CS 31: Intro to Systems
Deadlock (and other scary thread interactions)

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December 12, 2023

“Deadly Embrace”

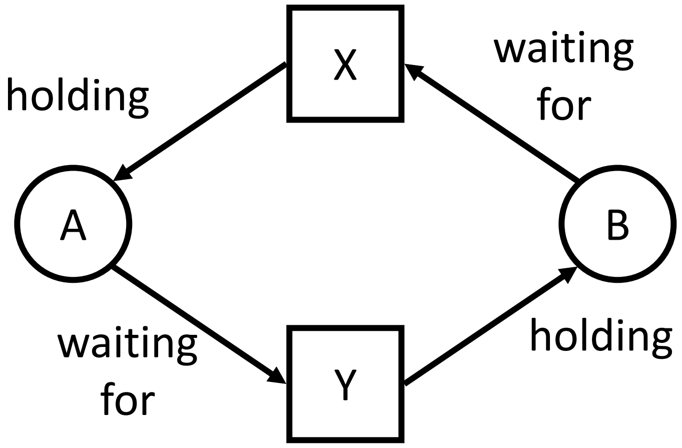
- *The Structure of the THE-Multiprogramming System* (Edsger Dijkstra, 1968)
- Also introduced semaphores
- Deadlock is as old as synchronization

What is Deadlock?

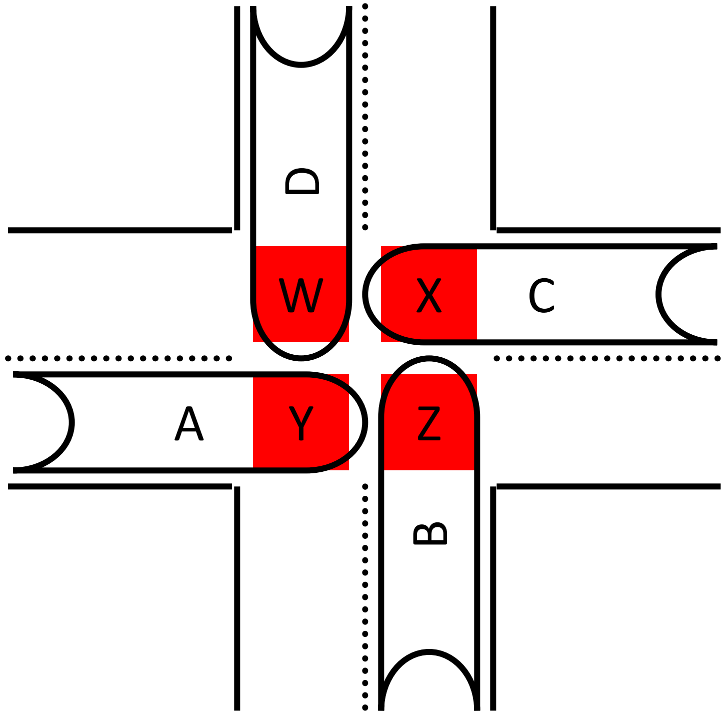
- Deadlock is a problem that can arise:
  – When processes compete for access to limited resources
  – When threads are incorrectly synchronized
- Definition:
  – Deadlock exists among a set of threads if every thread is waiting for an event that can be caused only by another thread in the set.

What is Deadlock?

- Set of threads are permanently blocked
  - Unblocking of one relies on progress of another
  - But none can make progress!
- Example
  - Threads A and B
  - Resources X and Y
  - A holding X, waiting for Y
  - B holding Y, waiting for X
  - Each is waiting for the other; will wait forever



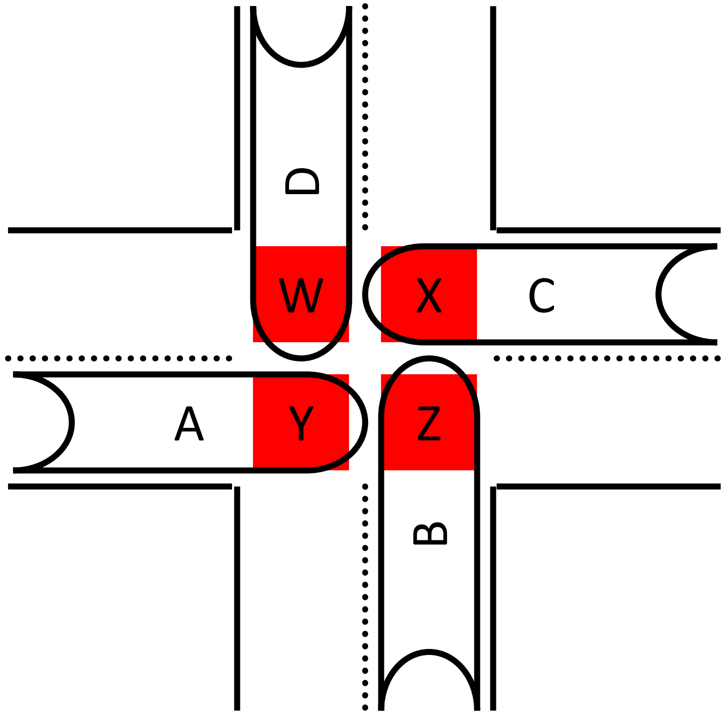
Traffic Jam as Example of Deadlock



Cars deadlocked
in an intersection

- Cars A, B, C, D
- Road W, X, Y, Z
- Car A holds road space Y, waiting for space Z
- “Gridlock”

