Distributed Real-Time Fault Tolerance on a Virtualized Multi-Core System

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Quest-V: Virtualized Multi-Core System

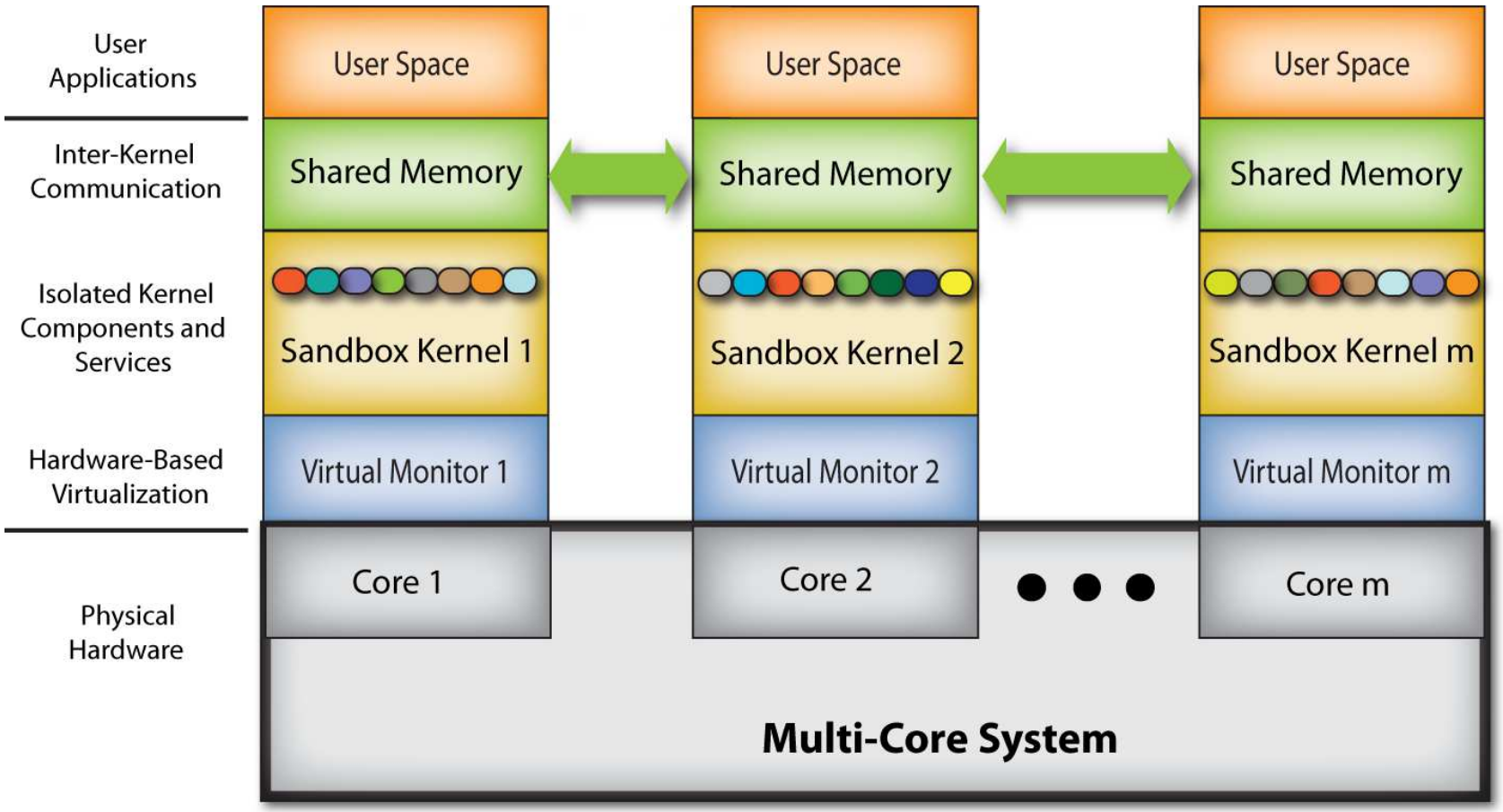
Quest-V Background:

- Boston University's in house operating system + hypervisor
- Developed for real-time and high-confidence systems

Key Features:

- Virtualized Separation Kernel
- Simplified Hypervisor:
  - **Sandboxes** are pinned to cores at boot, no need for scheduling
  - I/O devices are partitioned amongst sandboxes, not shared or emulated
  - Virtualization used for **encapsulation**
- Assume hypervisor is a trusted code base
- Communication through explicit shared memory channels

Quest-V Design



Motivation

- Safety critical systems requires component isolation and redundancy
  - Integrated Modular Avionics (IMA), Automobiles
- Multi-/many-core processors are increasingly popular in embedded systems
- Multi-core processors can be used to consolidate redundant services onto a single platform

