

15-410

“Delayed Impact”

Scheduling on Mars

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What Happened On Mars?

Mars Pathfinder probe (1997)

Nice launch

Nice transit

Nice de-orbit

Nice thump-down (inflatable air-bag)

Nice rover disembarkation

Nice rover *spontaneous reboots*

Internal Architecture

“Information bus” (blackboard/whiteboard/...)

- Housekeeping by high-priority bus manager thread

Meteorological data gathering

- Occasional activity
- Low-priority weather data thread

Communication with Earth

- Medium-priority communication thread

Watchdog thread

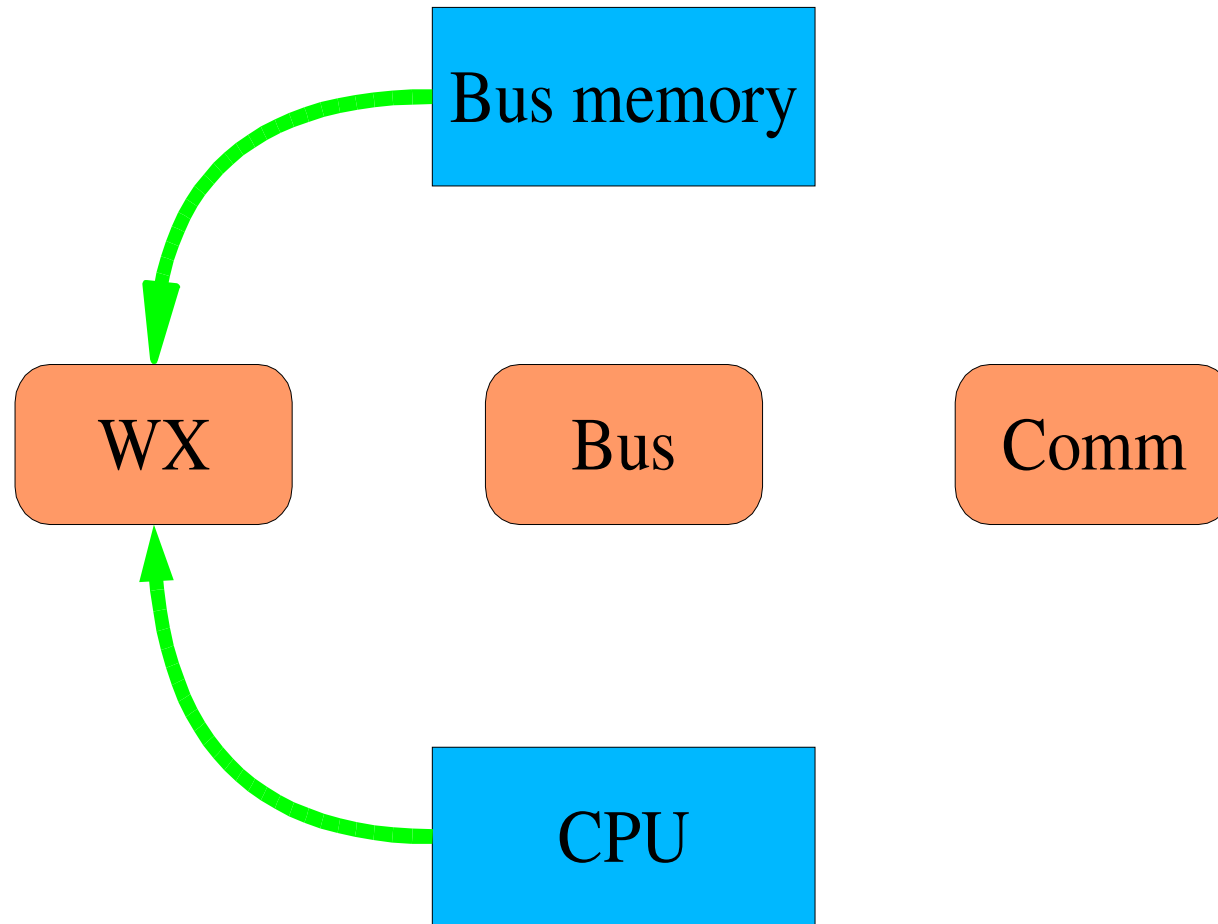
- “Too quiet”? *Reboot*
- “Shouldn't happen” event was happening repeatedly

What could go wrong?