Traffic Jam as Example of Deadlock



Cars deadlocked
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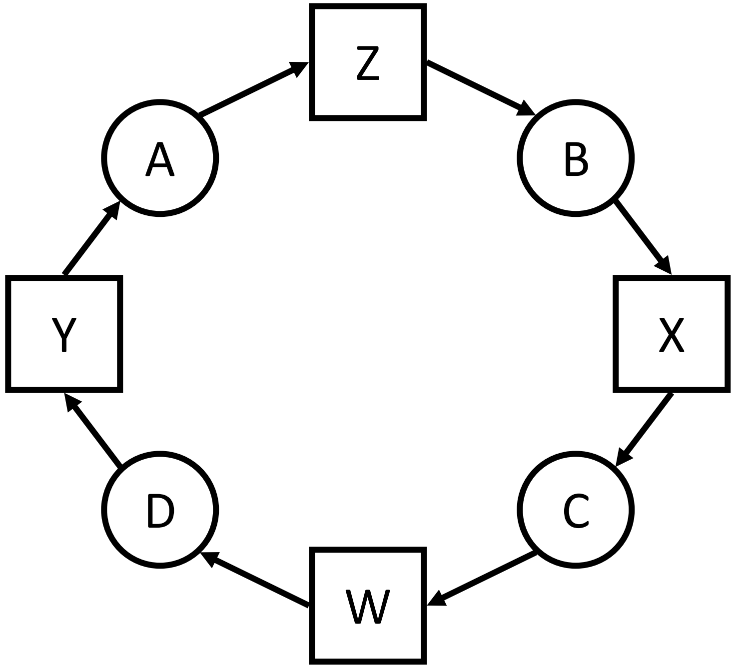

Resource Allocation
Graph

Four Conditions for Deadlock

1. Mutual Exclusion
   – Only one thread may use a resource at a time.
2. Hold-and-Wait
   – Thread holds resource while waiting for another.
3. No Preemption
   – Can’t take a resource away from a thread.
4. Circular Wait
   – The waiting threads form a cycle.

Four Conditions for Deadlock

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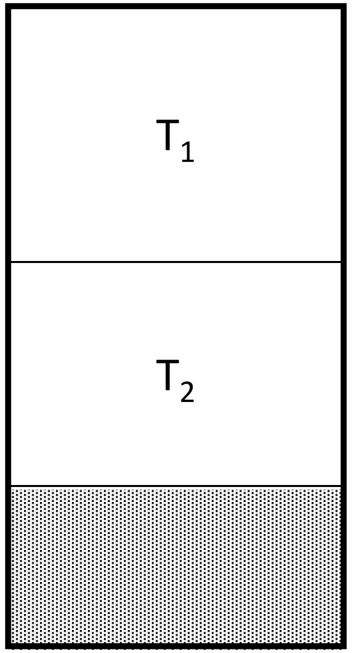
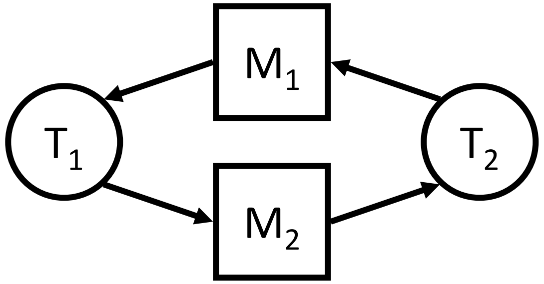
Examples of Deadlock

- Memory (a reusable resource)
  - total memory = 200KB
  - T_1 requests 80KB
  - T_2 requests 70KB
  - T_1 requests 60KB (wait)
  - T_2 requests 80KB (wait)
- Messages (a consumable resource)
  - T_1: receive M_2 from P_2
  - T_2: receive M_1 from P_1





Banking, Revisited

```
struct account {
  mutex lock;
  int balance;
}

Transfer(from_acct, to_acct, amt) {
  lock(from_acct.lock);
  lock(to_acct.lock)

  from_acct.balance -= amt;
  to_acct.balance += amt;

  unlock(to_acct.lock);
  unlock(from_acct.lock);
}
```

If multiple threads are executing this code, is there a race? Could a deadlock occur?

```
struct account {
  mutex lock;
  int balance;
}

Transfer(from_acct, to_acct, amt) {
  lock(from_acct.lock);
  lock(to_acct.lock)

  from_acct.balance -= amt;
  to_acct.balance += amt;

  unlock(to_acct.lock);
  unlock(from_acct.lock);
}
```

If there's potential for a race/deadlock, what execution ordering will trigger it?

Clicker Choice	Potential Race?	Potential Deadlock?
A	No	No
B	Yes	No
C	No	Yes
D	Yes	Yes

Common Deadlock

Thread 0

```
Transfer(acctA, acctB, 20);

Transfer(…) {
  lock(acctA.lock);
  lock(acctB.lock);
```

Thread 1

```
Transfer(acctB, acctA, 40);

Transfer(…) {
  lock(acctB.lock);
  lock(acctA.lock);
```

Common Deadlock

Thread 0

```
Transfer(acctA, acctB, 20);

Transfer(…) {
  lock(acctA.lock);
       T0 gets to here
  lock(acctB.lock);
```

Thread 1

```
Transfer(acctA, acctB, 40);

Transfer(…) {
  lock(acctB.lock);
       T1 gets to here
  lock(acctA.lock);
```

T_0 holds A's lock, will make no progress until it can get B's.
T_1 holds B's lock, will make no progress until it can get A's.

How to Attack the Deadlock Problem

- What should your OS do to help you?

- Deadlock Prevention
  - Make deadlock impossible by removing a condition
- Deadlock Avoidance (“Banker’s Algorithm”)
  - Avoid getting into situations that lead to deadlock
- Deadlock Detection
  - Don’t try to stop deadlocks
  - Rather, if they happen, detect and resolve

Which type of deadlock-handling scheme would you expect to see in a modern OS (Linux/Windows/OS X) ?

