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# Boost.Atomic

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# Introduction

## Presenting Boost.Atomic

**Boost.Atomic** is a library that provides `atomic` data types and operations on these data types, as well as memory ordering constraints required for coordinating multiple threads through atomic variables. It implements the interface as defined by the C++11 standard, but makes this feature available for platforms lacking system/compiler support for this particular C++11 feature.

Users of this library should already be familiar with concurrency in general, as well as elementary concepts such as "mutual exclusion".

The implementation makes use of processor-specific instructions where possible (via inline assembler, platform libraries or compiler intrinsics), and falls back to "emulating" atomic operations through locking.

## Purpose

Operations on "ordinary" variables are not guaranteed to be atomic. This means that with `int n=0` initially, two threads concurrently executing

```
void function()  
{  
    n ++;  
}
```

might result in `n==1` instead of 2: Each thread will read the old value into a processor register, increment it and write the result back. Both threads may therefore write 1, unaware that the other thread is doing likewise.

Declaring `atomic<int> n=0` instead, the same operation on this variable will always result in `n==2` as each operation on this variable is *atomic*: This means that each operation behaves as if it were strictly sequentialized with respect to the other.

Atomic variables are useful for two purposes:

- as a means for coordinating multiple threads via custom coordination protocols
- as faster alternatives to "locked" access to simple variables

Take a look at the [examples](#) section for common patterns.

# Thread coordination using Boost.Atomic

The most common use of **Boost.Atomic** is to realize custom thread synchronization protocols: The goal is to coordinate accesses of threads to shared variables in order to avoid "conflicts". The programmer must be aware of the fact that compilers, CPUs and the cache hierarchies may generally reorder memory references at will. As a consequence a program such as:

```
int x = 0, int y = 0;

thread1:
  x = 1;
  y = 1;

thread2
  if (y == 1) {
    assert(x == 1);
  }
```

might indeed fail as there is no guarantee that the read of `x` by thread2 "sees" the write by thread1.

**Boost.Atomic** uses a synchronisation concept based on the *happens-before* relation to describe the guarantees under which situations such as the above one cannot occur.

The remainder of this section will discuss *happens-before* in a "hands-on" way instead of giving a fully formalized definition. The reader is encouraged to additionally have a look at the discussion of the correctness of a few of the [examples](#) afterwards.

## Enforcing *happens-before* through mutual exclusion

As an introductory example to understand how arguing using *happens-before* works, consider two threads synchronizing using a common mutex:

```
mutex m;

thread1:
  m.lock();
  ... /* A */
  m.unlock();

thread2:
  m.lock();
  ... /* B */
  m.unlock();
```

The "lockset-based intuition" would be to argue that A and B cannot be executed concurrently as the code paths require a common lock to be held.

One can however also arrive at the same conclusion using *happens-before*: Either thread1 or thread2 will succeed first at `m.lock()`. If this is be thread1, then as a consequence, thread2 cannot succeed at `m.lock()` before thread1 has executed `m.unlock()`, consequently A *happens-before* B in this case. By symmetry, if thread2 succeeds at `m.lock()` first, we can conclude B *happens-before* A.

Since this already exhausts all options, we can conclude that either A *happens-before* B or B *happens-before* A must always hold. Obviously cannot state *which* of the two relationships holds, but either one is sufficient to conclude that A and B cannot conflict.

Compare the [spinlock](#) implementation to see how the mutual exclusion concept can be mapped to **Boost.Atomic**.

## *happens-before* through `release` and `acquire`

The most basic pattern for coordinating threads via **Boost.Atomic** uses `release` and `acquire` on an atomic variable for coordination: If ...

- ... thread1 performs an operation A,
- ... thread1 subsequently writes (or atomically modifies) an atomic variable with `release` semantic,
- ... thread2 reads (or atomically reads-and-modifies) the value this value from the same atomic variable with `acquire` semantic and
- ... thread2 subsequently performs an operation B,

... then A *happens-before* B.

