

# **15-410**

*“Delayed Impact”*

## **Scheduling on Mars**

**Mar. 16, 2005**

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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

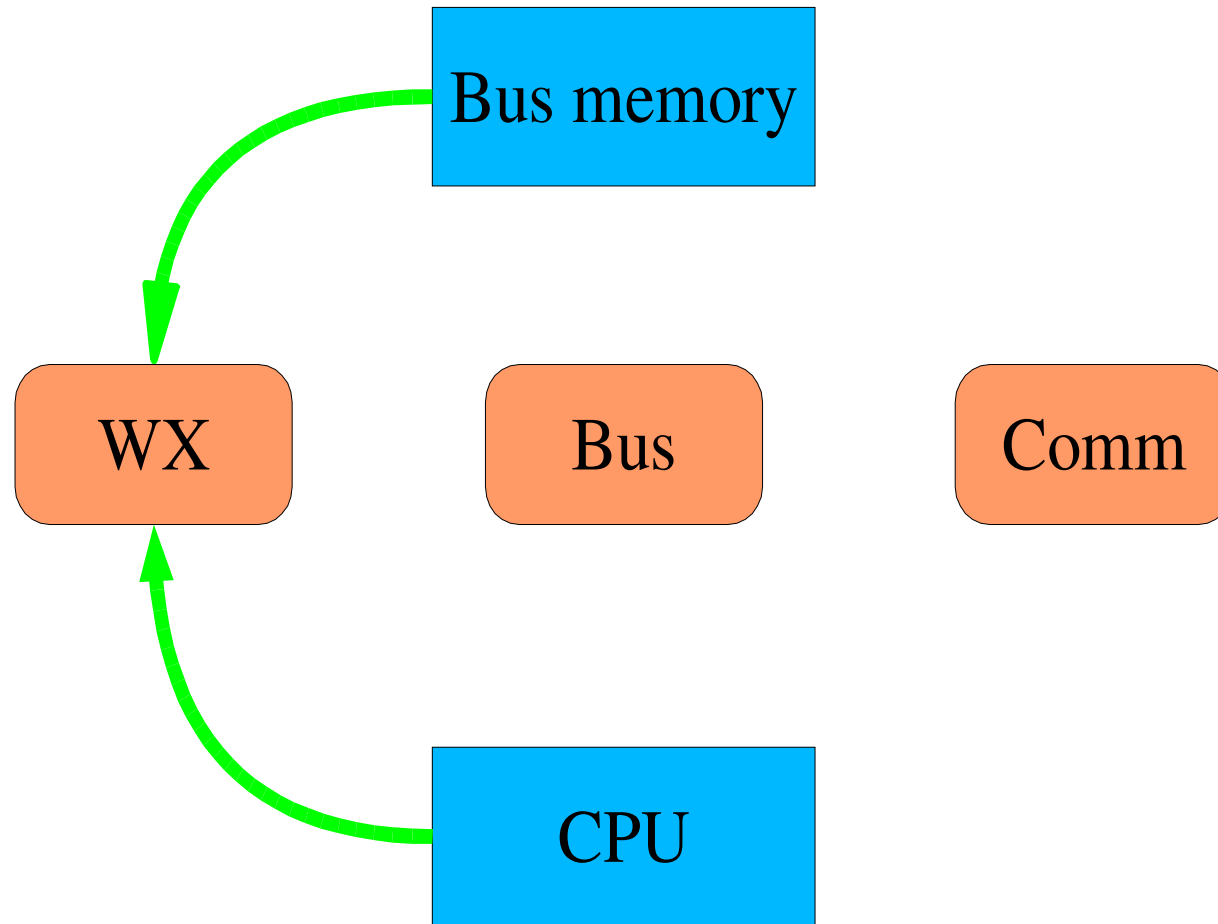
- “Too quiet”? *Reboot*
- “Shouldn't happen” event was happening repeatedly

