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Sep 30, 2013

Double-Checked Locking is Fixed In C++11

The **double-checked locking pattern** (DCLP) is a bit of a notorious case study in lock-free programming. Up until 2004, there was no safe way to implement it in Java. Before C++11, there was no safe way to implement it in portable C++.

The pattern gained attention for the shortcomings it exposed in those languages, and people began to write about it. In 2000, a group of high-profile Java developers got together and signed a declaration entitled "Double-Checked Locking Is Broken". In 2004, Scott Meyers and Andrei Alexandrescu published an article entitled "C++ and the Perils of Double-Checked Locking". Both papers are great primers on what DCLP is, and why, at the time, those languages were inadequate for implementing it.

All of that's in the past. Java now has a revised memory model, with new semantics for the `volatile` keyword, which makes it possible to implement DCLP safely. Likewise, C++11 has a shiny new memory model and atomic library which enable a wide variety of portable DCLP implementations. C++11, in turn, inspired Mintomic, a small library I released earlier this year which makes it possible to implement DCLP on some older C/C++ compilers as well.

In this post, I'll focus on the C++ implementations of DCLP.

What Is Double-Checked Locking?

Suppose you have a class which implements the well-known Singleton pattern, and you want to make it thread-safe. The obvious approach is to ensure mutual exclusivity by adding a lock. That way, if two threads call `Singleton::getInstance` simultaneously, only one of them will create the singleton.

```
Singleton* Singleton::getInstance() {
    Lock lock;      // scope-based lock, released automatically when the function returns
    if (m_instance == NULL) {
        m_instance = new Singleton;
    }
    return m_instance;
}
```

It's a totally valid approach, but once the singleton is created, there isn't really any need for the lock anymore. Locks aren't necessarily slow, but they don't scale well under heavy contention.

The double-checked locking pattern avoids this lock when the singleton already exists. However, it's not so simple, as the Meyers-Alexandrescu paper shows. In that paper, the authors describe several flawed attempts to implement DCLP in C++, dissecting each attempt to explain why it's unsafe. Finally, on page 12, they show an implementation which *is* safe, but which depends on unspecified, platform-specific memory barriers.

```
Singleton* Singleton::getInstance() {
    Singleton* tmp = m_instance;
    ...                     // insert memory barrier
    if (tmp == NULL) {
        Lock lock;
        tmp = m_instance;
        if (tmp == NULL) {
            tmp = new Singleton;
            ...             // insert memory barrier
            m_instance = tmp;
        }
    }
    return tmp;
}
```

Here, we see where the double-checked locking pattern gets its name: We only take a lock when the singleton pointer `m_instance` is `NULL`, which serializes the first group of threads which happen to see that value. Once inside the lock, `m_instance` is checked a second time, so that only the first thread will create the singleton.

This is very close to a working implementation. It's just missing some kind of memory barrier on the highlighted lines. At the time when the authors wrote the paper, there was no portable C/C++ function which could fill in the blanks. Now, with C++11, there is.

