CS 112/212 Project 1: Threads

Spring 2026

Getting Started

Pre-Reading

Before you read the description of this project, you should read all of the following:

- 1. Introduction, C. Coding Standards, E. Debugging Tools, and F. Development Tools.
- A.1 Loading through A.5 Memory Allocation
  - **especially A.2 Threads, A.3 Synchronization, A.4 Interrupt Handling**
- B. 4.4BSD Scheduler (read before implementing 2.2.4 Advanced Scheduler)

and *then* the assignment description/FAQ.

Understand how timer interrupts, sleeping, and synchronization work.

Look over + draft the design doc for each section *before* coding it!

General Tips

- Small, incremental changes
  - Go from working state to working state
- Merge changes at each step rather than waiting until the end
- **Pay attention to style; conform to the style of the starter code**
  - Make sure each line is <= 80 characters for easier readability
- **!!! Design, design, design (50% of your grade) !!!**
- Brush up on **GDB/debugging** (section E in previous slide) and **git**
- `lib/kernel` has nice data structures (for proj1, especially linked list)

Code TODOs

1. Alarm Clock
   a. Re-implement `timer_sleep()` without busy waiting
2. Priority Scheduler
   a. Threads set their own priorities, and run according to these priorities
   b. Priority donation for locks
3. Advanced Scheduler
   a. Thread priorities are calculated by the system, and run according to these priorities
   b. No priority donation
4. Design Doc
   a. Answer questions regarding your design and implementation for parts 1-3

How much code?

```
devices/timer.c       |   42 +++++-
threads/fixed-point.h |  120 ++++++++++++++++++    (new file)
threads/synch.c       |   88 ++++++++++++-
threads/thread.c      |  196 ++++++++++++++++++++++++++++++----
threads/thread.h      |   23 +++
5 files changed, 440 insertions(+), 29 deletions(-)
```

Alarm Clock

Alarm Clock Tasks (Section 2.2.2)

- Currently, `timer_sleep()` “busy waits”
  - if a thread wants to suspend execution for some time, it doesn’t actually go to sleep; execution just temporarily yields to other threads, but the “sleeping” thread will repeatedly loop/execute to check if the time is up yet (bad)
- You will implement the actual “sleeping” functionality and eliminate busy-waiting

Alarm Clock Considerations

- **How** will you avoid busy waiting?
- How will you keep track of **sleeping threads**?
- Where in the code will you **wake up** sleeping threads?
- Check out the design doc to see what **race conditions** to watch out for!

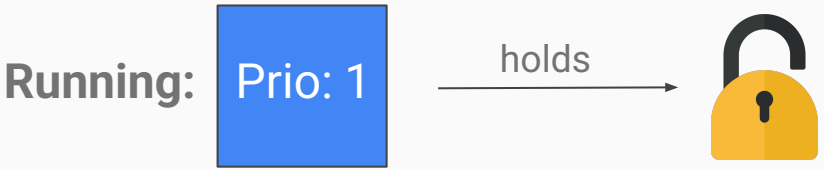
Priority Scheduling

Priority Scheduling Tasks (Section 2.2.3)

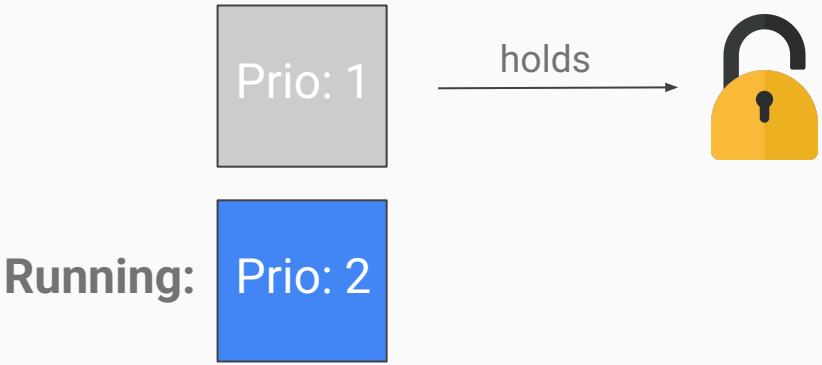
- Rather than just switching among all threads equally (round-robin), introduce a notion of ***priority***: higher-priority threads get run before lower-priority threads, until higher-priority threads can't run
- Priority scale [0, 63]; round-robin threads *of the same priority*
- When the currently running thread stops being the highest priority (either due to a new thread being added or the current thread's priority being lowered), the kernel should immediately switch to executing the highest-priority thread that is ready
- When threads are waiting for a lock, semaphore, or condition variable, the **highest priority** waiting thread should be **awakened first**