Consider the following example

```
atomic<int> a(0);

thread1:
... /* A */
a.fetch_add(1, memory_order_release);

thread2:
int tmp = a.load(memory_order_acquire);
if (tmp == 1) {
... /* B */
} else {
... /* C */
}
```

In this example, two avenues for execution are possible:

- The `store` operation by thread1 precedes the `load` by thread2: In this case thread2 will execute B and "A *happens-before* B" holds as all of the criteria above are satisfied.
- The `load` operation by thread2 precedes the `store` by thread1: In this case, thread2 will execute C, but "A *happens-before* C" does *not* hold: thread2 does not read the value written by thread1 through a.

Therefore, A and B cannot conflict, but A and C *can* conflict.

## Fences

Ordering constraints are generally specified together with an access to an atomic variable. It is however also possible to issue "fence" operations in isolation, in this case the fence operates in conjunction with preceding (for `acquire`, `consume` or `seq_cst` operations) or succeeding (for `release` or `seq_cst`) atomic operations.

The example from the previous section could also be written in the following way:

```

atomic<int> a(0);

thread1:
... /* A */
atomic_thread_fence(memory_order_release);
a.fetch_add(1, memory_order_relaxed);

thread2:
int tmp = a.load(memory_order_relaxed);
if (tmp == 1) {
    atomic_thread_fence(memory_order_acquire);
    ... /* B */
} else {
    ... /* C */
}

```

This provides the same ordering guarantees as previously, but elides a (possibly expensive) memory ordering operation in the case C is executed.

## *happens-before* through `release` and `consume`

The second pattern for coordinating threads via **Boost.Atomic** uses `release` and `consume` on an atomic variable for coordination: If ...

- ... thread1 performs an operation A,
- ... thread1 subsequently writes (or atomically modifies) an atomic variable with `release` semantic,
- ... thread2 reads (or atomically reads-and-modifies) the value this value from the same atomic variable with `consume` semantic and
- ... thread2 subsequently performs an operation B that is *computationally dependent on the value of the atomic variable*,

... then A *happens-before* B.

Consider the following example

```

atomic<int> a(0);
complex_data_structure data[2];

thread1:
data[1] = ...; /* A */
a.store(1, memory_order_release);

thread2:
int index = a.load(memory_order_consume);
complex_data_structure tmp = data[index]; /* B */

```

In this example, two avenues for execution are possible:

- The store operation by thread1 precedes the load by thread2: In this case thread2 will read `data[1]` and "A *happens-before* B" holds as all of the criteria above are satisfied.
- The load operation by thread2 precedes the store by thread1: In this case thread2 will read `data[0]` and "A *happens-before* B" does *not* hold: thread2 does not read the value written by thread1 through a.

Here, the *happens-before* relationship helps ensure that any accesses (presumably writes) to `data[1]` by thread1 happen before before the accesses (presumably reads) to `data[1]` by thread2: Lacking this relationship, thread2 might see stale/inconsistent data.

Note that in this example, the fact that operation B is computationally dependent on the atomic variable, therefore the following program would be erroneous:

```
atomic<int> a(0);
complex_data_structure data[2];

thread1:
    data[1] = ...; /* A */
    a.store(1, memory_order_release);

thread2:
    int index = a.load(memory_order_consume);
    complex_data_structure tmp;
    if (index == 0)
        tmp = data[0];
    else
        tmp = data[1];
```

consume is most commonly (and most safely! see [limitations](#)) used with pointers, compare for example the [singleton with double-checked locking](#).

## Sequential consistency

The third pattern for coordinating threads via **Boost.Atomic** uses `seq_cst` for coordination: If ...

- ... thread1 performs an operation A,
- ... thread1 subsequently performs any operation with `seq_cst`,
- ... thread1 subsequently performs an operation B,
- ... thread2 performs an operation C,
- ... thread2 subsequently performs any operation with `seq_cst`,
- ... thread2 subsequently performs an operation D,

then either "*A happens-before D*" or "*C happens-before B*" holds.

In this case it does not matter whether thread1 and thread2 operate on the same or different atomic variables, or use a "stand-alone" `atomic_thread_fence` operation.

