Synchronization

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Recap: Monitor

- Monitor
  - A lock (mutual exclusion) + condition variables (scheduling)
  - Some languages like Java natively support this, but you can use monitors in other languages like C/C++
- Lock: mutual exclusion
  - Protects the shared data structures inside the monitor
  - Always acquire it to enter the monitor
  - Always release it to leave the monitor
- Condition Variable: scheduling
  - Allow thread to wait on certain events inside the monitor
  - Key idea: to wait (sleep) inside the monitor, it first releases the lock and go to sleep atomically

Agenda

- Famous Synchronization Bugs
  - THERAC-25
  - Mars Pathfinder

Therac 25

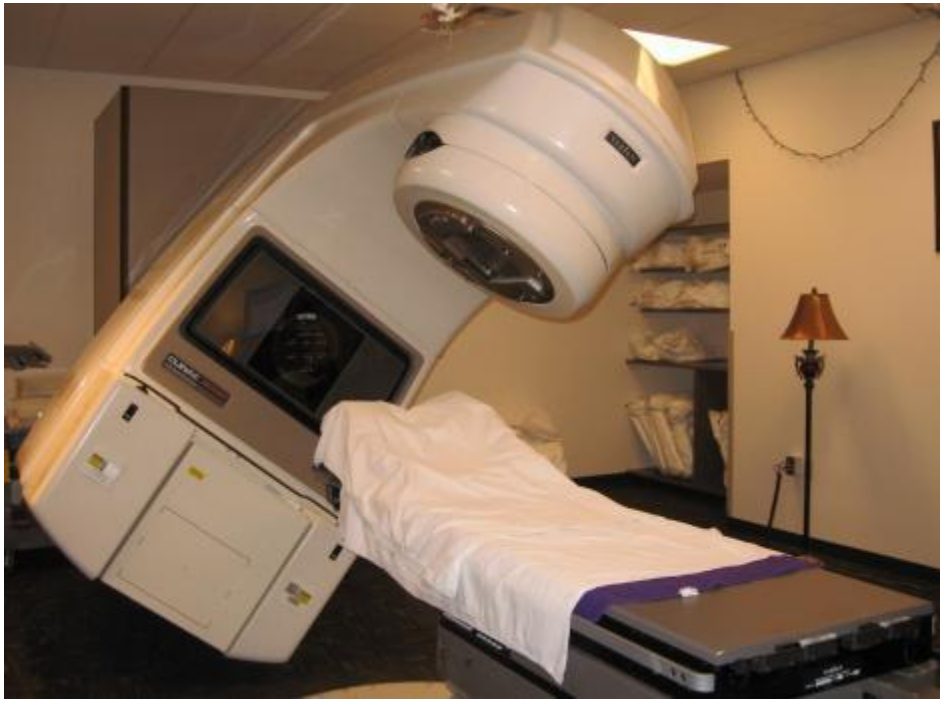

Image source: http://idg.bg/test/cwd/2008/7/14/21367-radiation_therapy.JPG

- Computer controlled medical X-ray treatments
- Six people died/injured due to massive overdoses (1985-1987)

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Accident History

Date	What happened
June 1985	First overdose
July-Dec 1985	2nd and 3rd overdoses. Lawsuit against the manufacturer and hospital
Jan-Feb 1986	Manufacturer denied the possibility of overdoses
Mar-Apr 1986	Two more overdoses
May-Dec 1986	FDA orders corrective action plans to the manufacturer
Jan 1987	Sixth overdose
Nov 1988	Final safety analysis report