Problem: priority inversion

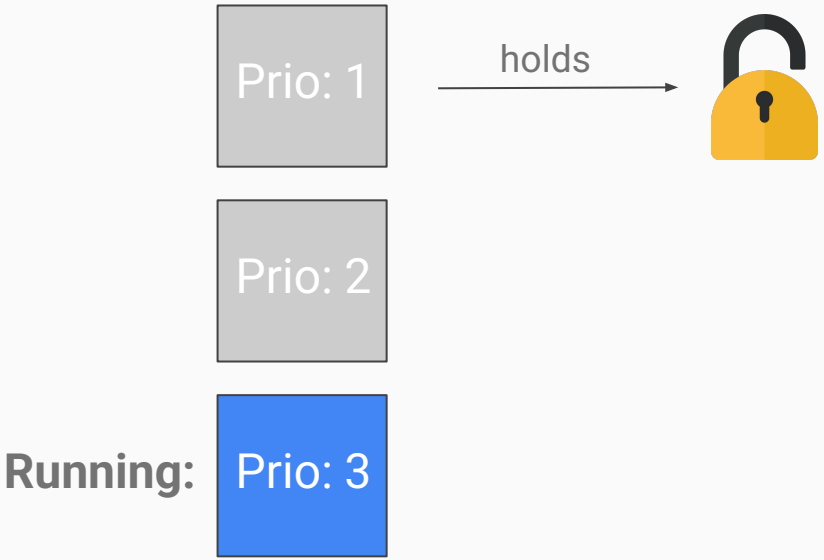
Priority Inversion



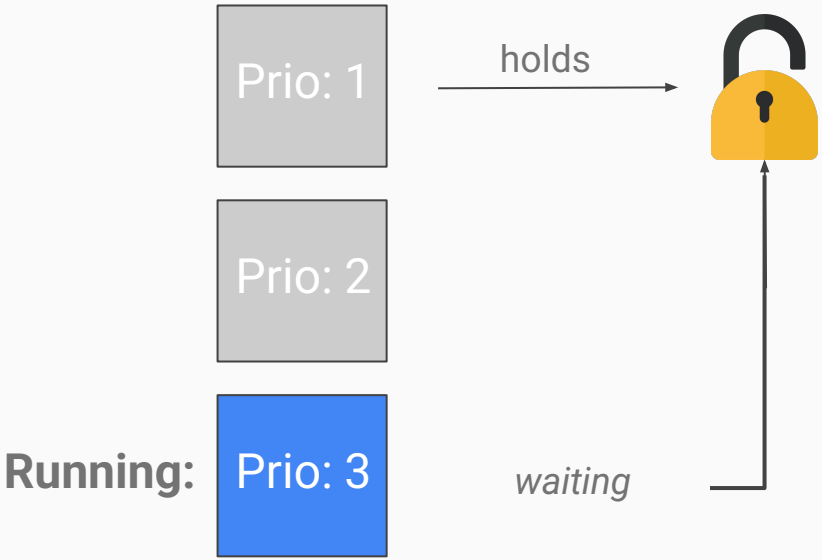
Priority Inversion



Priority Inversion



Priority Inversion



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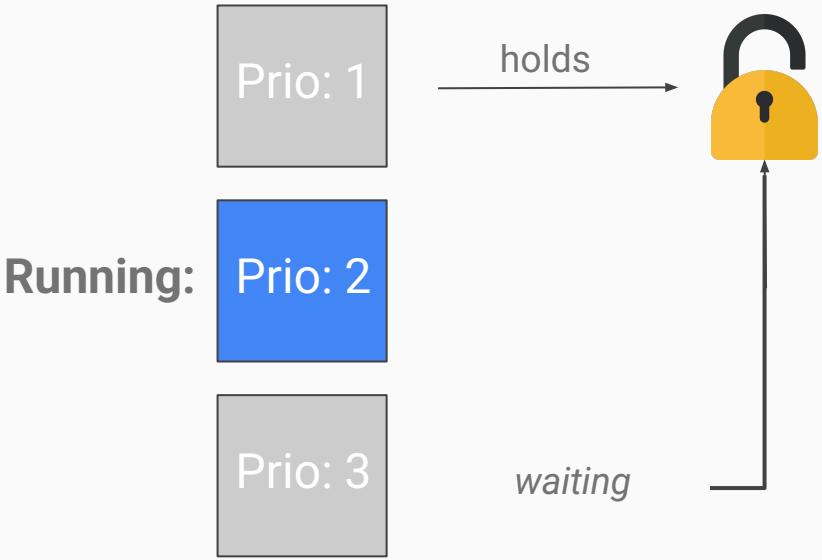

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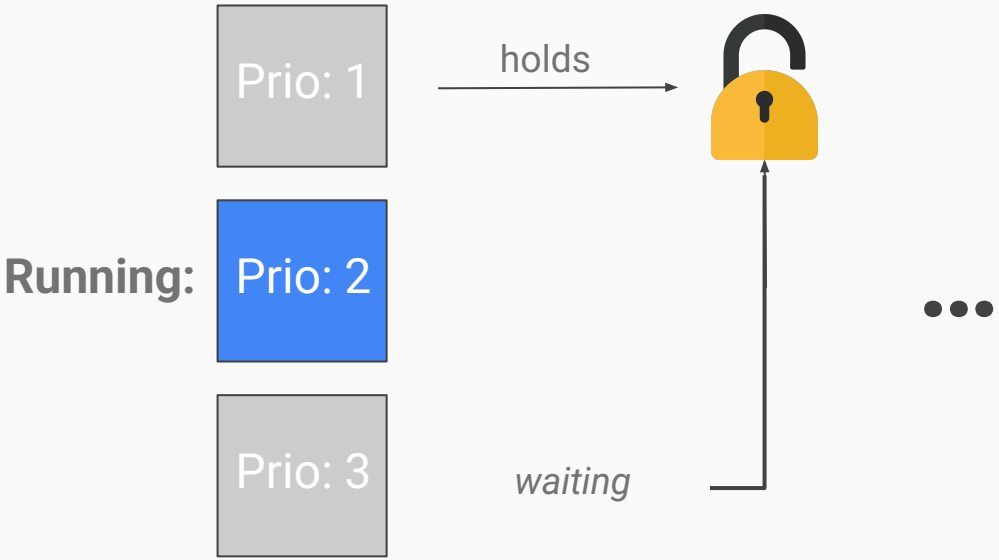