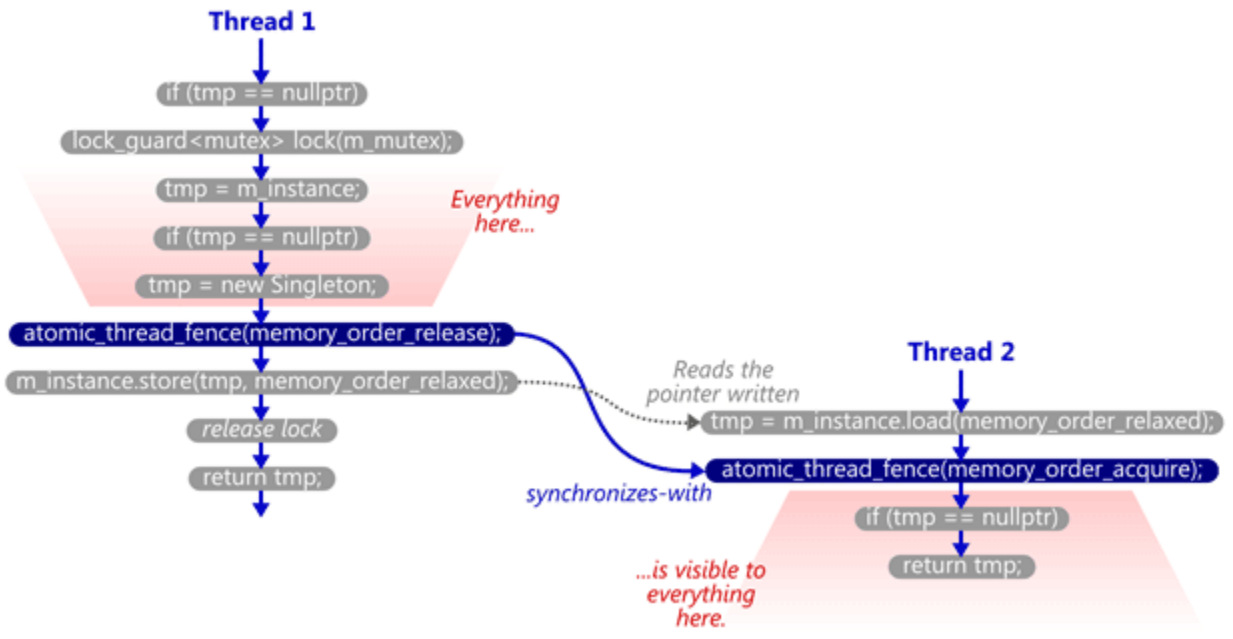
Using C++11 Acquire and Release Fences

You can safely complete the above implementation using acquire and release fences, a subject which I explained at length in my previous post. However, to make this code truly portable, you must also wrap `m_instance` in a C++11 atomic type and manipulate it using relaxed atomic operations. Here's the resulting code, with the acquire and release fences highlighted.

```
std::atomic<Singleton*> Singleton::m_instance;
std::mutex Singleton::m_mutex;

Singleton* Singleton::getInstance() {
    Singleton* tmp = m_instance.load(std::memory_order_relaxed);
    std::atomic_thread_fence(std::memory_order_acquire);
    if (tmp == nullptr) {
        std::lock_guard<std::mutex> lock(m_mutex);
        tmp = m_instance.load(std::memory_order_relaxed);
        if (tmp == nullptr) {
            tmp = new Singleton;
            std::atomic_thread_fence(std::memory_order_release);
            m_instance.store(tmp, std::memory_order_relaxed);
        }
    }
    return tmp;
}
```

This works reliably, even on multicore systems, because the memory fences establish a *synchronizes-with* relationship between the thread which creates the singleton and any subsequent thread which skips the lock. `Singleton::m_instance` acts as the guard variable, and the contents of the singleton itself are the payload.


Thread 1
if (tmp == nullptr)
lock_guard<mutex> lock(m_mutex);
tmp = m_instance;
if (tmp == nullptr)
tmp = new Singleton;
Everything here...
atomic_thread_fence(memory_order_release);
m_instance.store(tmp, memory_order_relaxed);
release lock
return tmp;
Reads the pointer written
Thread 2
tmp = m_instance.load(memory_order_relaxed);
atomic_thread_fence(memory_order_acquire);
synchronizes-with
if (tmp == nullptr)
return tmp;
...is visible to everything here.

That's what all those flawed DCLP implementations were missing: Without any *synchronizes-with* relationship, there was no guarantee that all the writes performed by the first thread – in particular, those performed in the `Singleton` constructor – were visible to the second thread, even if the `m_instance` pointer itself was visible! The lock held by the first thread didn't help, either, since the second thread doesn't acquire any lock, and can therefore run concurrently.

If you're looking for a deeper understanding of how and why these fences make DCLP work reliably, there's some background information in my previous post as well as in earlier posts on this blog.

