Backdoors: A Remote Healing Architecture for Cluster-based Systems

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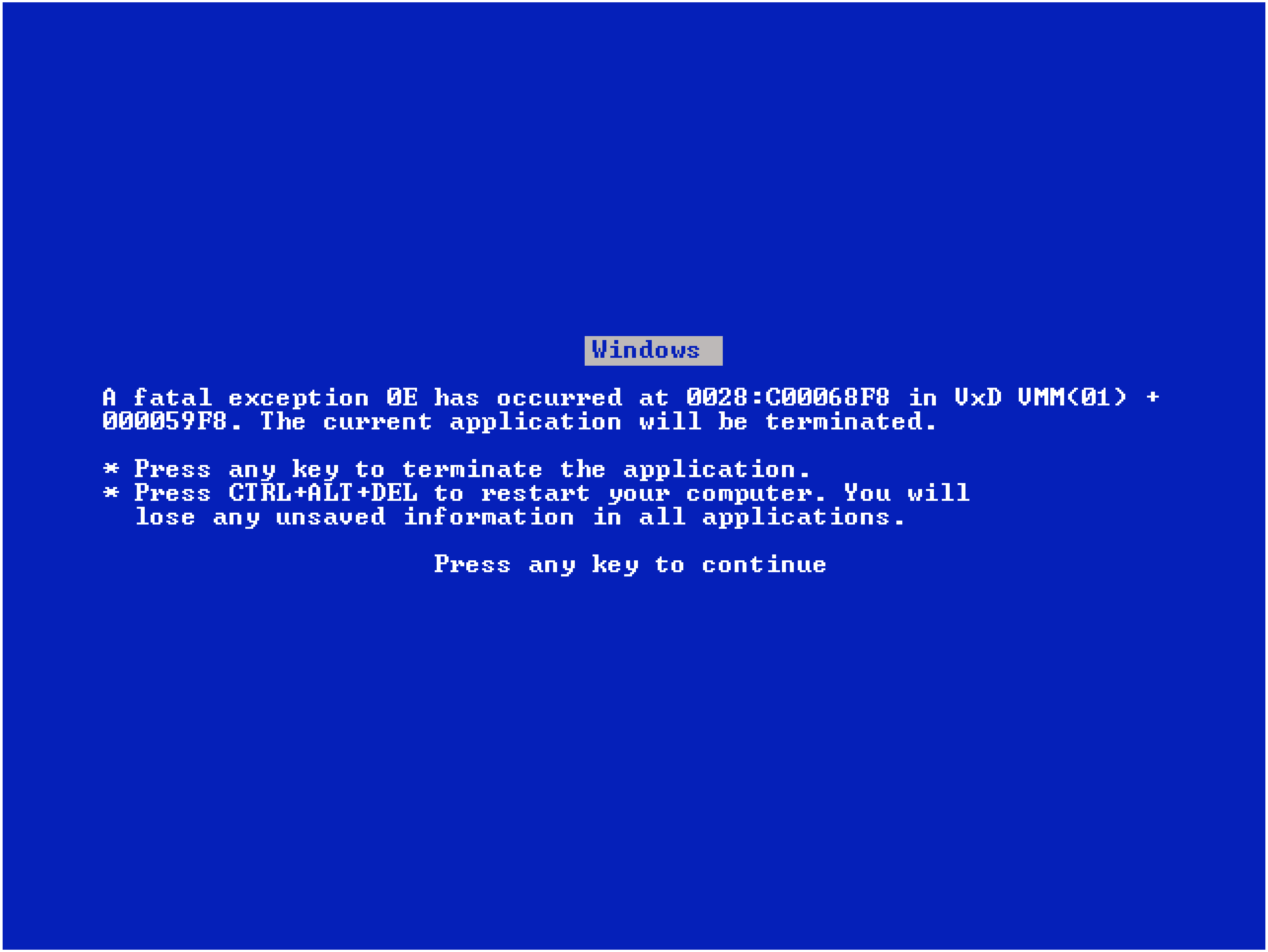
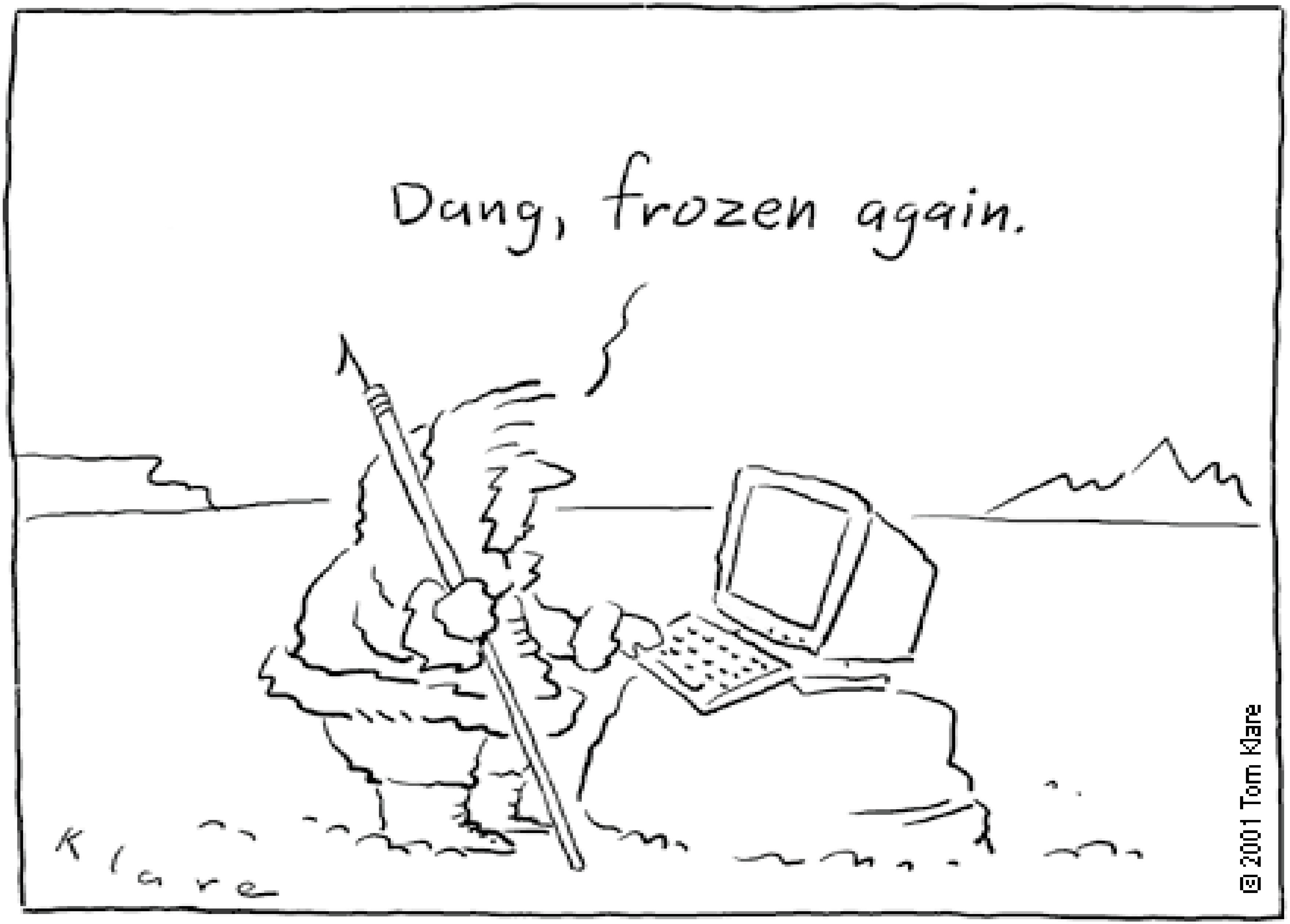
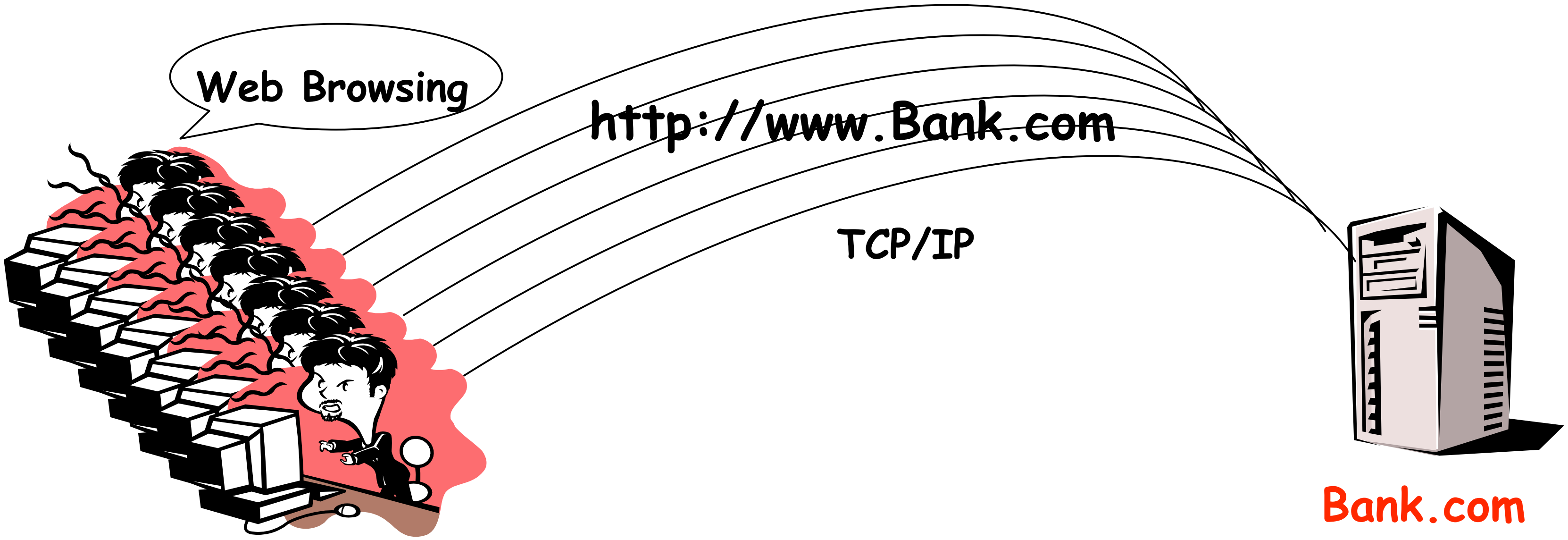

