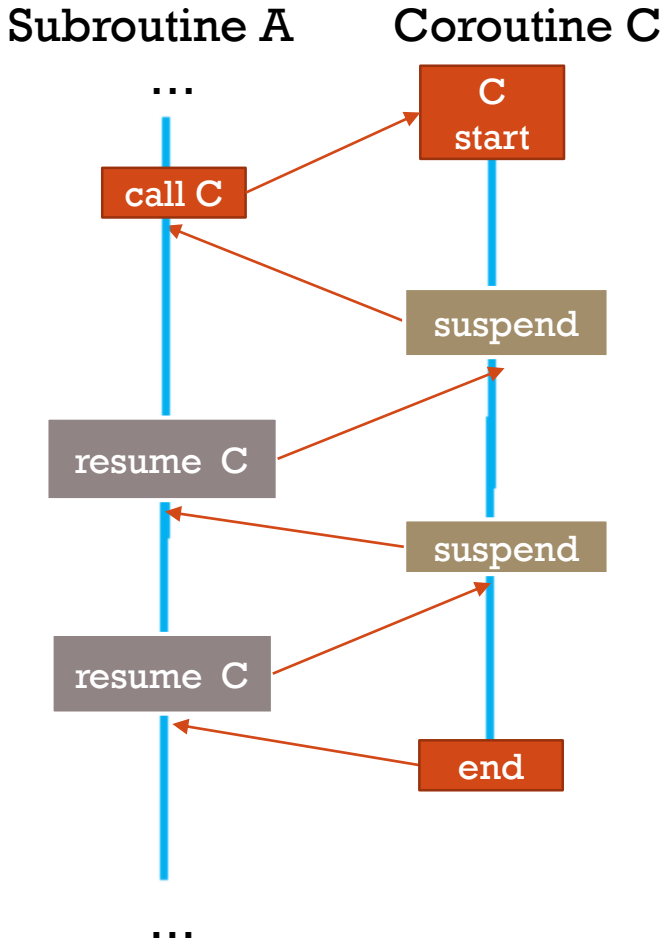
- **Scalable** (to **b**illions of concurrent coroutines)
- **Efficient** (resume and suspend operations comparable in cost to a function call overhead)
- Seamless interaction with existing facilities **with no overhead**
- **Open ended** coroutine machinery allowing library designers to develop coroutine libraries exposing various high-level semantics, such as generators, tasks, async streams and more.
- **Usable** in environments where **exceptions** are forbidden or **not available**

COROUTINES



- Introduced in 1958 by Melvin Conway
- Donald Knuth, 1968: "generalization of subroutine"

	subroutines	coroutines
call	Allocate frame, pass parameters	Allocate frame, pass parameters
return	Free frame, return result	Free frame, return eventual result
suspend	x	yes
resume	x	yes



8.4 Function definitions [dcl.fct.def]

8.4.4 Coroutines [dcl.fct.def.coroutine]

Add this subclause to 8.4.

> A function is a *coroutine* if it contains a *coroutine-return-statement* (6.6.3.1), an *await-expression* (5.3.8), a *yield-expression* (5.20), or a range-based `for` (6.5.4) with `co_await`.

```
generator<char> hello() {
   for (char ch: "Hello, world\n")
      co_yield ch;
}

int main() {
   for (char ch : hello())
      cout << ch;
}
```

```
future<void> sleepy() {
   cout << "Going to sleep…\n";
   co_await sleep_for(1ms);
   cout << "Woke up\n";
   co_return 42;
}

int main() {
   cout << sleepy.get();
}
```

C++ source #1

```
template <typename T>
generator<T> seq() {
  for (T i = {};; ++i)
    co_yield i;
}

template <typename T>
generator<T> take_until(generator<T>& g, T limit) {
  for (auto&& v: g)
    if (v < limit) co_yield v;
    else break;
}

template <typename T>
generator<T> multiply(generator<T>& g, T factor) {
  for (auto&& v: g)
    co_yield v * factor;
}

template <typename T>
generator<T> add(generator<T>& g, T adder) {
  for (auto&& v: g)
    co_yield v + adder;
}

int main() {
  auto s = seq<int>();
  auto t = take_until(s, 10);
  auto m = multiply(t, 2);
  auto a = add(m, 110);
  return std::accumulate(a.begin(), a.end(), 0);
}
```

x86-64 clang 5.0.0 (Editor #1, Compiler #1)