Motivation

- Many processors now feature hardware virtualization
  - ARM Cortex A15, Intel VT-x, AMD-V
- Hardware virtualization provides opportunity to efficiently partition resources amongst guest VMs
- Not trying to remove all hardware redundancy – just lessen it

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H/W Virtualization + Resource Partitioning/Isolation

=

Platform for Embedded Safety Critical Systems

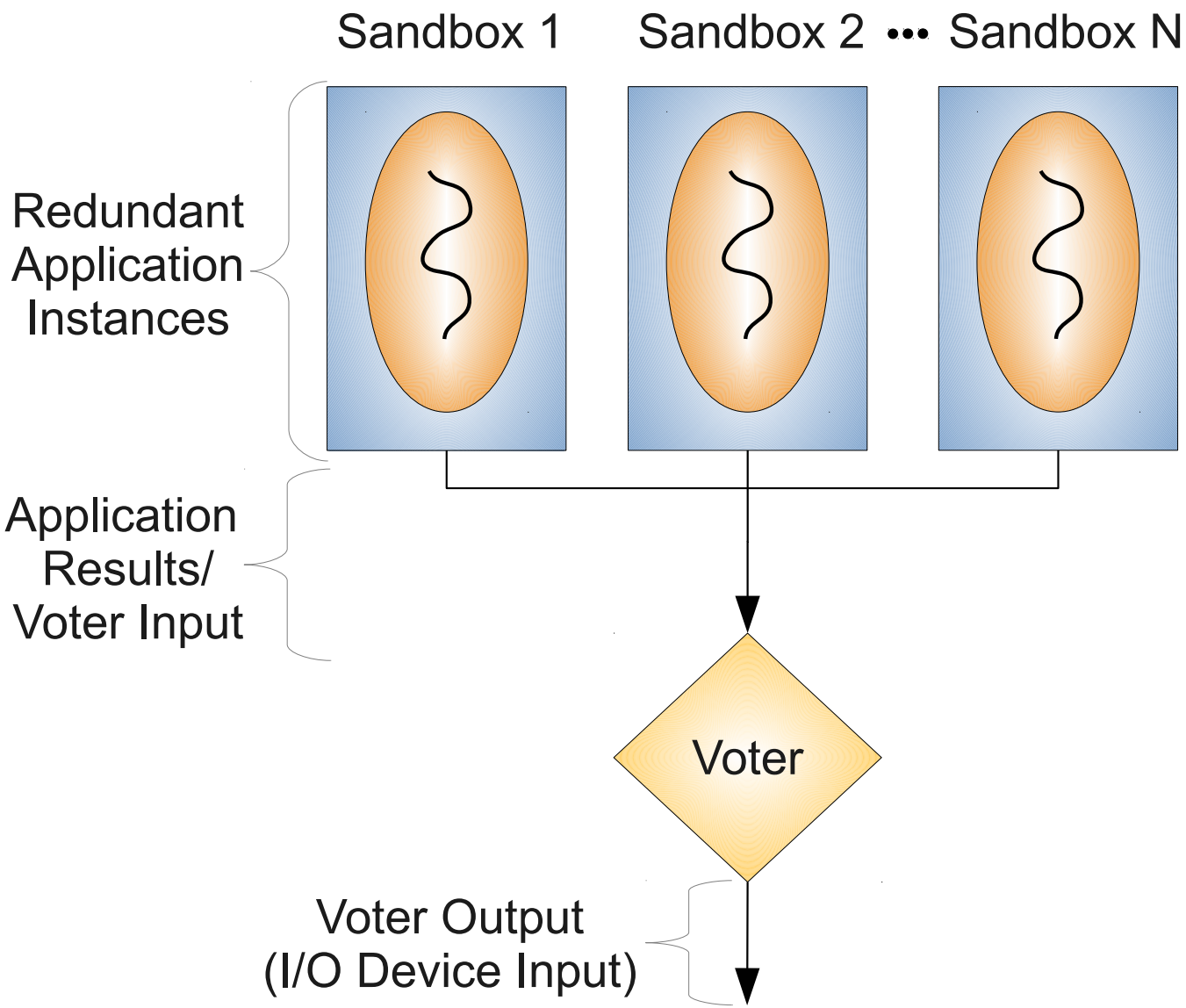
Motivation

- Focusing on hardware transient faults and software timing faults
  - Random bit flips from caused by radiation
  - Asynchronous bugs in faulty device drivers