Windows
A fatal exception 0E has occurred at 0028:C00068F8 in VxD VMM(01) +
000059F8. The current application will be terminated.
* Press any key to terminate the application.
* Press CTRL+ALT+DEL to restart your computer. You will
lose any unsaved information in all applications.
Press any key to continue


Dang, frozen again.
Klare
© 2001 Tom Klare

The Only Way Out…

…Not Good for All



What Do We Need?

- Monitor system health
  - OS/application failures
  - DoS attack, overload
  - intrusion
- Take action to heal the system
  - repair damaged state, clean-up corrupted state
  - extract and recover good state
  - contain fault/attack
  - repel intrusion
- Where should these operations be performed?

Self-Healing

- Consumes processor cycles (intrusive)
- Relies on processor availability
  - hang failures make healing impossible
- Relies on OS resources
  - sensitive to resource depletion/unavailability
- Relies on system integrity
  - state may be corrupted
  - system may be compromised by an attacker

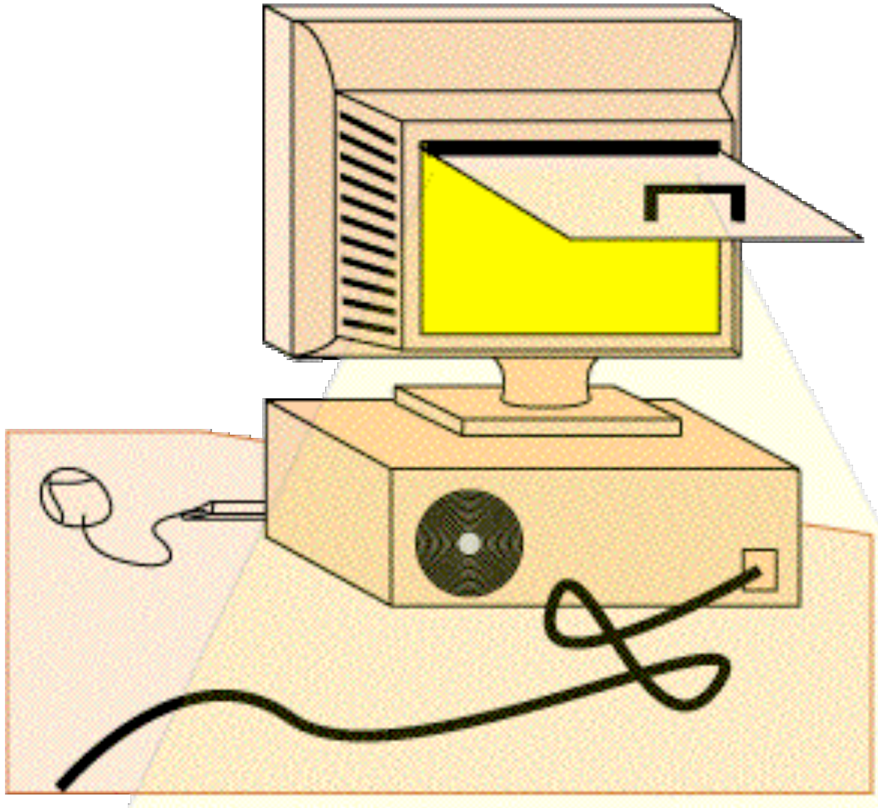
Alternative: Remote Healing

- Perform healing from another system
  - target system must allow remote access
  - the monitor system must be trusted
- Can we make remote healing nonintrusive?
  - no extra load on the target system
  - no reliance on target resources (processor, OS, etc.)