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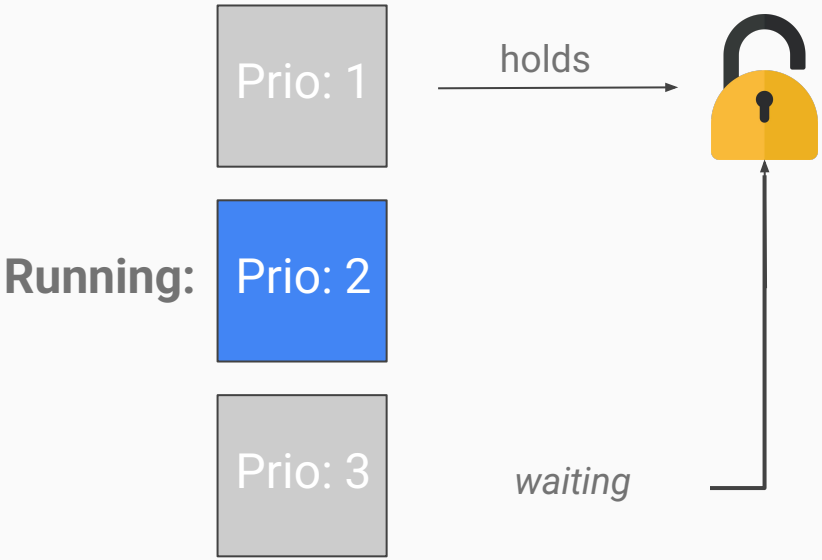
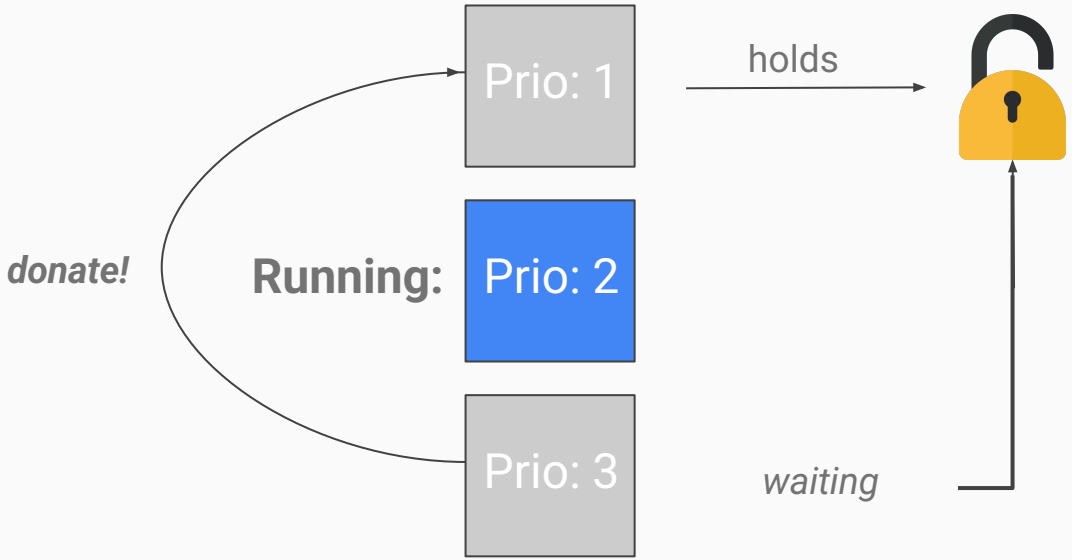


If the medium-priority task takes a long time, the low-priority task can't run to release the lock, and the high-priority task won't be able to proceed :(

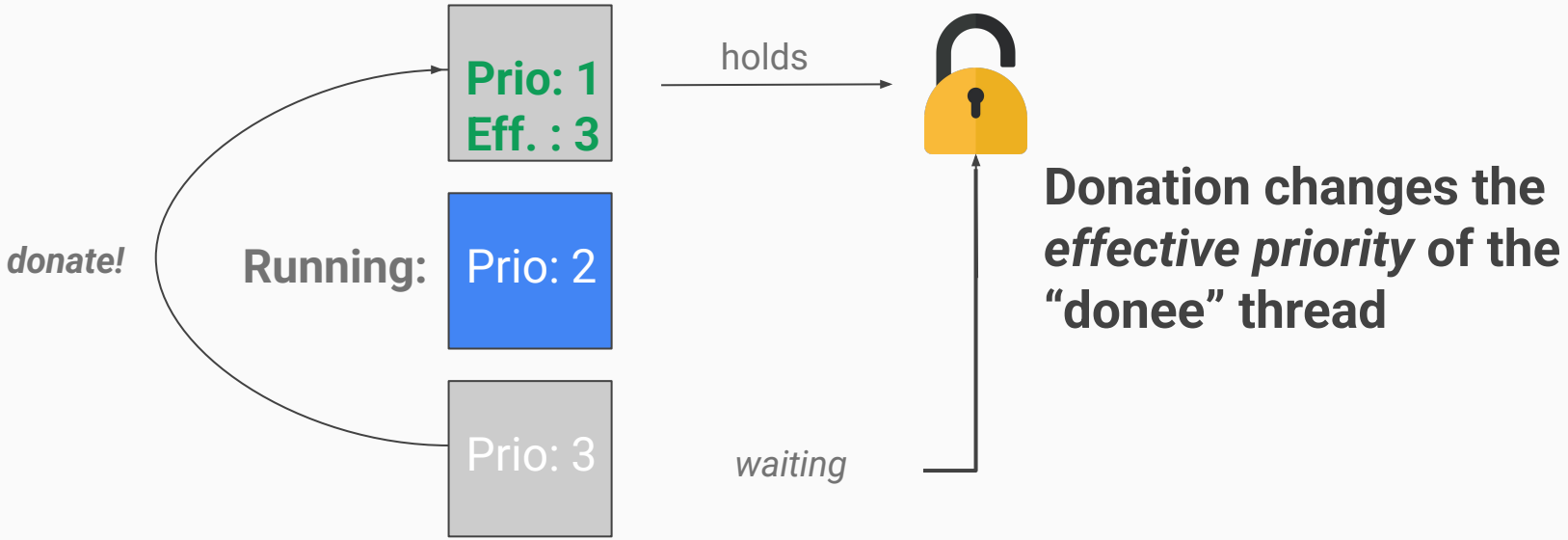
Solution: priority donation

Priority Donation



High-priority waiter thread temporarily “donates” its priority to the low-priority holder of the lock