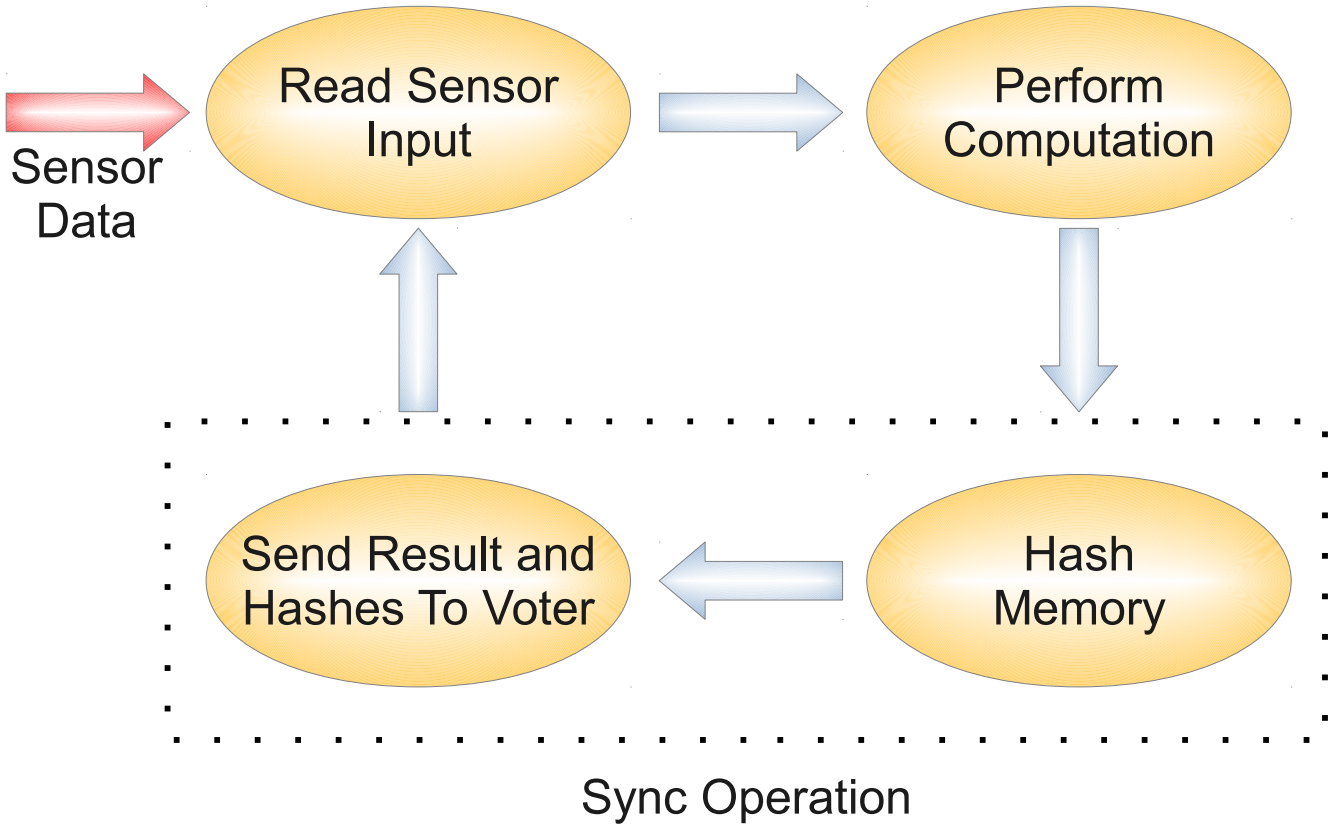
Quest-V N-Modular Redundancy

- N redundant copies of a program, one per sandbox (at least three)
- At least one voter
- Hash based fault detection and recovery
- Virtualized separation kernel platform provides new n-modular redundancy configurations
- Software based dual core lock step (DCLS)

