Prof. Philip Koopman

Carnegie Mellon University

Electrical & Computer ENGINEERING

Race Conditions

"The race is not always to the swift, nor the battle to the strong, but that's the way to bet."

– Hugh E. Keough

Race Conditions

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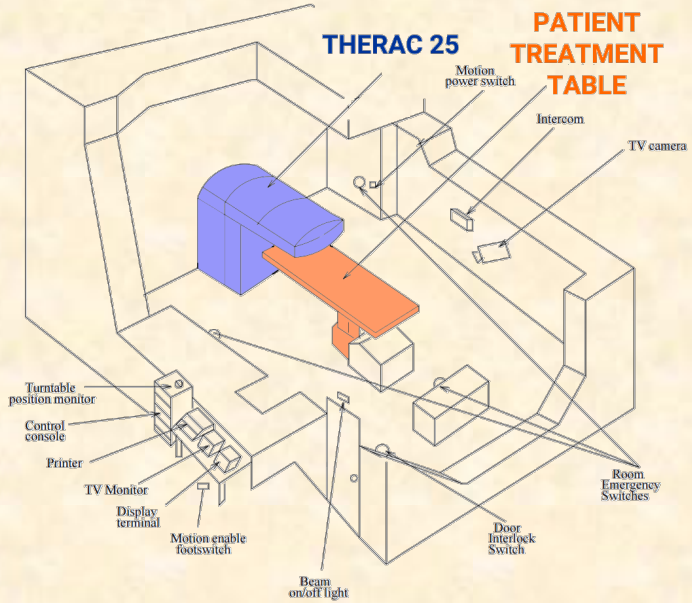
- Anti-Patterns for Race Conditions:
  - Unprotected access to shared variables
  - Shared variables not declared volatile
  - Not accounting for interrupts and task switching in timing analysis
  - Ignoring non-reproducible faults
- Race condition: multiple threads compete
  - Computation outcome depends upon timing
    - Usually it is infrequent and hard to debug
  - Concurrent access to shared variable
    - Need to lock shared resources
  - Not accounting for multi-tasking
    - Task switch or interrupt causes delays
    - "Starvation" and priority inversion

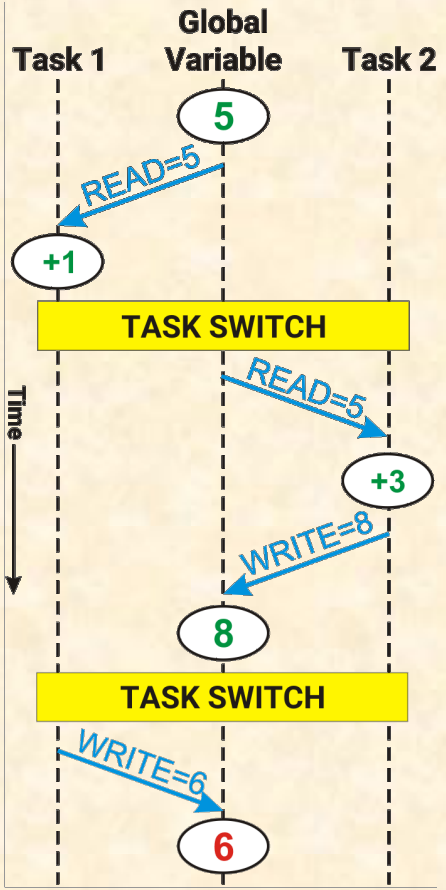


(1985 – 1987) THERAC 25
Software-Controlled Radiation Therapy Mishaps

Problems included:
- Operators "too fast" on keyboard (8 second window)
- Bypassed safety checks when counter rolled over to 0

Concurrency Management Bugs

- CPU switches among its tasks (multi-tasking)
  - What if switching happens at the wrong time?
- Concurrency bugs due to shared resources
  - Example: shared global variable, two tasks
    - Task 1 reads shared variable and computes new value
    - Task 2 preempts task 1, updates shared variable
    - Task 1 resumes, over-writing task 2's update
  - Results of concurrency bug depend upon ordering
    - Usually bug won't manifest (example: 9)
    - Sometimes bug will result in wrong value (example: 6, 8)



