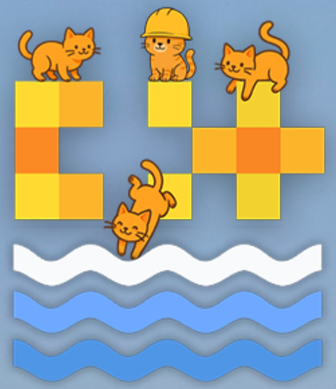

Building Robust Inter-Process Queues in C++

Jody Hagins

2025

MAYSTREET

C++ OnSea 2025

Building Robust Inter-Process Queues in C++

Jody Hagins
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What Are Inter-Process Queues

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- FIFO

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- Supports Multiple Message Types

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- Pollable

std::queue

std::queue

Just push and pop

std::queue

Just push and pop

And a constructor or two

std::queue

Just push and pop

And a constructor or two

std::queue<T,Container>::queue

`queue() : queue(Container()) {}`	(1)	(since C++11)
`explicit queue( const Container& cont = Container() );` `explicit queue( const Container& cont );`	(2)	(until C++11) (since C++11)
`explicit queue( Container&& cont );`	(3)	(since C++11)
`queue( const queue& other );`	(4)	(implicitly declared)
`queue( queue&& other );`	(5)	(since C++11) (implicitly declared)
`template< class InputIt >` `queue( InputIt first, InputIt last );`	(6)	(since C++23)
`template< class Alloc >` `explicit queue( const Alloc& alloc );`	(7)	(since C++11)
`template< class Alloc >` `queue( const Container& cont, const Alloc& alloc );`	(8)	(since C++11)
`template< class Alloc >` `queue( Container&& cont, const Alloc& alloc );`	(9)	(since C++11)
`template< class Alloc >` `queue( const queue& other, const Alloc& alloc );`	(10)	(since C++11)
`template< class Alloc >` `queue( queue&& other, const Alloc& alloc );`	(11)	(since C++11)
`template< class InputIt, class Alloc >` `queue( InputIt first, InputIt last, const Alloc& alloc );`	(12)	(since C++23)
`template< container-compatible-range<T> R>` `queue( std::from_range_t, R&& rg );`	(13)	(since C++23)
`template< container-compatible-range<T> R, class Alloc >` `queue( std::from_range_t, R&& rg, const Alloc& alloc );`	(14)	(since C++23)

std::queue

Just push and pop

And a constructor or two

And a destructor and assignment operators

std::queue

Just push and pop

And a constructor or two

And a destructor and assignment operators

And peek at the first and last???

Element access	
`front`	access the first element (public member function)
`back`	access the last element (public member function)

std::queue

Just push and pop

And a constructor or two

And a destructor and assignment operators

And peek at the first and last???

Query the capacity...

Capacity	
`empty`	checks whether the container adaptor is empty (public member function)
`size`	returns the number of elements (public member function)

std::queue

Just push and pop

And a constructor or two

And a destructor and assignment operators

And peek at the first and last???

Query the capacity...

More ways to push...

push_range (C++23)	inserts a range of elements at the end (public member function)
emplace (C++11)	constructs element in-place at the end (public member function)

std::queue

Just push and pop

And a constructor or two

And a destructor and assignment operators

And peek at the first and last???

Query the capacity...

More ways to push...

swap (C++11)	swaps the contents (public member function)

std::queue

Just push and pop

And a constructor or two

Non-member functions

operator== **operator!=** **operator<** **operator<=** **operator>** **operator>=** **operator<=>** (C++20)	lexicographically compares the values of two queues (function template)
std::swap(std::queue) (C++11)	specializes the `std::swap` algorithm (function template)

std::queue

Just push and pop

And a constructor or two

And a destructor and assignment operators

Helper classes

std::uses_allocator<std::queue> (C++11)	specializes the `std::uses_allocator` type trait (class template specialization)
std::formatter<std::queue> (C++23)	formatting support for `std::queue` (class template specialization)

Deduction guides (since C++17)

std::queue

Template parameters

T - The type of the stored elements. The program is ill-formed if T is not the same type as `Container::value_type`.

Container - The type of the underlying container to use to store the elements. The container must satisfy the requirements of *SequenceContainer*. Additionally, it must provide the following functions with the usual semantics:

- `back()`, e.g., `std::deque::back()`,
- `front()`, e.g. `std::list::front()`,
- `push_back()`, e.g., `std::deque::push_back()`,
- `pop_front()`, e.g., `std::list::pop_front()`.

The standard containers `std::deque` and `std::list` satisfy these requirements.

std::queue

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The standard containers `std::deque` and `std::list` satisfy these requirements.