Using Mintomic Fences

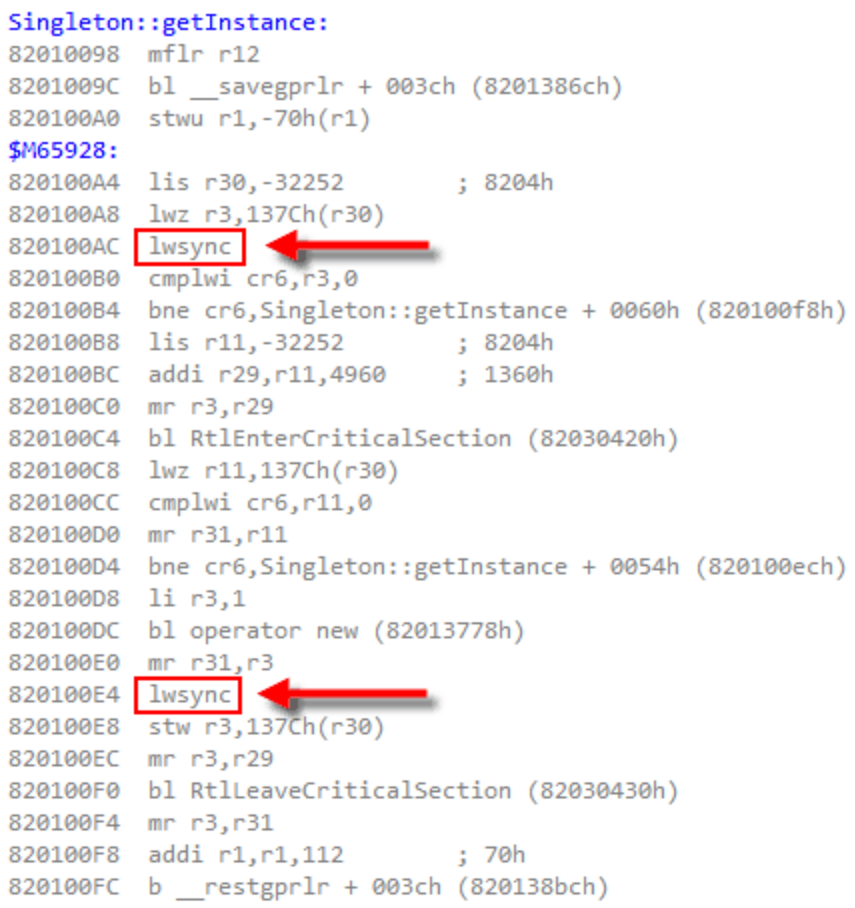
Mintomic is a small C library which provides a subset of functionality from C++11's atomic library, including acquire and release fences, and which works on older compilers. Mintomic relies on the assumptions of the C++11 memory model – specifically, the absence of out-of-thin-air stores – which is technically not guaranteed by older compilers, but it's the best we can do without C++11. Keep in mind that these are the circumstances in which we've written multithreaded C++ code for years. Out-of-thin-air stores have proven unpopular over time, and good compilers tend not to do it.

Here's a DCLP implementation using Mintomic's acquire and release fences. It's basically equivalent to the previous example using C++11's acquire and release fences.

```
mint_atomicPtr_t Singleton::m_instance = { 0 };
mint_mutex_t Singleton::m_mutex;

Singleton* Singleton::getInstance() {
    Singleton* tmp = (Singleton*) mint_load_ptr_relaxed(&m_instance);
    mint_thread_fence_acquire();
    if (tmp == NULL) {
        mint_mutex_lock(&m_mutex);
        tmp = (Singleton*) mint_load_ptr_relaxed(&m_instance);
        if (tmp == NULL) {
            tmp = new Singleton;
            mint_thread_fence_release();
            mint_store_ptr_relaxed(&m_instance, tmp);
        }
        mint_mutex_unlock(&m_mutex);
    }
    return tmp;
}
```

To implement acquire and release fences, Mintomic tries to generate the most efficient machine code possible on every platform it supports. For example, here's the resulting machine code on Xbox 360, which is based on PowerPC. On this platform, an inline `lwsync` is the leanest instruction which can serve as both an acquire and release fence.


```
Singleton::getInstance:
82010098  mflr r12
8201009C  bl __savegprlr + 003ch (8201386ch)
820100A0  stwu r1,-70h(r1)
$M65928:
820100A4  lis r30,-32252        ; 8204h
820100A8  lwz r3,137Ch(r30)
820100AC  lwsync
820100B0  cmplwi cr6,r3,0
820100B4  bne cr6,Singleton::getInstance + 0060h (820100f8h)
820100B8  lis r11,-32252        ; 8204h
820100BC  addi r29,r11,4960     ; 1360h
820100C0  mr r3,r29
820100C4  bl RtlEnterCriticalSection (82030420h)
820100C8  lwz r11,137Ch(r30)
820100CC  cmplwi cr6,r11,0
820100D0  mr r31,r11
820100D4  bne cr6,Singleton::getInstance + 0054h (820100ech)
820100D8  li r3,1
820100DC  bl operator new (82013778h)
820100E0  mr r31,r3
820100E4  lwsync
820100E8  stw r3,137Ch(r30)
820100EC  mr r3,r29
820100F0  bl RtlLeaveCriticalSection (82030430h)
820100F4  mr r3,r31
820100F8  addi r1,r1,112        ; 70h
820100FC  b __restgprlr + 003ch (820138bch)
```

The previous C++11-based example could (and ideally, would) generate the exact same machine code for PowerPC when optimizations are enabled. Unfortunately, I don't have access to a C++11-compliant PowerPC compiler to verify this.