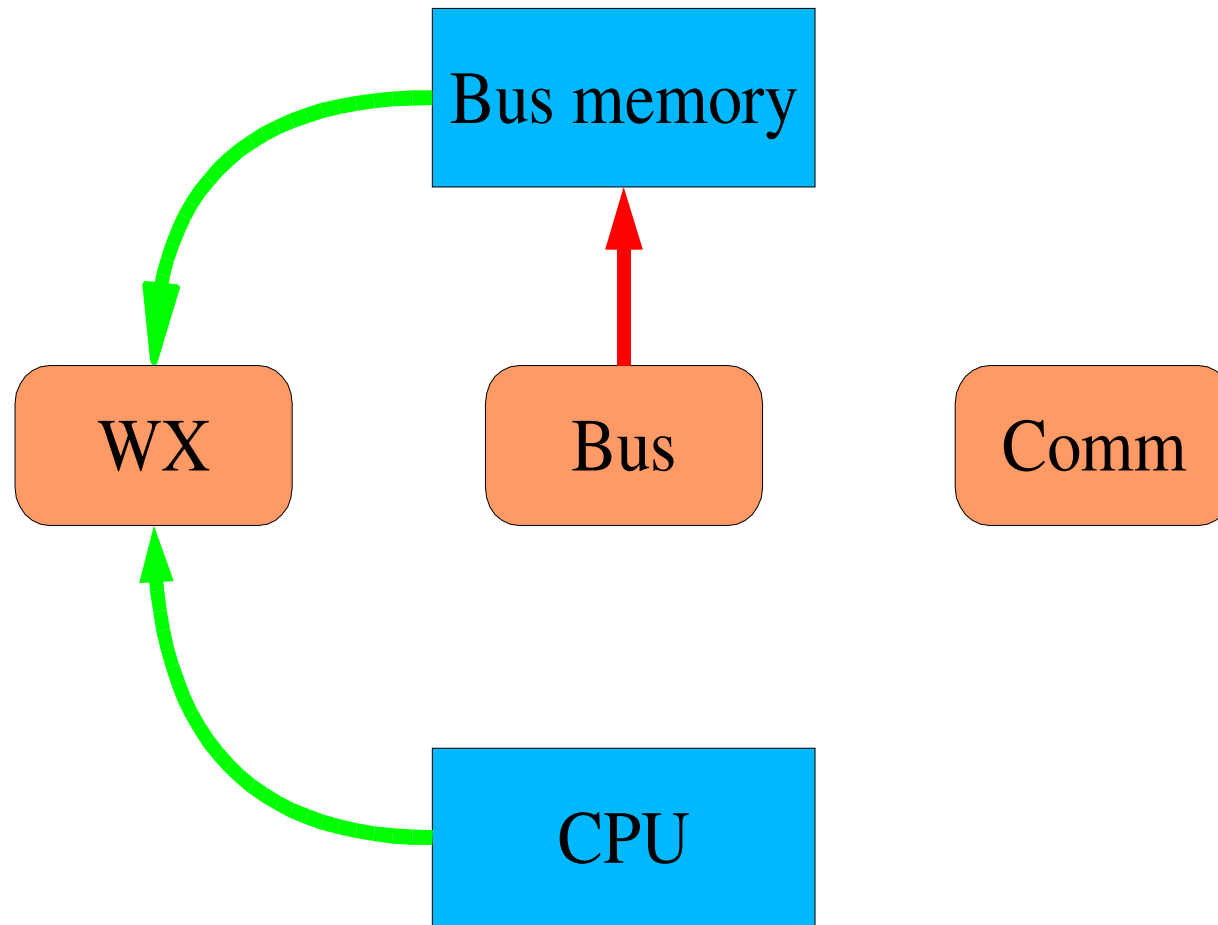
Weather data locks “bus” memory to publish

High-priority bus manager must wait

What could go wrong?