# Programming interfaces

## Configuration and building

The library contains header-only and compiled parts. The library is header-only for lock-free cases but requires a separate binary to implement the lock-based emulation. Users are able to detect whether linking to the compiled part is required by checking the [feature macros](#).

The following macros affect library behavior:

Macro	Description
<code>BOOST_ATOMIC_NO_CMPXCHG16B</code>	Affects 64-bit x86 MSVC builds. When defined, the library assumes the target CPU does not support <code>cmpxchg16b</code> instruction used to support 128-bit atomic operations. This is the case with some early 64-bit AMD CPUs, all Intel CPUs and current AMD CPUs support this instruction. The library does not perform runtime detection of this instruction, so running the code that uses 128-bit atomics on such CPUs will result in crashes, unless this macro is defined. Note that the macro does not affect GCC and compatible compilers because the library infers this information from the compiler-defined macros.
<code>BOOST_ATOMIC_FORCE_FALLBACK</code>	When defined, all operations are implemented with locks. This is mostly used for testing and should not be used in real world projects.
<code>BOOST_ATOMIC_DYN_LINK</code> and <code>BOOST_ALL_DYN_LINK</code>	Control library linking. If defined, the library assumes dynamic linking, otherwise static. The latter macro affects all Boost libraries, not just <b>Boost.Atomic</b> .
<code>BOOST_ATOMIC_NO_LIB</code> and <code>BOOST_ALL_NO_LIB</code>	Control library auto-linking on Windows. When defined, disables auto-linking. The latter macro affects all Boost libraries, not just <b>Boost.Atomic</b> .

Besides macros, it is important to specify the correct compiler options for the target CPU. With GCC and compatible compilers this affects whether particular atomic operations are lock-free or not.

Boost building process is described in the [Getting Started guide](#). For example, you can build **Boost.Atomic** with the following command line:

```
bjam --with-atomic variant=release instruction-set=core2 stage
```

## Memory order

```
#include <boost/memory_order.hpp>
```

The enumeration `boost::memory_order` defines the following values to represent memory ordering constraints:

Constant	Description
<code>memory_order_relaxed</code>	No ordering constraint. Informally speaking, following operations may be reordered before, preceding operations may be reordered after the atomic operation. This constraint is suitable only when either a) further operations do not depend on the outcome of the atomic operation or b) ordering is enforced through stand-alone <code>atomic_thread_fence</code> operations. The operation on the atomic value itself is still atomic though.
<code>memory_order_release</code>	Perform <code>release</code> operation. Informally speaking, prevents all preceding memory operations to be reordered past this point.
<code>memory_order_acquire</code>	Perform <code>acquire</code> operation. Informally speaking, prevents succeeding memory operations to be reordered before this point.
<code>memory_order_consume</code>	Perform <code>consume</code> operation. More relaxed (and on some architectures more efficient) than <code>memory_order_acquire</code> as it only affects succeeding operations that are computationally-dependent on the value retrieved from an atomic variable.
<code>memory_order_acq_rel</code>	Perform both <code>release</code> and <code>acquire</code> operation
<code>memory_order_seq_cst</code>	Enforce sequential consistency. Implies <code>memory_order_acq_rel</code> , but additionally enforces total order for all operations such qualified.

See section [happens-before](#) for explanation of the various ordering constraints.

## Atomic objects

```
#include <boost/atomic/atomic.hpp>
```

`boost::atomic<T>` provides methods for atomically accessing variables of a suitable type *T*. The type is suitable if it is *trivially copyable* (3.9/9 [basic.types]). Following are examples of the types compatible with this requirement:

- a scalar type (e.g. integer, boolean, enum or pointer type)
- a class or struct that has no non-trivial copy or move constructors or assignment operators, has a trivial destructor, and that is comparable via `memcmp`.

Note that classes with virtual functions or virtual base classes do not satisfy the requirements. Also be warned that structures with "padding" between data members may compare non-equal via `memcmp` even though all members are equal.