The Problem

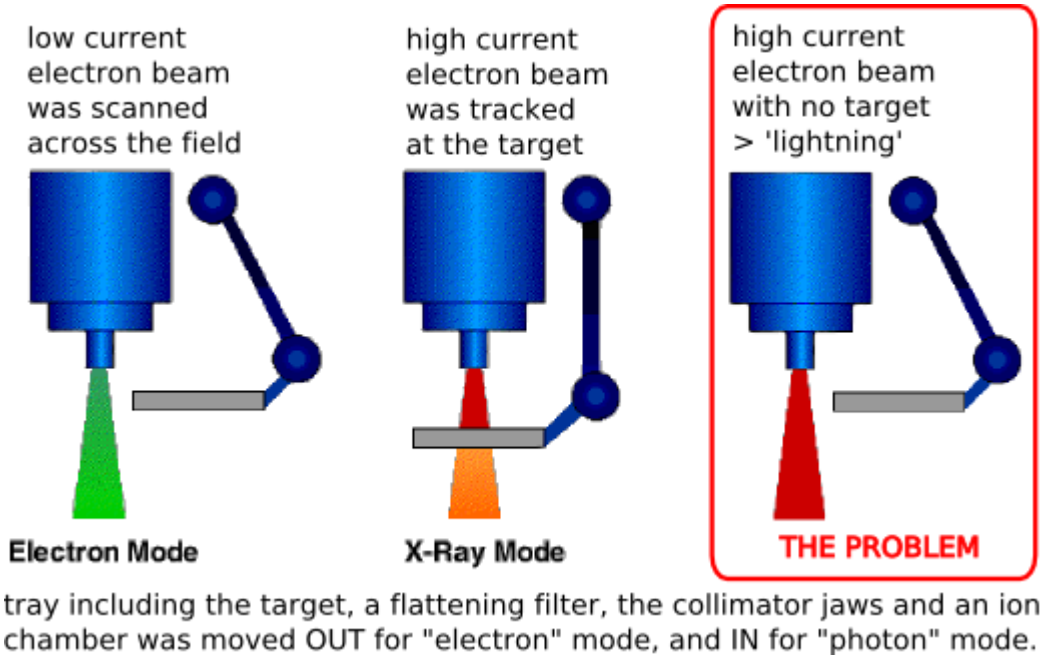


Image source: http://radonc.wdfiles.com/local--files/radiation-accident-therac25/Therac25.png

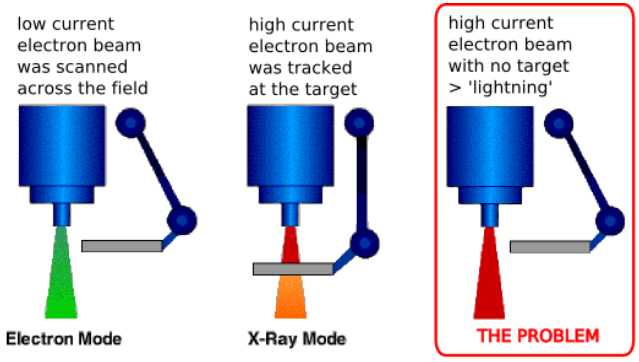
- X-ray must be dosed with the filter in place
- But sometimes, X-ray was dosed w/o the filter

The Bug

```
unsigned char in_progress = 1;

Thread 1 : // tray movement thread (periodic)
   if (system_is_ready())
       in_progress = 0;
   else
       in_progress++;


Thread 2 : // X-ray control thread.
   if (in_progress == 0)
       start_radiation();
```



tray including the target, a flattening filter, the collimator jaws and an ion chamber was moved OUT for "electron" mode, and IN for "photon" mode.

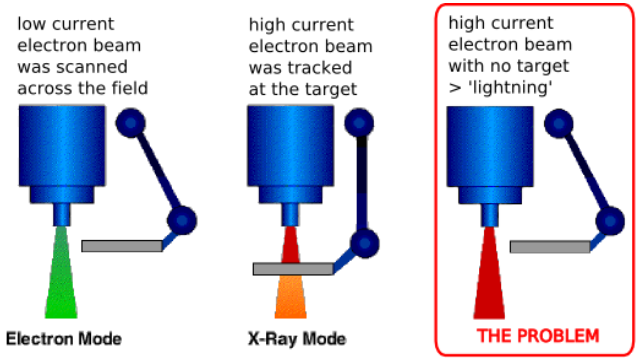
- Can you spot the bug?

Fixed Code

```
unsigned char in_progress;

Thread 1 : // tray movement thread (periodic)
   if (system_is_ready())
       in_progress = 0;
   else
       in_progress = 1;


Thread 2 : // X-ray control thread.
   if (in_progress == 0)
       start_radiation();
```



tray including the target, a flattening filter, the collimator jaws and an ion chamber was moved OUT for "electron" mode, and IN for "photon" mode.