Using C++11 Low-Level Ordering Constraints

C++11's acquire and release fences can implement DCLP correctly, and *should* be able to generate optimal machine code on the majority of today's multicore devices (as Mintomic does), but they're not considered very fashionable. The preferred way to achieve the same effect in C++11 is to use atomic operations with low-level ordering constraints. As I've shown previously, a write-release can *synchronize-with* a read-acquire.

```
std::atomic<Singleton*> Singleton::m_instance;
std::mutex Singleton::m_mutex;

Singleton* Singleton::getInstance() {
    Singleton* tmp = m_instance.load(std::memory_order_acquire);
    if (tmp == nullptr) {
        std::lock_guard<std::mutex> lock(m_mutex);
        tmp = m_instance.load(std::memory_order_relaxed);
        if (tmp == nullptr) {
            tmp = new Singleton;
            m_instance.store(tmp, std::memory_order_release);
        }
    }
    return tmp;
}
```

Technically, this form of lock-free synchronization is less strict than the form using standalone fences; the above operations are only meant to prevent memory reordering around *themselves*, as opposed to standalone fences, which are meant to prevent certain kinds of memory reordering around *neighboring operations*. Nonetheless, on the x86/64, ARMv6/v7, and PowerPC architectures, the best possible machine code is the same for both forms. For example, in an older post, I showed how C++11 low-level ordering constraints emit `dmb` instructions on an ARMv7 compiler, which is the same thing you'd expect using standalone fences.

One platform on which the two forms are likely to generate different machine code is Itanium. Itanium can implement C++11's `load(memory_order_acquire)` using a single CPU instruction, `ld.acq`, and `store(tmp, memory_order_release)` using `st.rel`. I'd love to investigate the performance difference of these instructions versus standalone fences, but have no access to an Itanium machine.

Another such platform is the recently introduced ARMv8 architecture. ARMv8 offers `ldar` and `stlr` instructions, which are similar to Itanium's `ld.acq` and `st.rel` instructions, except that they also enforce the heavier StoreLoad ordering between the `stlr` instruction and any subsequent `ldar`. In fact, ARMv8's new instructions are intended to implement C++11's SC atomics, described next.

Using C++11 Sequentially Consistent Atomics

C++11 offers an entirely different way to write lock-free code. (We can consider DCLP "lock-free" in certain codepaths, since not all threads take the lock.) If you omit the optional `std::memory_order` argument on all atomic library functions, the default value is `std::memory_order_seq_cst`, which turns all atomic variables into sequentially consistent (SC) atomics. With SC atomics, the whole algorithm is guaranteed to appear sequentially consistent as long as there are no data races. SC atomics are really similar to `volatile` variables in Java 5+.