### `boost::atomic<T>` template class

All atomic objects supports the following operations:



Syntax	Description
<code>atomic()</code>	Initialize to an unspecified value
<code>atomic(T initial_value)</code>	Initialize to <code>initial_value</code>
<code>bool is_lock_free()</code>	Checks if the atomic object is lock-free
<code>T load(memory_order order)</code>	Return current value
<code>void store(T value, memory_order order)</code>	Write new value to atomic variable
<code>T exchange(T new_value, memory_order order)</code>	Exchange current value with <code>new_value</code> , returning current value
<code>bool compare_exchange_weak(T &amp; expected, T desired, memory_order order)</code>	Compare current value with <code>expected</code> , change it to <code>desired</code> if matches. Returns <code>true</code> if an exchange has been performed, and always writes the previous value back in <code>expected</code> . May fail spuriously, so must generally be retried in a loop.
<code>bool compare_exchange_weak(T &amp; expected, T desired, memory_order success_order, memory_order failure_order)</code>	Compare current value with <code>expected</code> , change it to <code>desired</code> if matches. Returns <code>true</code> if an exchange has been performed, and always writes the previous value back in <code>expected</code> . May fail spuriously, so must generally be retried in a loop.
<code>bool compare_exchange_strong(T &amp; expected, T desired, memory_order order)</code>	Compare current value with <code>expected</code> , change it to <code>desired</code> if matches. Returns <code>true</code> if an exchange has been performed, and always writes the previous value back in <code>expected</code> .
<code>bool compare_exchange_strong(T &amp; expected, T desired, memory_order success_order, memory_order failure_order)</code>	Compare current value with <code>expected</code> , change it to <code>desired</code> if matches. Returns <code>true</code> if an exchange has been performed, and always writes the previous value back in <code>expected</code> .

`order` always has `memory_order_seq_cst` as default parameter.

The `compare_exchange_weak`/`compare_exchange_strong` variants taking four parameters differ from the three parameter variants in that they allow a different memory ordering constraint to be specified in case the operation fails.

In addition to these explicit operations, each `atomic<T>` object also supports implicit `store` and `load` through the use of "assignment" and "conversion to T" operators. Avoid using these operators, as they do not allow explicit specification of a memory ordering constraint.

## `boost::atomic<integral>` template class

In addition to the operations listed in the previous section, `boost::atomic<I>` for integral types `I` supports the following operations:

Syntax	Description
<code>T fetch_add(T v, memory_order order)</code>	Add <code>v</code> to variable, returning previous value
<code>T fetch_sub(T v, memory_order order)</code>	Subtract <code>v</code> from variable, returning previous value
<code>T fetch_and(T v, memory_order order)</code>	Apply bit-wise "and" with <code>v</code> to variable, returning previous value
<code>T fetch_or(T v, memory_order order)</code>	Apply bit-wise "or" with <code>v</code> to variable, returning previous value
<code>T fetch_xor(T v, memory_order order)</code>	Apply bit-wise "xor" with <code>v</code> to variable, returning previous value

order always has `memory_order_seq_cst` as default parameter.

In addition to these explicit operations, each `boost::atomic<I>` object also supports implicit pre-/post- increment/decrement, as well as the operators `+=`, `-=`, `&=`, `|=` and `^=`. Avoid using these operators, as they do not allow explicit specification of a memory ordering constraint.

### `boost::atomic<pointer>` template class

In addition to the operations applicable to all atomic object, `boost::atomic<P>` for pointer types *P* (other than `void` pointers) support the following operations:

Syntax	Description
<code>T fetch_add(ptrdiff_t v, memory_order order)</code>	Add <i>v</i> to variable, returning previous value
<code>T fetch_sub(ptrdiff_t v, memory_order order)</code>	Subtract <i>v</i> from variable, returning previous value

order always has `memory_order_seq_cst` as default parameter.

In addition to these explicit operations, each `boost::atomic<P>` object also supports implicit pre-/post- increment/decrement, as well as the operators `+=`, `-=`. Avoid using these operators, as they do not allow explicit specification of a memory ordering constraint.