- Can you do better using a monitor?

Monitor Version

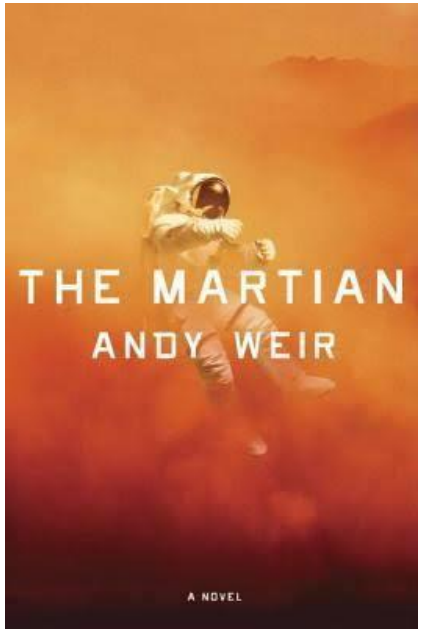
```
Mutex lock;
Condition ready;
unsigned char in_progress;

Thread 1 : // on finishing tray movement
   lock.acquire();
   in_progress = 0;
   ready.signal();
   lock.release();

Thread 2 : // X-ray control thread.
   lock.acquire();
   while (in_progress)
       ready.wait(&lock);
   start_radiation();
   lock.release();
```

- No periodic check is needed.