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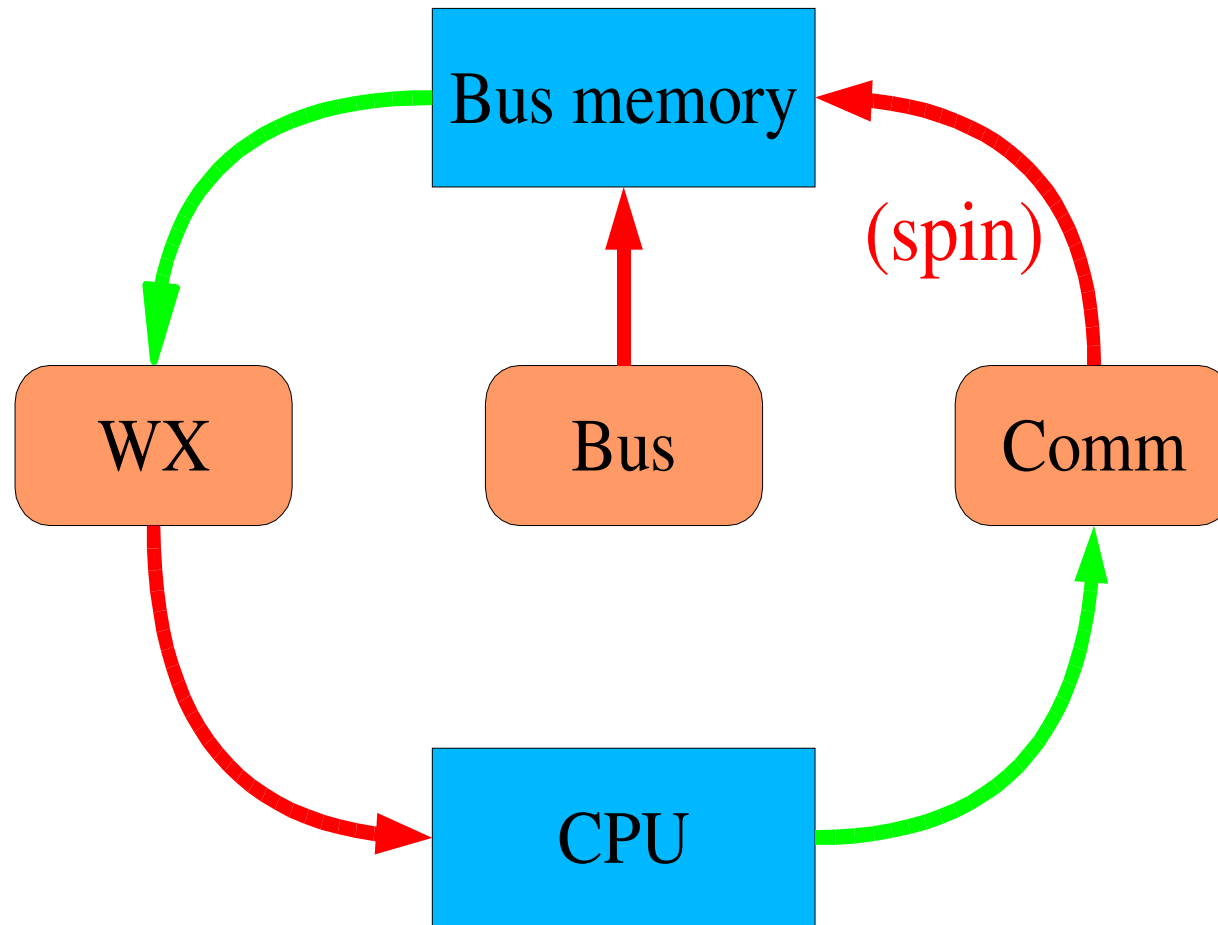
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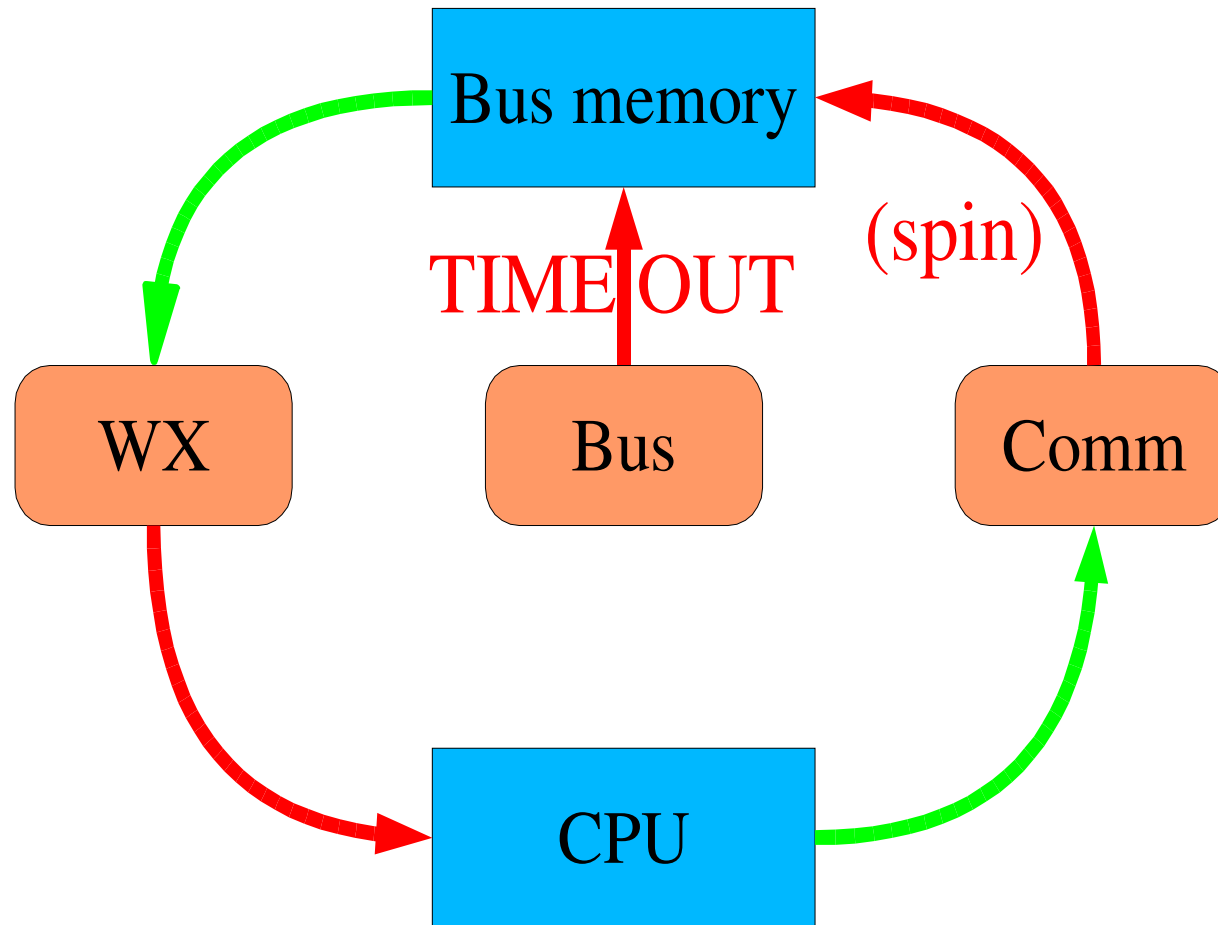
Interrupt makes **communication** runnable