x86-64 clang 5.0.0

-std=c++14 -O2 -stdlib=libc++ -fcoroutines-ts

11010 .LX0: .text // \s+ Intel Demangle

```
1 main:                                   # @main
2         mov     eax, 1190
3         ret
```

https://godbolt.org/g/26viuZ

clang version 5.0.0 (tags/RELEASE_500/final 312636)- *cached*

GIFTS FROM TORONTO 2017

Coroutine TS

Networking TS

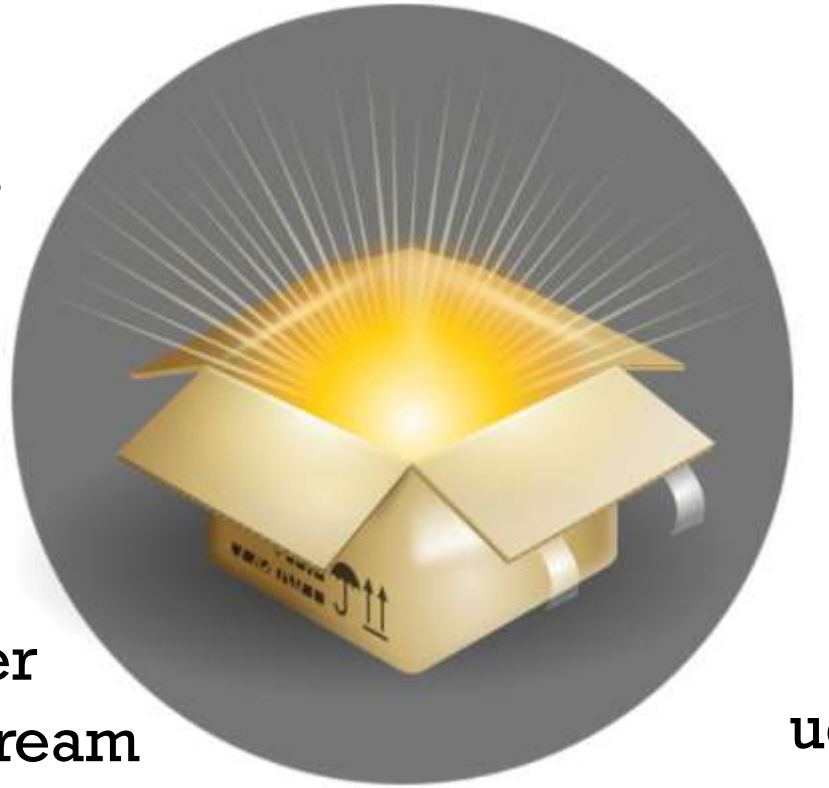
OPENING THE NETWORKING TS BOX!