Mutex For Concurrency Management

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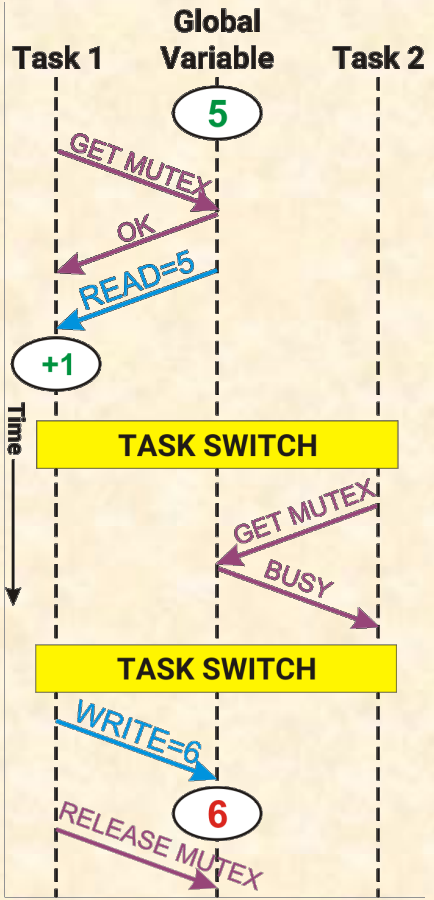
- Easy solution for concurrency bug:
  - Disable interrupts when touching shared variable
    - Inhibits task switches
    - But, need to keep it very brief to avoid timing problems
- To hold resources longer, use a mutex
  - "Mutual Exclusion" flag; True=busy / False=available
  - To access shared resource:
    - Get the mutex (wait for it to be false, then set to true)
    - Access shared resource
    - Other tasks will wait while mutex is locked (resource busy)
    - When done, set mutex to false to release resource
  - Mutexes are themselves a special type of shared variable
    - And therefore subject to race conditions!
    - Getting them right is tricky; let the RTOS do this for you