The Daugaard Queue

The Daugaard Queue

```
// Copyright 2018 Kaspar Daugaard. For educational purposes only.
// See http://daugaard.org/blog/writing-a-fast-and-versatile-spsc-ring-
buffer
```

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- How To Make Your SPSC Ring Buffer Do Nothing, More Efficiently
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// Copyright 2018 Kaspar Daugaard. For educational purposes only.
// See http://daugaard.org/blog/writing-a-fast-and-versatile-spsc-ring-
buffer
//
// I was unsure as to the license terms and what usage limitations may
// exist, so I reached out to Kaspar and asked.  His response is below.
//
// Hi Jody,
// Thanks for reaching out.
//
// It was more of a liability waiver, and because I felt the API
// probably needed some more work. I am happy for you to treat it as
// MIT licensed, if that works for you, and I will look into releasing
// it properly at some point.
//
// All the best
// Kaspar
```

The Daugaard Queue

```
class RingBuffer
{
```

Daugaard: Shared State

```
class RingBuffer
{
    // Writer and reader's shared positions.
    struct alignas(CACHE_LINE_SIZE) SharedState
    {
        std::atomic<size_t> pos;
    };

    SharedState m_WriterShared;
    SharedState m_ReaderShared;
```

Daugaard: Shared State

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Daugaard: Local State

```
class RingBuffer { // ...
    // Writer and reader's local state.
    struct alignas(CACHE_LINE_SIZE) LocalState
    {
        LocalState()
            : buffer(nullptr), pos(0), end(0), base(0), size(0) {}

        char* buffer;
        size_t pos;
        size_t end;
        size_t base;
        size_t size;
    };

    LocalState m_Writer;
    LocalState m_Reader;
```

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queue.Write(Command::ConsumeItems);
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// Send command to process array of items.
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```
// Write an element to the buffer.
template <typename T>
FORCE_INLINE void Write(const T& value)
{
    void* dest = PrepareWrite(sizeof(T), alignof(T));
    new(dest) T(value);
}
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Daugaard: Write

```
// Write an array of elements to the buffer.
template <typename T>
FORCE_INLINE void WriteArray(const T* values, size_t count)
{
    void* dest = PrepareWrite(sizeof(T) * count, alignof(T));
    for (size_t i = 0; i < count; i++)
        new(static_cast<T*>(dest) + i) T(values[i]);
}
```

```
queue.WriteArray(items, itemCount);

queue.FinishWrite();
```

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queue.WriteArray(items, itemCount);
queue.FinishWrite();
```

Daugaard: Write

```
void* RingBuffer::PrepareWrite(size_t size, size_t alignment)
{
    size_t pos = Align(m_Writer.pos, alignment);
    size_t end = pos + size;
    if (end > m_Writer.end)
        GetBufferSpaceToWriteTo(pos, end);
    m_Writer.pos = end;
    return m_Writer.buffer + pos;
}
```

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        GetBufferSpaceToWriteTo(pos, end);
    m_Writer.pos = end;
    return m_Writer.buffer + pos;
}
```

Daugaard: Write

```
void RingBuffer::GetBufferSpaceToWriteTo(size_t& pos, size_t& end)
{
    if (end > m_Writer.size)
    {
        end -= pos;
        pos = 0;
        m_Writer.base += m_Writer.size;
    }

    // More...
}
```

Daugaard: Write

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void RingBuffer::GetBufferSpaceToWriteTo(size_t& pos, size_t& end)
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    {
        end -= pos;
        pos = 0;
        m_Writer.base += m_Writer.size;
    }

    // More...
}
```

Daugaard: Write

```
    // snipped buffer adjustment

    for (;;)
    {
        size_t readerPos = m_ReaderShared.pos.load(
            std::memory_order_acquire);
        size_t available = readerPos - m_Writer.base + m_Writer.size;
        // Signed comparison (available can be negative)
        if (static_cast<ptrdiff_t>(available) >=
            static_cast<ptrdiff_t>(end))
        {
            m_Writer.end = std::min(available, m_Writer.size);
            break;
        }
    }
}
```

Daugaard: Write

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    // snipped buffer adjustment

    for (;;)
    {
        size_t readerPos = m_ReaderShared.pos.load(
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        size_t available = readerPos - m_Writer.base + m_Writer.size;
        // Signed comparison (available can be negative)
        if (static_cast<ptrdiff_t>(available) >=
            static_cast<ptrdiff_t>(end))
        {
            m_Writer.end = std::min(available, m_Writer.size);
            break;
        }
    }
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```
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queue.Write(Command::ConsumeItems);
queue.Write(itemCount);
queue.WriteArray(items, itemCount);
queue.FinishWrite();
```

Daugaard: Write

```
void RingBuffer::FinishWrite()
{
    m_WriterShared.pos.store(
        m_Writer.base + m_Writer.pos,
        std::memory_order_release);
}
```

Daugaard: Read

Daugaard: Read

```
Command cmd = queue.Read<Command>();
switch (cmd)
{
    case Command::ConsumeItems:
        int itemCount = queue.Read<int>();
        const Item* items = queue.ReadArray<Item>(itemCount);
        ConsumeItems(items, itemCount);
        queue.FinishRead();
        break;
}
```

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Daugaard: Read