io_context

+ and more nifty things

executors

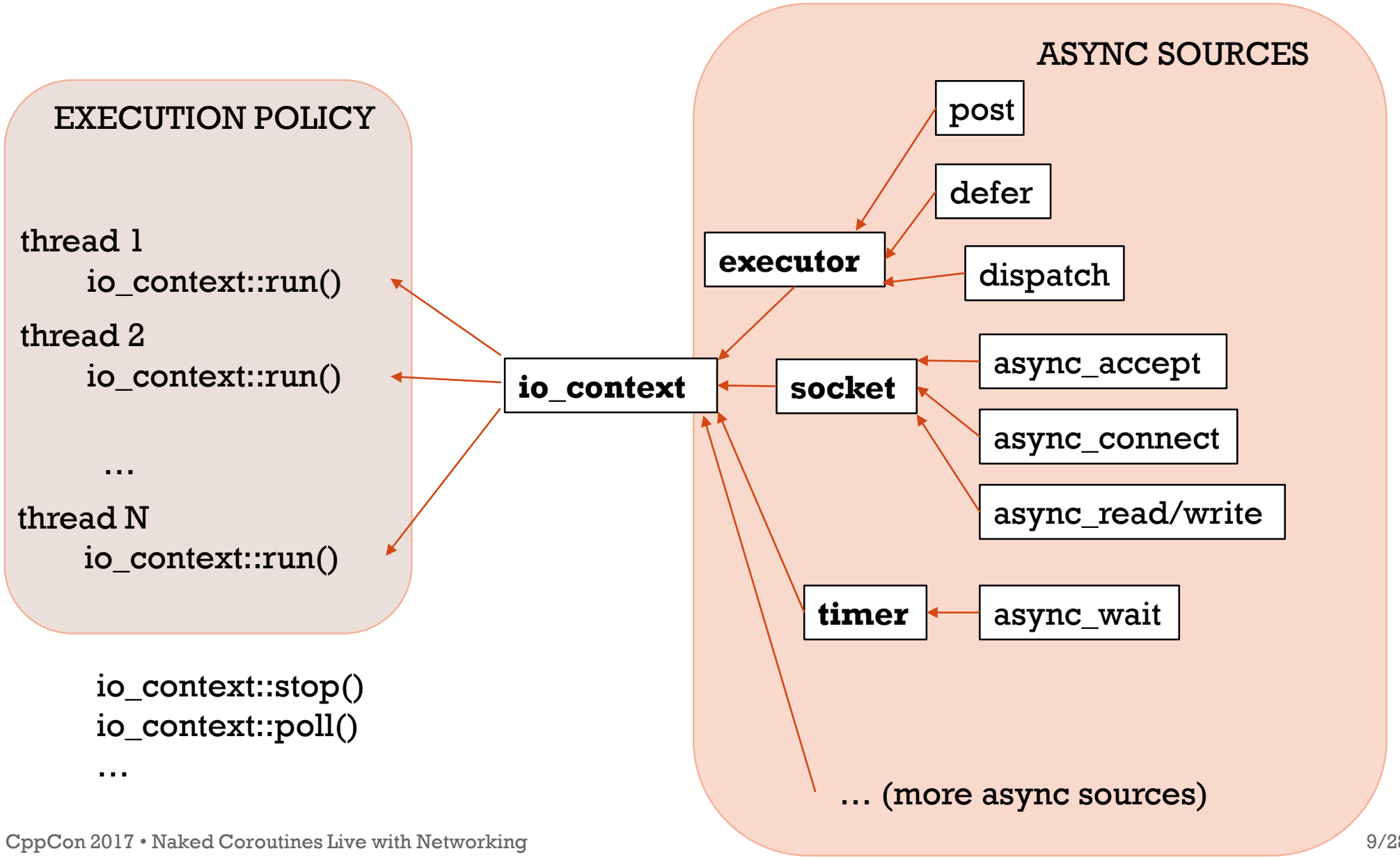
timers



tcp::endpoint
tcp::socket
tcp::acceptor
tcp::resolver
tcp::iostream

udp::endpoint
udp::socket
udp::resolver

NETWORKING TS – IO_CONTEXT



SIMPLE TIMER EXAMPLE

```
int main() {
  io_context io;

  system_timer slow_timer(io, hours(15));
  slow_timer.async_wait([](auto) {
    puts("Timer fired");
  });

  system_timer fast_timer(io, seconds(1));
  fast_timer.async_wait([&io](auto) {
    io.stop();
  });

  io.run();
}
```

BEAUTIFUL TCP SERVER

```
struct session {
  session(net::io_context &ioc, net::ip::tcp::socket s, size_t block_size)
      : io_context_(ioc), socket_(std::move(s)), block_size_(block_size),
        buf_(block_size), read_data_length_(0)
  {}

  void start() {
    std::error_code set_option_err;
    net::ip::tcp::no_delay no_delay(true);
    socket_.set_option(no_delay, set_option_err);
    if (!set_option_err) {
      socket_.async_read_some( net::buffer(buf_.data(), block_size_),
        make_custom_alloc_handler( allocator_,
          [this](auto ec, auto n) { handle_read(ec, n); }));
      return;
    }

    net::post(io_context_, [this] { destroy(this); });
  }

  void handle_read(const std::error_code &err, size_t length) {
    if (!err) {
      read_data_length_ = length;
      async_write(socket_, net::buffer(buf_.data(), read_data_length_),
        make_custom_alloc_handler( allocator_,
          [this](auto ec, auto) { handle_write(ec); }));
      return;
    }

    net::post(io_context_, [this] { destroy(this); });
  }

  void handle_write(const std::error_code &err) {
    if (!err) {
      socket_.async_read_some(net::buffer(buf_.data(), block_size_),
        make_custom_alloc_handler( allocator_,
          [this](auto ec, auto n) { handle_read(ec, n); }));
      return;
    }

    net::post(io_context_, [this] { destroy(this); });
  }

  static void destroy(session *s) { delete s; }

private:
  net::io_context &io_context_;
  net::ip::tcp::socket socket_;
  size_t block_size_;
  std::vector<char> buf_;
  size_t read_data_length_;
  handler_allocator allocator_;
};
```

```
struct server {
  server(net::io_context &ioc, const net::ip::tcp::endpoint &endpoint,
         size_t block_size)
      : io_context_(ioc), acceptor_(ioc, endpoint), block_size_(block_size)
  {
    acceptor_.listen();

    start_accept();
  }

  void start_accept()
  {
    acceptor_.async_accept(
        [this](auto ec, auto s) { handle_accept(ec, std::move(s)); });
  }

  void handle_accept(std::error_code err, net::ip::tcp::socket s)
  {
    if (!err) {
      session *new_session = new session(io_context_, std::move(s), block_size_);
      new_session->start();
    }
    start_accept();
  }

private:
  net::io_context &io_context_;
  net::ip::tcp::acceptor acceptor_;
  size_t block_size_;
};
```

