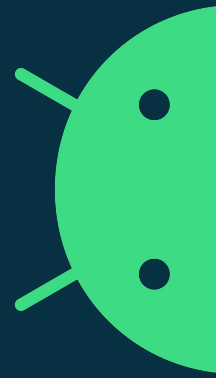
Dependency ordering in the Linux kernel



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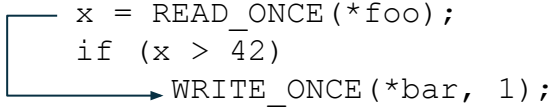
The sorry state of dependency ordering

Hardware	CPU architectures guarantee that some dependencies enforce externally-visible ordering between memory accesses
Performance	Dependency ordering is generally cheaper than using explicit fences, particularly where the dependency exists naturally as part of the algorithm.
Linux	The kernel relies on dependency ordering as a basis for RCU, but also to implement ring buffers and parts of the scheduler using volatile casts (`READ_ONCE/WRITE_ONCE`)
C Compiler	No high-performance implementations exist of `memory_order_consume` and the kernel does not follow the C11 memory model anyway.

Types of dependency

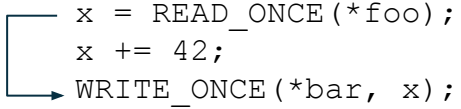
Please try to use this terminology!

Control dependency



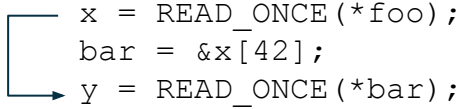
- Read -> write generally ordered by all CPU architectures
- Read -> read control dependencies can often be reordered by hardware!

Data dependency



- Read -> write only
- Supported by all CPU architectures

Address dependency



- Read -> read/write
- `rcu_dereference()`
- Ordered by all CPU architectures other than Alpha (where we insert a fence)

Harmful compiler transformations

Converting a read -> read address dependency into a control dependency breaks hardware ordering!

Address dependency

```
x = READ_ONCE(*foo);
bar = &x[42];
y = READ_ONCE(*bar);
```

Control dependency

```
x = READ_ONCE(*foo);
if (x == baz)
    bar = &baz[42];
else
    bar = &x[42];
y = READ_ONCE(*bar);
```

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https://lore.kernel.org/lkml/20150520005510.GA23559@linux.vnet.ibm.com/

Harmful compiler transformations

Converting a read -> read address dependency into a control dependency breaks hardware ordering!

Address dependency

```
seq = READ_ONCE(tkf->seq.sequence);
tkr = tkf->base + (seq & 0x01);
now = tkr->base;
```

Control dependency

```
tkr = tkf->base;
seq = READ_ONCE(tkf->seq.sequence);
if (seq & 0x01)
    tkr++;
now = tkr->base;
```

https://lore.kernel.org/kernel-hardening/20200625085745.GD117543@hirez.programming.kicks-ass.net/

We actually disable lots of "valid" (read: the standard allows them, but they are completely wrong for the kernel) optimizations because they are wrong.

[...]

So in general, we very much expect the compiler to do sane code generation, and not (for example) do store tearing on normal word-sized things or add writes that weren't there originally etc.

-- Linus Torvalds

https://lore.kernel.org/lkml/CAHk-=wi_KeD1M-_-_SU_H92vJ-yNkDnAGhAS=RR1yNNGWKW+aA@mail.gmail.com/

Some discussion points

Can we provide tooling to help the kernel use dependency ordering without disabling compiler optimisations on a case-by-case basis?

- How can we enforce dependencies at the source level?
- Can we detect broken dependencies and/or insert fences?
- Are annotations a non-starter?
- Does LTO make the situation worse?
- Where do we draw the line between “optimising compiler” and “portable assembler”?

Please don’t throw the standard at us! :)
https://wg21.link/p0124