# What could go wrong?

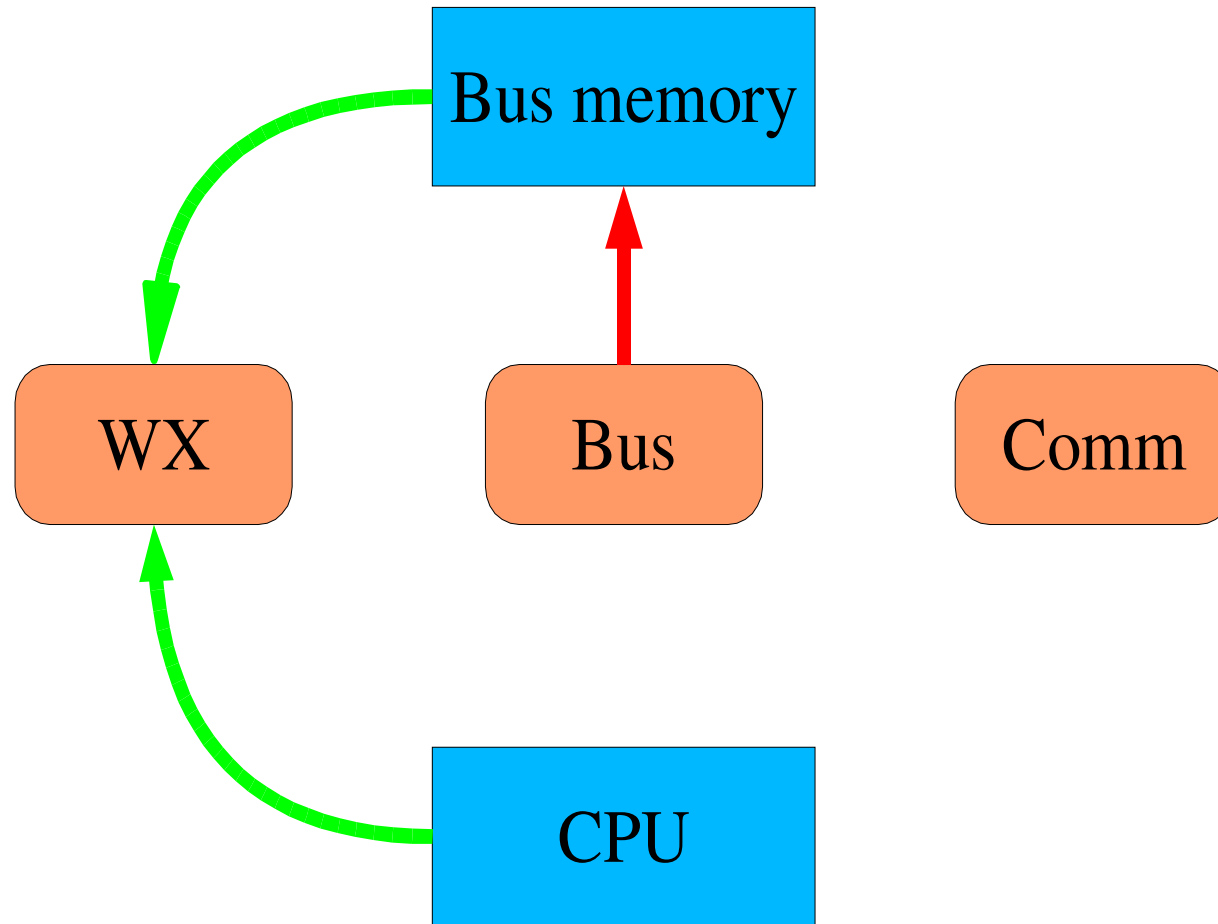
**Weather data** locks “bus” memory to publish reading

**High-priority bus manager** must wait

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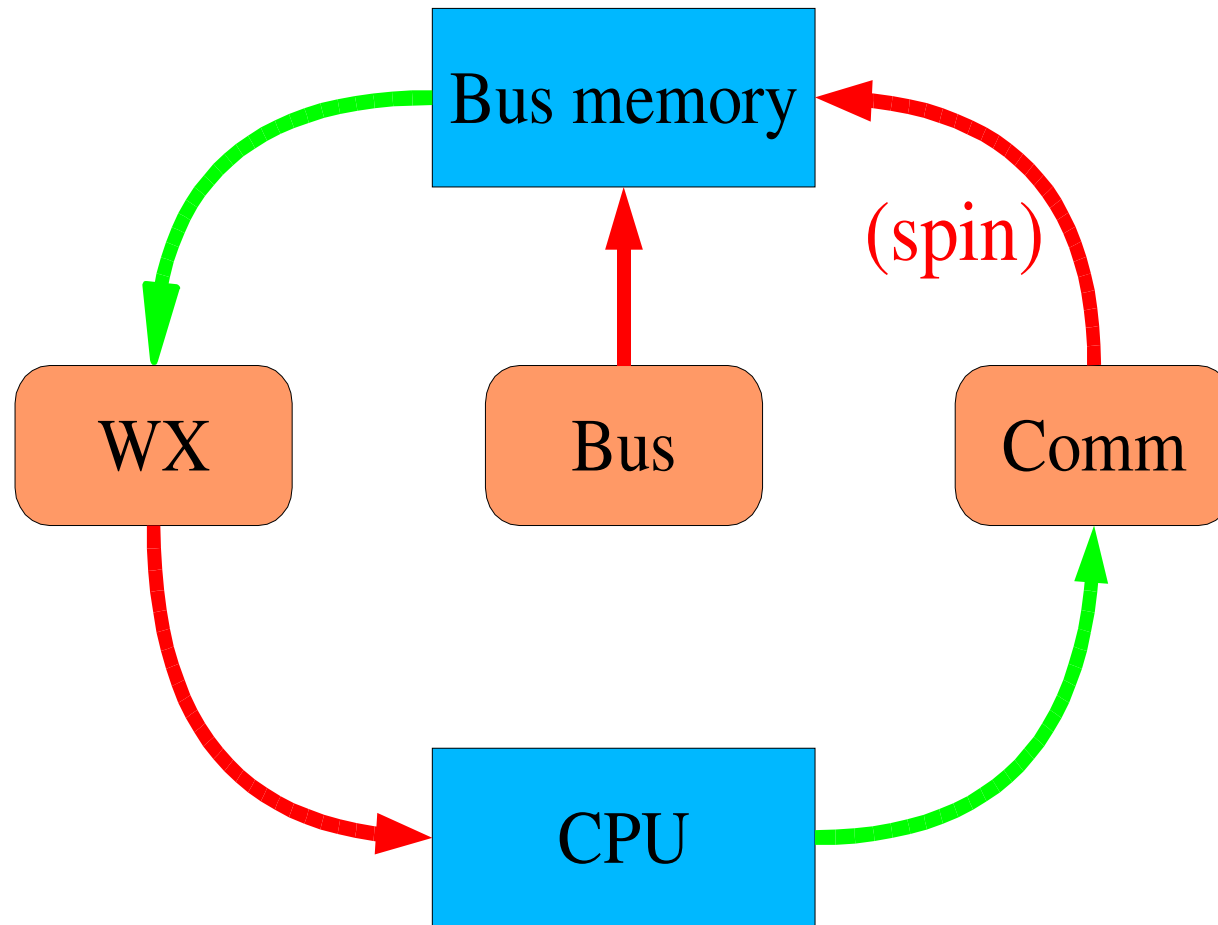
**Weather data** locks “bus” memory to publish