UNBOXING THE COROUTINES

and that is all you get!

suspend_never

suspend_always

coroutine_handle

coroutine_traits

```
co_await
co_yield
co_return
```

READ THE MANUAL?


LIVE

THE EASY WAY

ASYNC INITIATING FUNCTION

```
template <typename BufferSequence, typename CompletionToken>
auto async_xyz(BufferSequence const& buffers, CompletionToken handler)
{
  async_completion<CompletionToken, void(std::error_code, std::size_t)> init(handler);

  impl.real_async_xyz(buffers, init.completion_handler);
  return init.result.get();
}
```

CompletionToken →

- What to return
- What to pass as a callback to real implementation
- What executor to complete on
- What allocator to use

TRAIT SPECIALIZATION FOR USE_BOOST_FUTURE

```
template <>
struct async_result<use_boost_future_t,  void(std::error_code, size_t)> {
  using return_type = boost::future<size_t>;
  struct completion_handler_type {
     boost::promise<size_t> p;
     completion_handler_type(use_boost_future_t const&) {}
     void operator() (std::error_code const& ec, size_t n) {
       if (ec) p.set_exception(std::system_error(ec));
       else p.set_value(n);
     }
  };
  explicit async_result(completion_handler_type &h) : fut(h.p.get_future()) {}
  auto get() { return std::move(fut); }
private:
  boost::future<size_t> fut;
};
```


LIVE

BEAUTIFUL TCP SERVER

```
struct session {
  session(net::io_context &ioc, net::ip::tcp::socket s, size_t block_size)
      : io_context_(ioc), socket_(std::move(s)), block_size_(block_size),
        buf_(block_size), read_data_length_(0)
  {}

  void start() {
    std::error_code set_option_err;
    net::ip::tcp::no_delay no_delay(true);
    socket_.set_option(no_delay, set_option_err);
    if (!set_option_err) {
      socket_.async_read_some( net::buffer(buf_.data(), block_size_),
        make_custom_alloc_handler( allocator_,
          [this](auto ec, auto n) { handle_read(ec, n); }));
      return;
    }

    net::post(io_context_, [this] { destroy(this); });
  }

  void handle_read(const std::error_code &err, size_t length) {
    if (!err) {
      read_data_length_ = length;
      async_write(socket_, net::buffer(buf_.data(), read_data_length_),
        make_custom_alloc_handler( allocator_,
          [this](auto ec, auto) { handle_write(ec); }));
      return;
    }

    net::post(io_context_, [this] { destroy(this); });
  }

  void handle_write(const std::error_code &err) {
    if (!err) {
      socket_.async_read_some(net::buffer(buf_.data(), block_size_),
        make_custom_alloc_handler( allocator_,
          [this](auto ec, auto n) { handle_read(ec, n); }));
      return;
    }

    net::post(io_context_, [this] { destroy(this); });
  }

  static void destroy(session *s) { delete s; }

private:
  net::io_context &io_context_;
  net::ip::tcp::socket socket_;
  size_t block_size_;
  std::vector<char> buf_;
  size_t read_data_length_;
  handler_allocator allocator_;
};
```

```
struct server {
  server(net::io_context &ioc, const net::ip::tcp::endpoint &endpoint,
         size_t block_size)
      : io_context_(ioc), acceptor_(ioc, endpoint), block_size_(block_size)
  {
    acceptor_.listen();

    start_accept();
  }

  void start_accept()
  {
    acceptor_.async_accept(
        [this](auto ec, auto s) { handle_accept(ec, std::move(s)); });
  }

  void handle_accept(std::error_code err, net::ip::tcp::socket s)
  {
    if (!err) {
      session *new_session = new session(io_context_, std::move(s), block_size_);
      new_session->start();
    }
    start_accept();
  }

private:
  net::io_context &io_context_;
  net::ip::tcp::acceptor acceptor_;
  size_t block_size_;
};
```

