Priority Inheritance Protocol Proved Correct

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- Verification of PCP in PVS (2000)
  - A related protocol
  - Priority Ceiling Protocol

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- Some mentioning the complication

Some excerpts

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"I observed in the kernel code (to my disgust), the Linux PIP implementation is a nightmare: extremely heavy weight, involving maintenance of a full wait-for graph, and requiring updates for a range of events, including priority changes and interruptions of wait operations."

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- Formal specification at appropriate abstract level, convenient for:
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- Theorems usable to guide implementation, critical point:
  - Understanding the relationship with real OS code
  - Not yet formalized

Real-Time OSes

- Purpose: gurantee the most urgent task be processed in time
- Processes have priorities
- Resources can be locked and unlocked

Problem

High-priority process

Low-priority process

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High-priority process

Medium-priority process

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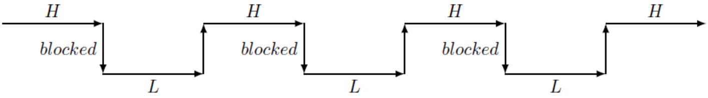
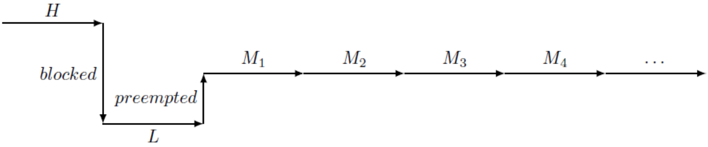
- Priority Inversion $\stackrel{\text{def}}{=}$ H < L
- avoid indefinite priority inversion

Priority Inversion

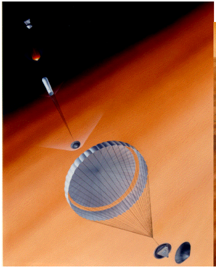
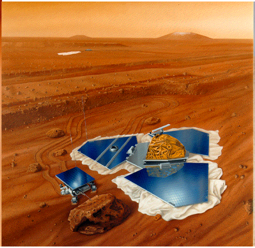
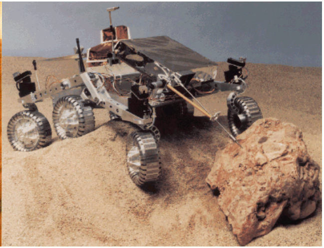


Prioirty Inversion



Indefinite Priority Inversion

Mars Pathfinder Mission 1997



Solution

Priority Inheritance Protocol (PIP):

High-priority process

Medium-priority process

Low-priority process

(temporarily raise its priority)

A Correctness "Proof" in 1990

- a paper⋆ in 1990 "proved" the correctness of an algorithm for PIP

  ... after the thread (whose priority has been raised) completes its critical section and releases the lock, it "returns to its original priority level".

⋆ in IEEE Transactions on Computers

High-priority process 1

High-priority process 2

Low-priority process

High-priority process 1

High-priority process 2

Low-priority process

- Solution:
  Return to highest remaining priority

Event Abstraction

- Use Inductive Approch of L. Paulson

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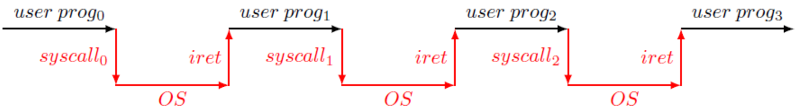
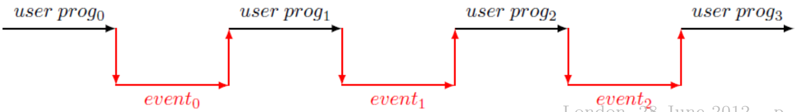


Execution of OS



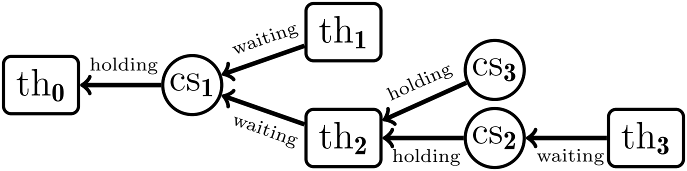
Events

Create thread priority
Exit thread
Set thread priority
Lock thread cs
Unlock thread cs

Precedences

$$\text{prec th s} \stackrel{\text{def}}{=} (\text{priority th s}, \text{last\_set th s})$$

RAGs



RAG wq $\stackrel{\text{def}}{=}$ {(T th, C cs) | waits wq th cs} ∪ {(C cs, T th) | holds wq th cs}

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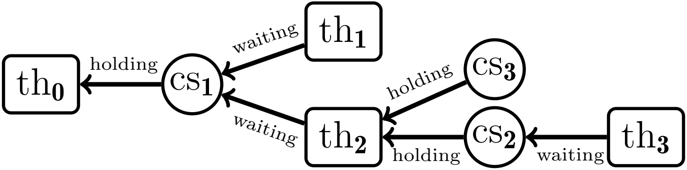

$$\text{RAG wq} \stackrel{\text{def}}{=} \{(\text{T th, C cs}) \mid \text{waits wq th cs}\} \cup \{(\text{C cs, T th}) \mid \text{holds wq th cs}\}$$

Good Next Events

$$\frac{\text{th} \notin \text{threads s}}{\text{step s (Create th prio)}}$$

$$\frac{\text{th} \in \text{running s} \quad \text{resources s th} = \varnothing}{\text{step s (Exit th)}}$$

$$\frac{\text{th} \in \text{running s}}{\text{step s (Set th prio)}}$$

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$$\frac{\text{th} \in \text{running s} \qquad (\text{C cs, T th}) \notin (\text{RAG s})^+}{\text{step s (P th cs)}}$$

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It does not matter which process gets a released lock.

Implementation

s = current state; s' = next state = e#s

When e = Create th prio, Exit th

- RAG s' = RAG s
- No precedence needs to recalculate

Implementation

s = current state; s' = next state = e#s

When e = Set th prio

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When e = Unlock th cs where there is a thread to take over

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  - Refinement to real code and relation between implemenations