Bounded Priority Inversion

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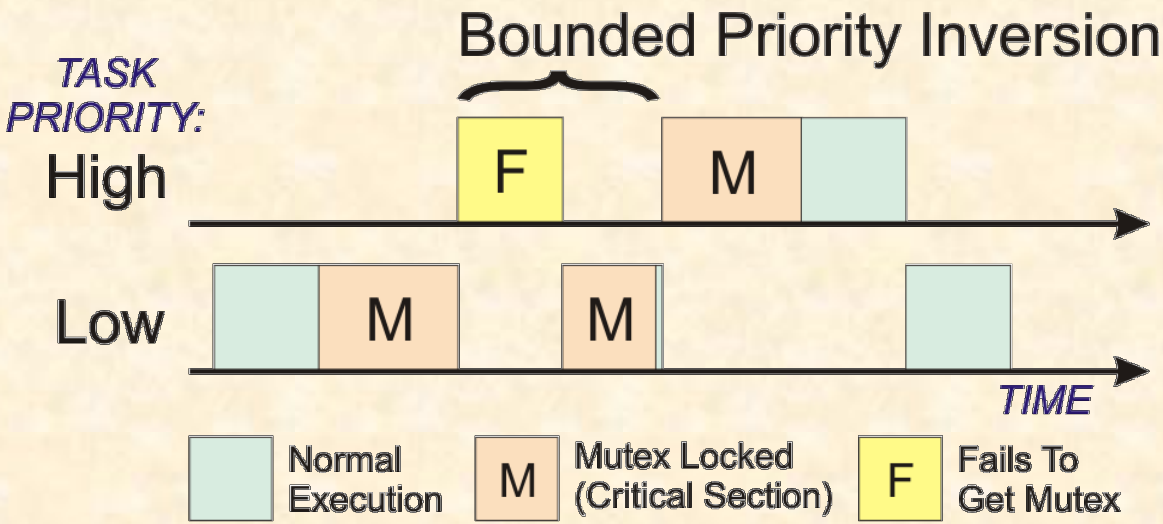
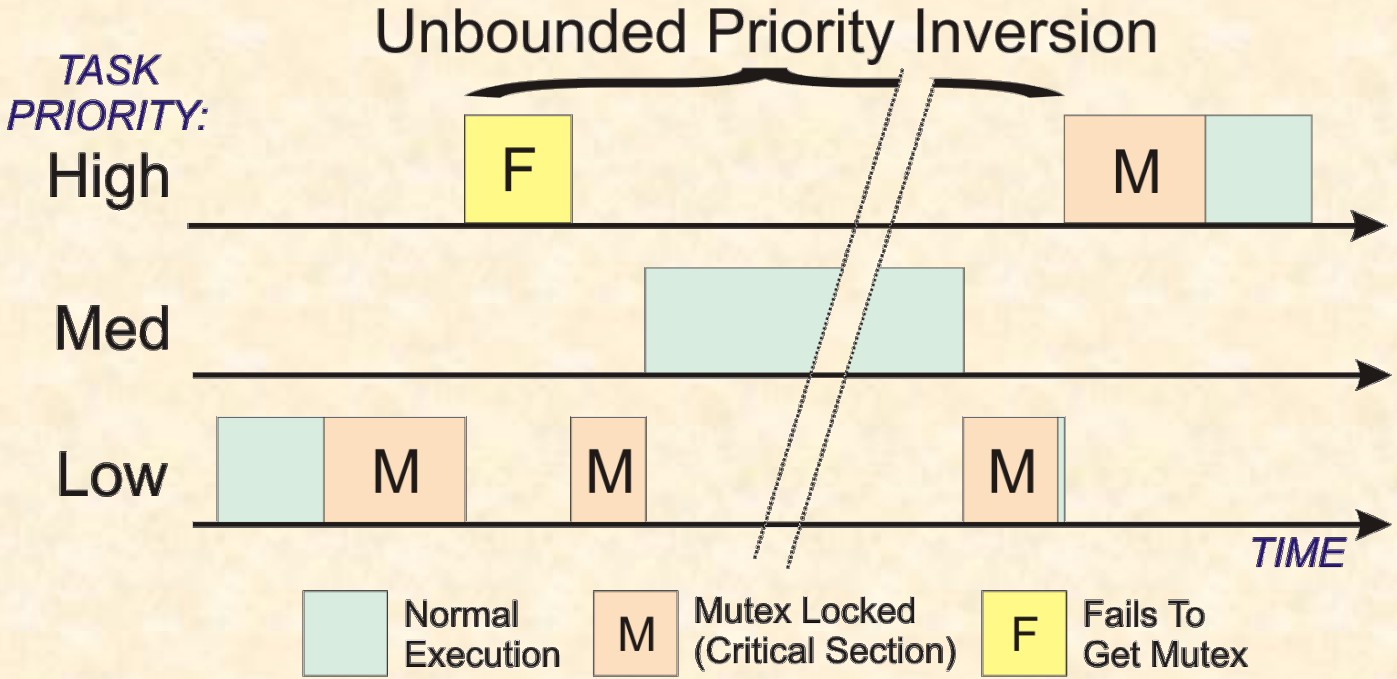
- Minimize time interrupts are disabled
  - Disabled task switching delays task switching
  - Blocking Time: high priority tasks can miss deadlines



- Mutexes indirectly cause blocking time
  - Priority Inversion: low priority task blocks high priority task
    - Locked mutex prevents high priority task from making progress
    - Only affects tasks that actually use mutex, not all tasks
    - BUT… there is a critical problem (next slide)