N-Modular Redundancy



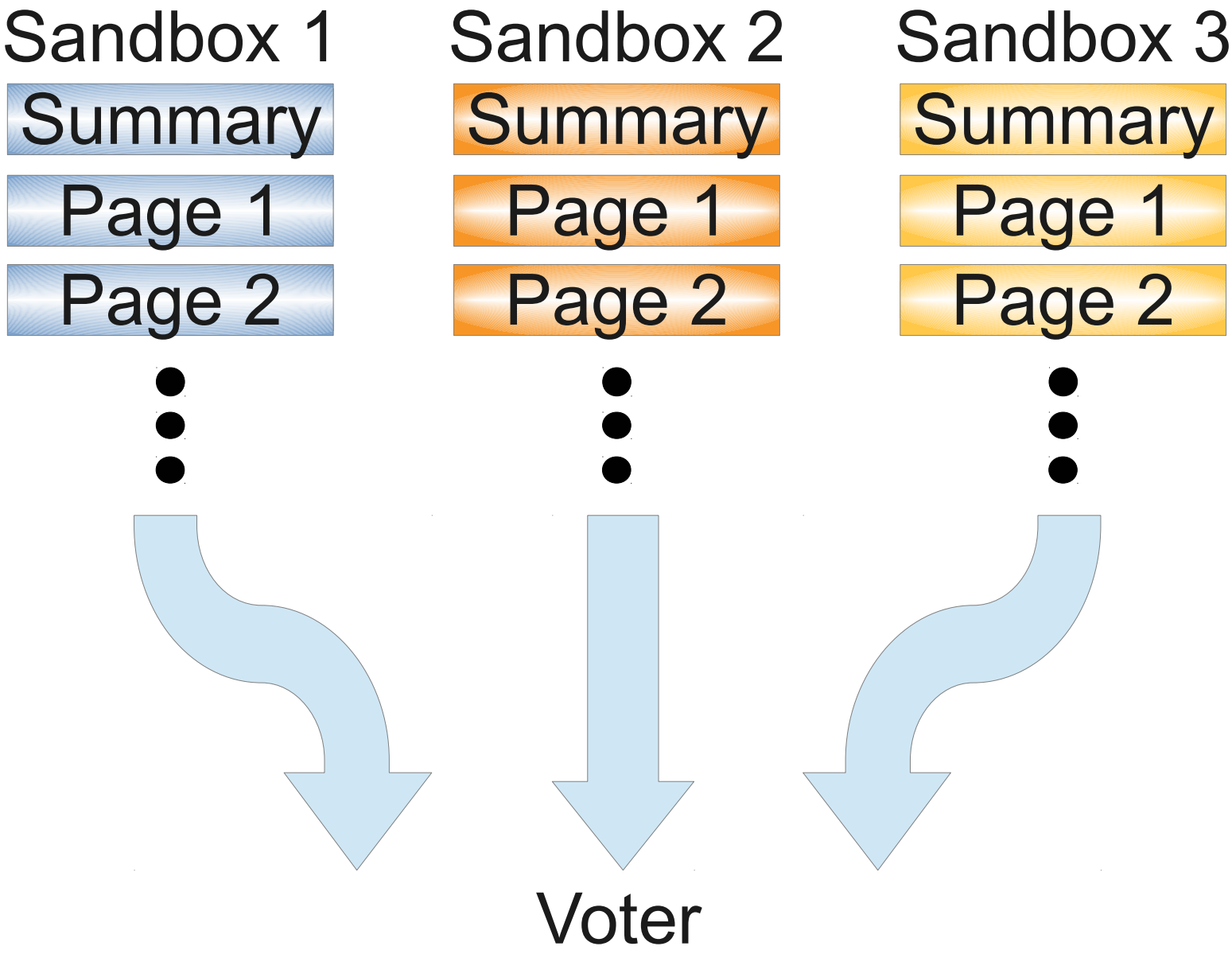
N-Modular Redundancy for Real-Time Applications



Fault Detection

- Typical n-modular redundancy compares the output of the computation
  - Pro: Fast
  - Con: Don't know what went wrong
- Proposed detection method: compare application memory on a per page basis via hashes
  - Pro: Faster and generic recovery for complicated applications (discussed later)
  - Con: Must hash memory state of process (slow)
  - Can speed on comparison using a "summary" hash