```
Command cmd = queue.Read<Command>();
```

```
// Read an element from the buffer.
template <typename T>
FORCE_INLINE const T& Read()
{
    void* src = PrepareRead(sizeof(T), alignof(T));
    return *static_cast<T*>(src);
}
```

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```

```
template <typename T>
FORCE_INLINE const T* ReadArray(size_t count)
{
    void* src = PrepareRead(sizeof(T) * count, alignof(T));
    return static_cast<T*>(src);
}
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Daugaard: Read

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    case Command::ConsumeItems:
        int itemCount = queue.Read<int>();
        const Item* items = queue.ReadArray<Item>(itemCount);
        ConsumeItems(items, itemCount);
        queue.FinishRead();
        break;
}
```

Daugaard: Initialization

Daugaard: Initialization

```
// Initialize. Buffer must have required alignment. Size must be a
// power of two.
void Initialize(void* buffer, size_t size)
{
    Reset();
    m_Reader.buffer = m_Writer.buffer = static_cast<char*>(buffer);
    m_Reader.size = m_Writer.size = m_Writer.end = size;
}

void Reset()
{
    m_Reader = m_Writer = LocalState();
    m_ReaderShared.pos = m_WriterShared.pos = 0;
}
```

The Daugaard Queue

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- Between Unrelated Processes
- Low Latency
- Resumable
- Recoverable MCAST Queues
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Daugaard: Local State

```
class RingBuffer { // ...
    // Writer and reader's local state.
    struct alignas(CACHE_LINE_SIZE) LocalState
    {
        LocalState()
            : buffer(nullptr), pos(0), end(0), base(0), size(0) {}

        char* buffer;
        size_t pos;
        size_t end;
        size_t base;
        size_t size;
    };

    LocalState m_Writer;
    LocalState m_Reader;
```

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The Hinnant Rule

compiler implicitly declares

user declares	default constructor	destructor	copy constructor	copy assignment	move constructor	move assignment
Nothing	defaulted	defaulted	defaulted	defaulted	defaulted	defaulted
Any constructor	not declared	defaulted	defaulted	defaulted	defaulted	defaulted
default constructor	user declared	defaulted	defaulted	defaulted	defaulted	defaulted
destructor	defaulted	user declared	defaulted	defaulted	not declared	not declared
copy constructor	not declared	defaulted	user declared	defaulted	not declared	not declared
copy assignment	defaulted	defaulted	defaulted	user declared	not declared	not declared
move constructor	not declared	defaulted	deleted	deleted	user declared	not declared
move assignment	defaulted	defaulted	deleted	deleted	not declared	user declared

Implicit Lifetime

Implicit Lifetime

```
auto i = reinterpret_cast<int *>(malloc(sizeof(int)));
*i = 42;
```

Implicit Lifetime

```
auto i = reinterpret_cast<int *>(malloc(sizeof(int)));
*i = 42;

auto s = reinterpret_cast<std::string *>(malloc(sizeof(std::string)));
*s = "hello";
```

Implicit Lifetime

10 Some operations are described as *implicitly creating objects* within a specified region of storage. For each operation that is specified as implicitly creating objects, that operation implicitly creates and starts the lifetime of zero or more objects of implicit-lifetime types (6.8) in its specified region of storage if doing so would result in the program having defined behavior. If no such set of objects would give the program defined behavior, the behavior of the program is undefined. If multiple such sets of objects would give the program defined behavior, it is unspecified which such set of objects is created. [*Note*: Such operations do not start the lifetimes of subobjects of such objects that are not themselves of implicit-lifetime types. — *end note*]

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Implicit Lifetime

12 [*Example*:

```
#include <cstdlib>
struct X { int a, b; };
X *make_x() {
  // The call to std::malloc implicitly creates an object of type X
  // and its subobjects a and b, and returns a pointer to that X object
  // (or an object that is pointer-interconvertible (6.8.2) with it),
  // in order to give the subsequent class member access operations
  // defined behavior.
  X *p = (X*)std::malloc(sizeof(struct X));
  p->a = 1;
  p->b = 2;
  return p;
}
```

— *end example*]

Implicit Lifetime

9 Arithmetic types (6.8.1), enumeration types, pointer types, pointer-to-member types (6.8.2), `std::nullptr_t`, and cv-qualified (6.8.3) versions of these types are collectively called *scalar types*. Scalar types, trivially copyable class types (11.2), arrays of such types, and cv-qualified versions of these types are collectively called *trivially copyable types*. Scalar types, trivial class types (11.2), arrays of such types and cv-qualified versions of these types are collectively called *trivial types*. Scalar types, standard-layout class types (11.2), arrays of such types and cv-qualified versions of these types are collectively called *standard-layout types*. Scalar types, implicit-lifetime class types (11.2), array types, and cv-qualified versions of these types are collectively called *implicit-lifetime types*.

Implicit Lifetime

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```
class Foo
{
    // ...
    Foo(tag_t) = default;
};
```