SAME BEAUTIFUL TCP SERVER BUT NOW WITH A BIGGER FONT

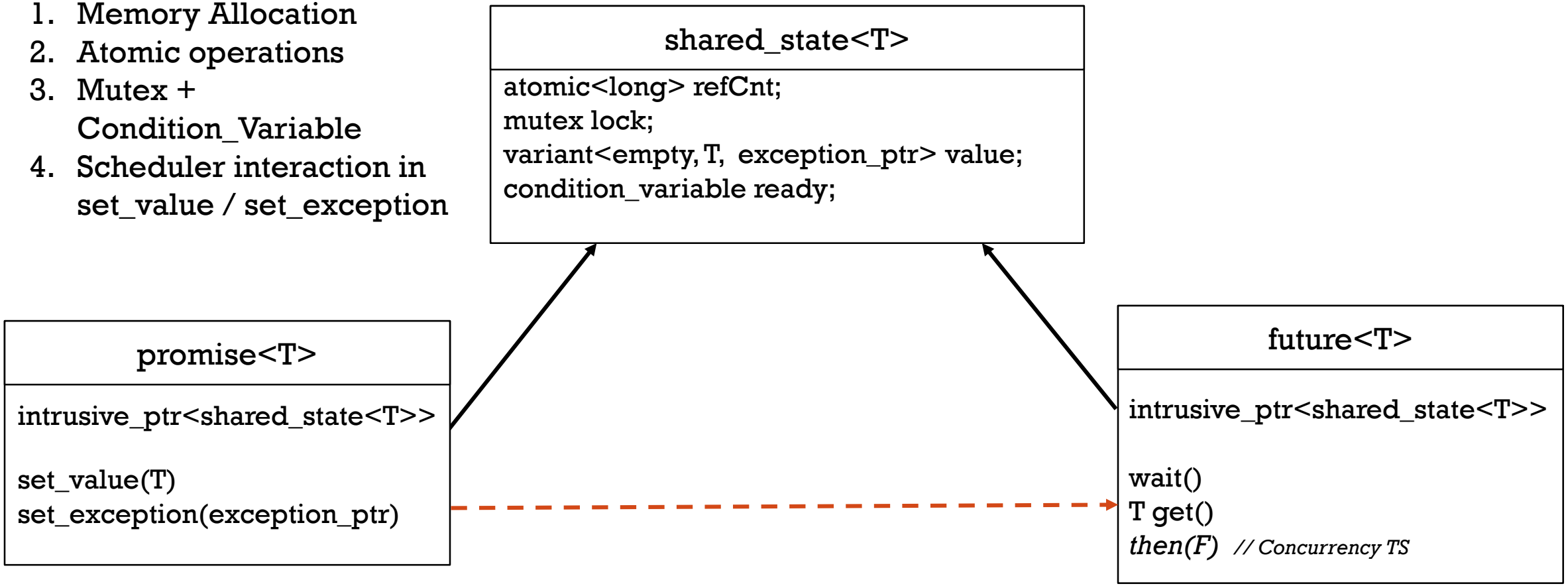
```
std::future<void> session(tcp::socket s, size_t block_size)
{
  s.set_option(tcp::no_delay(true));
  std::vector<char> buf(block_size);

  for(;;) {
    size_t n = co_await async_read_some(s, buffer(buf.data(), block_size));
    n = co_await async_write(s, buffer(buf.data(), n));
  }
}
```

```
std::future<void> server(io_context &io, tcp::endpoint const &endpoint,
                         size_t block_size)
{
  tcp::acceptor acceptor(io, endpoint);
  acceptor.listen();
  for (;;)
    session(co_await async_accept(acceptor), block_size);
}
```

STD::FUTURE<T> AND STD::PROMISE<T>

1. Memory Allocation
2. Atomic operations
3. Mutex + Condition_Variable
4. Scheduler interaction in set_value / set_exception