**High-priority bus manager** must wait

***Interrupt*** makes **communication** runnable

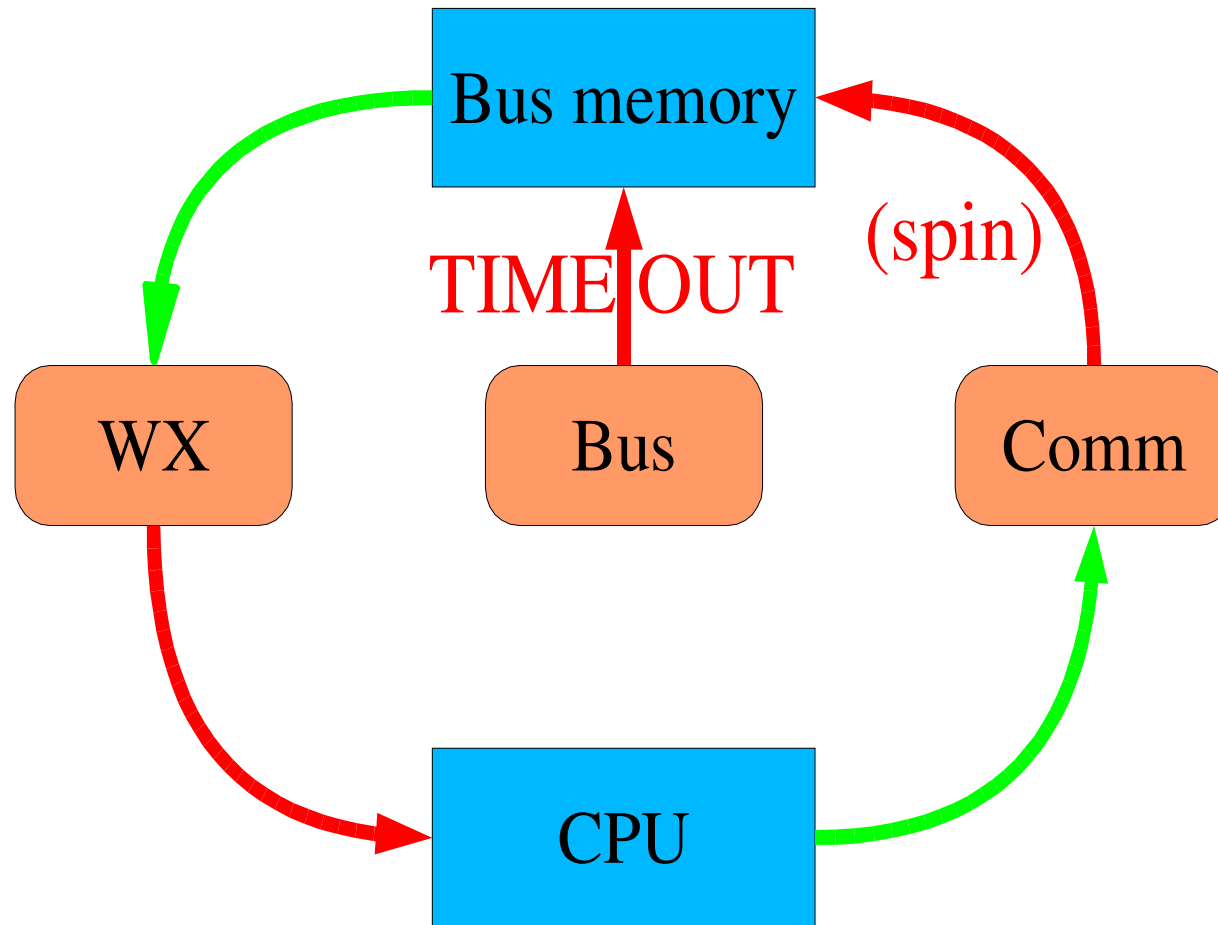
- “Medium” priority, so preempts **weather data**
- **communication** then attempts to lock bus
- Highest-priority runnable task, so it spin-waits

