- [ ] 1. Last time
- [ ] 2. Deadlock, continued
- [ ] 3. Other progress issues
- [ ] 4. Performance issues
- [ ] 5. Programmability issues
- [ ] 6. Mutexes and interleaving

ONE HANDOUT

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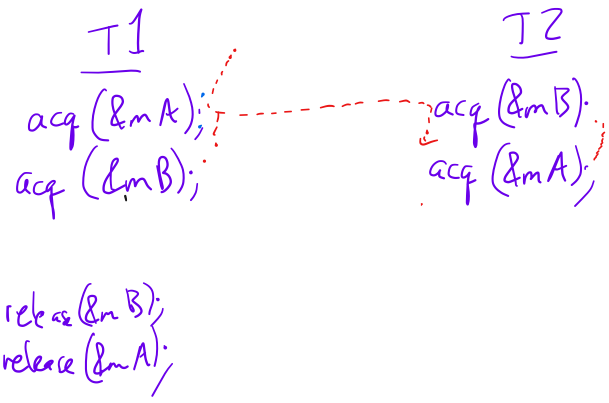
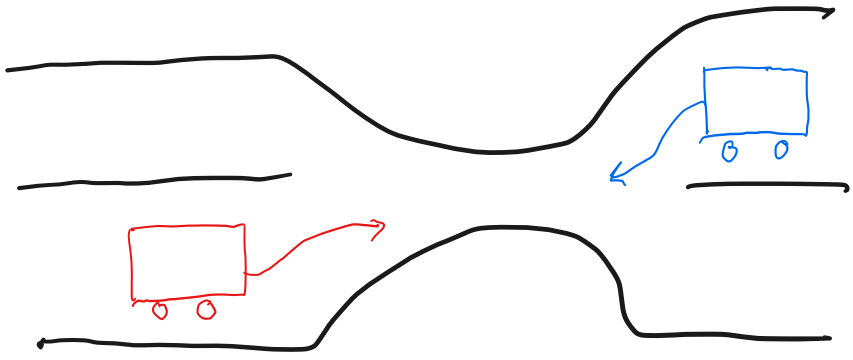
2. Deadlock



Happens when all four of these conditions are present:

i. mutual exclusion
ii. hold and wait
iii. no pre-emption
iv. circular wait



What can we do about deadlock?

(a) ignore it
(b) detect + recover
(c) avoid algorithmically
(d) negate one of the 4 conditions
(e) static/dynamic detection tools

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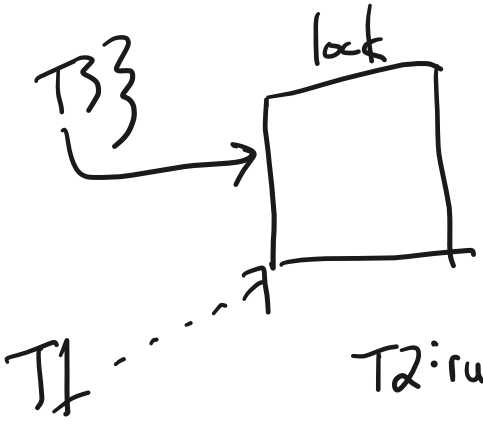
3. Other progress issues

- Starvation

- Priority inversion



T1: highest
T2: medium
T3: lowest

Assume: highest-prio runnable thread runs.

4. Performance issues and tradeoffs

(a) Invoking spinlocks/mutexes can be expensive

MCS locks

futexes

(b) Coarse locks limit available parallelism...

(c) ... but fine-grained locking leads to complexity and hence bugs

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5. Programmability issues

- loss of modularity

printf("....");

- what's the fundamental problem?

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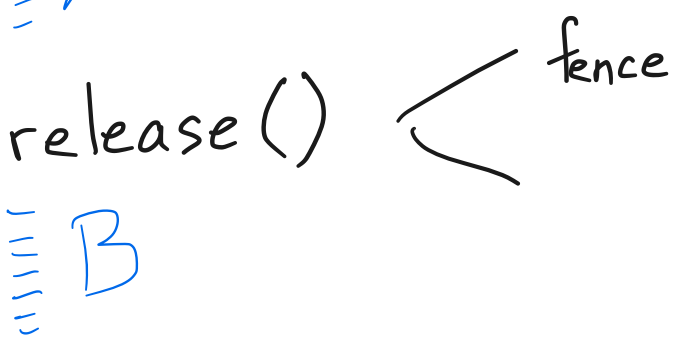
6. mutexes and interleavings