- “Medium” priority, so preempts **weather data**
- **communication** then attempts to lock bus
- Highest-priority runnable task, so it spin-waits

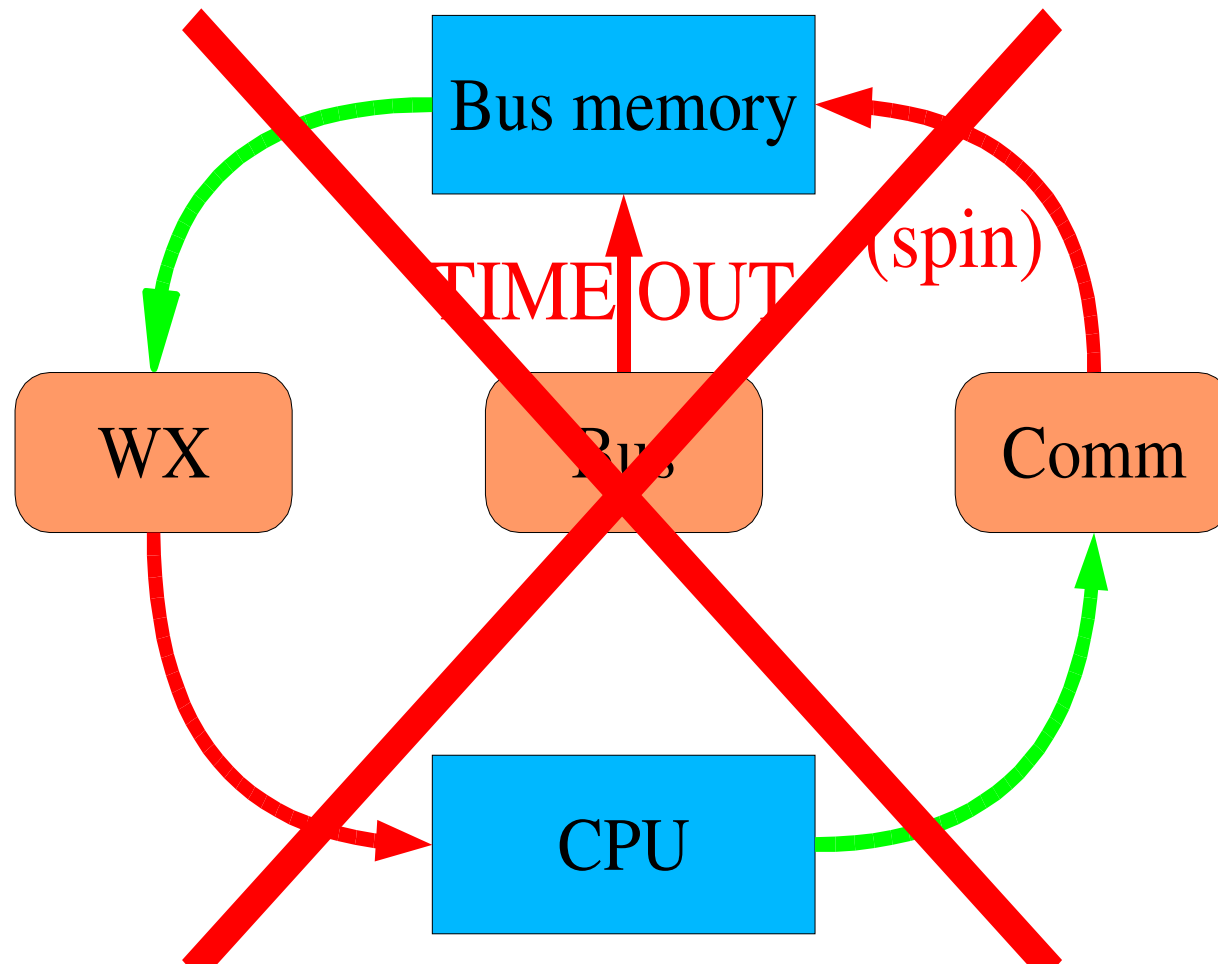
What could go wrong?



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What could go wrong?



Solution?