Priority Donation



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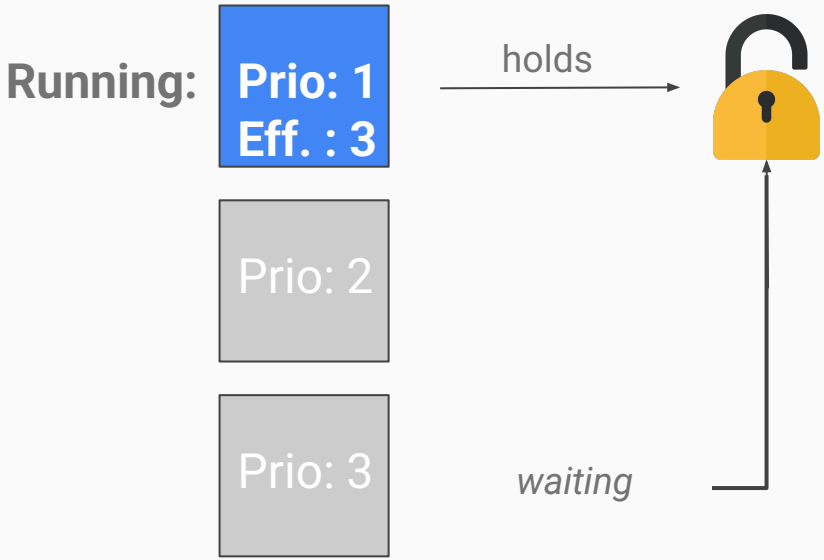

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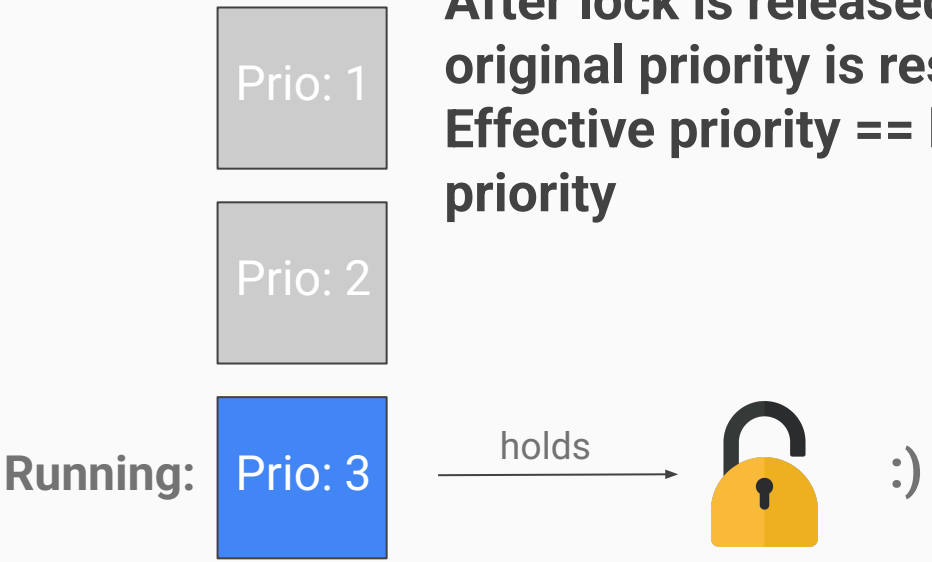

After lock is released, original priority is restored
Effective priority == base priority

Priority Donation: More Cases

- To how many threads can a donor donate its priority?
- From how many threads may a donee receive priority?
- What happens when a priority recipient *itself* donates to another thread?

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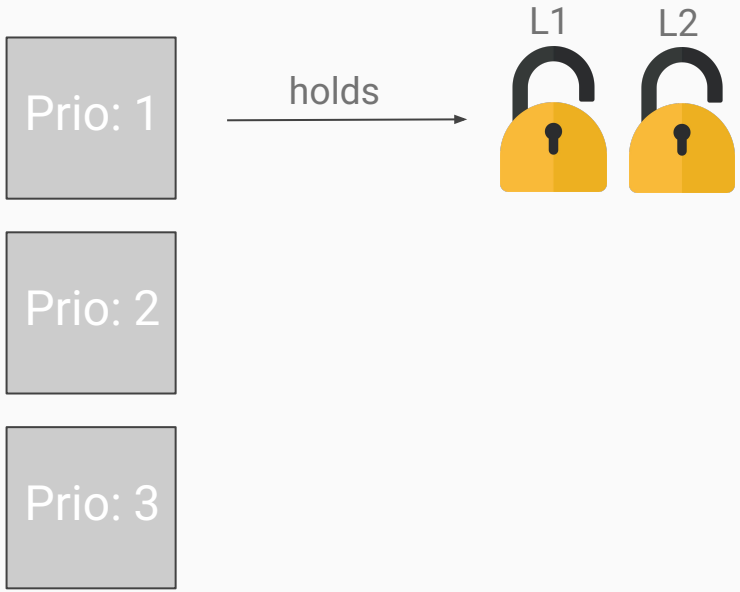
Priority Inversion: *Multiple* Donation