# What could go wrong?

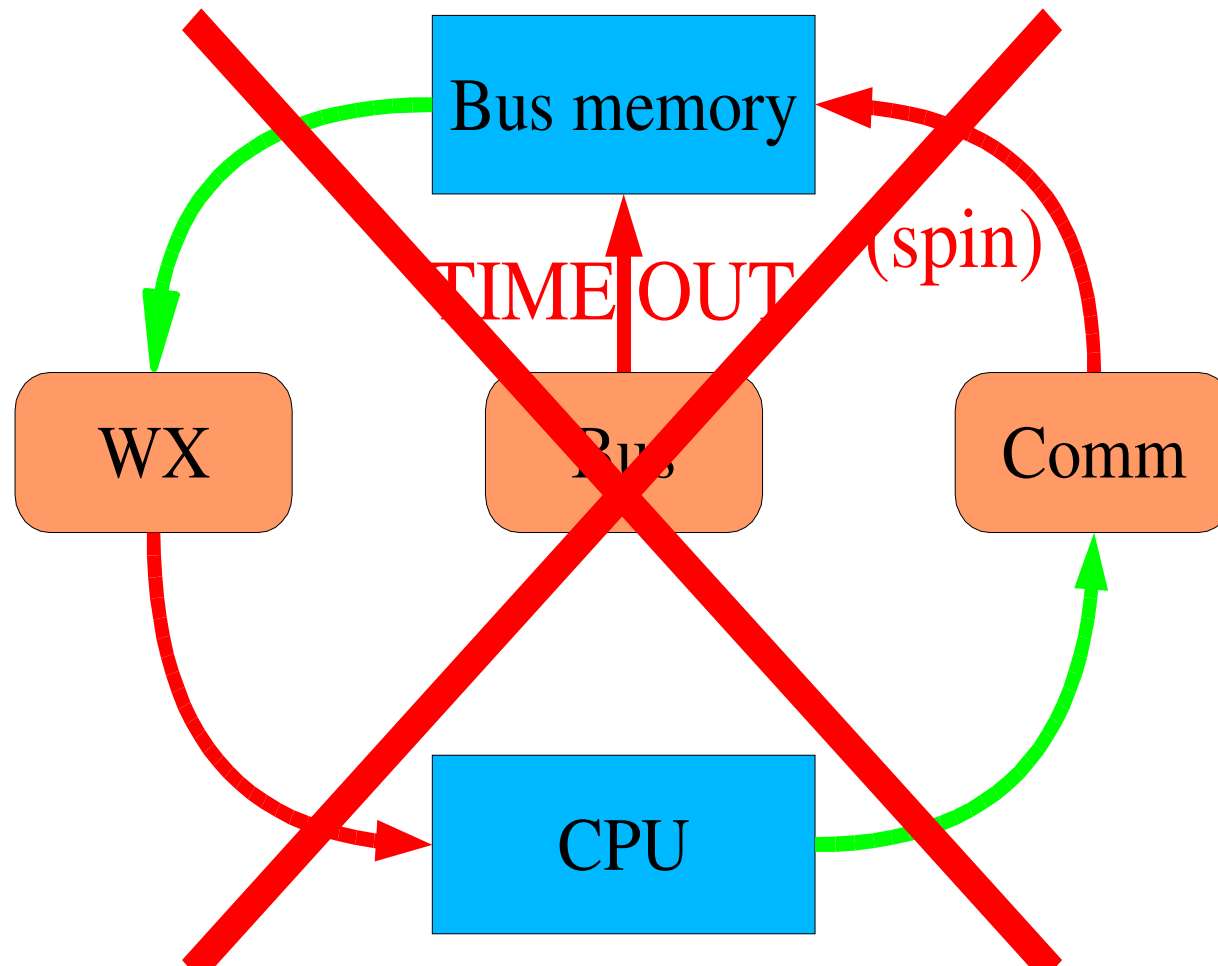




# What could go wrong?



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# Solution?