VxWorks has two mutex flavors

- Normal
- *Priority Inheritance*

Rover code initialized flavors via global variables

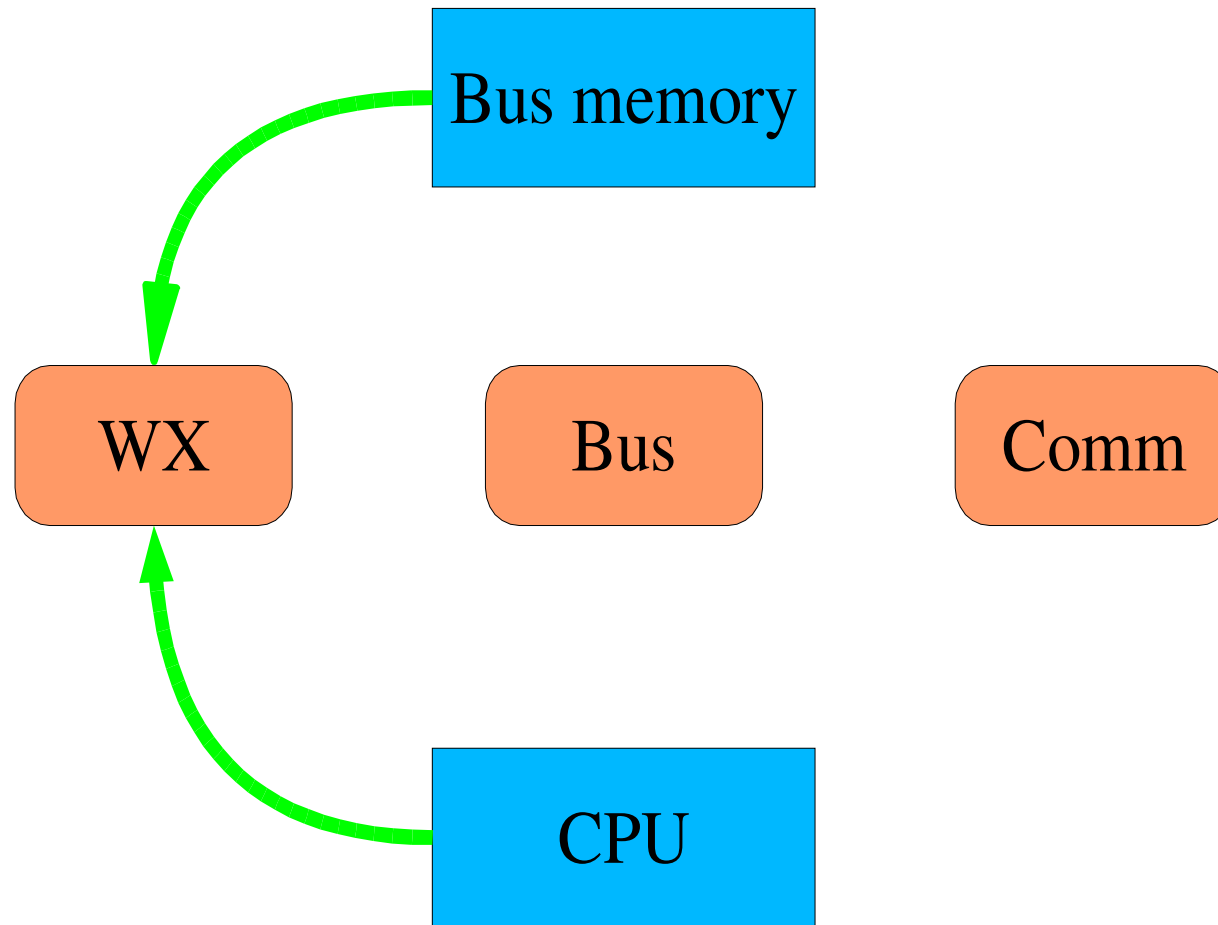
- `mutex_init(&bus_mem_mutex, bus_mutex_flavor);`