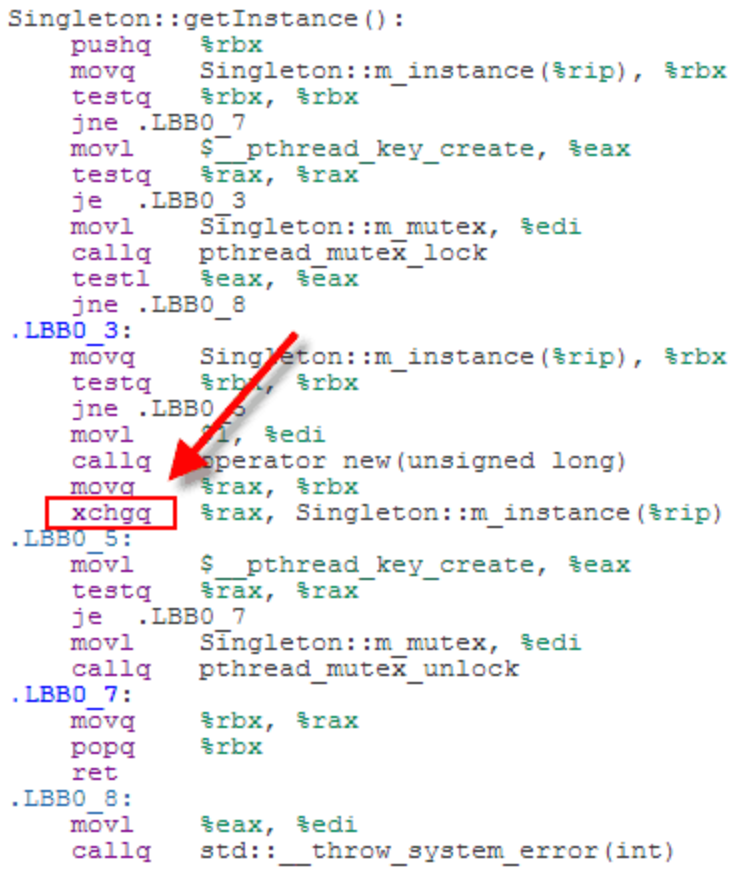
Here's a DCLP implementation which uses SC atomics. As in all previous examples, the second highlighted line will *synchronize-with* the first once the singleton is created.

```
std::atomic<Singleton*> Singleton::m_instance;
std::mutex Singleton::m_mutex;

Singleton* Singleton::getInstance() {
    Singleton* tmp = m_instance.load();
    if (tmp == nullptr) {
        std::lock_guard<std::mutex> lock(m_mutex);
```

```
            tmp = m_instance.load();
            if (tmp == nullptr) {
                tmp = new Singleton;
                m_instance.store(tmp);
            }
        }
        return tmp;
    }
```

SC atomics are considered easier for programmers to reason about. The tradeoff is that the generated machine code tends to be less efficient than that of the previous examples. For example, here’s some x64 machine code for the above code listing, as generated by Clang 3.3 with optimizations enabled:



```
Singleton::getInstance():
    pushq   %rbx
    movq    Singleton::m_instance(%rip), %rbx
    testq   %rbx, %rbx
    jne .LBB0_7
    movl    $__pthread_key_create, %eax
    testq   %rax, %rax
    je  .LBB0_3
    movl    Singleton::m_mutex, %edi
    callq   pthread_mutex_lock
    testl   %eax, %eax
    jne .LBB0_8
.LBB0_3:
    movq    Singleton::m_instance(%rip), %rbx
    testq   %rbx, %rbx
    jne .LBB0_5
    movl    $1, %edi
    callq   operator new(unsigned long)
    movq    %rax, %rbx
    xchgq   %rax, Singleton::m_instance(%rip)
.LBB0_5:
    movl    $__pthread_key_create, %eax
    testq   %rax, %rax
    je  .LBB0_7
    movl    Singleton::m_mutex, %edi
    callq   pthread_mutex_unlock
.LBB0_7:
    movq    %rbx, %rax
    popq    %rbx
    ret
.LBB0_8:
    movl    %eax, %edi
    callq   std::__throw_system_error(int)
```

Because we’ve used SC atomics, the store to `m_instance` has been implemented using an `xchg` instruction, which acts as a full memory fence on x64. That’s heavier instruction than DCLP really needs on x64. A plain `mov` instruction would have done the job. It doesn’t matter too much, though, since the `xchg` instruction is only issued once, in the codepath where the singleton is first created.

On the other hand, if you compile SC atomics for PowerPC or ARMv6/v7, you’re pretty much guaranteed lousy machine code. For the gory details, see 00:44:25 - 00:49:16 of Herb Sutter’s atomic<> Weapons talk, part 2.

Using C++11 Data-Dependency Ordering

In all of the above examples I've shown here, there's a *synchronizes-with* relationship between the thread which creates the singleton and any subsequent thread which avoids the lock. The guard variable is the singleton pointer, and the payload is the contents of the singleton itself. In this case, the payload is considered a **data dependency** of the guard pointer.

It turns out that when working with data dependencies, a read-acquire operation, which all of the above examples use, is actually overkill! We can do better by performing a **consume operation** instead. Consume operations are cool because they eliminate one of the `lwsync` instructions on PowerPC, and one of the `dmb` instructions on ARMv7. I'll write more about data dependencies and consume operations in a future post.

Using a C++11 Static Initializer

Some readers already know the punch line to this post: C++11 doesn't require you to jump through any of the above hoops to get a thread-safe singleton. You can simply use a static initializer.