## Fences

```
#include <boost/atomic/fences.hpp>
```

Syntax	Description
<code>void atomic_thread_fence(memory_order order)</code>	Issue fence for coordination with other threads.
<code>void atomic_signal_fence(memory_order order)</code>	Issue fence for coordination with signal handler (only in same thread).

## Feature testing macros

```
#include <boost/atomic/capabilities.hpp>
```

**Boost.Atomic** defines a number of macros to allow compile-time detection whether an atomic data type is implemented using "true" atomic operations, or whether an internal "lock" is used to provide atomicity. The following macros will be defined to 0 if operations on the data type always require a lock, to 1 if operations on the data type may sometimes require a lock, and to 2 if they are always lock-free:

Macro	Description
BOOST_ATOMIC_FLAG_LOCK_FREE	Indicate whether <code>atomic_flag</code> is lock-free
BOOST_ATOMIC_BOOL_LOCK_FREE	Indicate whether <code>atomic&lt;bool&gt;</code> is lock-free
BOOST_ATOMIC_CHAR_LOCK_FREE	Indicate whether <code>atomic&lt;char&gt;</code> (including signed/unsigned variants) is lock-free
BOOST_ATOMIC_CHAR16_T_LOCK_FREE	Indicate whether <code>atomic&lt;char16_t&gt;</code> (including signed/unsigned variants) is lock-free
BOOST_ATOMIC_CHAR32_T_LOCK_FREE	Indicate whether <code>atomic&lt;char32_t&gt;</code> (including signed/unsigned variants) is lock-free
BOOST_ATOMIC_WCHAR_T_LOCK_FREE	Indicate whether <code>atomic&lt;wchar_t&gt;</code> (including signed/unsigned variants) is lock-free
BOOST_ATOMIC_SHORT_LOCK_FREE	Indicate whether <code>atomic&lt;short&gt;</code> (including signed/unsigned variants) is lock-free
BOOST_ATOMIC_INT_LOCK_FREE	Indicate whether <code>atomic&lt;int&gt;</code> (including signed/unsigned variants) is lock-free
BOOST_ATOMIC_LONG_LOCK_FREE	Indicate whether <code>atomic&lt;long&gt;</code> (including signed/unsigned variants) is lock-free
BOOST_ATOMIC_LLONG_LOCK_FREE	Indicate whether <code>atomic&lt;long long&gt;</code> (including signed/unsigned variants) is lock-free
BOOST_ATOMIC_ADDRESS_LOCK_FREE or BOOST_ATOMIC_POINTER_LOCK_FREE	Indicate whether <code>atomic&lt;T *&gt;</code> is lock-free
BOOST_ATOMIC_THREAD_FENCE	Indicate whether <code>atomic_thread_fence</code> function is lock-free
BOOST_ATOMIC_SIGNAL_FENCE	Indicate whether <code>atomic_signal_fence</code> function is lock-free

In addition to these standard macros, **Boost.Atomic** also defines a number of extension macros, which can also be useful. Like the standard ones, these macros are defined to values 0, 1 and 2 to indicate whether the corresponding operations are lock-free or not.

Macro	Description
BOOST_ATOMIC_INT8_LOCK_FREE	Indicate whether <code>atomic&lt;int8_type&gt;</code> is lock-free.
BOOST_ATOMIC_INT16_LOCK_FREE	Indicate whether <code>atomic&lt;int16_type&gt;</code> is lock-free.
BOOST_ATOMIC_INT32_LOCK_FREE	Indicate whether <code>atomic&lt;int32_type&gt;</code> is lock-free.
BOOST_ATOMIC_INT64_LOCK_FREE	Indicate whether <code>atomic&lt;int64_type&gt;</code> is lock-free.
BOOST_ATOMIC_INT128_LOCK_FREE	Indicate whether <code>atomic&lt;int128_type&gt;</code> is lock-free.
BOOST_ATOMIC_NO_ATOMIC_FLAG_INIT	Defined after including <code>atomic_flag.hpp</code> , if the implementation does not support the <code>BOOST_ATOMIC_FLAG_INIT</code> macro for static initialization of <code>atomic_flag</code> . This macro is typically defined for pre-C++11 compilers.