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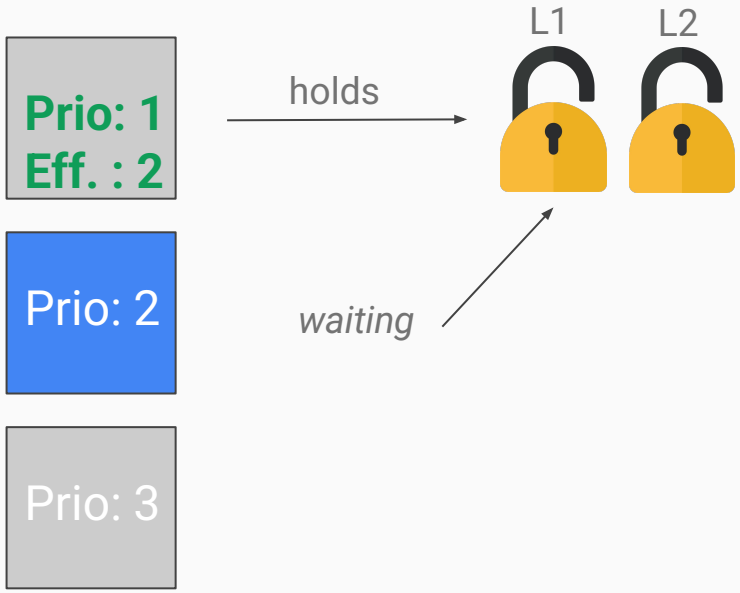

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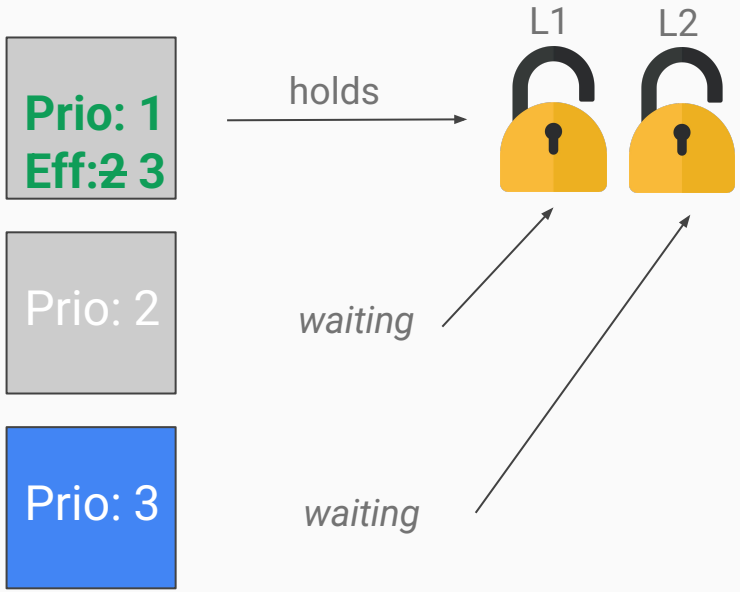
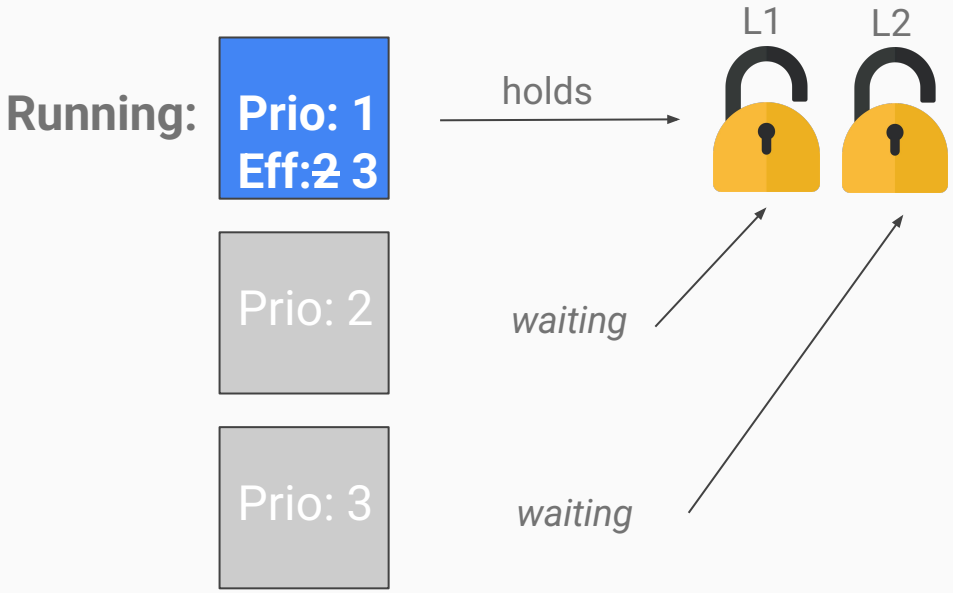


Both donate!