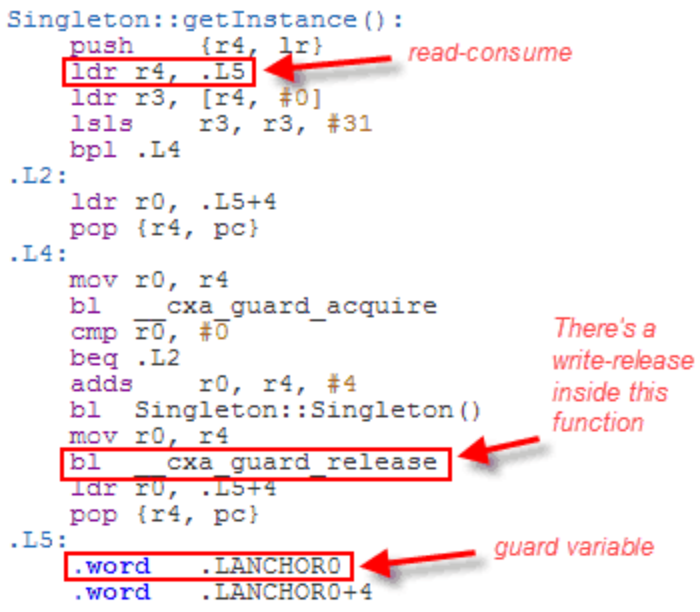
[Update: Beware! As Rober Baker points out in the comments, this example doesn't work in Visual Studio 2012 SP4. It only works in compilers that fully comply with this part of the C++11 standard.]

```
Singleton& Singleton::getInstance() {
    static Singleton instance;
    return instance;
}
```

The C++11 standard's got our back in §6.7.4:

> If control enters the declaration concurrently while the variable is being initialized, the concurrent execution shall wait for completion of the initialization.

It's up to the compiler to fill in the implementation details, and DCLP is the obvious choice. There's no guarantee that the compiler will use DCLP, but it just so happens that some (perhaps most) C++11 compilers do. Here's some machine code generated by GCC 4.6 when compiling for ARM with the `-std=c++0x` option:



```
Singleton::getInstance():
    push     {r4, lr}
    ldr r4, .L5
    ldr r3, [r4, #0]
    lsls     r3, r3, #31
    bpl .L4
.L2:
    ldr r0, .L5+4
    pop {r4, pc}
.L4:
    mov r0, r4
    bl   __cxa_guard_acquire
    cmp r0, #0
    beq .L2
    adds     r0, r4, #4
    bl  Singleton::Singleton()
    mov r0, r4
    bl   __cxa_guard_release
    ldr r0, .L5+4
    pop {r4, pc}
.L5:
    .word    .LANCHOR0
    .word    .LANCHOR0+4
```

Since the `Singleton` is constructed at a fixed address, the compiler has introduced a separate guard variable for synchronization purposes. Note in particular that there's no `dmb` instruction to act as an acquire fence after the initial read of this guard variable. The guard variable is a pointer to the singleton, and therefore the compiler can take advantage of the data dependency to omit the `dmb` instruction. `__cxa_guard_release` performs a write-release on the guard, is therefore *dependency-ordered-before* the read-consume once the guard has been set, making the whole thing resilient against memory reordering, just like all the previous examples.

As you can see, we've come a long way with C++11. Double-checked locking is fixed, and then some!

Personally, I've always thought that if you want to initialize a singleton, best to do it at program startup. But DCLP can certainly help you out of a jam. And as it happens, you can also use DCLP to store arbitrary value types in a lock-free hash table. More about that in a future post as well.

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« Acquire and Release Fences Acquire and Release Fences Don't Work the Way You'd Expect »

Comments (23)

Umar · *106 weeks ago*

What are your thoughts on using std::call_once instead of DCL?

Reply **2 replies** · *active 54 weeks ago*

Jeff Preshing · *106 weeks ago*

`std::call_once` is a totally viable option since the first (successful) call *synchronizes-with* all subsequent calls (30.4.4.3). And compilers can implement it in a way that closely resembles DCLP. I could add an example to this post, but it's already long enough and besides, I mainly wanted to focus on the implementations which use atomic operations explictly.

Reply

Brian · *54 weeks ago*

I did some benchmarking of various Singleton implementations, and found those using std::call_once() to be quite slow compared to those using static initialization.