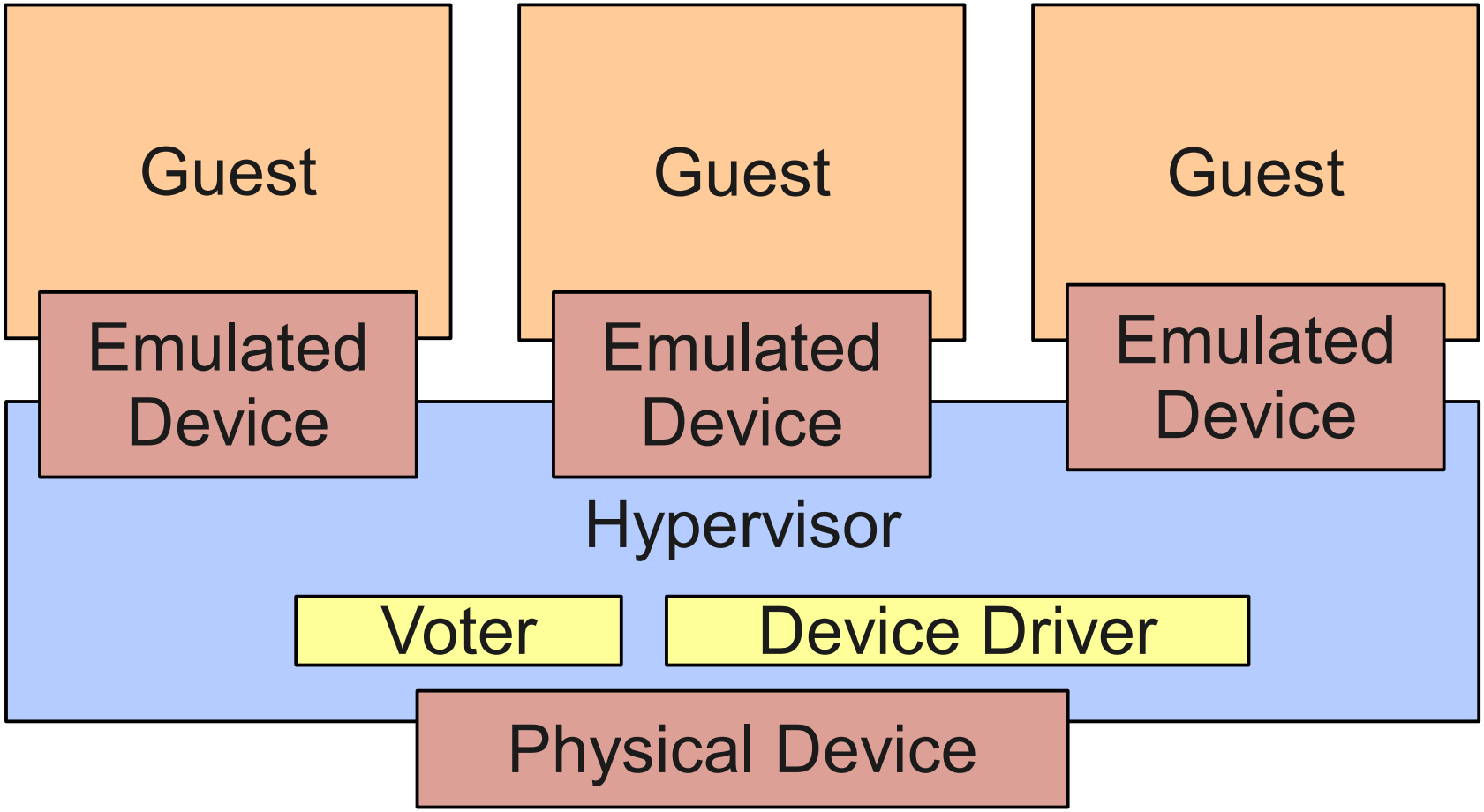
Fault Detection



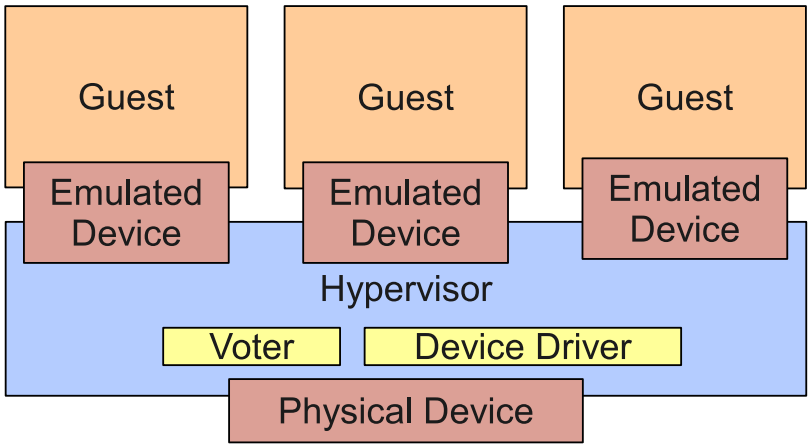
N-Modular Redundancy Configurations

- Voting mechanism and device driver in the hypervisor
- Voting mechanism and device driver in one sandbox
- Voting mechanism distributed across sandboxes and device driver is shared