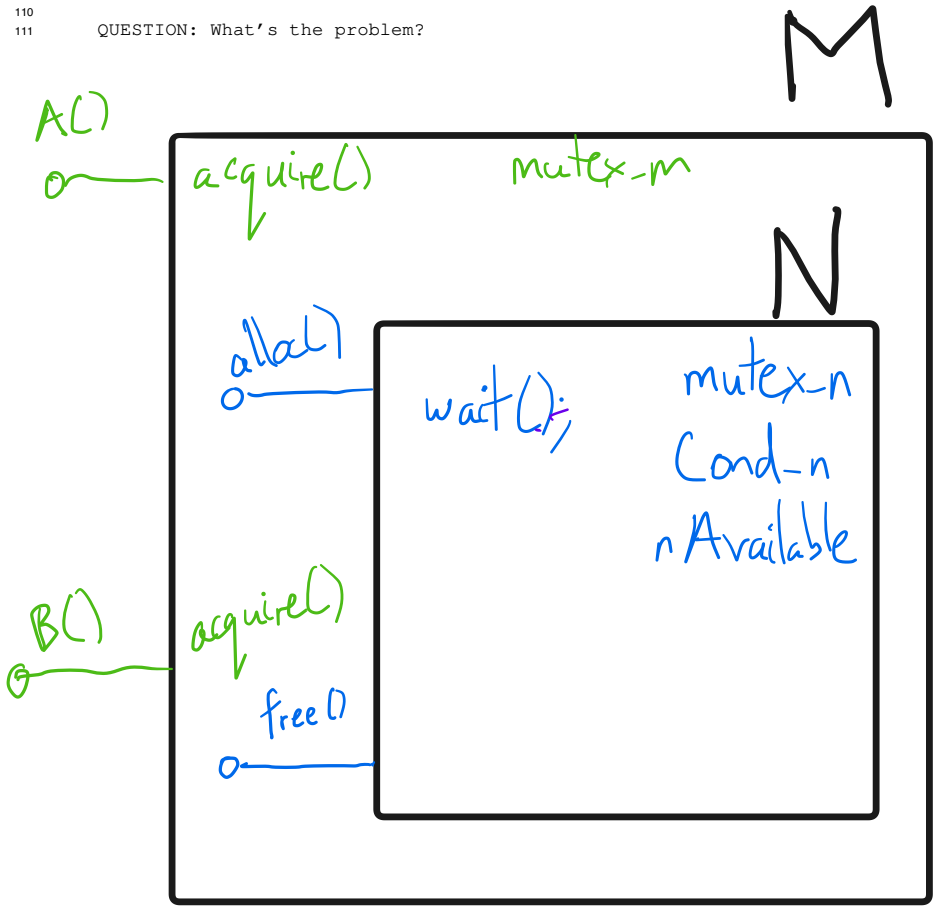
"A stuff" happens before "B stuff"
although, within A and B, the "stuff"
can happen out of order from the perspective
of other cores, assuming they could view the
operations separately.

```
CS 202
Handout 7 (Class 8)

1. Simple deadlock example

    T1:
        acquire(mutexA);
        acquire(mutexB);

        // do some stuff

        release(mutexB);
        release(mutexA);

    T2:
        acquire(mutexB);
        acquire(mutexA);

        // do some stuff

        release(mutexA);
        release(mutexB);

```



```
2. More subtle deadlock example

    Let M be a monitor (shared object with methods protected by mutex)
    Let N be another monitor

    class M {
        private:
            Mutex mutex_m;

            // instance of monitor N
            N another_monitor;

            // Assumption: no other objects in the system hold a pointer
            // to our "another_monitor"

        public:
            M();
            ~M();
            void methodA();
            void methodB();
    };

    class N {
        private:
            Mutex mutex_n;
            Cond cond_n;
            int navailable;

        public:
            N();
            ~N();
            void* alloc(int nwanted);
            void  free(void*);
    }

    int
    N::alloc(int nwanted) {
        acquire(&mutex_n);
        while (navailable < nwanted) {
            wait(&cond_n, &mutex_n);
        }

        // peel off the memory

        navailable -= nwanted;
        release(&mutex_n);
    }

    void
    N::free(void* returning_mem) {

        acquire(&mutex_n);

        // put the memory back

        navailable += returning_mem;

        broadcast(&cond_n, &mutex_n);

        release(&mutex_n);
    }