Implicit Lifetime

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Daugaard: Local State

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```
class RingBuffer { // ...
    // Writer and reader's local state.
    struct alignas(CACHE_LINE_SIZE) LocalState
    {
        LocalState()
            : buffer(nullptr), pos(0), end(0), base(0), size(0) {}

        char* buffer;
        size_t pos;
        size_t end;
        size_t base;
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    };

    LocalState m_Writer;
    LocalState m_Reader;
```

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        size_t size;
    };

    LocalState m_Writer;
    LocalState m_Reader;
```

Daugaard: Shared State

Daugaard: Shared State

```
class RingBuffer
{
    // Writer and reader's shared positions.
    struct alignas(CACHE_LINE_SIZE) SharedState
    {
        std::atomic<size_t> pos;
    };

    SharedState m_WriterShared;
    SharedState m_ReaderShared;
```

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{
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```

5 [*Note*: Operations that are lock-free should also be address-free. That is, atomic operations on the same memory location via two different addresses will communicate atomically. The implementation should not depend on any per-process state. This restriction enables communication by memory that is mapped into a process more than once and by memory that is shared between two processes. — *end note*]

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```

std::atomic<T>::atomic

`atomic() noexcept = default;`	(1)	(since C++11) (until C++20)
`constexpr atomic() noexcept(std::is_nothrow_default_constructible_v<T>);`		(since C++20)
`constexpr atomic( T desired ) noexcept;`	(2)	(since C++11)
`atomic( const atomic& ) = delete;`	(3)	(since C++11)

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Daugaard: Shared State

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class RingBuffer
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    // Writer and reader's shared positions.
    struct alignas(CACHE_LINE_SIZE) SharedState
    {
        size_t pos;
    };

    SharedState m_WriterShared;
    SharedState m_ReaderShared;
```

Daugaard: Shared State

```
class RingBuffer
{
    // Writer and reader's shared positions.
    struct alignas(CACHE_LINE_SIZE) SharedState
    {
        Atomic<size_t> pos;
    };

    SharedState m_WriterShared;
    SharedState m_ReaderShared;
```

std::atomic

std::atomic

```
template <typename T>
struct implicit_lifetime_wrapper
{
    using type = T;
};

template <typename T>
inline constexpr bool is_implicit_lifetime_wrapper = false;
template <typename T>
inline constexpr bool
    is_implicit_lifetime_wrapper<implicit_lifetime_wrapper<T>> = true;
```

std::atomic

```
template <typename T>
class atomic
{
    using type = t_or_implicit_lifetime_wrapped<T>;
    type t;

public:
    atomic()
    requires is_implicit_lifetime_wrapper<T>
    = default;

    atomic()
    requires(not is_implicit_lifetime_wrapper<T>)
    : t{}
    { }
};
```

Implicit Lifetime

- Messages must be implicit lifetime
- Must become comfortable with this for sharing data across processes

Daugaard: Cache Lines

Daugaard: Cache Lines

```
#define CACHE_LINE_SIZE 64
```

Daugaard: Cache Lines

```
#if defined(CACHE_LINE_SIZE)
inline constexpr std::size_t cache_line_size = CACHE_LINE_SIZE;
#elif defined(__cpp_lib_hardware_interference_size) && \
    (__cpp_lib_hardware_interference_size >= 201703L)
inline constexpr std::size_t cache_line_size =
    std::hardware_destructive_interference_size;
#else
    #error "cache_line_size cannot be defined"
#endif
```

Daugaard: Cache Lines

Is std::hardware_destructive_interference_size right for Macs?

Asked 2 months ago Modified 2 months ago Viewed 124 times

5

Question, but also PSA.

The latest version of apple-clang has dropped: `Apple clang version 17.0.0 (clang-1700.0.13.3)`

It finally has `std::hardware_destructive_interference_size` and `std::hardware_constructive_interference_size`, but they seem wrong, at least on my architecture.

I'd expect 128, but they provide 64. Is my understanding correct? Is apple-clang wrong?

Is my understanding that the results for `std::hardware_destructive_interference_size

```
$ cat /tmp/a.cpp && g++ -std=c++20 /tmp/a.cpp && ./a.out && sysctl hw.cachelines
#include <iostream>
#include <new>