In the table above, `intN_type` is a type that fits storage of contiguous  $N$  bits, suitably aligned for atomic operations.

# Usage examples

## Reference counting

The purpose of a *reference counter* is to count the number of pointers to an object. The object can be destroyed as soon as the reference counter reaches zero.

## Implementation

```
#include <boost/intrusive_ptr.hpp>
#include <boost/atomic.hpp>

class X {
public:
    typedef boost::intrusive_ptr<X> pointer;
    X() : refcount_(0) {}

private:
    mutable boost::atomic<int> refcount_;
    friend void intrusive_ptr_add_ref(const X * x)
    {
        x->refcount_.fetch_add(1, boost::memory_order_relaxed);
    }
    friend void intrusive_ptr_release(const X * x)
    {
        if (x->refcount_.fetch_sub(1, boost::memory_order_release) == 1) {
            boost::atomic_thread_fence(boost::memory_order_acquire);
            delete x;
        }
    }
};
```

## Usage

```
X::pointer x = new X;
```

## Discussion

Increasing the reference counter can always be done with `memory_order_relaxed`: New references to an object can only be formed from an existing reference, and passing an existing reference from one thread to another must already provide any required synchronization.

It is important to enforce any possible access to the object in one thread (through an existing reference) to *happen before* deleting the object in a different thread. This is achieved by a "release" operation after dropping a reference (any access to the object through this reference must obviously happened before), and an "acquire" operation before deleting the object.

It would be possible to use `memory_order_acq_rel` for the `fetch_sub` operation, but this results in unneeded "acquire" operations when the reference counter does not yet reach zero and may impose a performance penalty.

## Spinlock

The purpose of a *spin lock* is to prevent multiple threads from concurrently accessing a shared data structure. In contrast to a mutex, threads will busy-wait and waste CPU cycles instead of yielding the CPU to another thread. *Do not use spinlocks unless you are certain that you understand the consequences.*

## Implementation

```
#include <boost/atomic.hpp>

class spinlock {
private:
    typedef enum {Locked, Unlocked} LockState;
    boost::atomic<LockState> state_;

public:
    spinlock() : state_(Unlocked) {}

    void lock()
    {
        while (state_.exchange(Locked, boost::memory_order_acquire) == Locked) {
            /* busy-wait */
        }
    }
    void unlock()
    {
        state_.store(Unlocked, boost::memory_order_release);
    }
};
```

## Usage

```
spinlock s;

s.lock();
// access data structure here
s.unlock();
```

## Discussion

The purpose of the spinlock is to make sure that one access to the shared data structure always strictly "happens before" another. The usage of acquire/release in lock/unlock is required and sufficient to guarantee this ordering.

It would be correct to write the "lock" operation in the following way:

```
lock()
{
    while (state_.exchange(Locked, boost::memory_order_relaxed) == Locked) {
        /* busy-wait */
    }
    atomic_thread_fence(boost::memory_order_acquire);
}
```

This "optimization" is however a) useless and b) may in fact hurt: a) Since the thread will be busily spinning on a blocked spinlock, it does not matter if it will waste the CPU cycles with just "exchange" operations or with both useless "exchange" and "acquire" operations. b) A tight "exchange" loop without any memory-synchronizing instruction introduced through an "acquire" operation will on some systems monopolize the memory subsystem and degrade the performance of other system components.

## Singleton with double-checked locking pattern

The purpose of the *Singleton with double-checked locking pattern* is to ensure that at most one instance of a particular object is created. If one instance has been created already, access to the existing object should be as light-weight as possible.