Rover flew with “debug” interpreter enabled

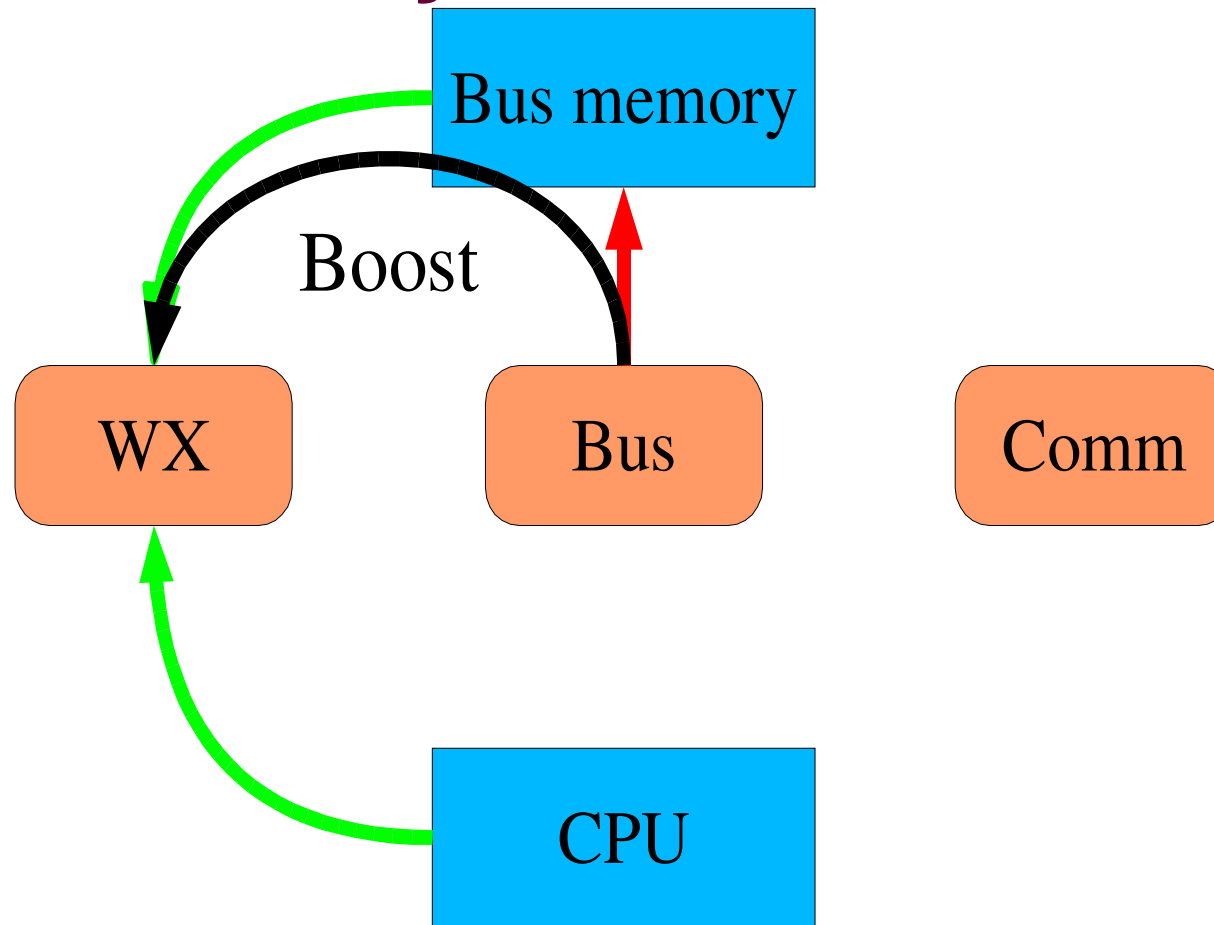
- Read-eval loop waiting for commands
- `% assign bus_mutex_flavor = MF_P_INHERIT`