int main()
{
    std::cout << std::hardware_destructive_interference_size << '\n';
    std::cout << std::hardware_constructive_interference_size << '\n';
}
64
64
hw.cachelinesize: 128
```

The Daugaard Queue

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Separation of Concerns

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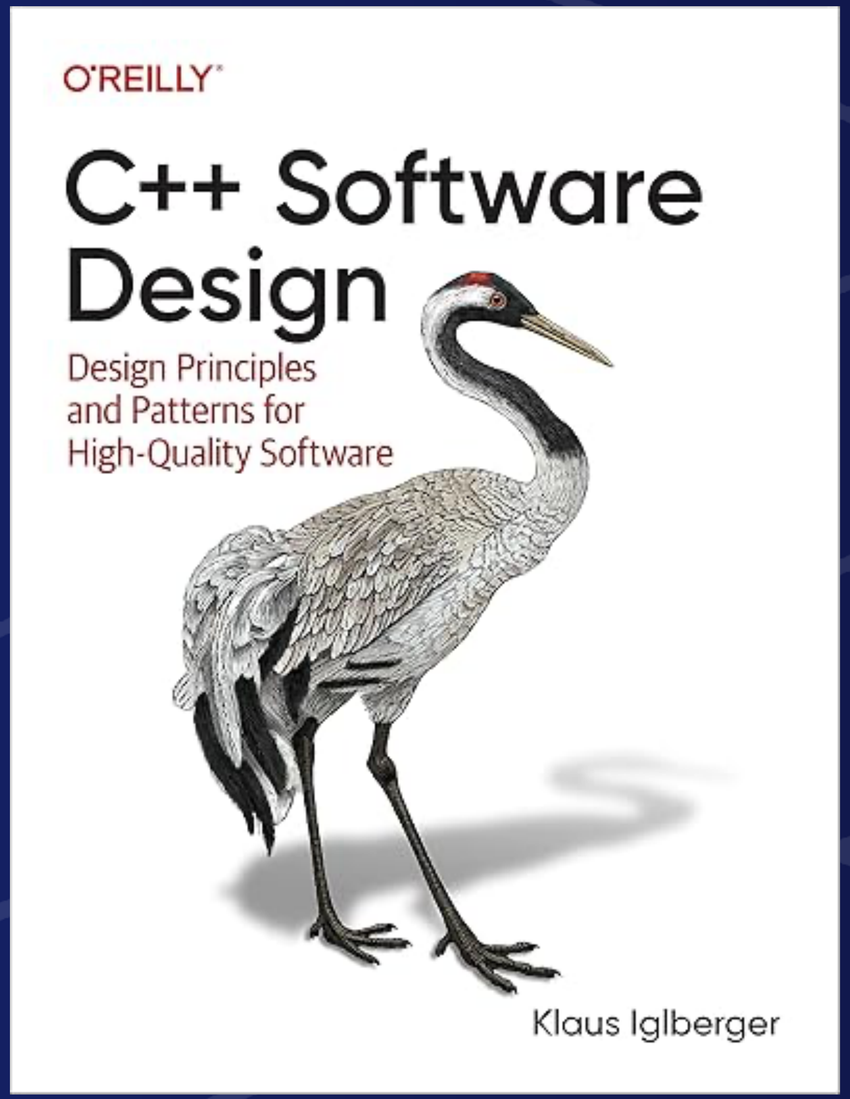

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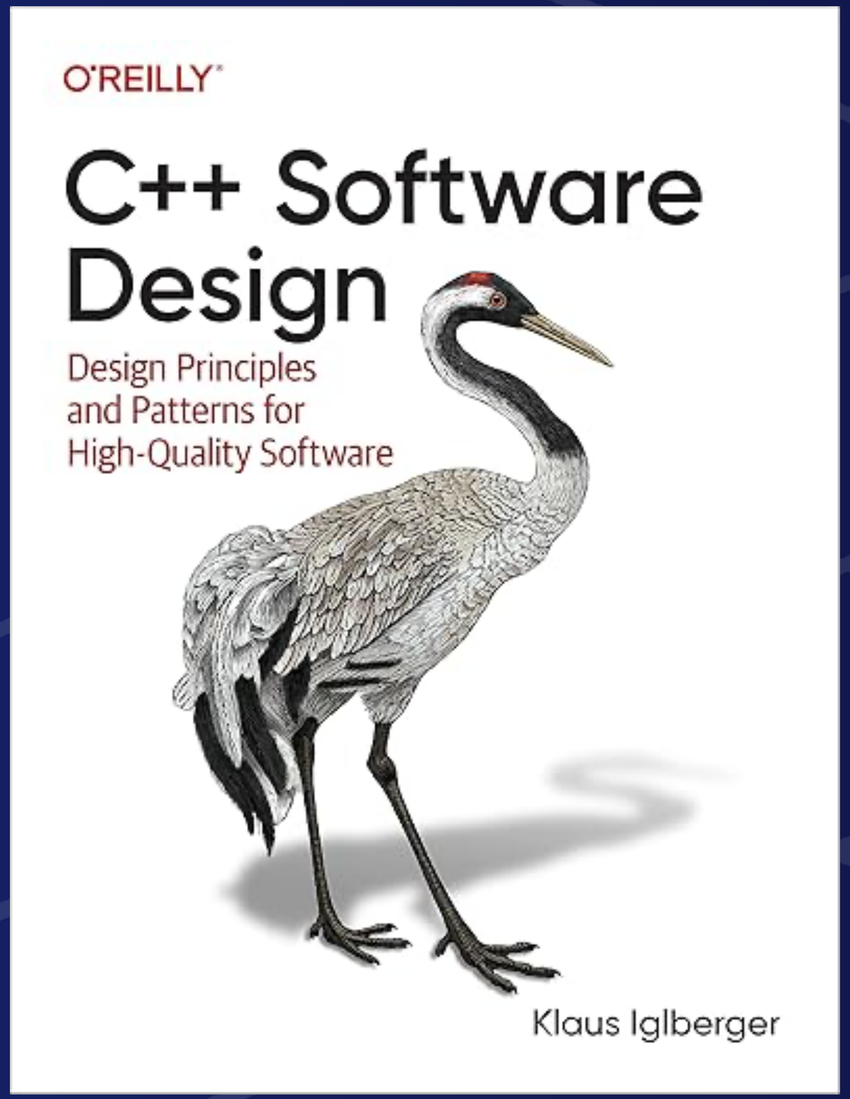

Separation of Concerns

- The Queue
  - Construction (metadata and buffer)
  - Synchronization (races with processes starting)
- The Producer
  - Must have an existing Queue
  - Highlander Rule
  - Can only write into queue
- The Consumer
  - Must have and existing Queue
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  - Can only read from queue

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Not Optional

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Advisory File Lock