Target Failures

- OS/application hangs or cannot sustain service
  - hw: processor, network, disk, etc.
  - OS: driver bug, deadlock, resource exhaustion, etc.
  - DoS attack, overload
- Memory still available, yet not accessible via conventional paths (IP stack, console, etc.)
- Solution
  - monitor and detect failures
  - recover or repair software state of the affected system

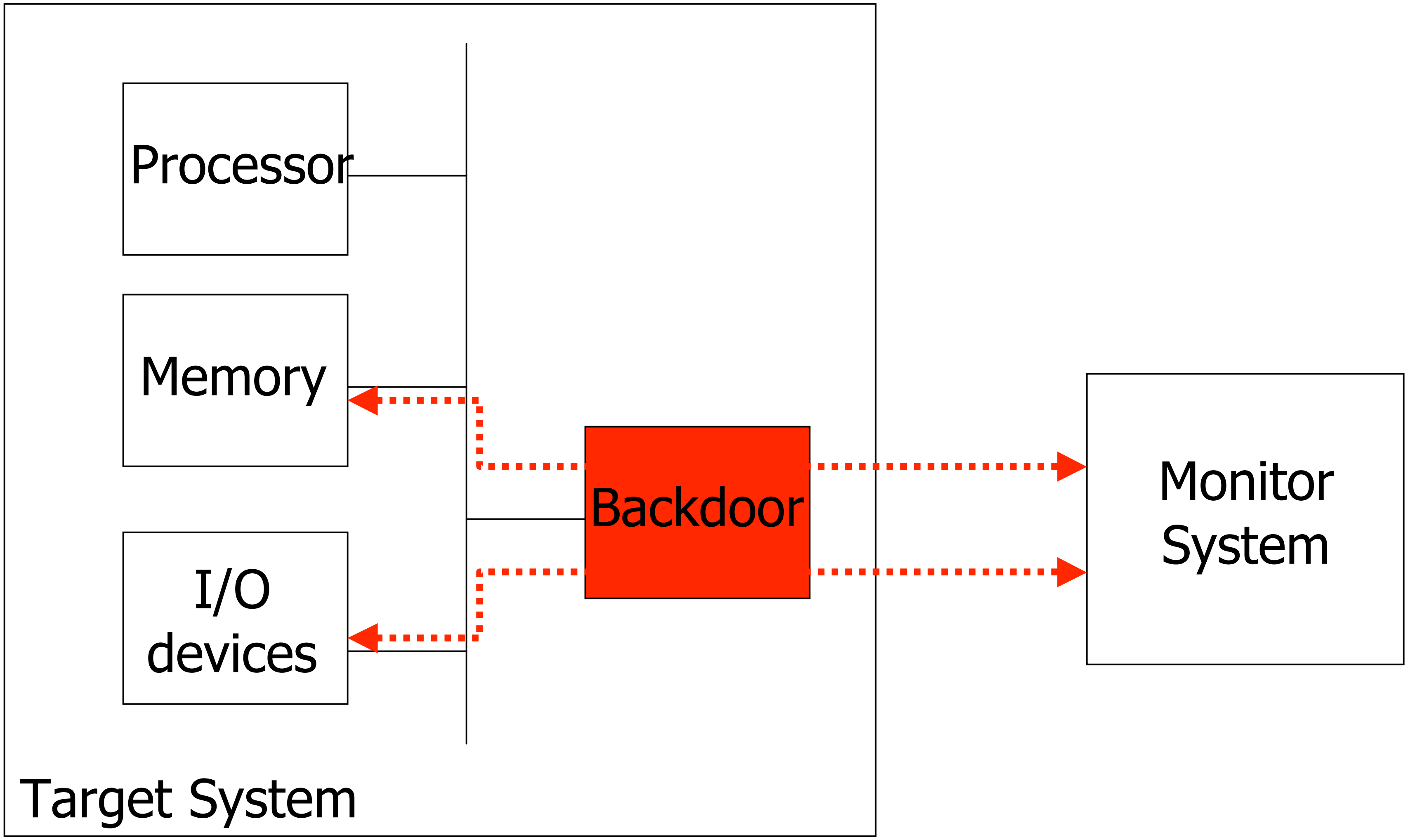
The Backdoor



backdoor: a hidden software or hardware mechanism, usually created for testing and troubleshooting