A. Deadlock prevention

B. Deadlock avoidance

C. Deadlock detection/recovery

D. Something else

"Ostrich Algorithm"

How to Attack the Deadlock Problem

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  – Don’t try to stop deadlocks
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- <u>These all have major drawbacks…</u>

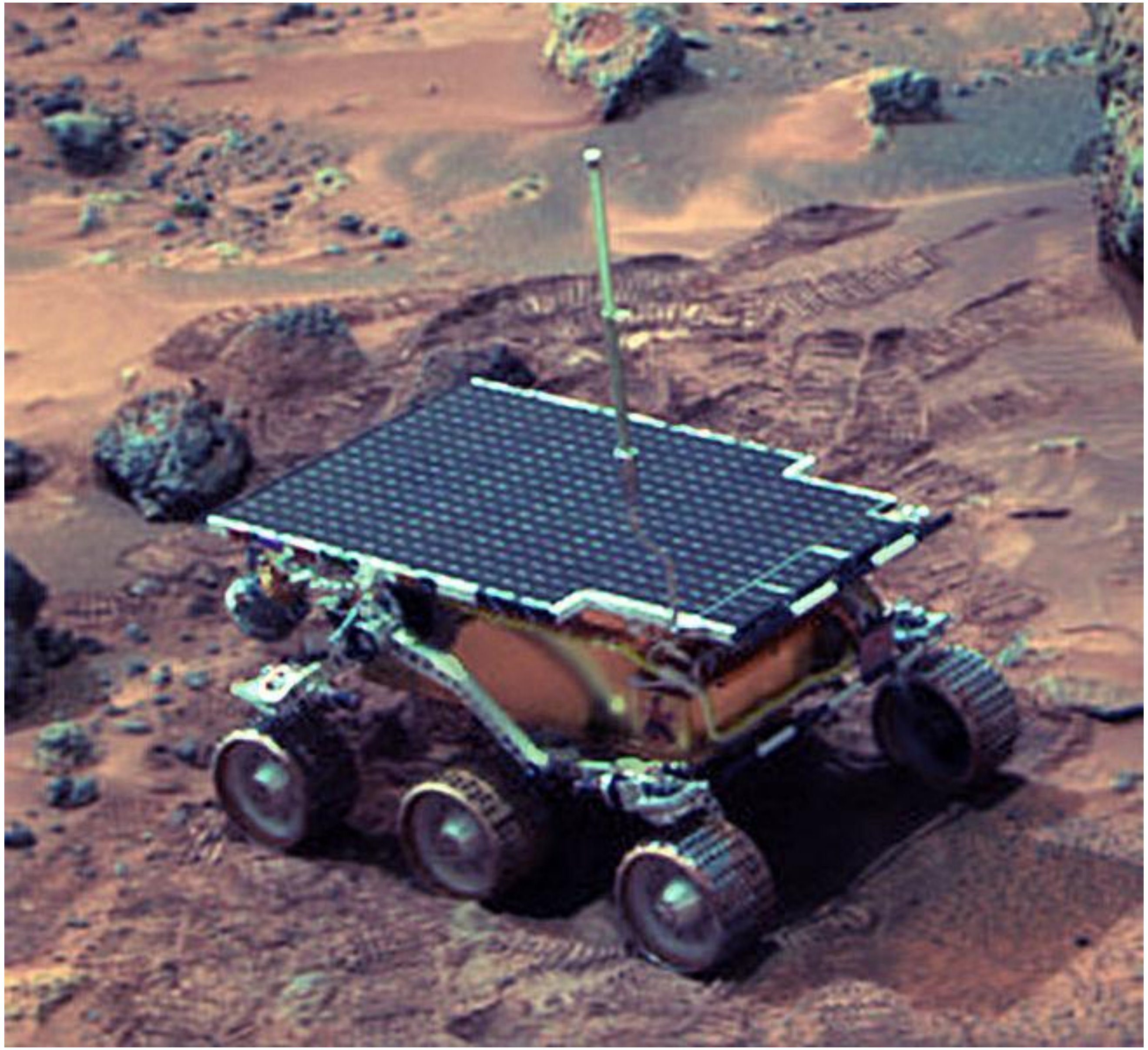
Other Thread Complications

- Deadlock is not the only problem
- Performance: too much locking?
- Priority inversion
- …

Priority Inversion

- Problem: Low priority thread holds lock, high priority thread waiting for lock.
  - What needs to happen: boost low priority thread so that it can finish, release the lock
  - What sometimes happens in practice: low priority thread not scheduled, can't release lock

- Example: Mars Pathfinder (1997)



Sojourner Rover on Mars

Mars Rover

- Three periodic tasks:
  1. Low priority: collect meteorological data
  2. Medium priority: communicate with NASA
  3. High priority: data storage/movement

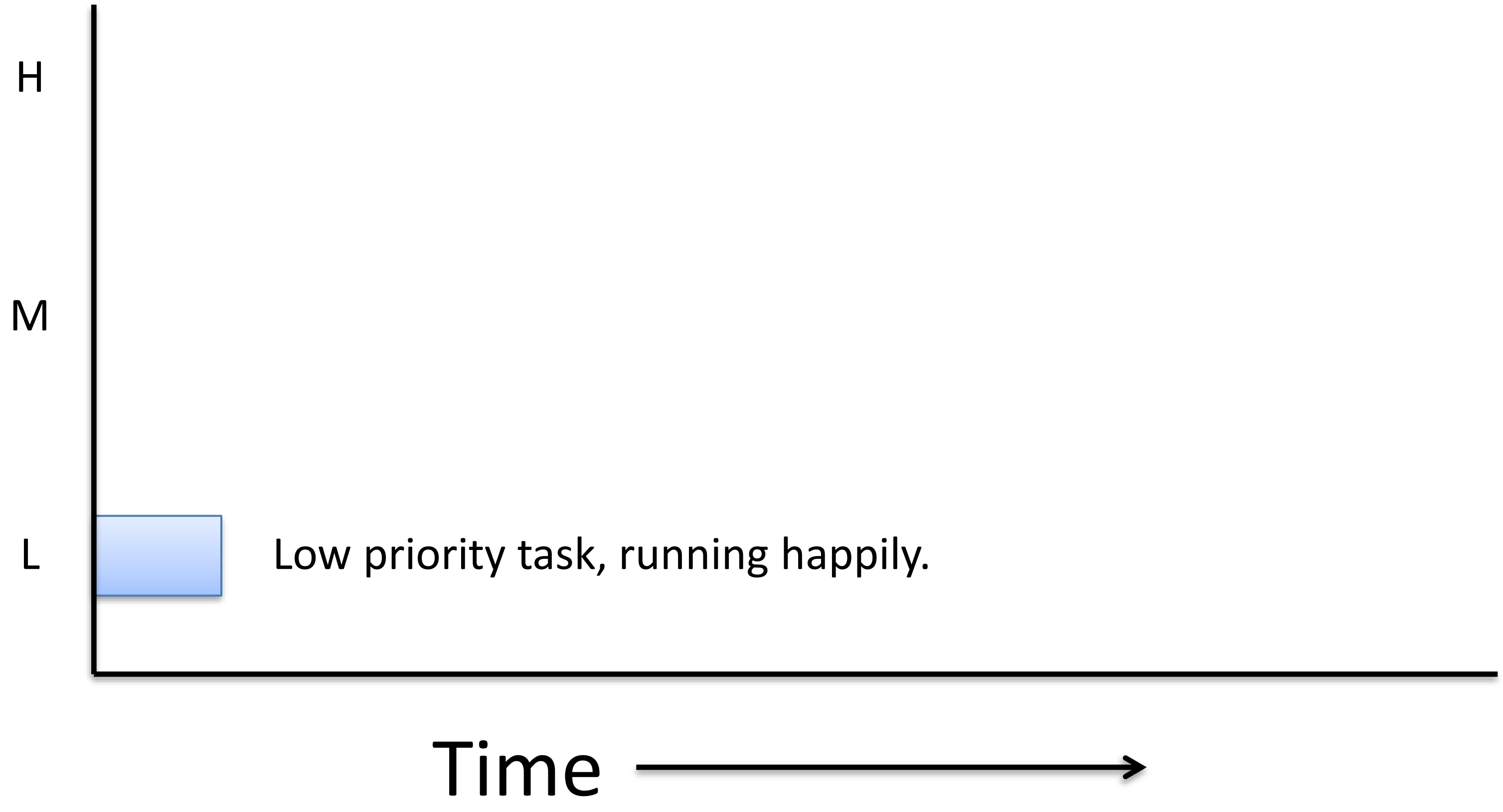
- Tasks 1 and 3 require exclusive access to a hardware bus to move data.
  – Bus protected by a mutex.