## Implementation

```
#include <boost/atomic.hpp>
#include <boost/thread/mutex.hpp>

class X {
public:
    static X * instance()
    {
        X * tmp = instance_.load(boost::memory_order_consume);
        if (!tmp) {
            boost::mutex::scoped_lock guard(instantiation_mutex);
            tmp = instance_.load(boost::memory_order_consume);
            if (!tmp) {
                tmp = new X;
                instance_.store(tmp, boost::memory_order_release);
            }
        }
        return tmp;
    }
private:
    static boost::atomic<X *> instance_;
    static boost::mutex instantiation_mutex;
};

boost::atomic<X *> X::instance_(0);
```

## Usage

```
X * x = X::instance();
// dereference x
```

## Discussion

The mutex makes sure that only one instance of the object is ever created. The `instance` method must make sure that any dereference of the object strictly "happens after" creating the instance in another thread. The use of `memory_order_release` after creating and initializing the object and `memory_order_consume` before dereferencing the object provides this guarantee.

It would be permissible to use `memory_order_acquire` instead of `memory_order_consume`, but this provides a stronger guarantee than is required since only operations depending on the value of the pointer need to be ordered.

## Wait-free ring buffer

A *wait-free ring buffer* provides a mechanism for relaying objects from one single "producer" thread to one single "consumer" thread without any locks. The operations on this data structure are "wait-free" which means that each operation finishes within a constant number of steps. This makes this data structure suitable for use in hard real-time systems or for communication with interrupt/signal handlers.

## Implementation

```
#include <boost/atomic.hpp>

template<typename T, size_t Size>
class ringbuffer {
public:
    ringbuffer() : head_(0), tail_(0) {}

    bool push(const T & value)
    {
        size_t head = head_.load(boost::memory_order_relaxed);
        size_t next_head = next(head);
        if (next_head == tail_.load(boost::memory_order_acquire))
            return false;
        ring_[head] = value;
        head_.store(next_head, boost::memory_order_release);
        return true;
    }
    bool pop(T & value)
    {
        size_t tail = tail_.load(boost::memory_order_relaxed);
        if (tail == head_.load(boost::memory_order_acquire))
            return false;
        value = ring_[tail];
        tail_.store(next(tail), boost::memory_order_release);
        return true;
    }
private:
    size_t next(size_t current)
    {
        return (current + 1) % Size;
    }
    T ring_[Size];
    boost::atomic<size_t> head_, tail_;
};
```

## Usage

```
ringbuffer<int, 32> r;

// try to insert an element
if (r.push(42)) { /* succeeded */ }
else { /* buffer full */ }

// try to retrieve an element
int value;
if (r.pop(value)) { /* succeeded */ }
else { /* buffer empty */ }
```

## Discussion

The implementation makes sure that the ring indices do not "lap-around" each other to ensure that no elements are either lost or read twice.

Furthermore it must guarantee that read-access to a particular object in `pop` "happens after" it has been written in `push`. This is achieved by writing `head_` with "release" and reading it with "acquire". Conversely the implementation also ensures that read access to a particular ring element "happens before" before rewriting this element with a new value by accessing `tail_` with appropriate ordering constraints.



## Wait-free multi-producer queue

The purpose of the *wait-free multi-producer queue* is to allow an arbitrary number of producers to enqueue objects which are retrieved and processed in FIFO order by a single consumer.

### Implementation

```
template<typename T>
class waitfree_queue {
public:
    struct node {
        T data;
        node * next;
    };
    void push(const T &data)
    {
        node * n = new node;
        n->data = data;
        node * stale_head = head_.load(boost::memory_order_relaxed);
        do {
            n->next = stale_head;
        } while (!head_.compare_exchange_weak(stale_head, n, boost::memory_order_release));
    }

    node * pop_all(void)
    {
        T * last = pop_all_reverse(), * first = 0;
        while(last) {
            T * tmp = last;
            last = last->next;
            tmp->next = first;
            first = tmp;
        }
        return first;
    }

    waitfree_queue() : head_(0) {}

    // alternative interface if ordering is of no importance
    node * pop_all_reverse(void)
    {
        return head_.exchange(0, boost::memory_order_consume);
    }
private:
    boost::atomic<node *> head_;
};
```

## Usage

```
waitfree_queue<int> q;

// insert elements
q.push(42);
q.push(2);

// pop elements
waitfree_queue<int>::node * x = q.pop_all()
while(x) {
    X * tmp = x;
    x = x->next;
    // process tmp->data, probably delete it afterwards
    delete tmp;
}
```

## Discussion

The implementation guarantees that all objects enqueued are processed in the order they were enqueued by building a singly-linked list of object in reverse processing order. The queue is atomically emptied by the consumer and brought into correct order.