--American National Standard for Telecommunications

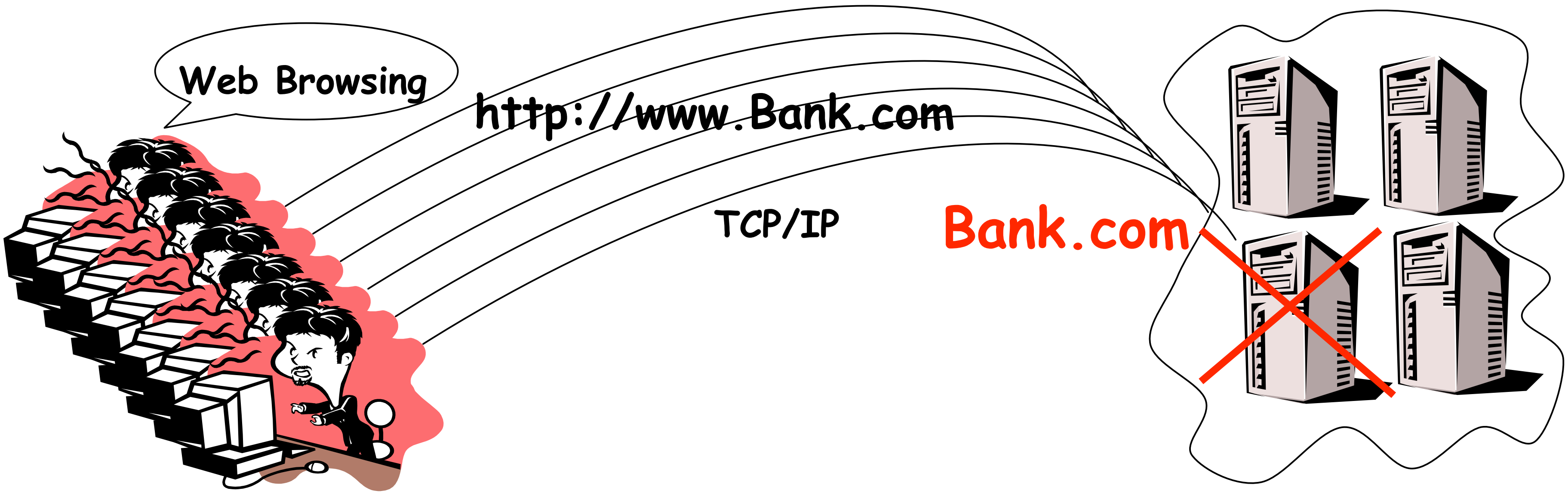
The Backdoor (BD) Architecture



Outline

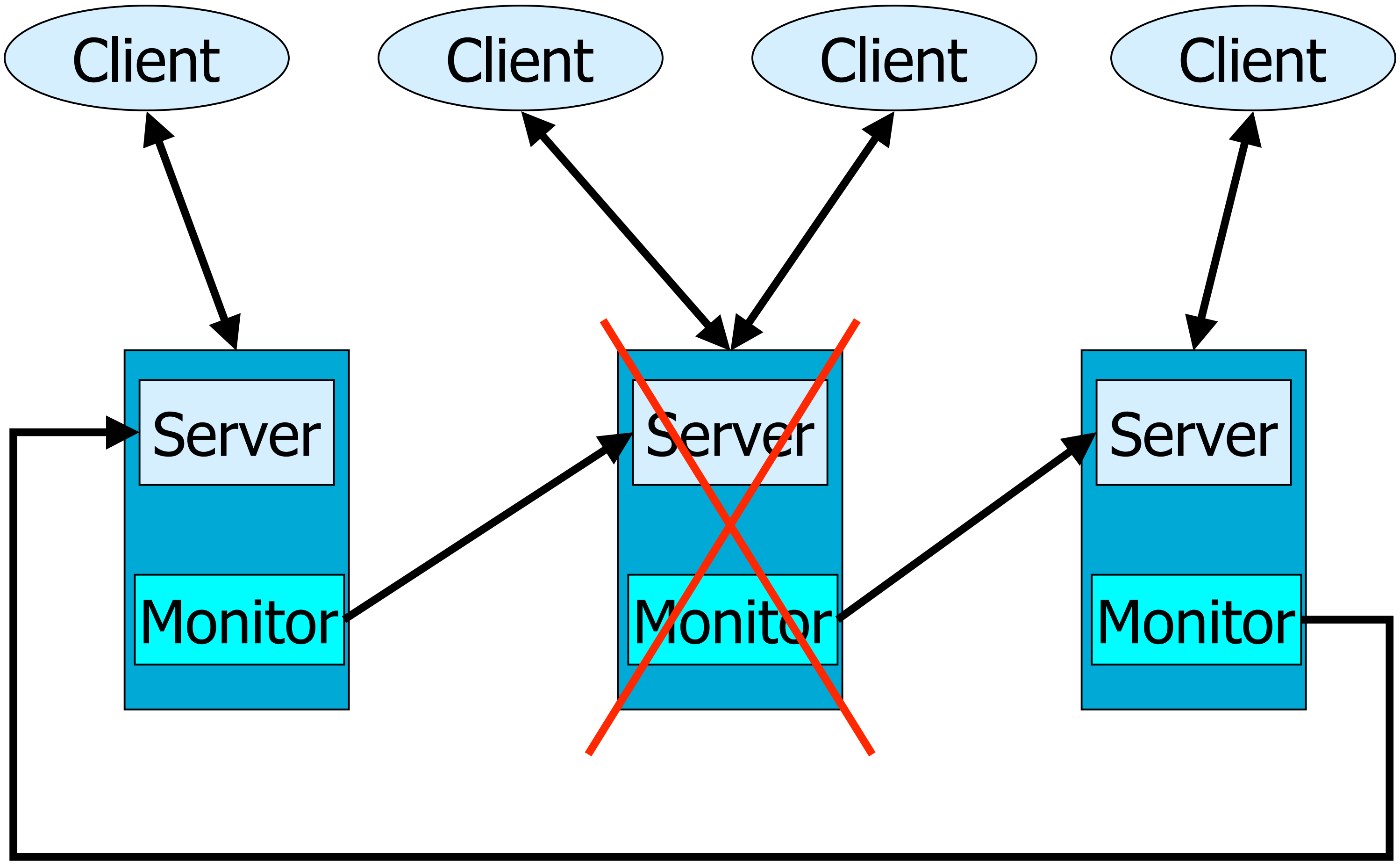
- Introduction
- Remote Healing in Clusters of Computers
- Backdoor Architecture
- Case Study: Recovery in Internet Services
- Prototype
- Conclusions