## VxWorks has two mutex flavors

- Normal
- *Priority Inheritance*

## Rover code initialized flavors via global variables

```
mutex_init(&bus_mem_mutex, bus_mutex_flavor);
```

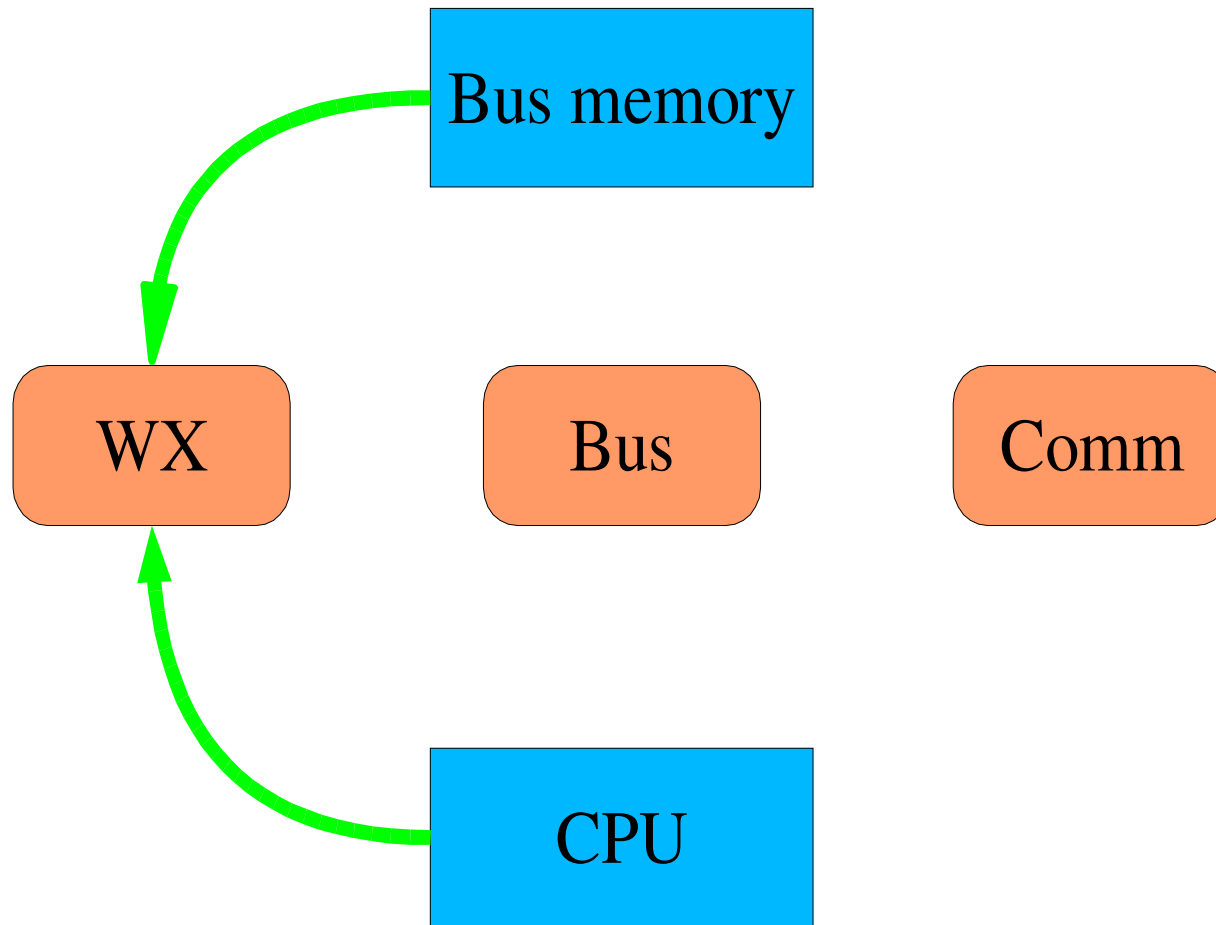
## Rover flew with “debug” interpreter enabled