Mars Rover

- Failsafe timer (watchdog): if high priority task doesn’t complete in time, reboot system
- Observation: uh-oh, this thing seems to be rebooting a lot, we’re losing data…

JPL engineers later confessed that one or two system resets had occurred in their months of pre-flight testing. They had never been reproducible or explainable, and so the engineers, in a very human-nature response of denial, decided that they probably weren't important, using the rationale "it was probably caused by a hardware glitch".

What Happened: Priority Inversion



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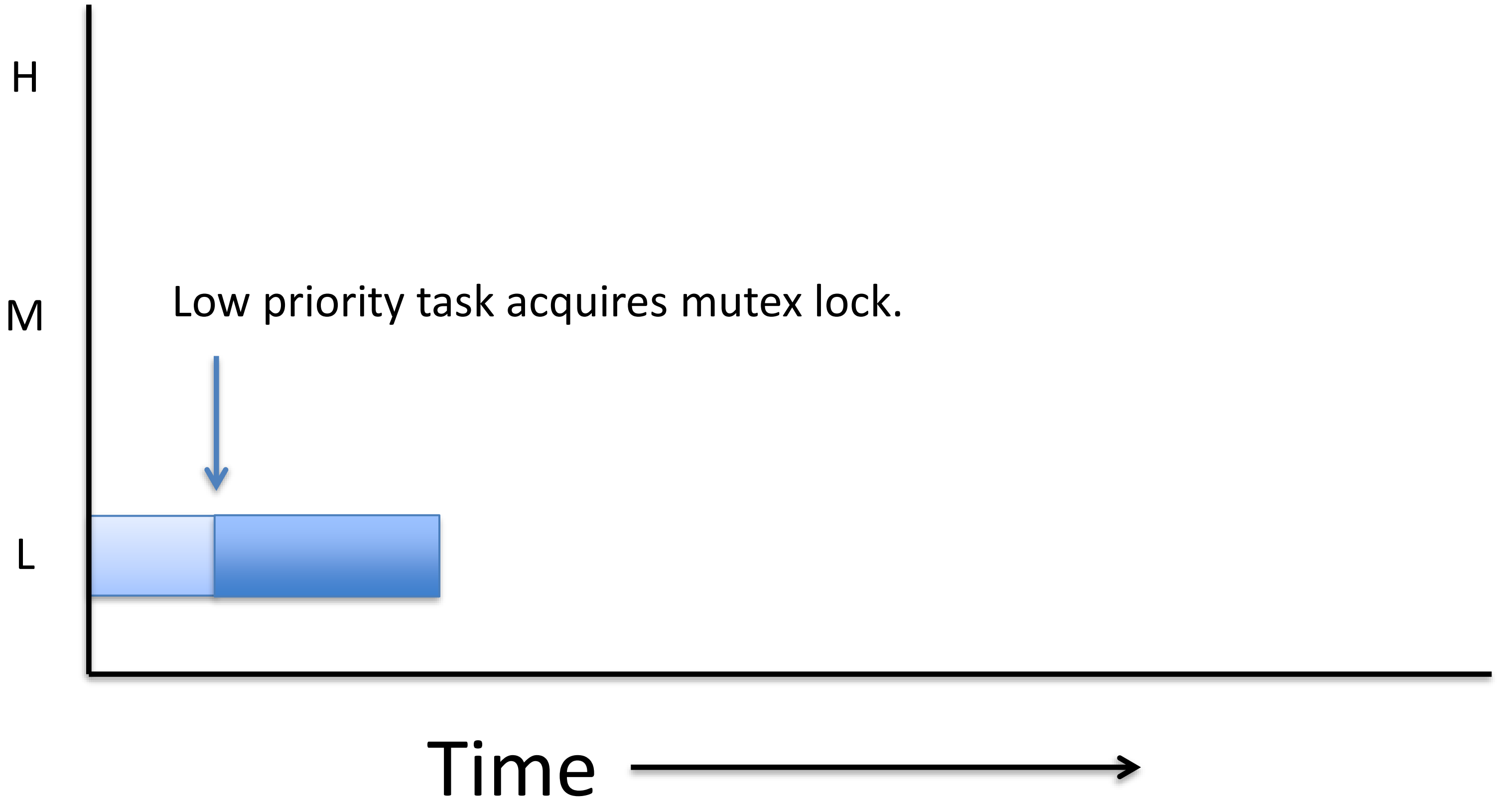