COMPLICATIONS

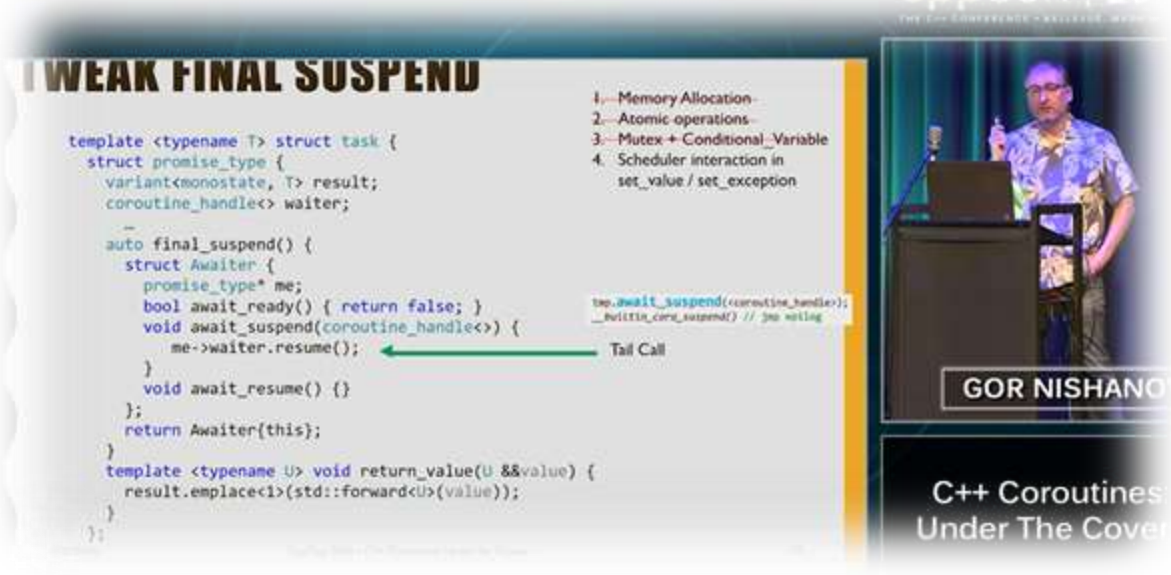
Cancellation and allocation


LIVE

BEYOND THE TS

Two possible additions to C++ Coroutines

SYMMETRIC CONTROL TRANSFER



- Available only in clang trunk
- Not in MSVC or clang 5
- Not part of the TS (yet)

```
coroutine_handle<> await_suspend(coroutine_handle<>) {
  return me->waiter;
}
```

PEEKING AT COROUTINE ARGUMENTS FROM PROMISE

```
// Coroutine object returned in an usual place
HRESULT f(X x, Y y, Z z, SomeSmartPtr<MyCoro>* p);

// Would like have access to executor in initial_suspend
void g(executor& e);

// Would like to check whether we are cancelled at every
// suspend point
void h(cancellation_token& c);
```

NOT VERY GOOD WORKAROUND

```
struct promise_type {

  template <typename... Args>
  void* operator new(size_t size, Args const&... args) {
    // stash what you need into a thread_local
  }

  promise_type() {
    // get what you wanted out of a thread_local
  }
  ...
};
```

LET PROMISE CONSTRUCTOR PEEK AT ARGS!

```
struct promise_type {

  template <typename... Args>
  promise_type(Args const&... args) {
    // get what you want
  }
  ...
};
```

- Opt-in feature. Empty construct will work fine
- Will observe stable parameters (parameter copies)
- Implicit object parameter passed as a first argument
- Not part of the TS
- Not available in any compiler

CONCLUSION

- Networking and Coroutine TS are great together
- At the moment, for the best performance use "the hard way"
- Hopefully can be addressed before C++20 ships
- Coroutines are available in
  - MSVC 2017 (/await)
  - clang 5.0 (-fcoroutines-ts –stdlib=libc++)
- Networking TS implementation:
  - https://github.com/chriskohlhoff/networking-ts-impl
- Look at good open source coroutine libraries:
  Example: https://github.com/lewissbaker/cppcoro
- Snippets we used during the live part will be available at:
  https://github.com/GorNishanov/await/tree/master/2017_CppCon

QUESTIONS?