Reply

Tobias Bruell · *105 weeks ago*

I do not understand the part about "Using C++11 Low-Level Ordering Constraints" completely. Is the code in that section still a 100% valid standard-conforming implementation of the DCLP?

Also, I do not understand what you mean by saying that "this form is less strict". And I find the "around themselves" and "around all neighboring operations" somewhat unclear.

Very interesting read anyway. I think this whole blog should be wrapped up into a book.

Reply **1 reply** · *active 105 weeks ago*

Jeff Preshing · *105 weeks ago*

All the C++11 examples in this post are valid and standard-conforming. I've obviously left out the class definitions (header file), but you can easily infer what those should be. I suppose I could have gone further and created a Github repository with a working project, but I don't think a lot of people would build/run it.

As for the difference between atomic memory operations which prevent reordering only around themselves, versus memory fences which prevent reordering around all neighboring operations, I'll try to clarify that further in the next post!

Reply

Anirban Mitra · *104 weeks ago*

Would this be a valid DCLP

```
Singleton* Singleton::m_instance;
std::mutex Singleton::m_mutex;

Singleton* Singleton::getInstance() {
std::atomic_thread_fence(std::memory_order_acquire);
Singleton* tmp = m_instance;

if (tmp == nullptr) {
std::lock_guard<std::mutex> lock(m_mutex);
tmp = m_instance.load(std::memory_order_relaxed);
if (tmp == nullptr) {
tmp = new Singleton;
m_instance = tmp, std;
std::atomic_thread_fence(std::memory_order_release);
}
}
return tmp;
}
```

if yes, then why is the first one better. Also, how is it that release and acquire synchronizes means the the atomic statements before the acquire and after the release will also synchronize?

Reply **1 reply** · *active 104 weeks ago*

Jeff Preshing · *104 weeks ago*

That's not a valid DCLP implementation, because:
1. Your fences are out of place. As a result, there is no *synchronizes-with* relationship anywhere. One loose way of understanding it: A write-release *synchronizes-with* a read-acquire if it sees the write, but an acquire fence can only promote a *preceding* read to a read-acquire, and a release fence can only promote a *following* write to a write-release.
2. Singleton::m_instance ought to be wrapped in a std::atomic<>, like the examples in this post, to ensure it's always manipulated atomically regardless which platform you're compiling for.

To answer your second question, we don't tend to say that the statements before the acquire and after the release *synchronize-with* each other, but they do *happen-before* each other, because *happens-before* is transitive. Review my previous three posts for more background on that.

Reply

alexxys · *100 weeks ago*

One more great chapter in your great online book!

I found one minor typo:
Here http://preshing.com/images/two-cones-dclp.png in the line
m_instance.store(1, std::memory_order_relaxed);

you have to use tmp instead of 1.

Jeff, thank you very much for your great blog!

Reply **1 reply** · *active 99 weeks ago*

Jeff Preshing · *99 weeks ago*

I've corrected the diagram. Thanks!

Reply

Rob Baker · *98 weeks ago*

Sadly, the really neat, simple example of 'Using a C++11 Static Initializer' doesn't work in VS2012 SP4, despite my yearning for it to do so. A fraught debugging session tells me that we're waiting for Microsoft to play catchup with the C++11 standard.

Reply **1 reply** · *active 98 weeks ago*

Jeff Preshing · *98 weeks ago*

Thanks for the heads up! I updated the post to mention it.

Reply

Igipit · *95 weeks ago*

May be vs2012 Doesn't work with the static singleton, but I used it massively since 2003 with out problems on vs2003, vs2005, vs2008, vs2010 and Now with vs2013. I dont remember where i saw it the first time, may be in Herb Sutter book.

Reply **1 reply** · *active 90 weeks ago*

Rob Baker · *90 weeks ago*

Did you try it with multiple threads all hitting it at the same time? It's the concurrent access that screwed up for me, though in a single-threaded environment it functioned well enough - as you'd expect.

Reply

Ankur · *74 weeks ago*

Thanks for this informative article.

However I have a doubt. In the example for "Using C++11 Acquire and Release Fences"

what if 1st thread is executing :-
tmp = new Singleton;

and as main problem of DCLP, it gets suspended by CPU due to which tmp point to memory which has not been constructed. This can happen since tmp is NOT atomic (only m_instance is atomic.)

wont this give rise to same DCLP problem as 2nd thread access memory which has not been constructed yet.