Voting Mechanism and Device Driver in the Hypervisor



Voting Mechanism and Device Driver in the Hypervisor



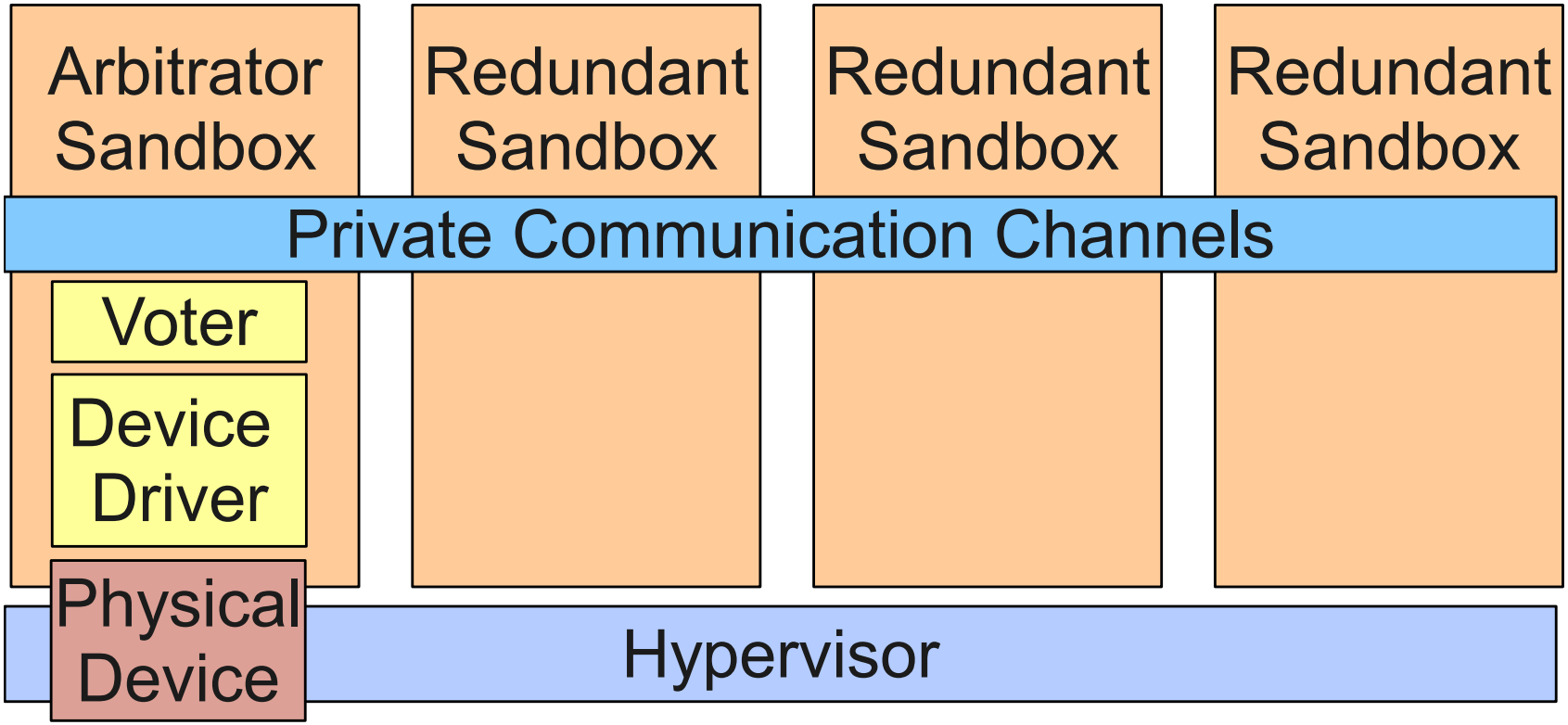
Pros:

- No need to modify operating system - could apply to Linux as well as Quest
- Need only n sandboxes

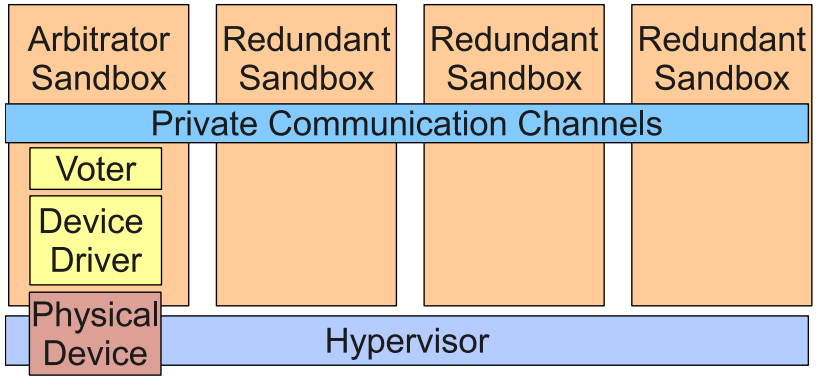
Cons:

- Conflicts with Quest-V hypervisor design
- Faulty device driver could jeopardize the entire system
- Need to duplicate the entire guest