- Read-eval loop waiting for commands

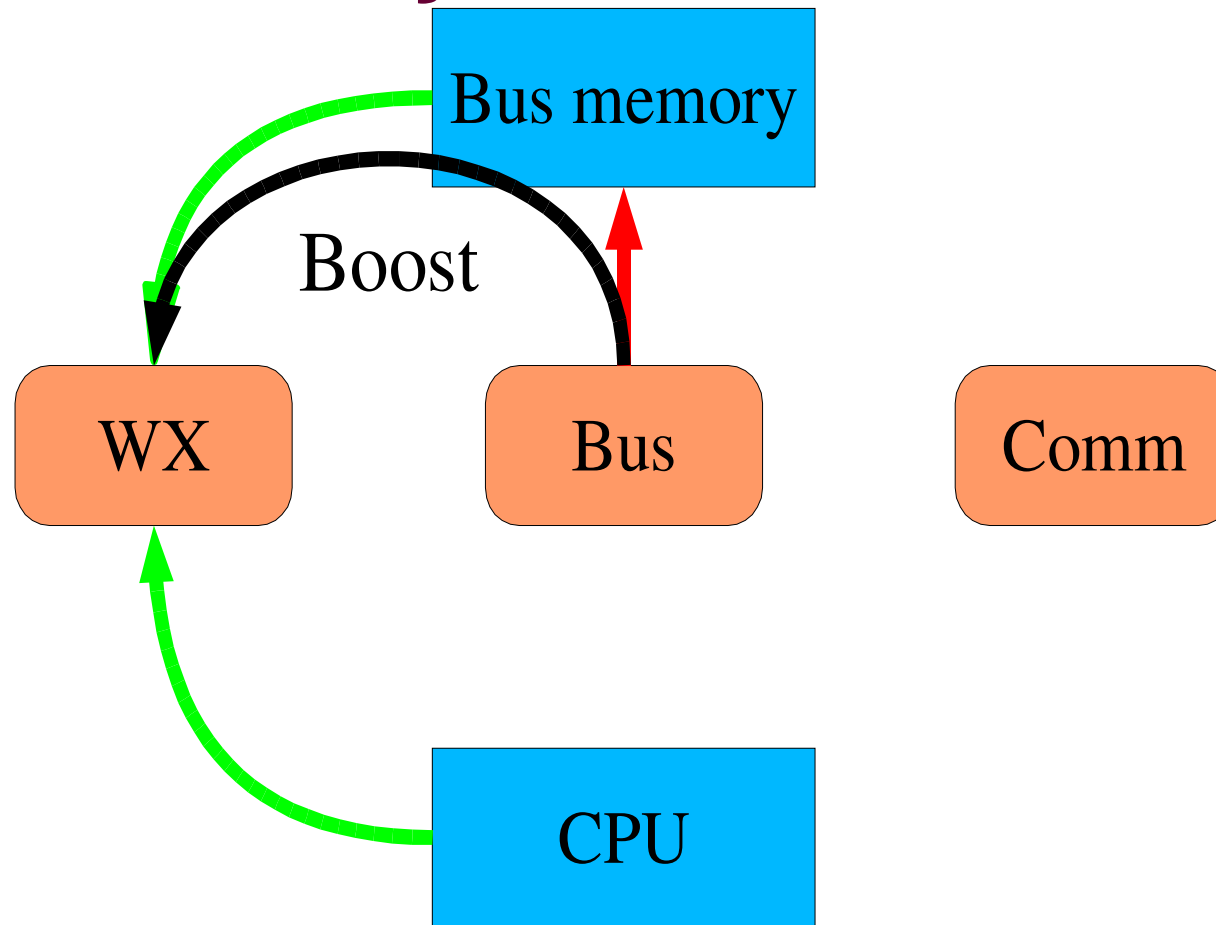
```
% assign bus_mutex_flavor = MF_P_INHERIT
```