How std::atomic_thread_fence(std::memory_order_acquire) solve this issue as we have not yet called std::atomic_thread_fence(std::memory_order_release) in 1st thread. Does 2nd thread keeps waiting till release operation is complete. Then it looks like its mutex locking.

Reply **5 replies** · *active 69 weeks ago*

Jeff Preshing · *74 weeks ago*

tmp is a local variable, not a shared variable. Each thread has its own tmp. So it's harmless if the first thread gets suspended at the point you describe. m_instance, the shared variable, simply remains null. That's the only thing the other threads are checking.

If a second thread comes along while the first thread is still suspended on that line, then yes, the second thread will block on std::lock_guard<std::mutex> lock(m_mutex). But the 2nd thread doesn't wait for the 1st thread to complete the release operation. (Acquire/release operations are non-blocking). It waits for the 1st thread to release the mutex by exiting the scope containing the lock_guard.

Reply

Ankur · *74 weeks ago*

Thanks Jeff. Thats very useful. I did not notice the local variable part.

Just to clarify. In above scenario. 1st thread is suspended at tmp = new Singleton; while 2nd thread gets stuck at Lock acquisition.

Now thread 1 resumes and m_instance points Singelton object. After release, its available to all other threads as final value.

Now, thread 2 contiune , loads m_instance. It sees thats its not empty. So, it access the singleton object. Great.

But where did Acquire becomes useful for us. Is it beacuse if we dont use acquire fence then "Singleton* tmp = m_instance.load(std::memory_order_relaxed);" and "tmp = m_instance.load(std::memory_order_relaxed);
" might be redorderd ?

Thanks for your help.

Reply

Jeff Preshing · *74 weeks ago*

Well, the lock (m_mutex) makes sure that only one thread has write access to m_instance at a time. Looks like you get that part.

The read-acquire is performed by a thread without taking the lock -- it doesn't wait. Therefore, it can run concurrently with another thread that is modifying m_instance. We need there to be a synchronizes-with relationship between those two threads. That's why one performs a write-release, and the other performs a read-acquire.

Reply

Ankur · *73 weeks ago*

I have read so many tutorials and articles about acquire & release. Can you guide me exactly how compiler does that "synchronize".

Thanks

Reply

Jeff Preshing · *73 weeks ago*

Try This Is Why They Call It a Weakly-Ordered CPU.

Reply

Alexei Kruglikov · *65 weeks ago*

Thank you for article... one question.

Release memory fence (std::atomic_thread_fence(std::memory_order_release);) in 1st C++ 11 implementation ("Using C++11 Acquire and Release Fences") seems excessive to me. For temp is local thread stack variable not in contention from other threads and CPU guarantees m_instance.store() would execute after it for that (same) thread.

Reply **3 replies** · *active 64 weeks ago*

Jeff Preshing · *65 weeks ago*

Without the release fence, the write to m_instance could become visible to other threads before the contents of the Singleton are visible.

Reply

Alexei Kruglikov · *64 weeks ago*

I do not see how that is possible, could you elaborate...

These line are lock protected and executed by no more than 1 thread at any time:
tmp = new Singleton;
std::atomic_thread_fence(std::memory_order_release);
m_instance.store(tmp, std::memory_order_relaxed);

For single thread you would not need the fence, hence by the time CPU executes atomic store, singleton should be fully constructed and temp point to it.

Reply

Jeff Preshing · *64 weeks ago*

The lock is only there to prevent creating multiple copies of the singleton. The lock does not help in any way between the thread that creates the singleton and other threads that just *use* the singleton after it's created. Note that once m_instance (the pointer itself) is initialized and visible to other threads, those threads don't even take the lock anymore! In other words, there is concurrent access to m_instance (the pointer itself) between the writer thread and reader threads. That's why we need to concern ourselves with memory ordering.

Also note that "tmp = new Singleton" is a statement that breaks into several steps. It calls the constructor of Singleton, which can (and usually does) write to shared memory: for example, by initializing Singleton::x to 42. On a multiprocessor system, we want to make sure that when m_instance (the pointer itself) becomes visible to other threads, Singleton::x is already visible to those threads, too! That's we need acquire and release semantics.

Even on a uniprocessor system, there is a risk of memory reordering between m_instance and Singleton::x, due to compiler transformations (optimizations).

You should probably read the Meyers-Alexandrescu paper to gain a complete appreciation for the DCLP problem.

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