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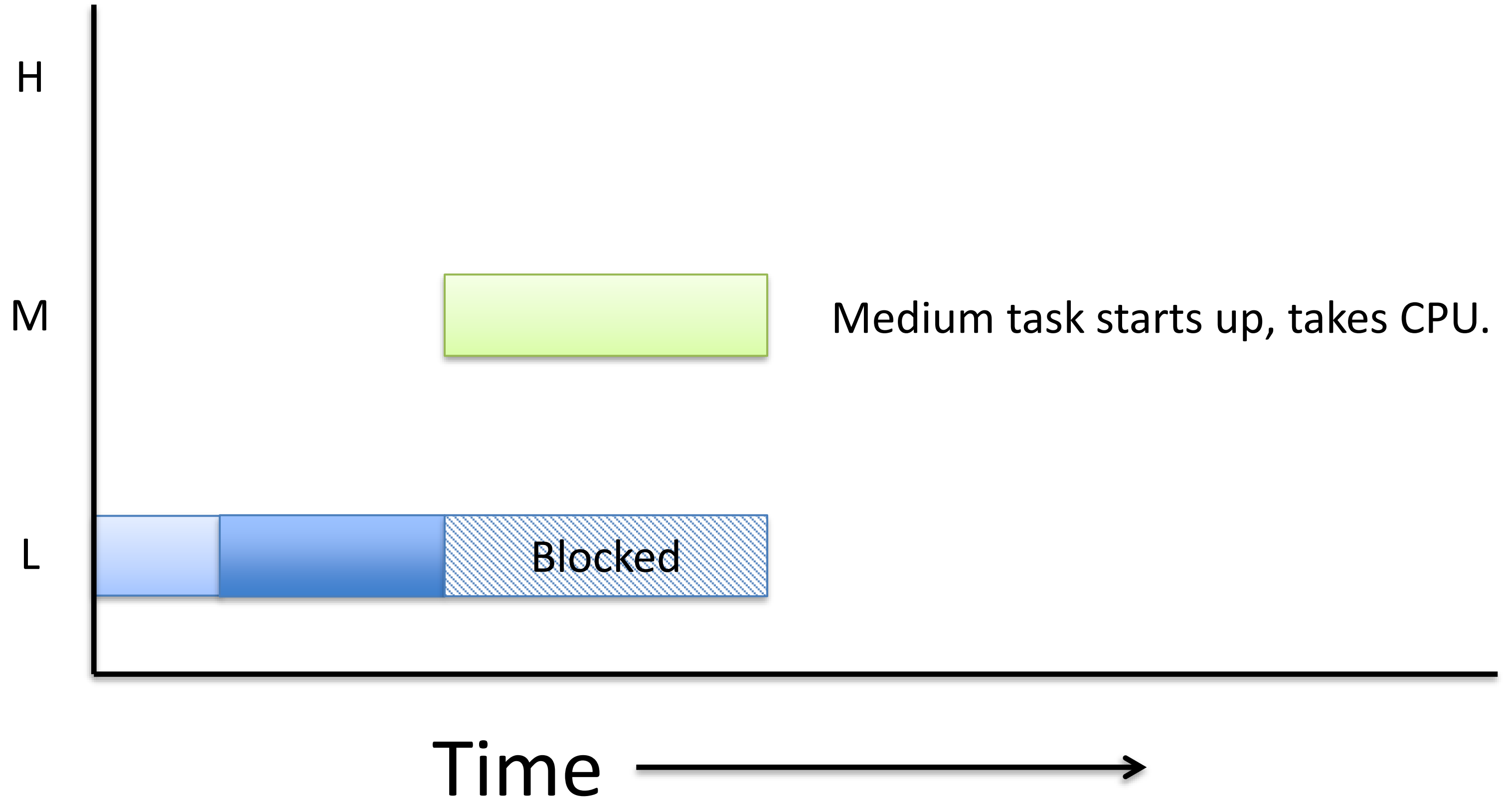