Internet Services Today

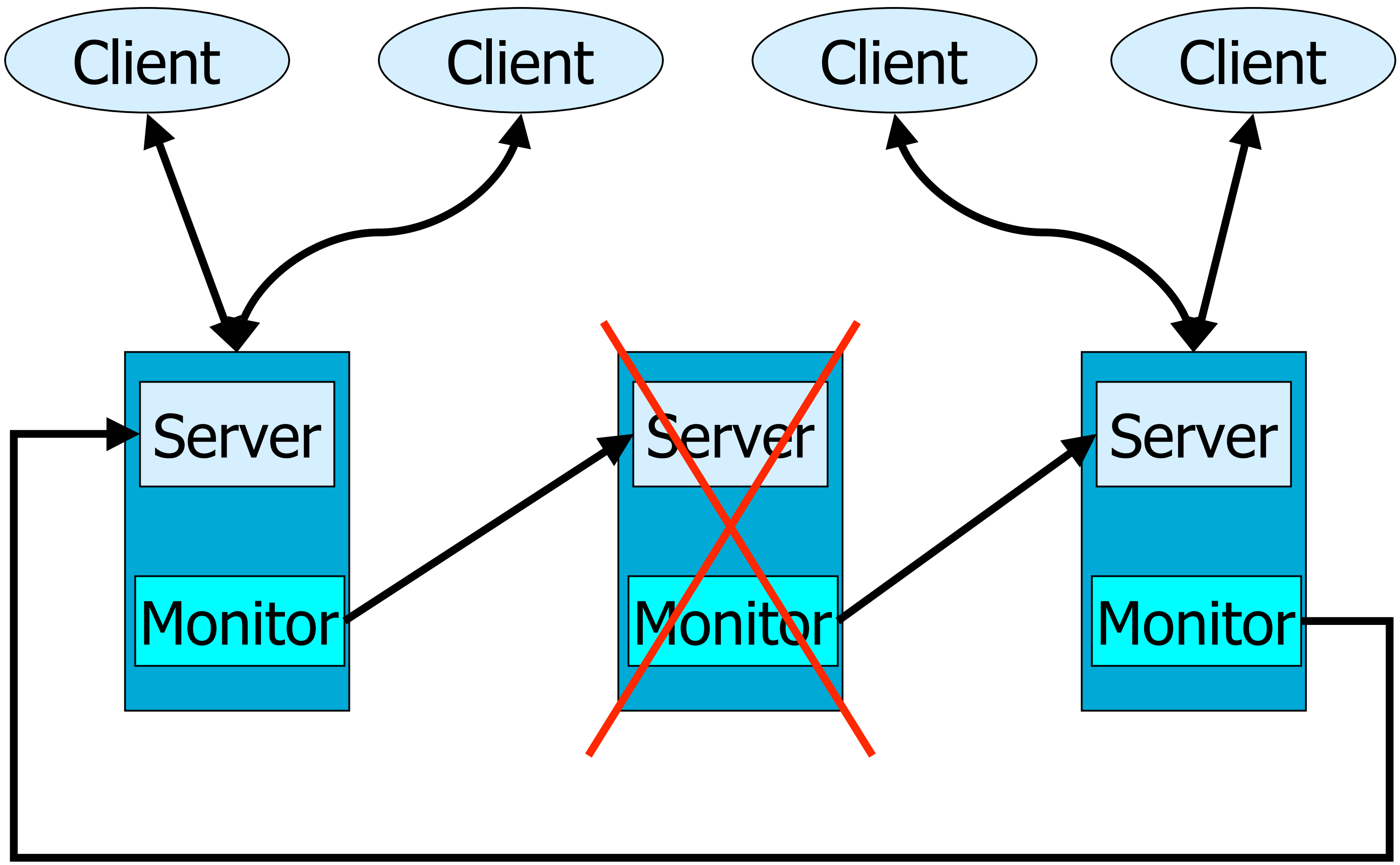


- Commercial shift in using the Internet
  - e-commerce, banking, trading, auctioning, etc.
  - transactional, time-critical services
  - economic incentive to fault tolerance and service continuity

Cluster-based Internet Services



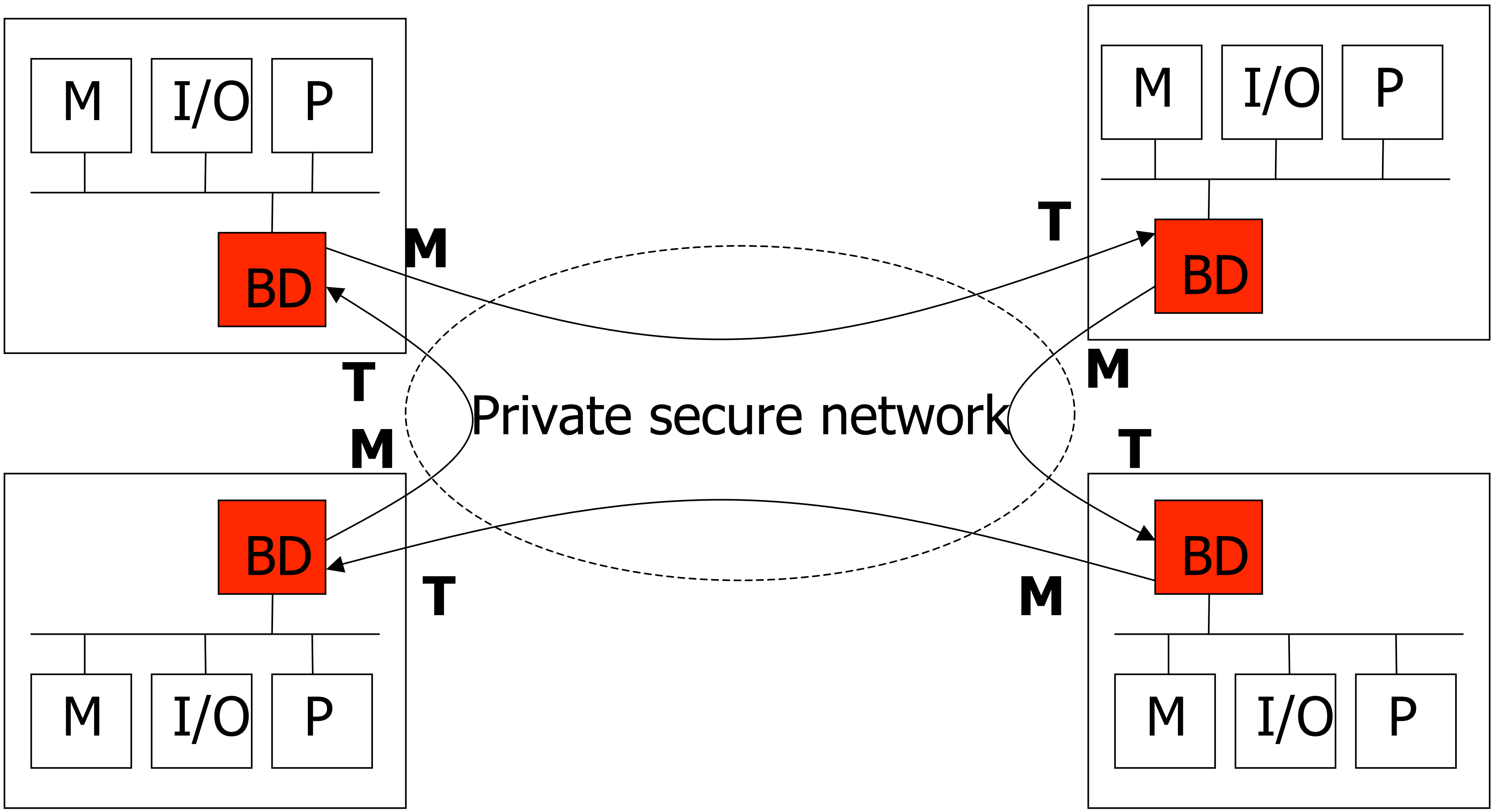
Cluster-based Internet Services



Remote Healing in Clusters

- Goal: survivability of live service state
  - OS and application-specific
- Target: state critical to service continuity
- Remote monitoring and diagnosis
  - detect failure, bad state, attack, intrusion
- Remote intervention
  - recovery of useful state from failed nodes
  - in-place repair of bad state