Voting Mechanism and Device Driver in One Sandbox



Voting Mechanism and Device Driver in One Sandbox



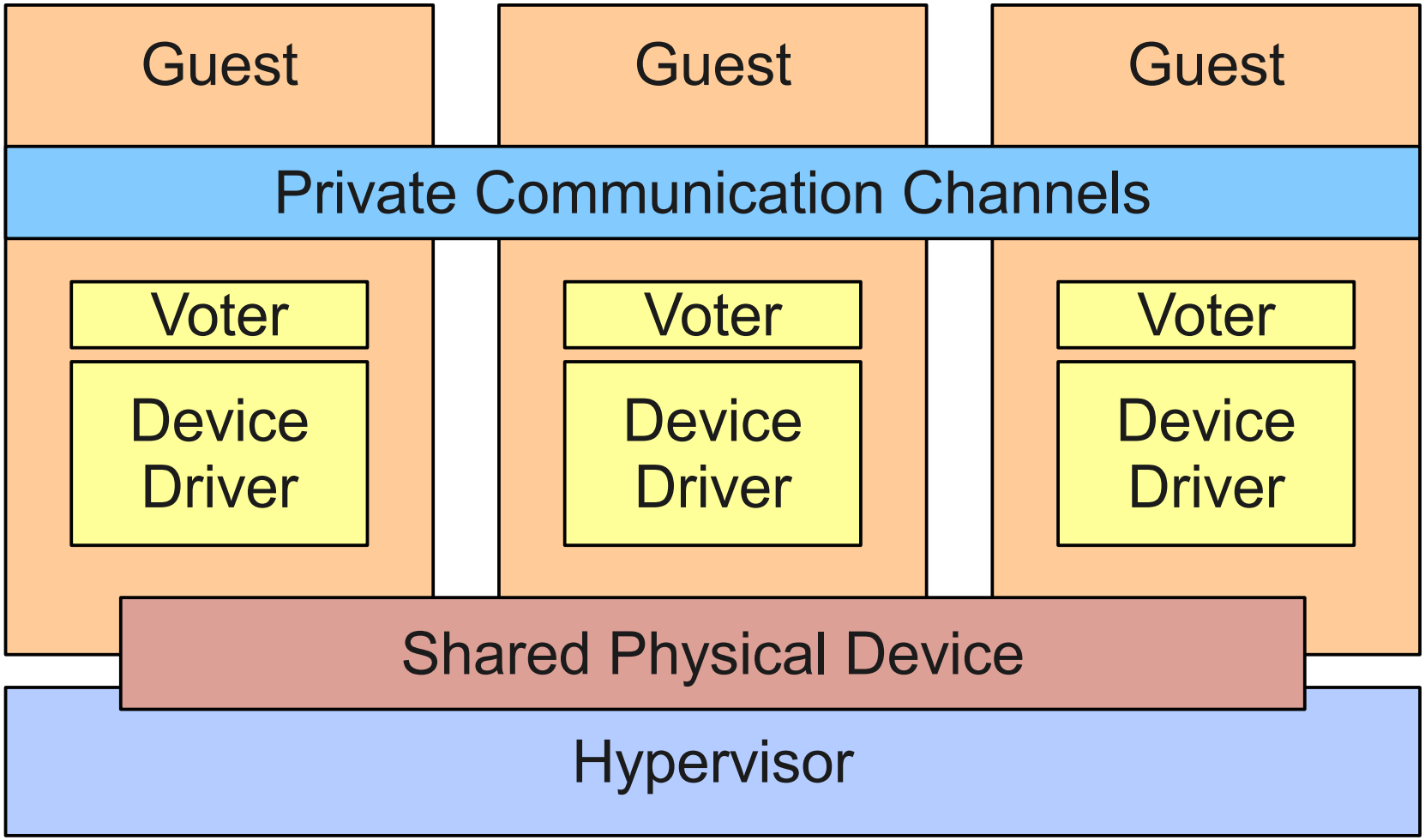
Pros:

- Simpler hypervisor
- Application level redundancy, don't need to copy the entire sandbox

Cons:

- Need (n+1) sandboxes
- Need to modify guest

Voting is Distributed and Device Driver is Shared



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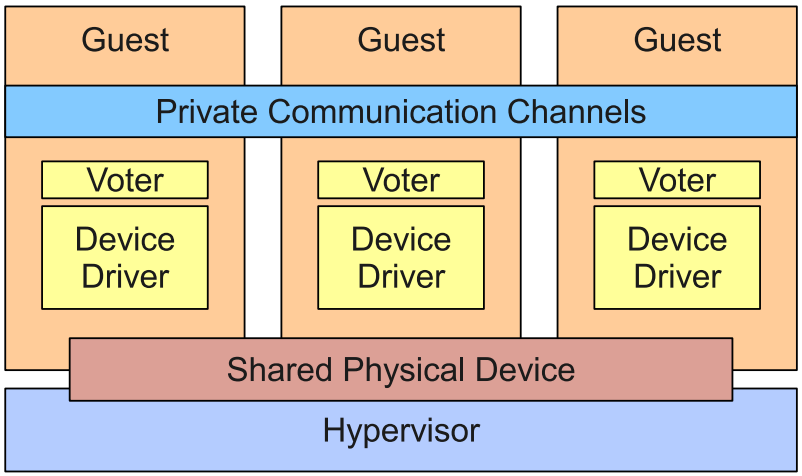


Pros:

- Need only n sandboxes
- Application level redundancy, don't need to copy the entire sandbox