It must be guaranteed that any access to an object to be enqueued by the producer "happens before" any access by the consumer. This is assured by inserting objects into the list with *release* and dequeuing them with *consume* memory order. It is not necessary to use *acquire* memory order in `waitfree_queue::pop_all` because all operations involved depend on the value of the atomic pointer through dereference

## Limitations

While **Boost.Atomic** strives to implement the atomic operations from C++11 as faithfully as possible, there are a few limitations that cannot be lifted without compiler support:

- **Using non-POD-classes as template parameter to `atomic<T>` results in undefined behavior:** This means that any class containing a constructor, destructor, virtual methods or access control specifications is not a valid argument in C++98. C++11 relaxes this slightly by allowing "trivial" classes containing only empty constructors. **Advise:** Use only POD types.
- **C++98 compilers may transform computation- to control-dependency:** Crucially, `memory_order_consume` only affects computationally-dependent operations, but in general there is nothing preventing a compiler from transforming a computation dependency into a control dependency. A C++11 compiler would be forbidden from such a transformation. **Advise:** Use `memory_order_consume` only in conjunction with pointer values, as the compiler cannot speculate and transform these into control dependencies.
- **Fence operations enforce "too strong" compiler ordering:** Semantically, `memory_order_acquire/memory_order_consume` and `memory_order_release` need to restrain reordering of memory operations only in one direction. Since there is no way to express this constraint to the compiler, these act as "full compiler barriers" in this implementation. In corner cases this may result in a less efficient code than a C++11 compiler could generate.
- **No interprocess fallback:** using `atomic<T>` in shared memory only works correctly, if `atomic<T>::is_lock_free() == true`.

# Porting

## Unit tests

**Boost.Atomic** provides a unit test suite to verify that the implementation behaves as expected:

- **fallback\_api.cpp** verifies that the fallback-to-locking aspect of **Boost.Atomic** compiles and has correct value semantics.
- **native\_api.cpp** verifies that all atomic operations have correct value semantics (e.g. "fetch\_add" really adds the desired value, returning the previous). It is a rough "smoke-test" to help weed out the most obvious mistakes (for example width overflow, signed/unsigned extension, ...).
- **lockfree.cpp** verifies that the **BOOST\_ATOMIC\_\*\_LOCKFREE** macros are set properly according to the expectations for a given platform, and that they match up with the **is\_lock\_free** member functions of the **atomic** object instances.
- **atomicity.cpp** lets two threads race against each other modifying a shared variable, verifying that the operations behave atomic as appropriate. By nature, this test is necessarily stochastic, and the test self-calibrates to yield 99% confidence that a positive result indicates absence of an error. This test is very useful on uni-processor systems with preemption already.
- **ordering.cpp** lets two threads race against each other accessing multiple shared variables, verifying that the operations exhibit the expected ordering behavior. By nature, this test is necessarily stochastic, and the test attempts to self-calibrate to yield 99% confidence that a positive result indicates absence of an error. This only works on true multi-processor (or multi-core) systems. It does not yield any result on uni-processor systems or emulators (due to there being no observable reordering even the order=relaxed case) and will report that fact.

## Tested compilers

**Boost.Atomic** has been tested on and is known to work on the following compilers/platforms:

- gcc 4.x: i386, x86\_64, ppc32, ppc64, sparcv9, armv6, alpha
- Visual Studio Express 2008/Windows XP, x86, x64, ARM

## Acknowledgements

- Adam Wulkiewicz created the logo used on the [GitHub project page](#). The logo was taken from his [collection](#) of Boost logos.