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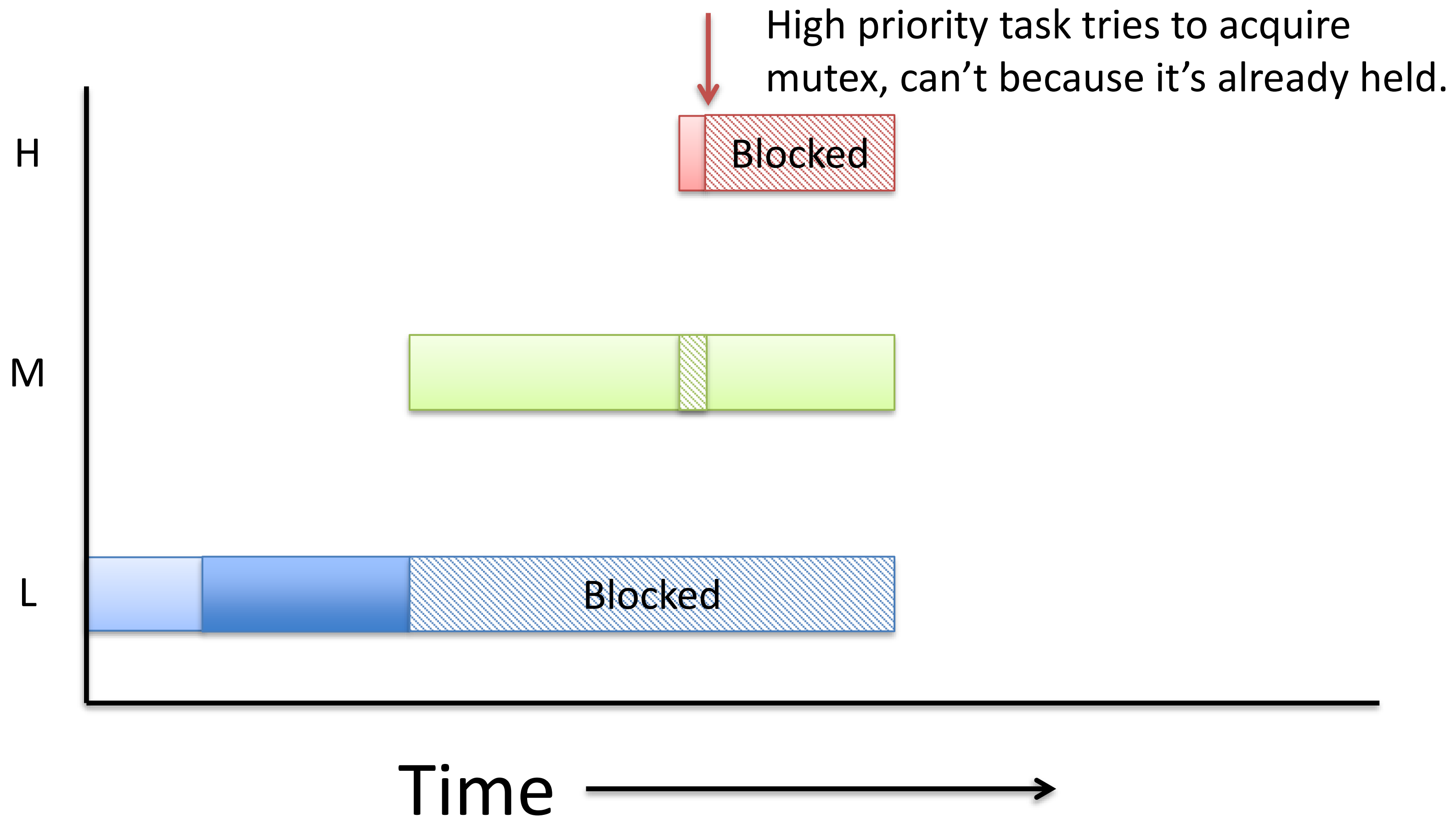

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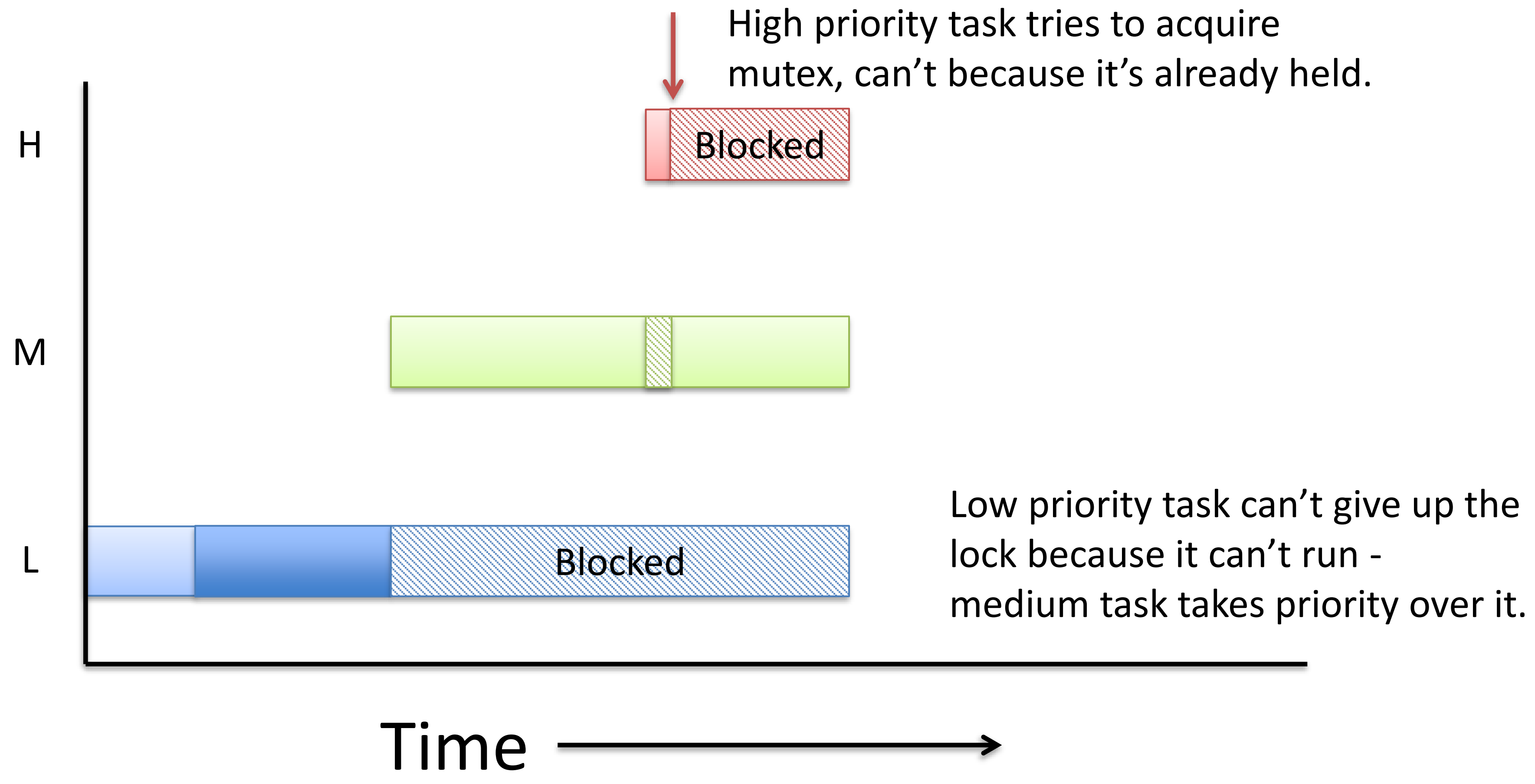