BACKUP

C++ COROUTINES

COMMON PATTERN FOR ASYNC AND SYNC I/O

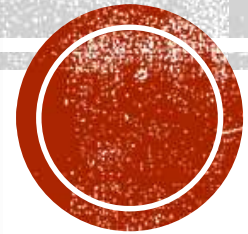
SNEAK PEEK at the bright future

async

```
future<int> tcp_reader(int total)
{
    char buf[64 * 1024];
    auto conn = co_await Tcp::Connect("127.0.0.1", 1337);
    for (;;)
    {
        auto bytesRead = co_await conn.read(buf, sizeof(buf));
        total -= bytesRead;
        if (total <= 0 || bytesRead == 0) co_return total;
    }
}
```

sync

```
expected<int> tcp_reader(int total)
{
    char buf[64 * 1024];
    auto conn = co_await Tcp::Connect("127.0.0.1", 1337, block);
    for (;;)
    {
        auto bytesRead = co_await conn.read(buf, sizeof(buf), block);
        total -= bytesRead;
        if (total <= 0 || bytesRead == 0) co_return total;
    }
}
```



C++ COROUTINES

REACTIVE STREAMS MEET COROUTINES

SNEAK PEEK at the bright future

Source

Produces 0.1.2.3...
each 1ms

```
async_stream<int> Ticks()
{
    for (int tick = 0;; ++tick)
    {
        co_yield tick;
        co_await sleep_for(1ms);
    }
}
```

Transformer

Transforms stream of $v_1.v_2.v_3$...
into a stream of
$(v_1,t_1).(v_2,t_2).(v_3,t_3)$...
where t_i is a timestamp of when
v_i was received

```
template<class T>
auto AddTimestamp(AsyncStream<T>& S)
{
    for await(auto&& v: S)
        co_yield make_pair(v,system_clock::now());
}
```

Sink

Reduces an asynchronous
stream to a sum of its values

```
future<int> Sum(AsyncStream<int>& input)
{
    int sum = 0;
    for co_await(v: input)
        sum += v;
    co_return sum;
}
```

N4134: RESUMABLE FUNCTIONS V2

GENERATORS AND ITERABLES AND AGGREGATE INITIALIZATION

generators

```
generator<char> hello() {
   for (ch: "Hello, world\n") yield ch;
}
int main() {
   for (ch : hello()) cout << ch;
}
```

SNEAK PEEK (more later)

Not in N4134

constexpr generators

```
int a[] = { []{ for(int x = 0; x < 10; ++x) yield x*x; } };
```

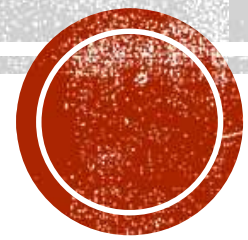
Equivalent to

```
int a[] = { 0,1,4,9,16,25,36,49,64,81 };
```

Recursive Generators

```
auto flatten(node* n) -> generator<decltype(n->value)> {
    if (n != nullptr) {
        yield flatten(n->left);
        yield n->value;
        yield flatten(n->right);
    }
}
bool same_fringe(node* tree1, node* tree2)
{
    auto seq1 = flatten(tree1);
    auto seq2 = flatten(tree2);
    return equal(begin(seq1), end(seq1),
                 begin(seq2), end(seq2));
}
```

Checks if in-order depth first traversal of two trees yields the same sequence of values



WARNING: DO NOT DO THIS!

```
template <typename R>
auto operator co_await(std::future<R>&& f) {
  struct Awaiter {
    std::future<R>&& f;
    bool await_ready() {
      return f.wait_for(0s) != future_status::ready();
    }
    void await_suspend(std::experimental::coroutine_handle<> h) {
       std::thread([&]() mutable {f.wait(); h.resume();}).detach();
    }
    auto await_resume() { return f.get(); }
  };
  return Awaiter{ std::forward<std::future<R>>(f) };
}
```

WITH USE_FUTURE, BEHAVES AS IF IT WERE

```
template <typename BufferSequence>
auto async_xyz(BufferSequence const& buffers, use_future_t)
{
  std::promise<size_t> p;
  auto result = p.get_future();

  impl.real_async_xyz(buffers, [p = std::move(p)](auto ec, auto n) {
    if (ec) p.set_exception(std::system_error(ec));
    else (p.
  });
  return result;
}
```

Implementation:

https://github.com/chriskohlhoff/networking-ts-impl/blob/master/include/experimental/__net_ts/impl/use_future.hpp