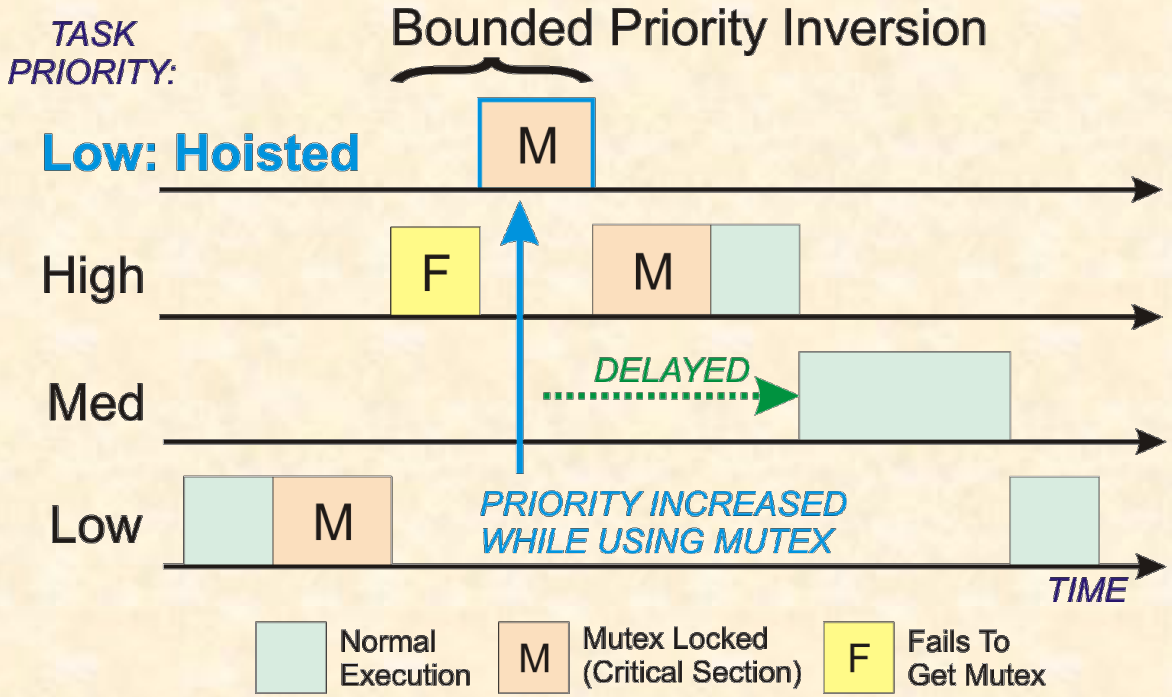
Unbounded Priority Inversion

- Priority inversion can be unbounded for three tasks:
  - Medium priority task blocks high task *without ever touching mutex:*



Priority Inheritance

- Solution to unbounded priority inversion: priority inheritance
  - Task priority elevated when locking mutex; restored when frees mutex
  - This is complicated! Let the RTOS handle it



Mars Pathfinder Incident

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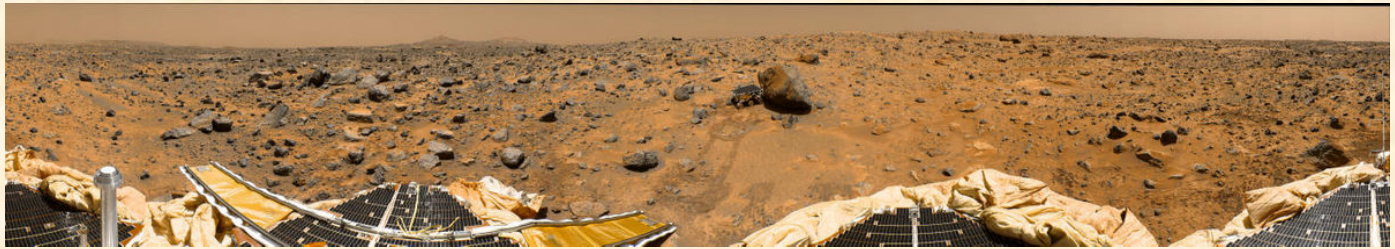
- July 4, 1997 – Pathfinder lands on Mars
  - First US Mars landing since Vikings in 1976; first rover
- But, a few days later…
  - Multiple system resets occur via VxWorks RTOS
    - Watchdog timer saves the day! Sets system to safe state
    - Reproduced on ground; patch uploaded to fix it
  - Scenario pretty much identical to High/Medium/Low priority picture
    - Developers didn't have Priority Inheritance turned on!
    - Why? "The data bus task executes very frequently and is time-critical -- we shouldn't spend the extra time in it to perform priority inheritance" [Jones07]

Sojourner Rover



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Best Practices Avoiding Race Conditions

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- Always consider task interactions
  - What if task switches at a bad time?
  - What if tasks read data at different times?
  - What if half-formed data structure is read?
  - What if multiple writers compete for data?
  - Use RTOS services to help
- Pitfalls:
  - Failing to use interrupt masking or mutexes
    - Failing to deal with unbounded priority inversion
    - Failing to declared shared variables volatile
  - Assuming that non-reproducible problems aren't bugs
  - Trying to write your own bullet-proof concurrency services

https://goo.gl/AjS3cX

18-348 Lecture explaining mutex operation at: https://goo.gl/wH9Q44