```

```
86      void
87      M::methodA() {
88
89          acquire(&mutex_m);
90
91          void* new_mem = another_monitor.alloc(int nbytes);
92
93          // do a bunch of stuff using this nice
94          // chunk of memory n allocated for us
95
96          release(&mutex_m);
97      }
98
99      void
100     M::methodB() {
101
102         acquire(&mutex_m);
103
104         // do a bunch of stuff
105
106         another_monitor.free(some_pointer);
107
108         release(&mutex_m);
109     }
110
111     QUESTION: What's the problem?
```




```
1   2. Locking brings a performance vs. complexity trade-off
2
3   // SPDX-License-Identifier: GPL-2.0-only
4   /*
5    *      linux/mm/filemap.c
6    *
7    * Copyright (C) 1994-1999  Linus Torvalds
8    */
9
10  /*
11   * This file handles the generic file mmap semantics used by
12   * most "normal" filesystems (but you don't /have/ to use this:
13   * the NFS filesystem used to do this differently, for example)
14   */
15  #include <linux/export.h>
16  #include <linux/compiler.h>
17  #include <linux/dax.h>
18  #include <linux/fs.h>
19  #include <linux/sched/signal.h>
20  #include <linux/uaccess.h>
21  #include <linux/capability.h>
22  #include <linux/kernel_stat.h>
23  #include <linux/gfp.h>
24  #include <linux/mm.h>
25  #include <linux/swap.h>
26  #include <linux/swapops.h>
27  #include <linux/syscalls.h>
28  #include <linux/mman.h>
29  #include <linux/pagemap.h>
30  #include <linux/file.h>
31  #include <linux/uio.h>
32  #include <linux/error-injection.h>
33  #include <linux/hash.h>
34  #include <linux/writeback.h>
35  #include <linux/backing-dev.h>
36  #include <linux/pagevec.h>
37  #include <linux/security.h>
38  #include <linux/cpuset.h>
39  #include <linux/hugetlb.h>
40  #include <linux/memcontrol.h>
41  #include <linux/shmem_fs.h>
42  #include <linux/rmap.h>
43  #include <linux/delayacct.h>
44  #include <linux/psi.h>
45  #include <linux/ramfs.h>
46  #include <linux/page_idle.h>
47  #include <linux/migrate.h>
48  #include <linux/pipe_fs_i.h>
49  #include <linux/splice.h>
50  #include <linux/rcupdate_wait.h>
51  #include <linux/sched/mm.h>
52  #include <linux/fsnotify.h>
53  #include <asm/pgalloc.h>
54  #include <asm/tlbflush.h>
55  #include "internal.h"
56
57  #define CREATE_TRACE_POINTS
58  #include <trace/events/filemap.h>
59
60  /*
61   * FIXME: remove all knowledge of the buffer layer from the core VM
62   */
63  #include <linux/buffer_head.h> /* for try_to_free_buffers */
64
65  #include <asm/mman.h>
66
67  #include "swap.h"
68
69  /*
70   * Shared mappings implemented 30.11.1994. It's not fully working yet,
71   * though.
72   *
73   * Shared mappings now work. 15.8.1995  Bruno.
```

```
 *
 * finished 'unifying' the page and buffer cache and SMP-threaded the
 * page-cache, 21.05.1999, Ingo Molnar <mingo@redhat.com>
 *
 * SMP-threaded pagemap-LRU 1999, Andrea Arcangeli <andrea@suse.de>
 */

/*
 * Lock ordering:
 *
 *  ->i_mmap_rwsem              (truncate_pagecache)
 *    ->private_lock            (__free_pte->block_dirty_folio)
 *      ->swap_lock             (exclusive_swap_page, others)
 *        ->i_pages lock
 *
 *  ->i_rwsem
 *    ->invalidate_lock         (acquired by fs in truncate path)
 *      ->i_mmap_rwsem          (truncate->unmap_mapping_range)
 *
 *  ->mmap_lock
 *    ->i_mmap_rwsem
 *      ->page_table_lock or pte_lock   (various, mainly in memory.c)
 *        ->i_pages lock        (arch-dependent flush_dcache_mmap_lock)
 *
 *  ->mmap_lock
 *    ->invalidate_lock         (filemap_fault)
 *      ->lock_page             (filemap_fault, access_process_vm)
 *
 *  ->i_rwsem                   (generic_perform_write)
 *    ->mmap_lock               (fault_in_readable->do_page_fault)
 *
 *  bdi->wb.list_lock