```
struct AdvisoryFileLock
{
    struct Create { mode_t mode; };

    explicit AdvisoryFileLock(std::filesystem::path path);
    explicit AdvisoryFileLock(
        std::filesystem::path path, Create create);

    void swap(AdvisoryFileLock & that) noexcept;

    bool try_lock();
    void lock();
    void unlock() noexcept;

    std::filesystem::path const & path() const;
};
```

Characteristics

```
struct Characteristics
{
    struct Signature
    {
        std::array<char, 32> value_;

        std::string str() const
        {
            auto v = std::string_view(value_.data(), value_.size());
            return std::string(
                v.data(), std::min(v.size(), v.find('\0')));
        }

        constexpr auto operator <=> (Signature const &) const = default;
    };
```

Characteristics

```
struct UUID
{
    std::array<std::byte, 16> value_;

    std::string str() const;

    static UUID make();

    constexpr auto operator <=> (UUID const &) const = default;
};

enum struct Capacity : std::uint64_t
{
};
```

Characteristics

```
enum struct MsgSize : std::uint32_t
{
};

enum struct MsgAlignment : std::uint32_t
{
};

enum struct CacheLineSize : std::uint16_t
{
};
```

Characteristics

```
enum Flags : std::uint16_t
{
    SingleProducer = 0x0001,
    MultiProducer = 0x0002,
    SingleProducerBlocks = 0x0004,
    MultiProducerBlocks = 0x0008,
    SingleConsumer = 0x0010,
    MultiConsumer = 0x0020,
    SingleConsumerBlocks = 0x0040,
    MultiConsumerBlocks = 0x0080,
    Interprocess = 0x0100,
    Multicast = 0x0200,
    Broadcast = Multicast,
    None = 0x0000,
    All = 0xffff,
};
```

MetaData

```
template <typename PidLockT>
requires ProcessIdLockC<PidLockT>
struct MetaData
{
    using PidLock = PidLockT;

    enum struct BufferOffset : std::size_t
    {
    };

    constexpr MetaData() = default;
    explicit MetaData(Characteristics const & c);
    explicit MetaData(
        Characteristics const & c,
        BufferOffset buffer_offset);
```

MetaData

```
std::unique_lock<PidLock> producer_lock()
{
    return std::unique_lock<PidLock>(producer_lock_);
}

std::unique_lock<PidLock> producer_lock(std::try_to_lock_t arg)
{
    return std::unique_lock<PidLock>(producer_lock_, arg);
}

std::unique_lock<PidLock> try_producer_lock()
{
    return producer_lock(std::try_to_lock);
}
```

MetaData

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std::unique_lock<PidLock> consumer_lock()
{
    return std::unique_lock<PidLock>(consumer_lock_);
}

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}

std::unique_lock<PidLock> try_consumer_lock()
{
    return consumer_lock(std::try_to_lock);
}
```

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Process ID Lock

Process ID Lock

```
template <typename BlockPolicyT>
struct TProcessIdLock
{
    using BlockPolicy = BlockPolicyT;
```

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struct TProcessIdLock
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    TProcessIdLock() = default;
```

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template <typename BlockPolicyT>
struct TProcessIdLock
{
    using BlockPolicy = BlockPolicyT;

    TProcessIdLock() = default;

    explicit TProcessIdLock(std::in_place_t inplace);
```

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```
template <typename BlockPolicyT>
struct TProcessIdLock
{
    using BlockPolicy = BlockPolicyT;

    TProcessIdLock() = default;

    explicit TProcessIdLock(std::in_place_t inplace);

    bool try_lock()
    {
        return pidlock_detail::try_lock_impl(
            data_.pid,
            ProcessId::current());
    }
```

Process ID Lock