## All fixed

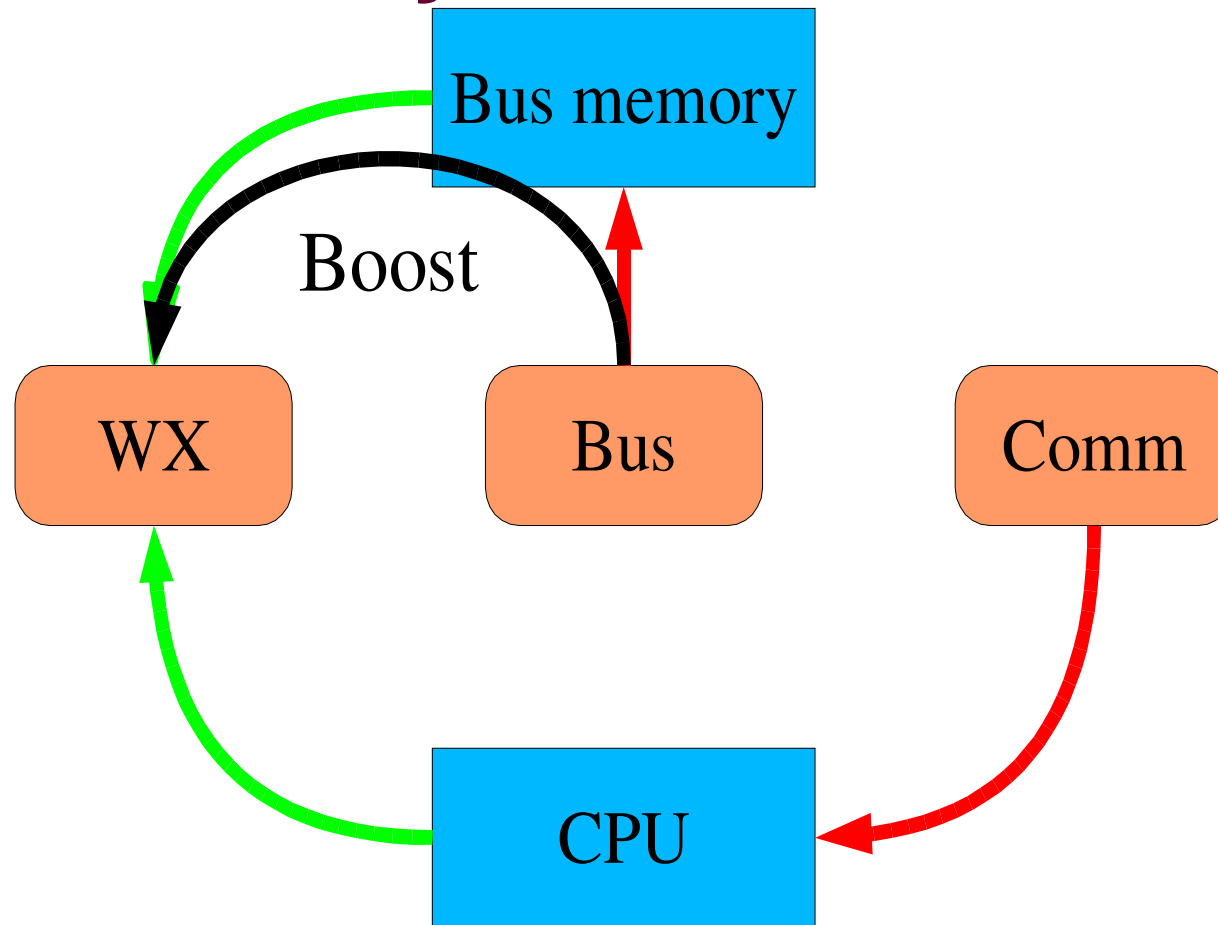
# Weather Thread is Busy



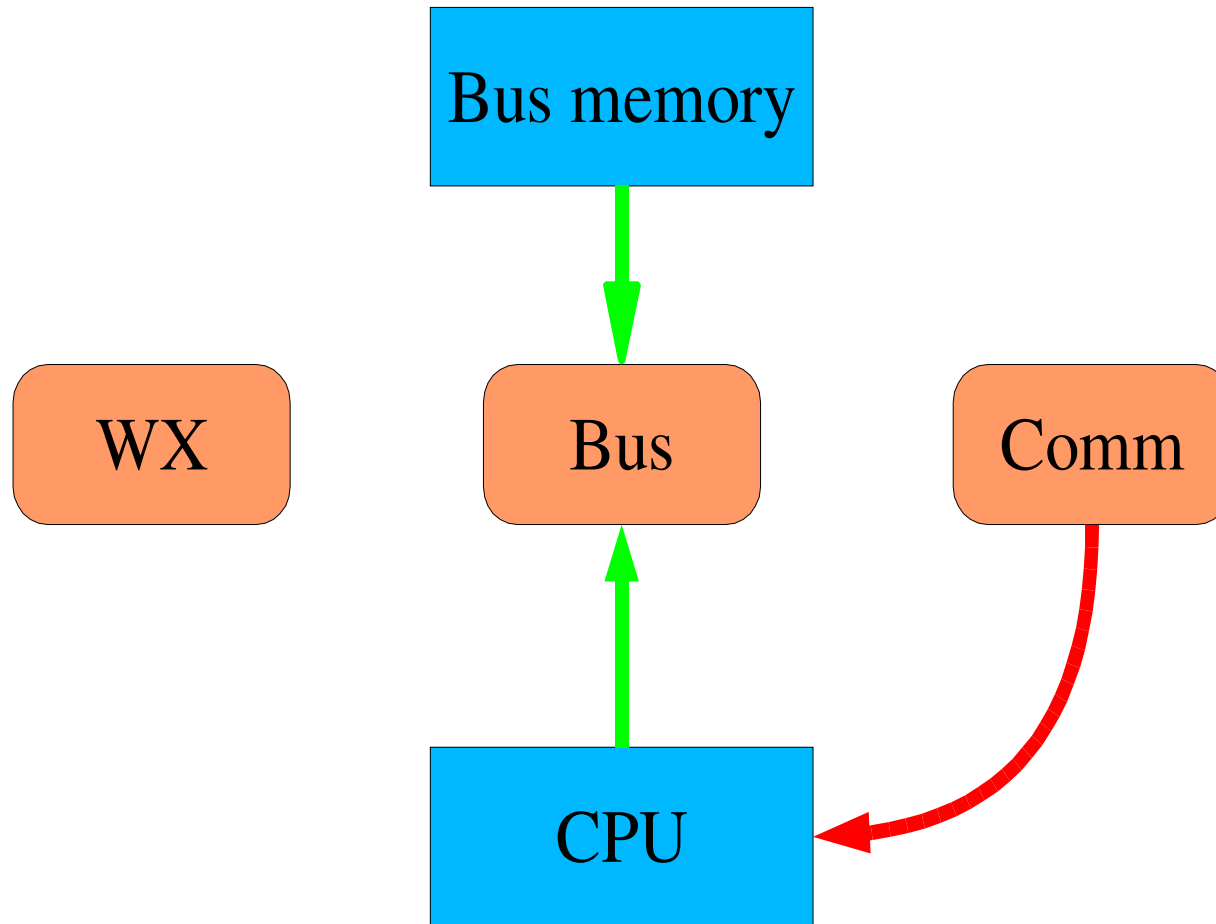
# Bus Thread Waits: Priority Inherited by WX