Mars Pathfinder

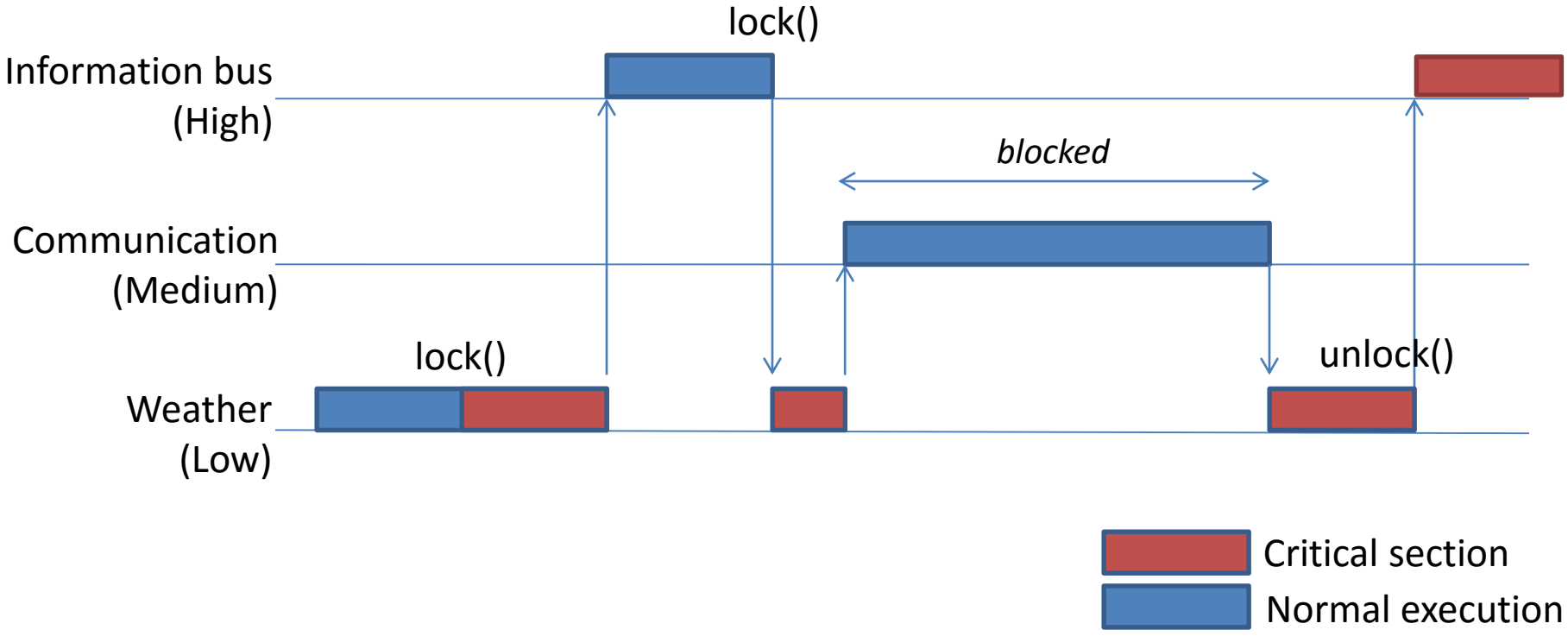


- Landed on Mars, July 4, 1997
- After operating for a while, it rebooted itself

The Bug

- Three threads with priorities
  - Weather data thread (low priority)
  - Communication thread (medium priority)
  - Information bus thread (high priority)
- Each thread obtains a lock to write data on the shared memory
- High priority thread can't acquire the lock for a very long time → something must be wrong. Let's reboot!

Priority Inversion



- High priority thread is delayed by the medium priority thread (potentially) indefinitely!!!

More reading: [What really happened on Mars?]

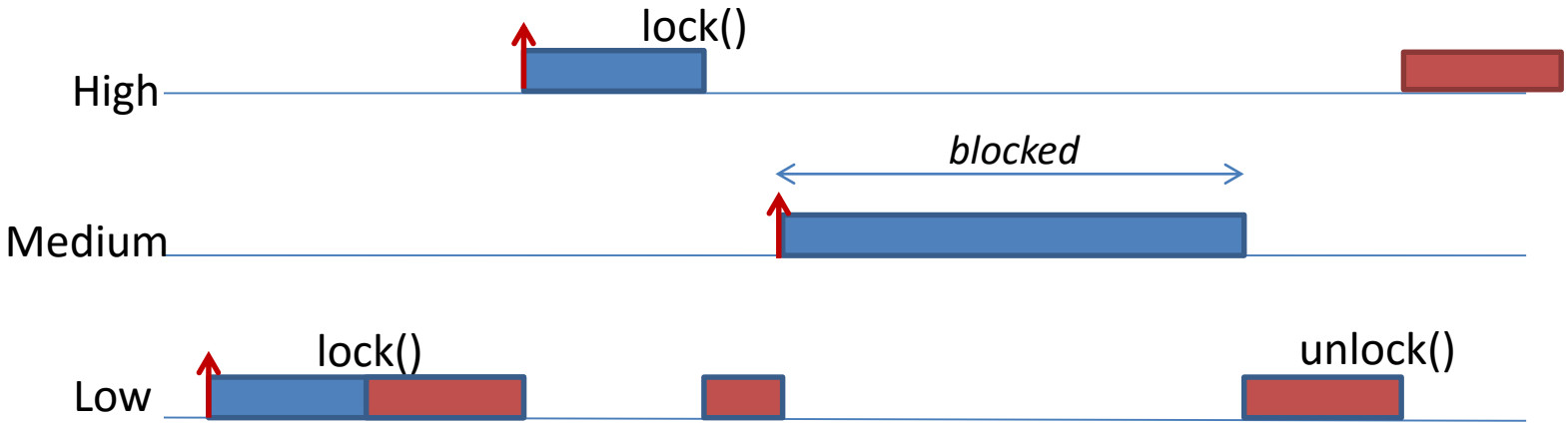
Solution

- Priority inheritance protocol [Sha'90]
  - If a high priority thread is waiting on a lock, boost the priority of the lock owner thread (low priority) to that of the high priority thread.
- Remotely patched the code
  - To use the priority inheritance protocol in the lock
  - First-ever(?) interplanetary remote debugging