```
void lock()
{
    auto const me = ProcessId::current();
    for (int i = 0; i < 10; ++i) {
        if (pidlock_detail::try_lock_impl(data_.pid, me)) {
            return;
        }
        std::this_thread::yield();
    }
    data_.block_policy().wait([&] {
        return pidlock_detail::try_lock_impl(data_.pid, me);
    });
}
```

Process ID Lock

```
void unlock()
{
    auto me = ProcessId::current();
     data_.pid.compare_exchange_strong(
         me,
         ProcessId::null());
     data_.block_policy().notify_one();
}
```

Process ID Lock

```
void unlock()
{
    auto me = ProcessId::current();
     data_.pid.compare_exchange_strong(
         me,
         ProcessId::null());
     data_.block_policy().notify_one();
}

ProcessId pid() const
{
     return data_.pid.load(std::memory_order_acquire);
}
```

Process ID Lock

```
bool try_lock_impl(wjh::Atomic<ProcessId> & pid, ProcessId const & me)
{
    auto expected = PID::null();
    if (exchange(pid, expected, me)) return true;
    if (expected != me) {
        if (auto p = PID::maybe(expected.pid());
            not p || expected != *p)
        {
            exchange(pid, expected, PID::null());
            expected = PID::null();
            if (exchange(pid, expected, me)) return true;
        }
    }
    return false;
}
```

Process ID

Process ID

```
ProcessId
ProcessId::
current()
{
    static ProcessId id = [] {


        return ProcessId{::getpid()};
    }();
    return id;
}
```

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Process ID

```
ProcessId
ProcessId::
current()
{
    static ProcessId id = [] {
        ::pthread_atfork(
            nullptr, // prepare
            nullptr, // parent
            [] { id = ProcessId{::getpid()}; });
        return ProcessId{::getpid()};
    }();
    return id;
}
```

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}
```
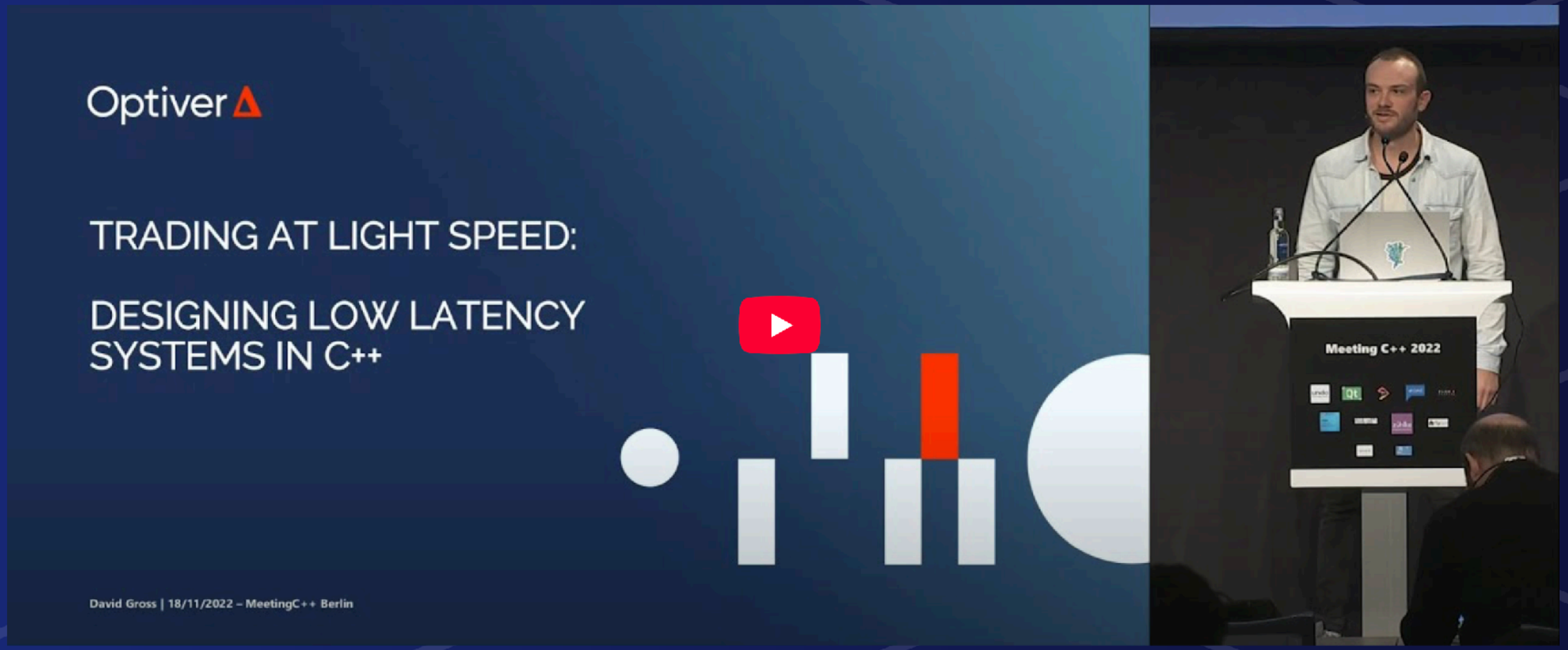