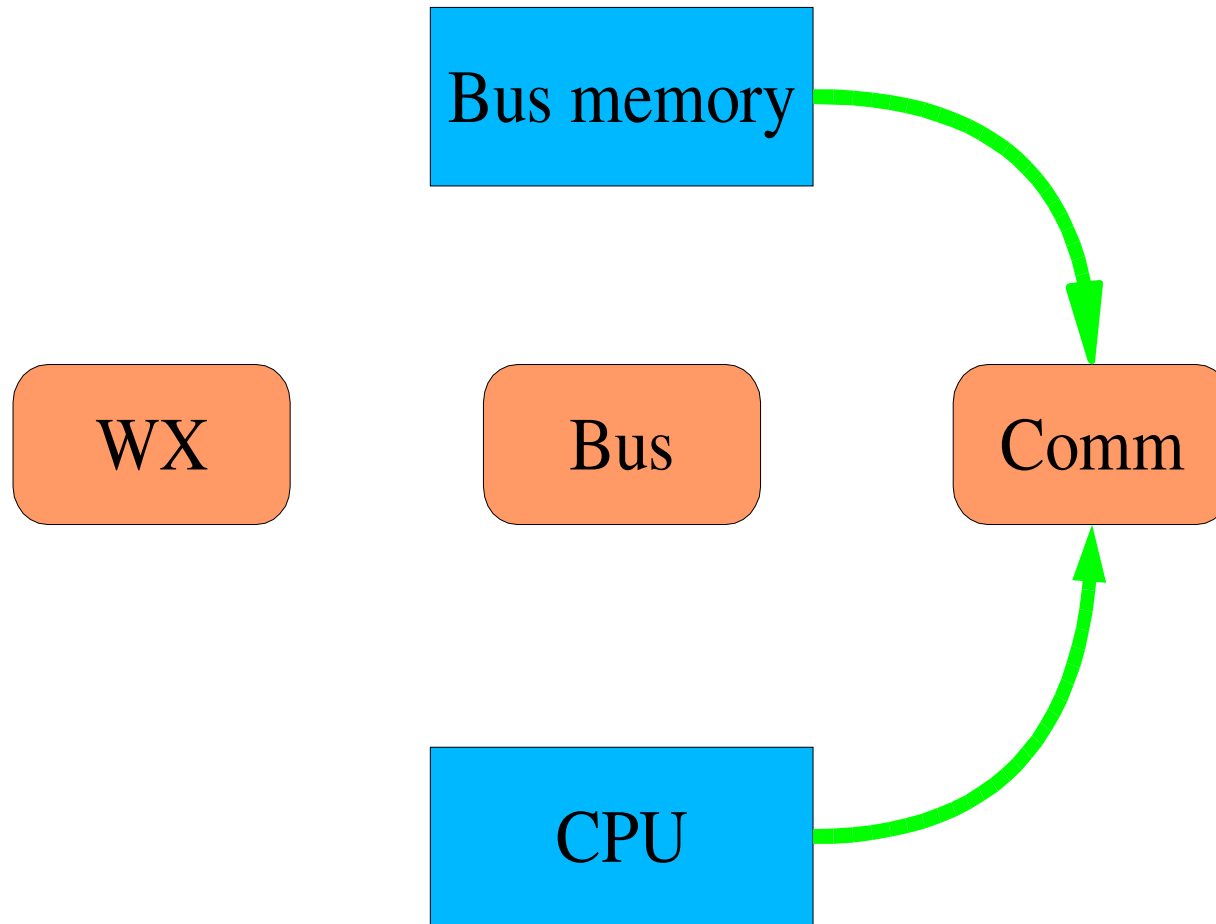
# Bus Thread Waits: Priority Inherited by WX



# “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/~rajkumar/mars.html>