Priority Inversion: *Multiple* Donation



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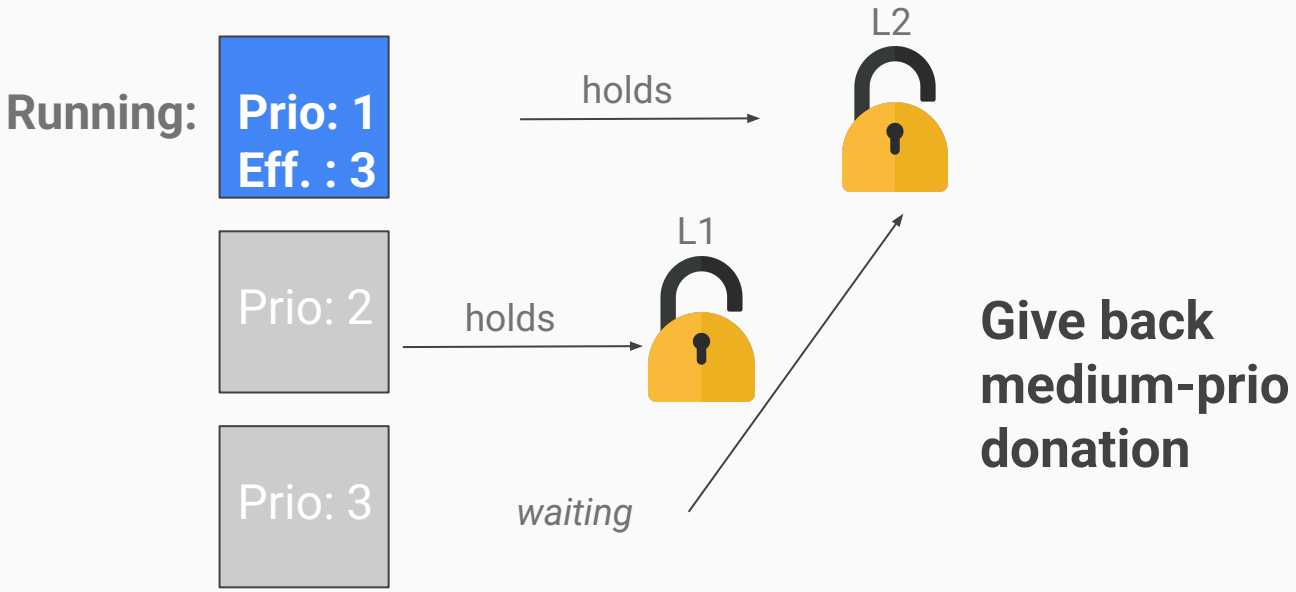
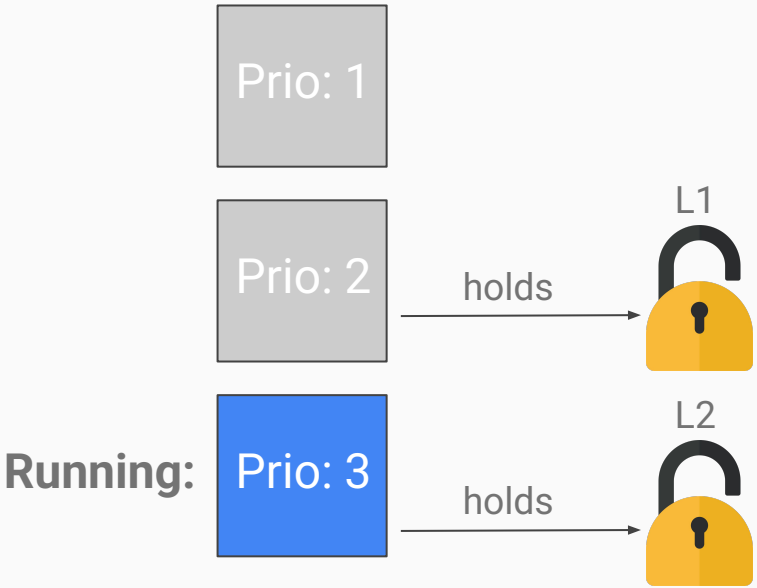