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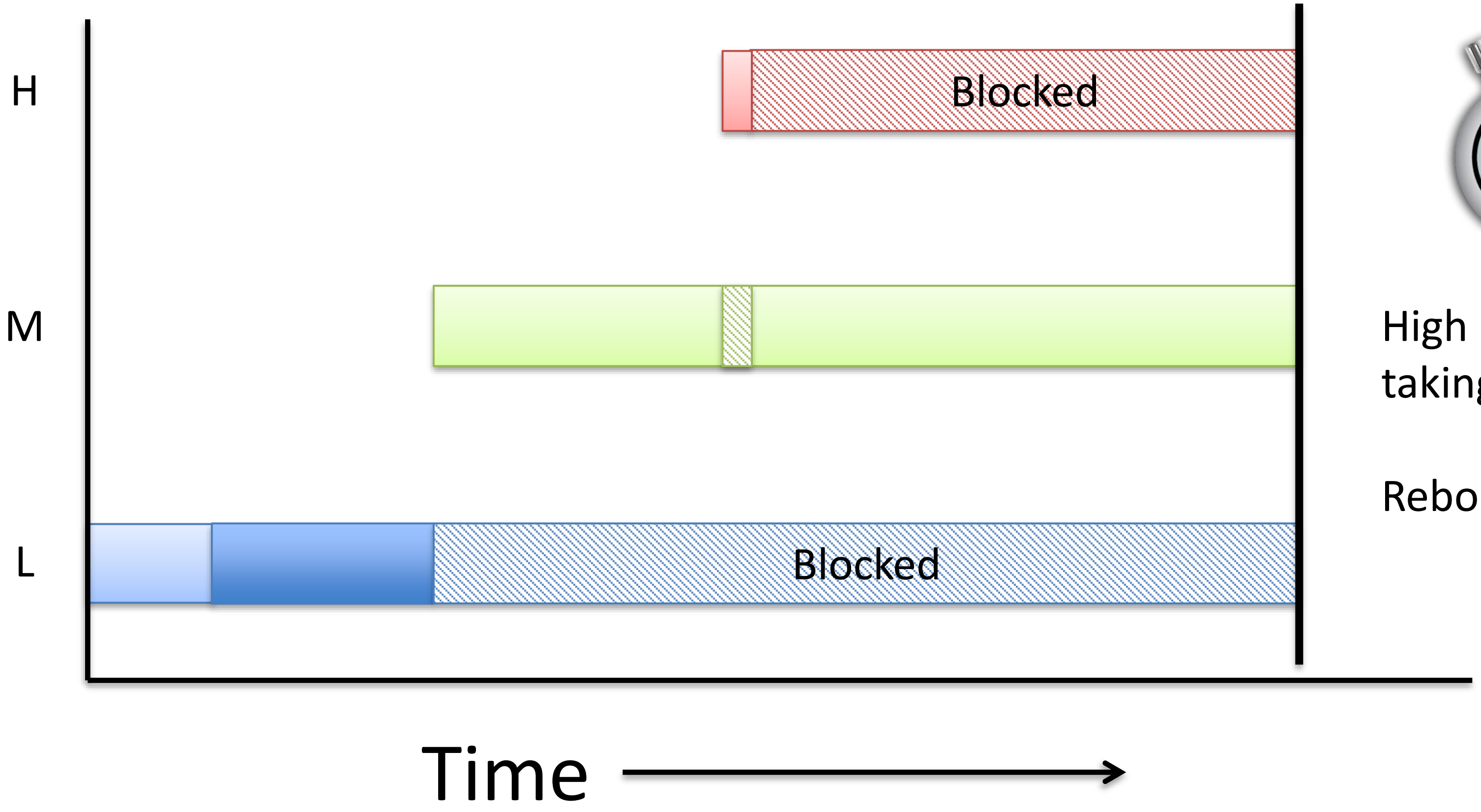
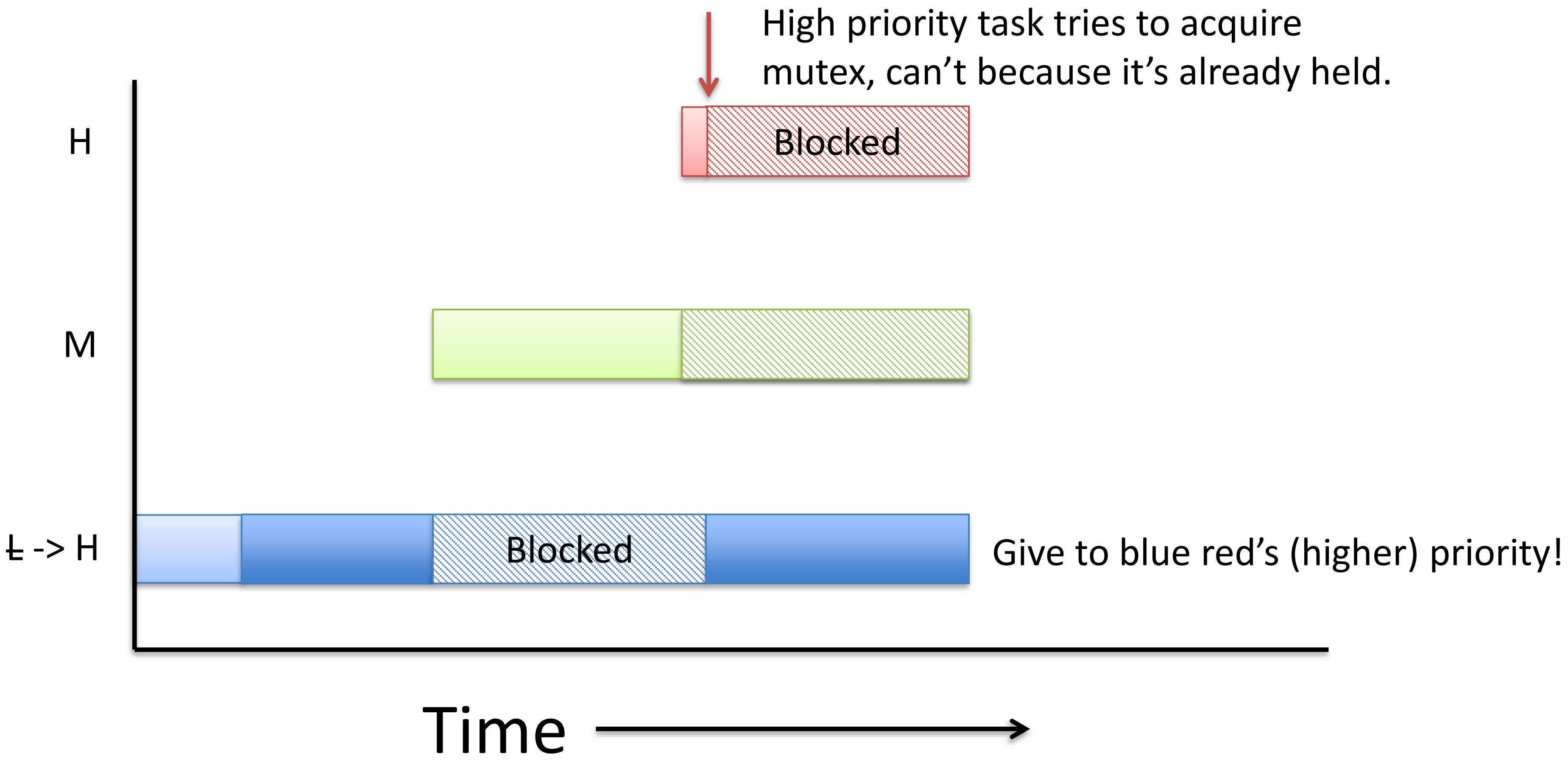