All fixed

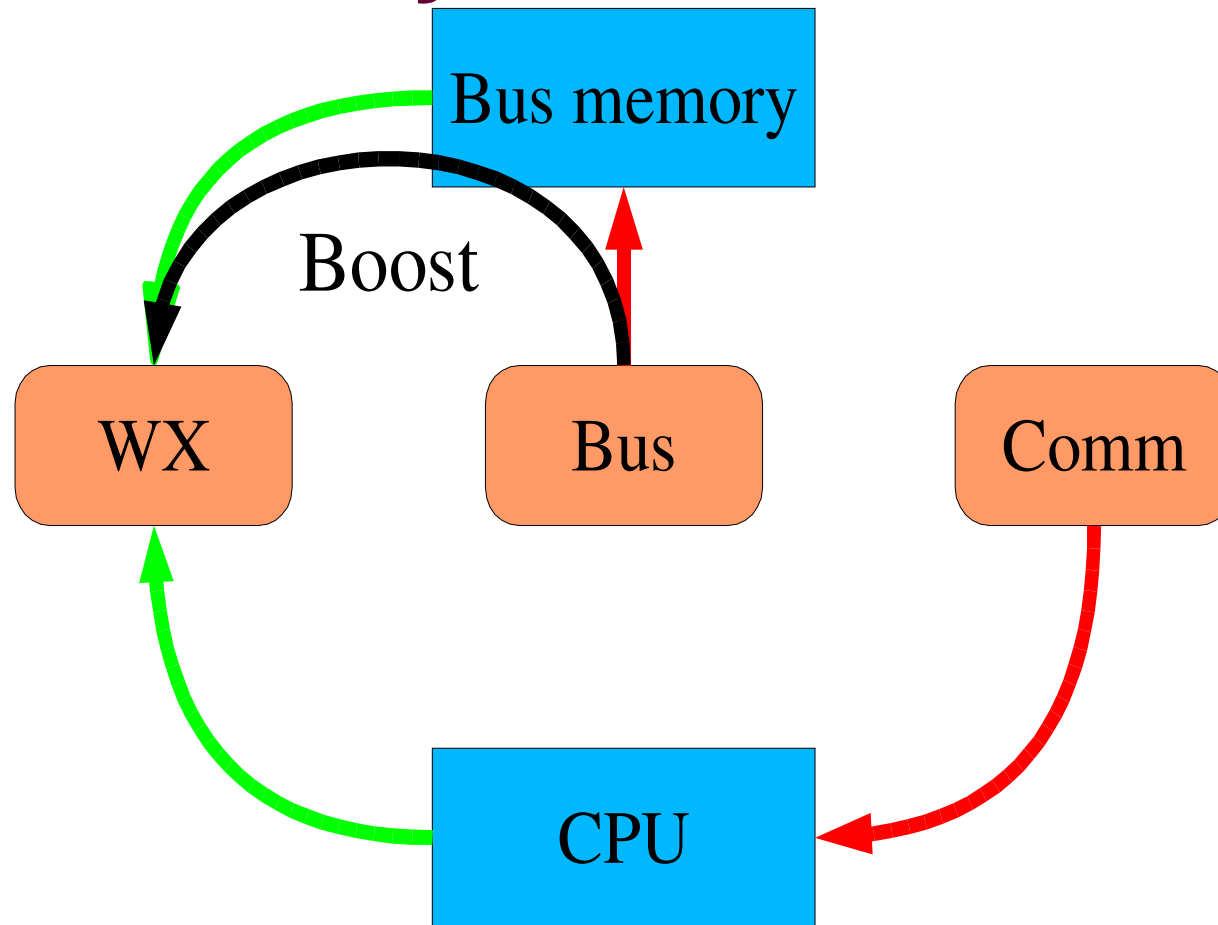
Weather Thread is Busy



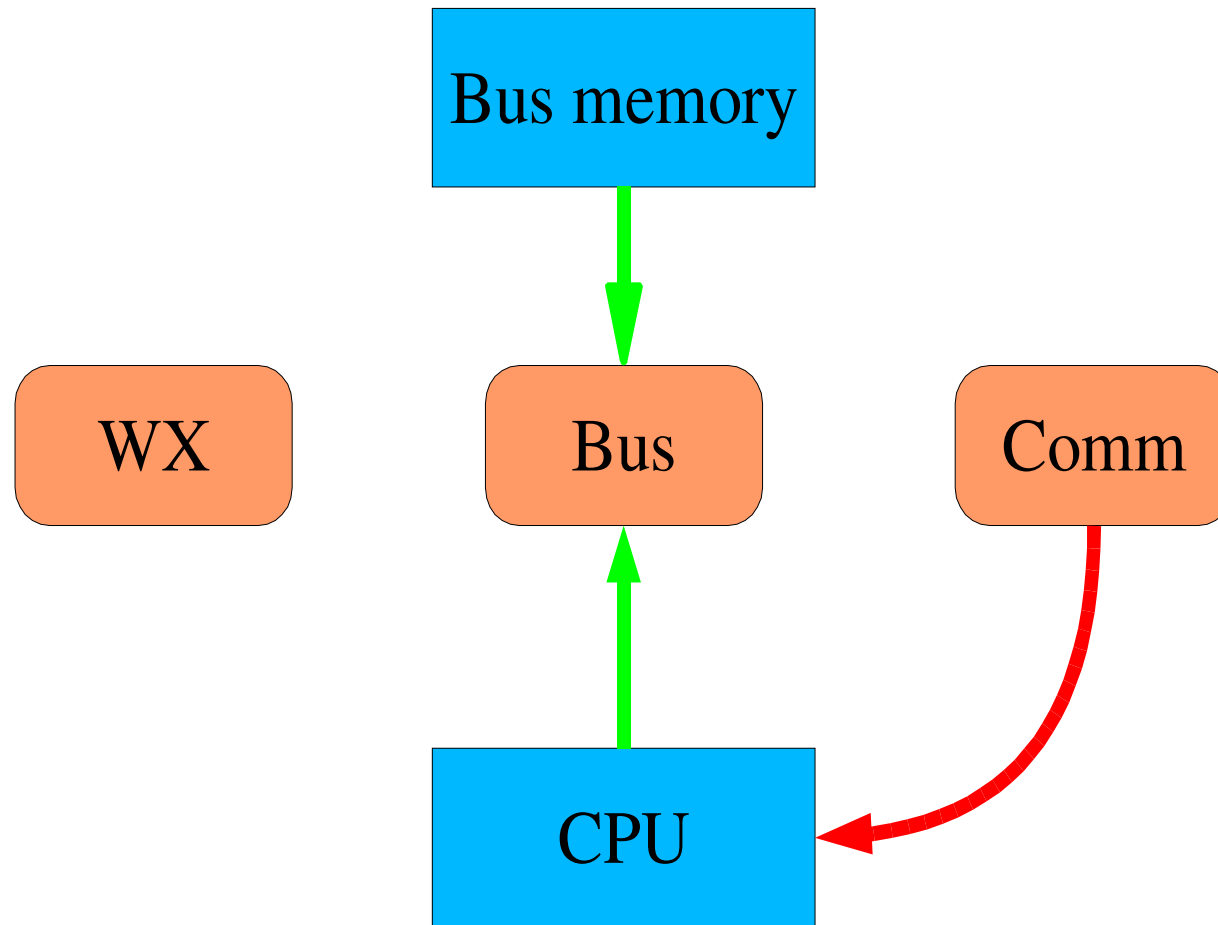
Bus Thread Waits: Priority Inherited by WX