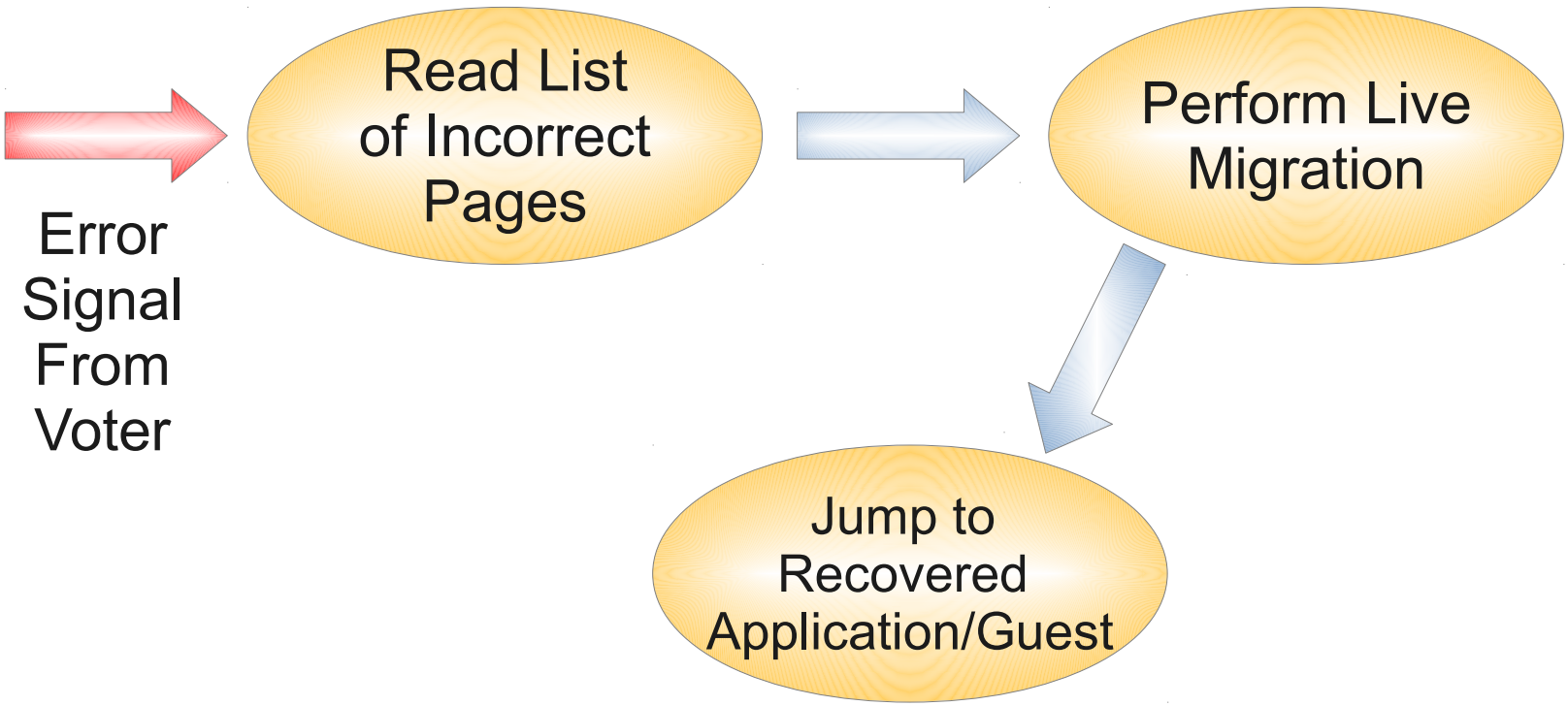
Cons:

- Need to modify guest
- Complicated shared device driver

Recovery

- Want recovery to be as generic as possible
- Simple applications – rebooting might be sufficient
- Complicated applications – rebooting could cause important state to be lost
- Perform live migrations of either application or guest machine

Recovery

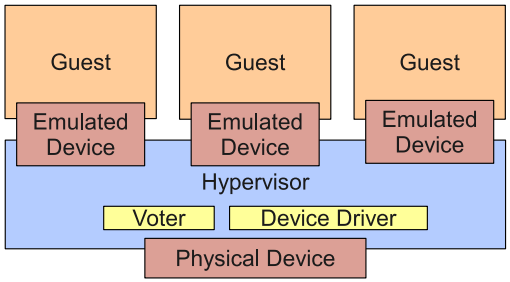


All performed within the context of the thread's sporadic server

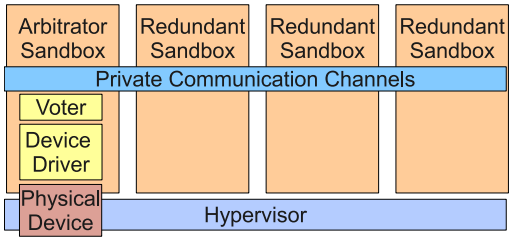
Quick Summary - Key Points to Take Away

- Per-page hash based fault detection and recovery
- Three n-modular redundancy configurations in a virtualized separation kernel

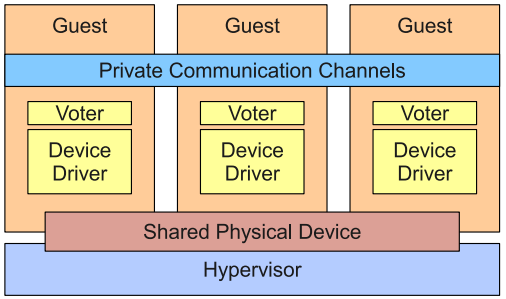
Hypervisor Voting



Sandbox Voting



Distributed Voting



Conclusion

So what's left?

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Further implementation and comparison

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Further implementation and comparison

Figure out solution for voter single point of failure:
Possibilities include arithmetic encoding and memory scrubbing

Conclusion

- More Info: www.questos.org

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- Questions?