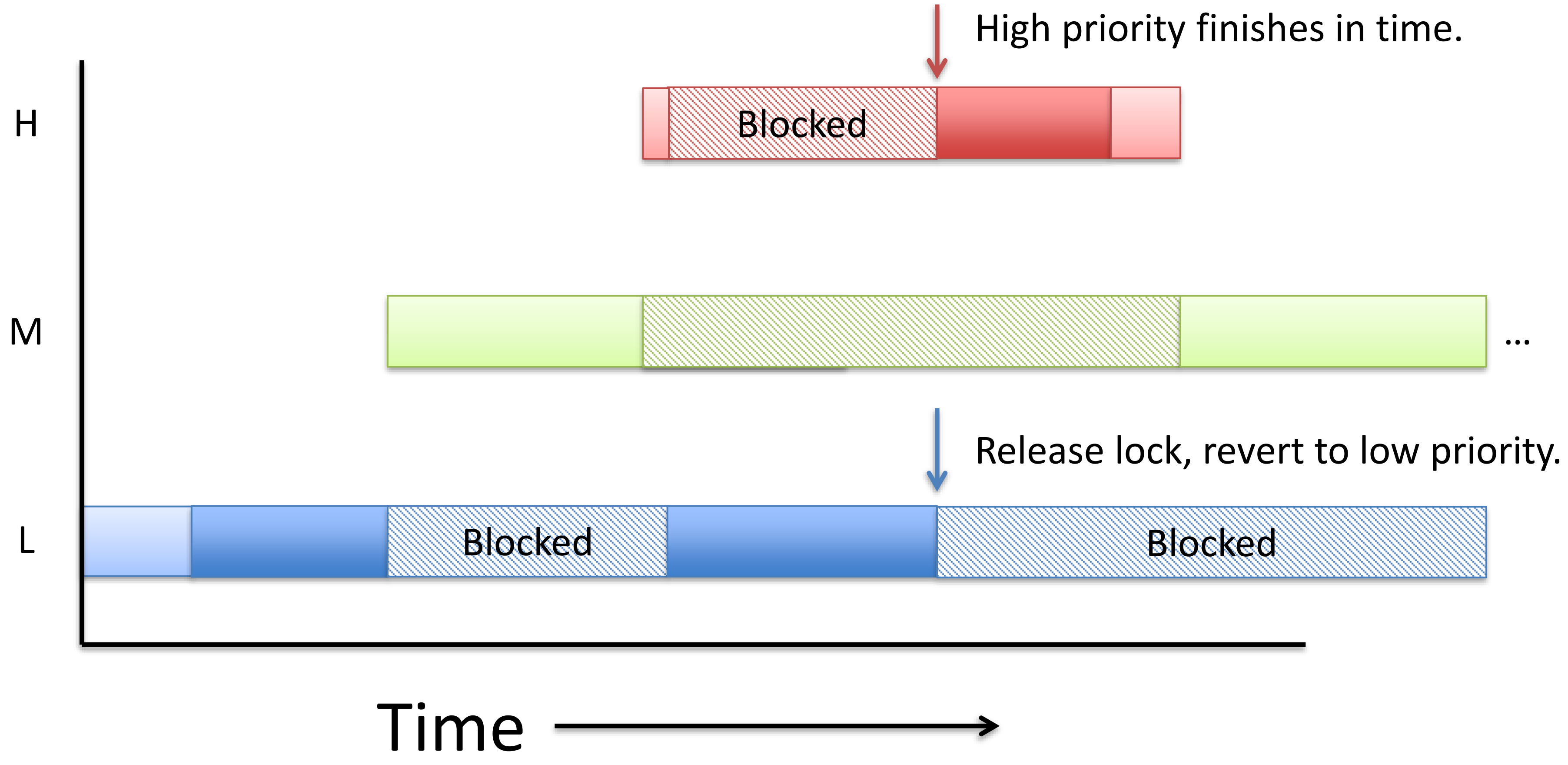
High priority is taking too long.

Reboot!

Solution: Priority Inheritance



Solution: Priority Inheritance



Deadlock Summary

- Deadlock occurs when threads are waiting on each other and cannot make progress.
- Deadlock requires four conditions:
  – Mutual exclusion, hold and wait, no resource preemption, circular wait
- Approaches to dealing with deadlock:
  – Ignore it – Living life on the edge (most common!)
  – Prevention – Make one of the four conditions impossible
  – Avoidance – Banker's Algorithm (control allocation)
  – Detection and Recovery – Look for a cycle, preempt/abort