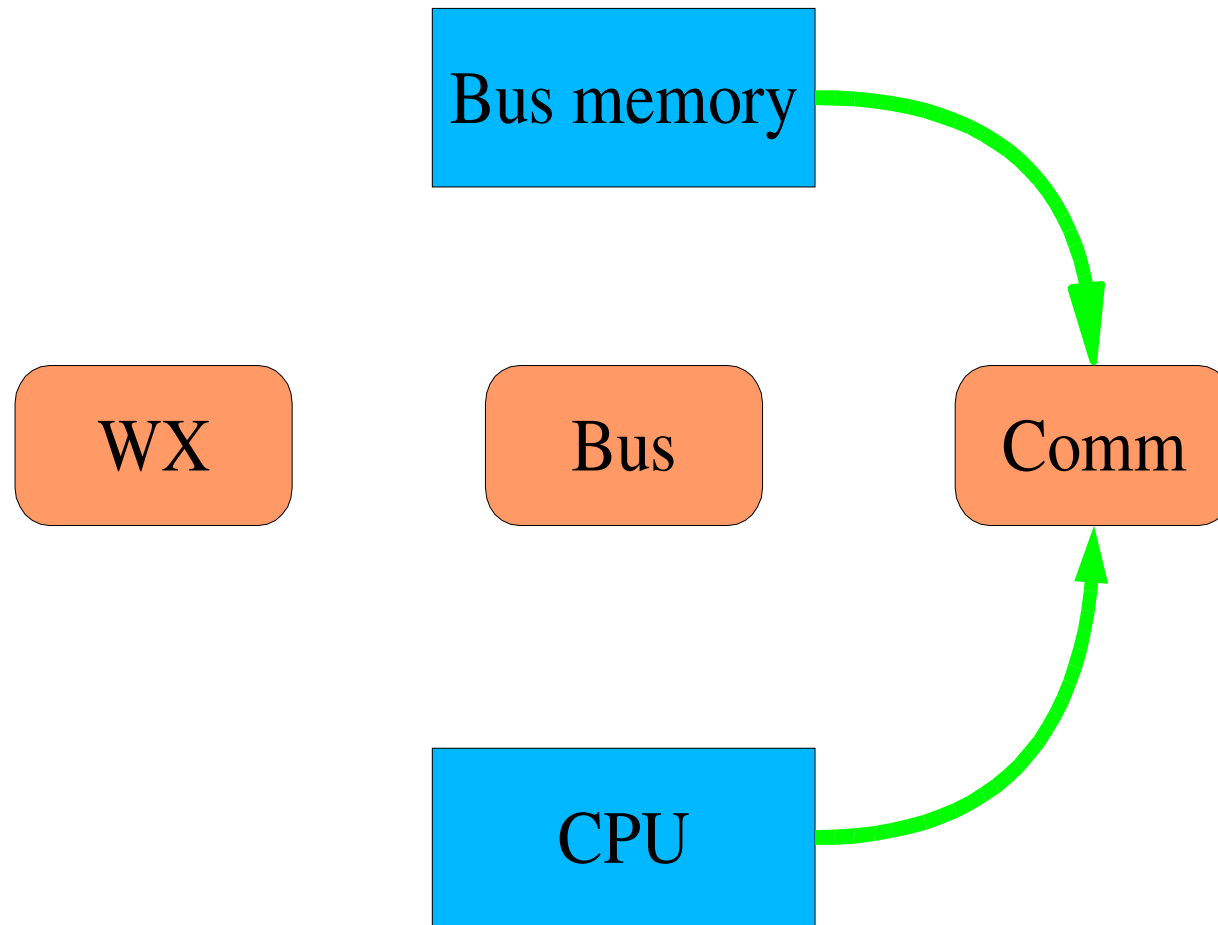
Bus Thread Waits: Priority Inherited by WX



“Low-Priority” Thread Finishes Fast



“Low-Priority” Thread Finishes Fast



History of an Idea

Priority Inheritance Protocols: An Approach to Real-Time Synchronization

- IEEE Transactions on Computers 39:9
 - Lui Sha (CMU SEI)
 - Rangunathan Rajkumar (IBM Research $\Rightarrow$ CMU ECE)
 - John Lehoczky (CMU Statistics)

History of an Idea

Events

- 1987-12 “Manuscript” received
- 1988-05 Revised
- 1990-09 Published
- 1997-07 Rescues Mars Pathfinder

History courtesy of Mike Jones

- <http://www.cs.cmu.edu/~raj कुमार/mars.html>