Priority Inversion: *Multiple* Donation

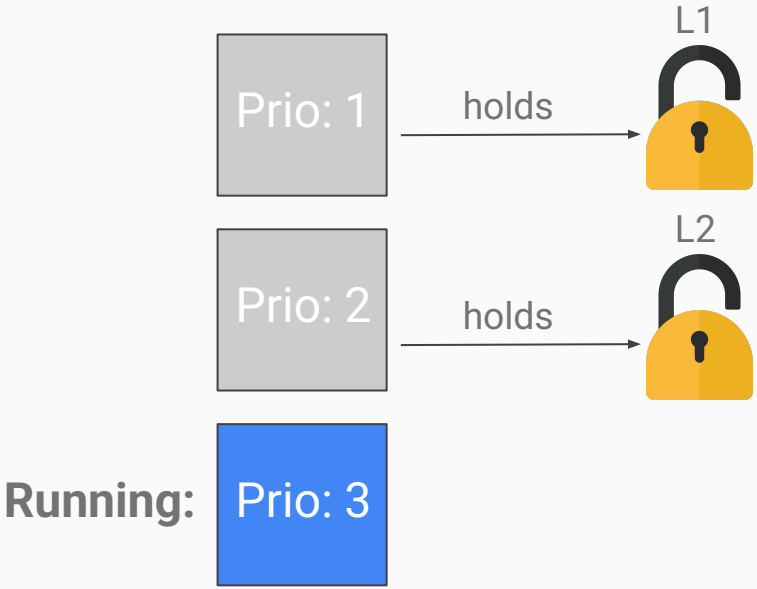


Give back high-prio donation

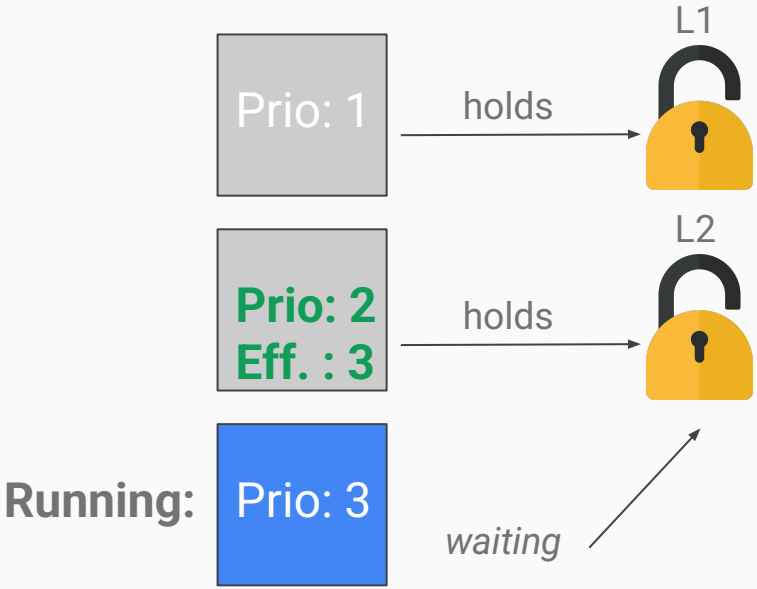
Priority Donation: More Cases

- To how many threads can a donor donate its priority?
- From how many threads may a donee receive priority?
- **What happens when a priority recipient *itself* donates to another thread?**

Priority Inversion: *Nested* Donation



Priority Inversion: *Nested* Donation



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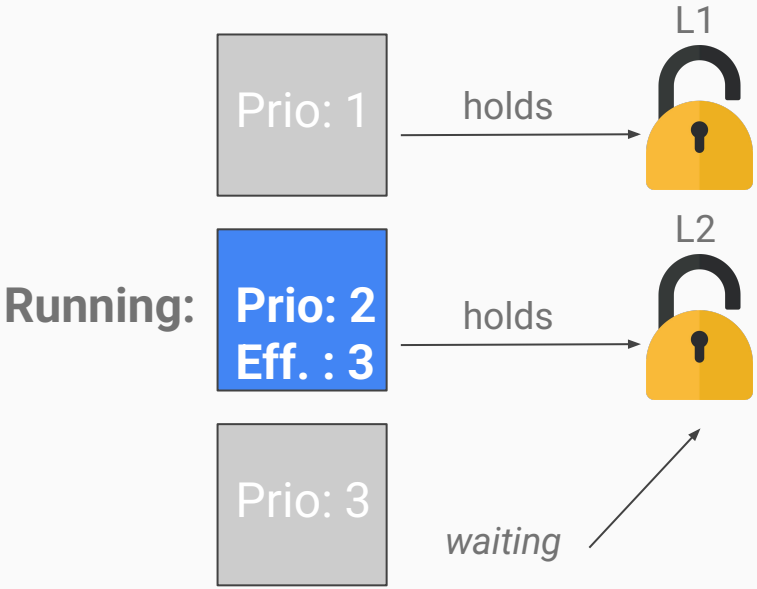

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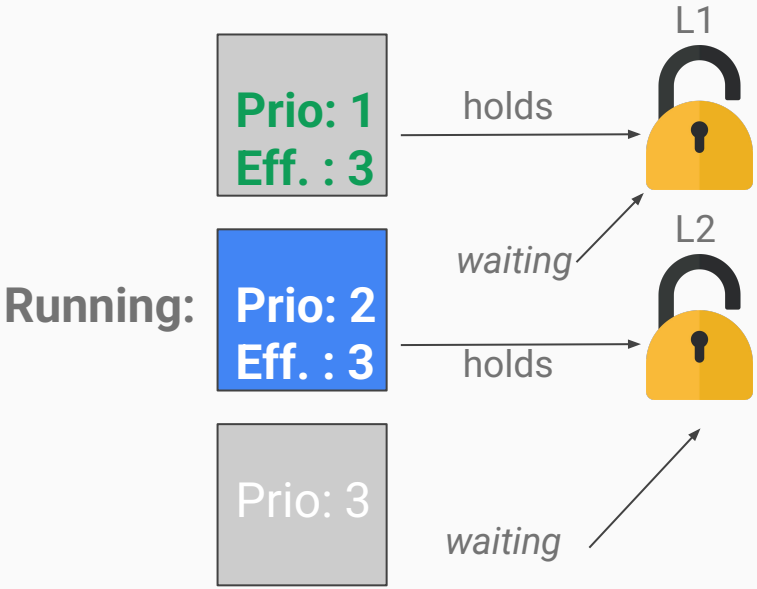

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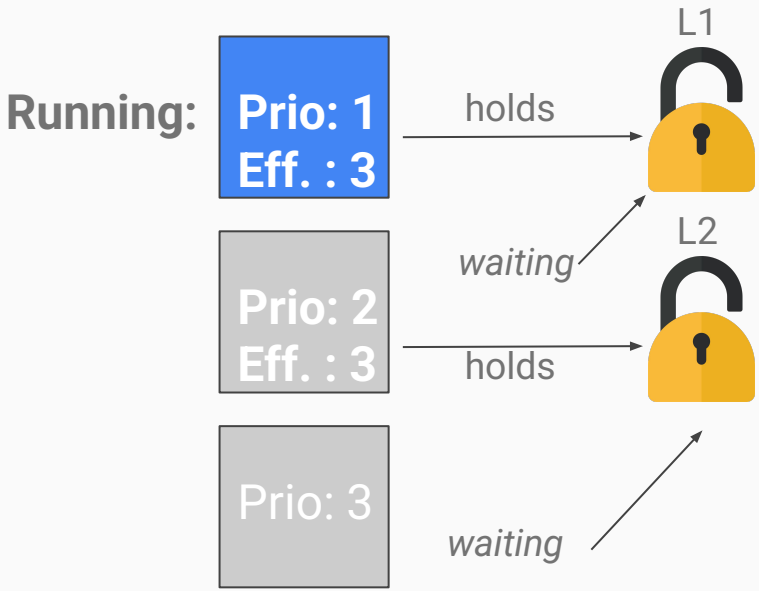