MCAST Queues

MCAST Queues

- Single Producer, Multiple Consumers
- Every consumer gets every message (mcast, broadcast)
- Producer never blocks
- Slow consumers may miss messages
- Most really fast ones have some kind of UB (seqlock, etc)

MCAST Queues



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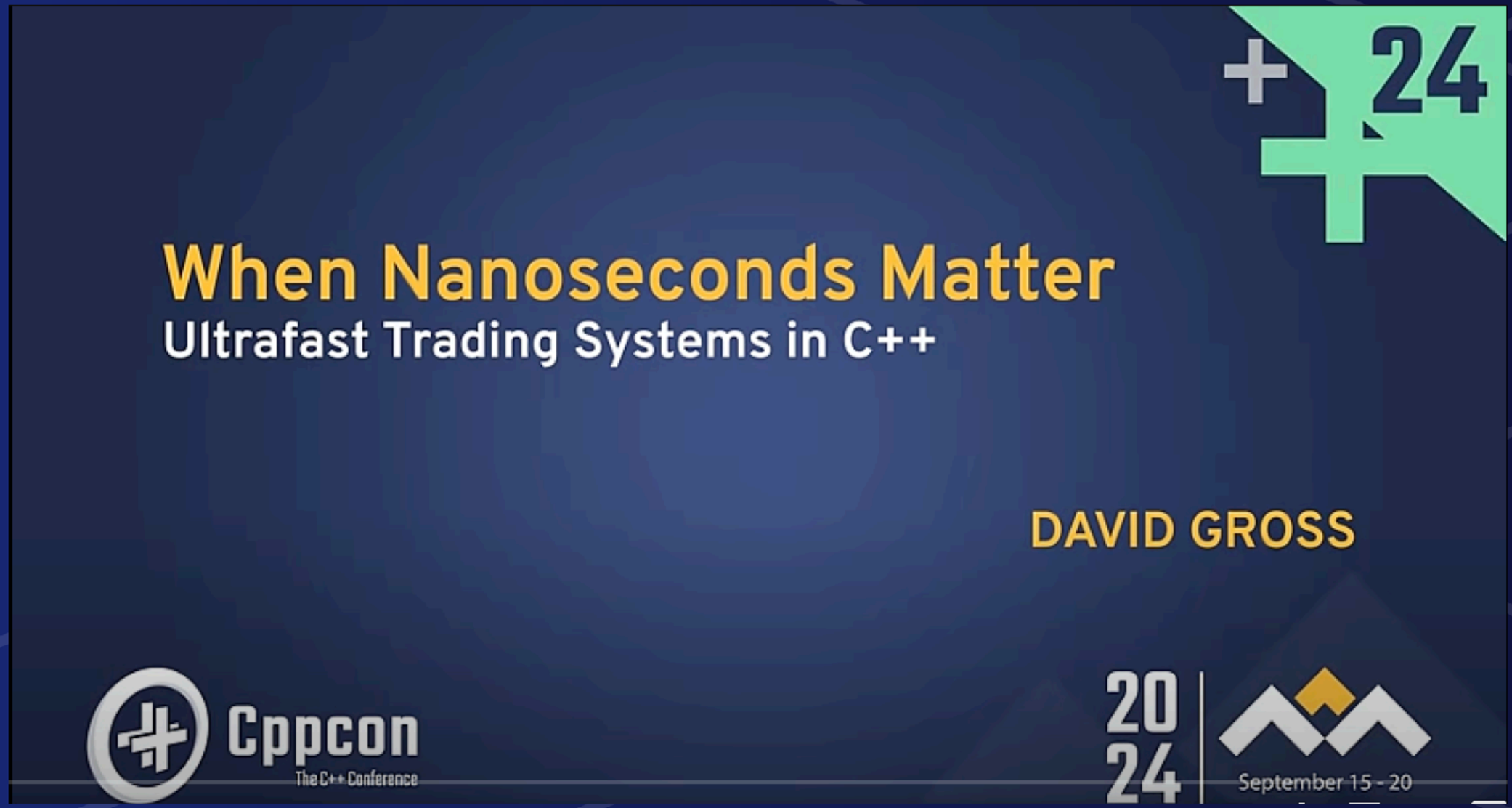

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MCAST Queues

- The Queue
  - Lock for becoming the producer
  - If enabled, a lock for becoming the special consumer

MCAST Queues

- The Producer
  - Uses TMP or concepts
    - If has a special consumer
      - Writes block on a single special consumer
    - Otherwise, writes never block

MCAST Queues

- Multi Consumer
  - Polls for message arrival
  - Can be lapped buy producer
  - Needs to detect missed messages
    - Usually crashes, but could recover and catch up

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- The Special Consumer
  - Reads block on the producer
  - Needs to be ultra lightweight and fast
  - Measure and collect statistics
  - Neither producer nor consumer should ever block
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SEPARATE CONCERNS