 *    sb_lock                   (fs/fs-writeback.c)
 *    ->i_pages lock            (__sync_single_inode)
 *
 *  ->i_mmap_rwsem
 *    ->anon_vma.lock           (vma_merge)
 *
 *  ->anon_vma.lock
 *    ->page_table_lock or pte_lock     (anon_vma_prepare and various)
 *
 *  ->page_table_lock or pte_lock
 *    ->swap_lock               (try_to_unmap_one)
 *    ->private_lock            (try_to_unmap_one)
 *    ->i_pages lock            (try_to_unmap_one)
 *    ->lruvec->lru_lock        (follow_page_mask->mark_page_accessed)
 *    ->lruvec->lru_lock        (check_pte_range->folio_isolate_lru)
 *    ->private_lock            (folio_remove_rmap_pte->set_page_dirty)
 *    ->i_pages lock            (folio_remove_rmap_pte->set_page_dirty)
 *    bdi.wb->list_lock         (folio_remove_rmap_pte->set_page_dirty)
 *    ->inode->i_lock           (folio_remove_rmap_pte->set_page_dirty)
 *    bdi.wb->list_lock         (zap_pte_range->set_page_dirty)
 *    ->inode->i_lock           (zap_pte_range->set_page_dirty)
 *    ->private_lock            (zap_pte_range->block_dirty_folio)
 */

static void page_cache_delete(struct address_space *mapping,
                                   struct folio *folio, void *shadow)
{
        XA_STATE(xas, &mapping->i_pages, folio->index);
        long nr = 1;

[the point is: fine-grained locking leads to complexity.]
```



```
3. Cautionary tale

Consider the code below:

    struct foo {
        int abc;
        int def;
    };
    static int ready = 0;
    static mutex_t mutex;
    static struct foo* ptr = 0;

    void
    doublecheck_alloc()
    {
        if (!ready) { /* <-- accesses shared variable w/out holding mutex */

            mutex_acquire(&mutex);
            if (!ready) {
                ptr = alloc_foo(); /* <-- sets ptr to be non-zero */
                ready = 1;
            }

            mutex_release(&mutex);

        }
        return;
    }

This is an example of the so-called "double-checked locking pattern."
The programmer's intent is to avoid a mutex acquisition in the common
case that 'ptr' is already initialized.  So the programmer checks a flag
called 'ready' before deciding whether to acquire the mutex and
initialize 'ptr'. The intended use of doublecheck_alloc() is something
like this:

    void f() {
        doublecheck_alloc();
        ptr->abc = 5;
    }

    void g() {
        doublecheck_alloc();
        ptr->def = 6;
    }

We assume here that mutex_acquire() and mutex_release() are implemented
correctly (each contains memory barriers internally, etc.). Furthermore,
we assume that the compiler does not reorder instructions.

NEVERTHELESS, on multi-CPU machines that do not offer sequential
consistency, doublecheck_alloc() is broken. What is the bug?

------------------------

Unfortunately, double-checked initialization (or double-checked locking
as it's sometimes known) is a common coding pattern. Even some
references on threads suggest it! Still, it's broken.

While you can fix it (in C) by adding barriers (exercise:
where?), this is not recommended, as the code is tricky to reason about.
One of the points of this example is to show you why it's so important
to protect global data with a mutex, even if "all" one is doing is
reading memory, and even if the shortcut looks harmless.
```

```
Finally, here are some references on this topic:

    --http://www.aristeia.com/Papers/DDJ_Jul_Aug_2004_revised.pdf
     explores issues with this pattern in C++

    --The "Double-Checked Locking is Broken" Declaration:
    http://www.cs.umd.edu/~pugh/java/memoryModel/DoubleCheckedLocking.html

    --C++11 provides a way to implement the pattern correctly and
    portably (again, using memory barriers):
    https://preshing.com/20130930/double-checked-locking-is-fixed-in-cpp11/
```