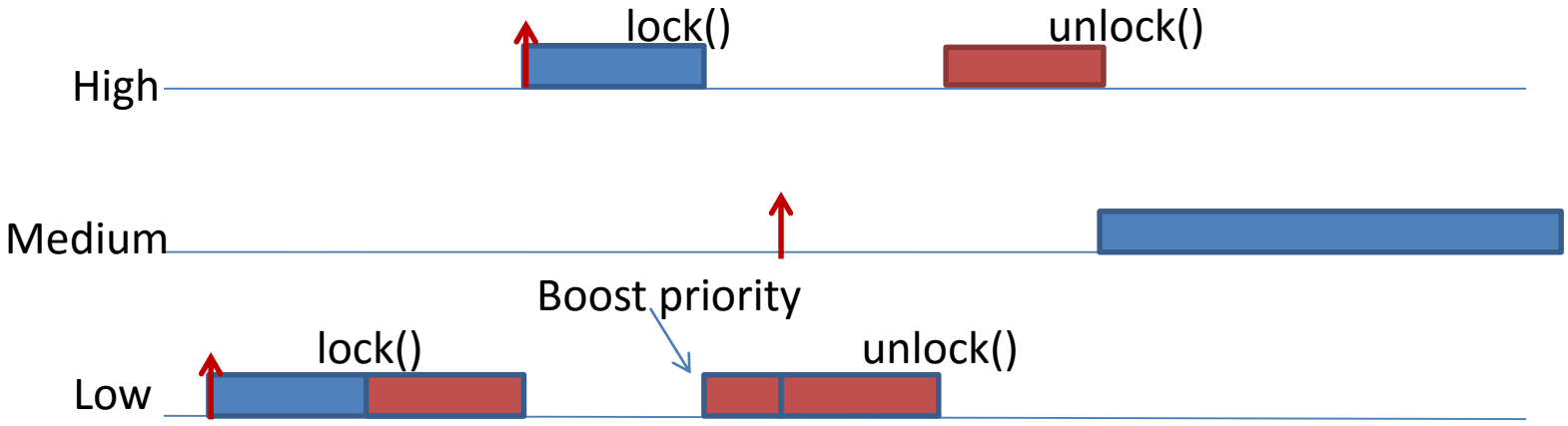
L. Sha, R. Rajkumar, and J. P. Lehoczky. Priority Inheritance Protocols: An Approach to Real-Time Synchronization. In IEEE Transactions on Computers, vol. 39, pp. 1175-1185, Sep. 1990.

Priority Inheritance

Old



New



Summary

- Race condition
  - A situation when two or more threads **read and write** shared data at the same time
- Critical section
  - Code sections of potential race conditions
- Mutual exclusion
  - If a thread executes its critical section, *no other threads* can enter their critical sections
- Peterson's solution
  - Software only solution providing mutual exclusion

Summary

- Spinlock
  - Spin on waiting
  - Use synchronization instructions (test&set)
- Mutex
  - Sleep on waiting
- Semaphore
  - Powerful tool, but often difficult to use
- Monitor
  - Powerful and (relatively) easy to use

Quiz

```
Mutex lock;
Condition full, empty;

produce (item)
{
    _____________
    while (queue.isFull())
        empty.wait(&lock);
    queue.enqueue(item);
    full.signal();
    _____________
}

consume()
{
    _____________
    while (queue.isEmpty())
        _____________
    item = queue.dequeue(item);
    _____________
    _____________
    return item;
}
```

```
Semaphore mutex = 1, full = 0,
empty = N;

produce (item)
{
    _____________;
    P(&mutex);
    queue.enqueue(item);
    V(&mutex);
     _____________;
}

consume()
{
    _____________;
    P(&mutex);
    item = queue.dequeue();
    V(&mutex);
    _____________;
    return item;
}
```

Quiz

```
Mutex lock;
Condition full, empty;

produce (item)
{
    lock.acquire();
    while (queue.isFull())
        empty.wait(&lock);
    queue.enqueue(item);
    full.signal();
    lock.release();
}

consume()
{
    lock.acquire();
    while (queue.isEmpty())
        full.wait(&lock);
    item = queue.dequeue(item);
    empty.signal();
    lock.release();
    return item;
}
```

```
Semaphore mutex = 1, full = 0,
empty = N;

produce (item)
{
    P(&empty);
    P(&mutex);
    queue.enqueue(item);
    V(&mutex);
    V(&full);
}

consume()
{
    P(&full);
    P(&mutex);
    item = queue.dequeue();
    V(&mutex);
    V(&empty);
    return item;
}
```