Note: You may impose a reasonable limit on depth of nested priority donation, such as 8 levels

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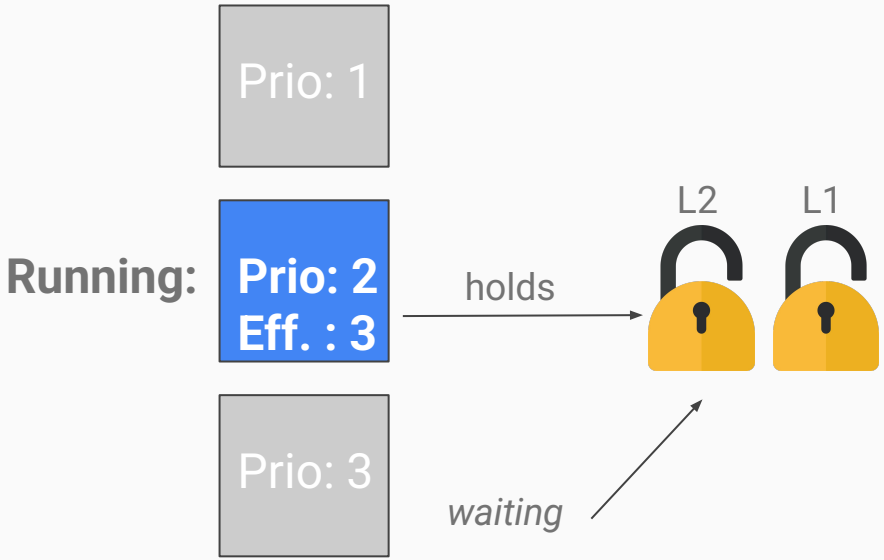

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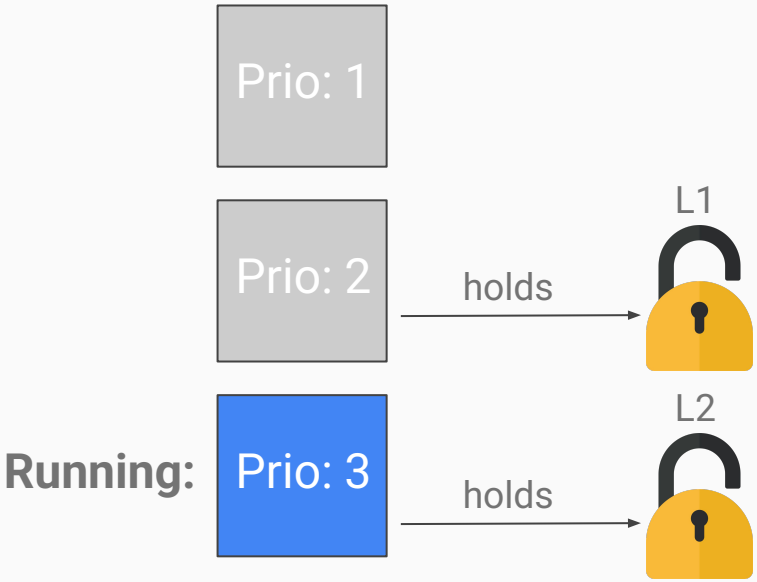


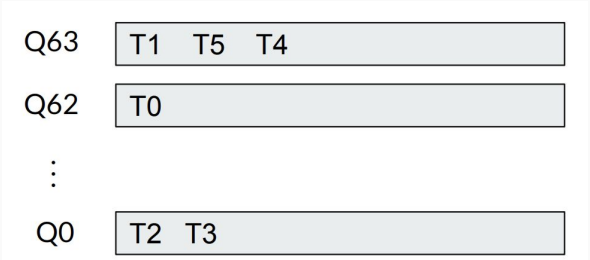
Priority Scheduling Considerations

- Data structure for donations? Where should it go?
- When is a donation executed? When is it “un-donated” (when is the donee’s original priority restored)?
- How will you ensure that the highest priority thread waiting for a lock, semaphore, or condition variable is woken up?

Advanced Scheduler (MLFQ)

Multi-Level Feedback Queue (Section 2.24 and Appendix B)

- Still based on priorities, but ***no*** priority donation
  - So we recommend that before starting this part, you have a working version of the basic priority scheduler (except possibly priority donation)
- Maintain several queues, each representing a different priority
  - Pick from highest-priority non-empty queue
  - Round-robin within each queue
- Scheduler dynamically updates priorities
  - "Niceness" = how generous to be to other threads
  - priority = PRI_MAX - (recent_cpu / 4) - (nice * 2)
  - Scheduler updates priority every 4th tick if recent_cpu changed (recent_cpu calculated every 1 sec)
- Algorithm tries to boost priority of threads that have used less CPU time recently



Note: Fixed-Point Arithmetic

- Detailed formulas for Advanced Scheduler's priority calculation and related metrics in Appendix B (uses both integers and real numbers)
- Can't use actual floating-point arithmetic: too slow for kernel code
- Carefully approximate floating-point calculations with integers: implementation also detailed in appendix

TL;DR

Reminders (TL;DR part 1)

- Do the pre-readings first
- Give **lots** of attention to design
- If some of these examples were unclear:
  - The appendix/Pintos docs are very detailed
  - More about synchronization & scheduling in next week's lectures
  - Come to Office Hours or post on Ed!

Code Tasks (TL;DR part 2)

1. Alarm Clock
   a. Re-implement `timer_sleep()` without busy waiting
2. Priority Scheduler
   a. Threads set their own priorities, and run according to these priorities
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   a. Answer questions regarding your design and implementation for parts 1-3