Backdoor-based Remote Healing



Backdoor Architecture Principles

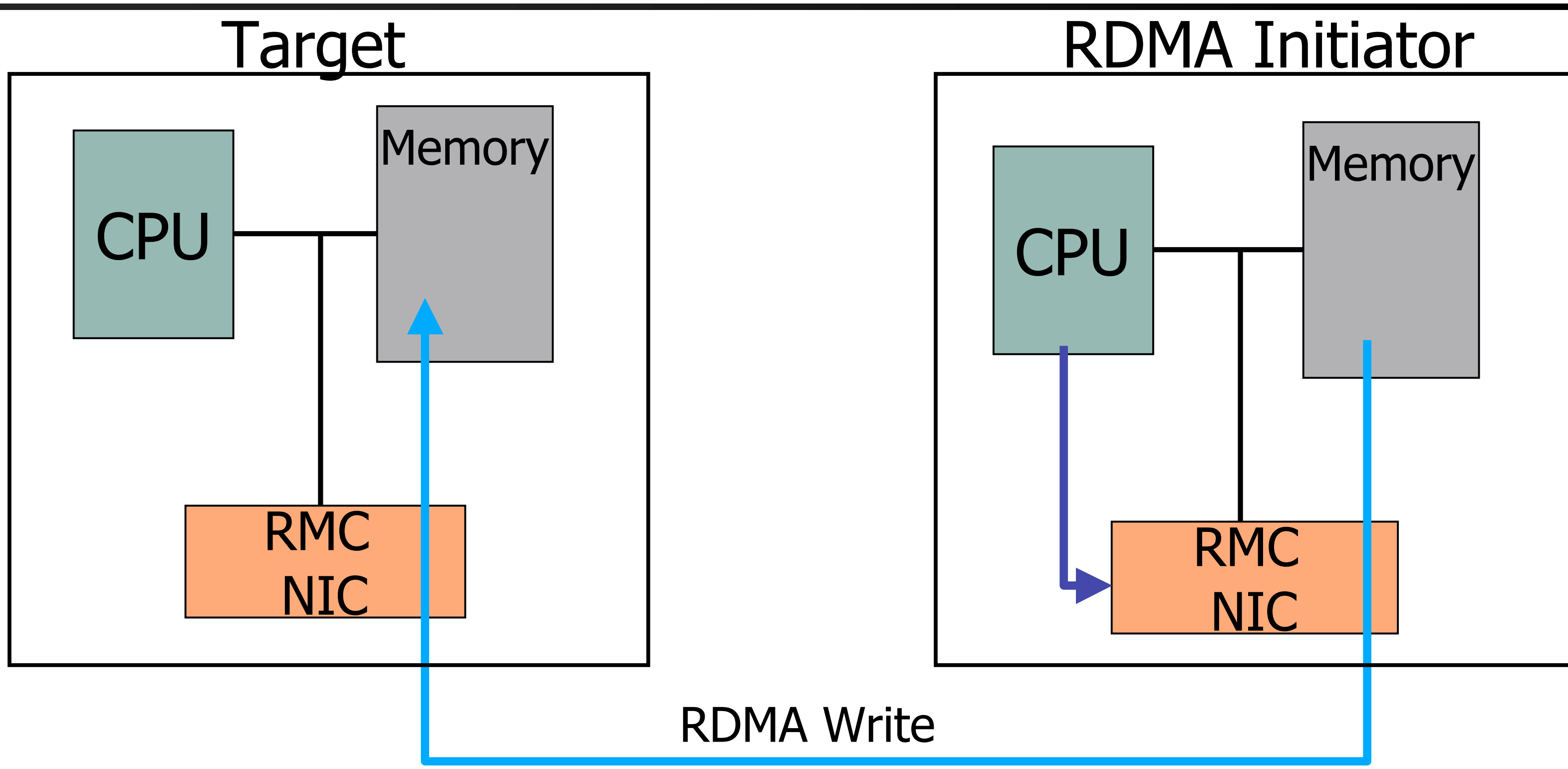
1. Bidirectional access
   - both remote input and output operations must be supported
2. Remote memory access
   - memory must be accessible remotely
   - remote I/O?
3. Availability
   - failure must not impair BD
4. Nonintrusive operation
   - BD operations must not involve processors of the target system

Backdoor Architecture Principles (cont)

5. Transparency
   - BD operation must not be visible to target
6. Access control
   - monitor and target negotiate access permissions at the beginning
   - target cannot “close” the BD afterwards
7. Tamper resistance
   - target cannot modify the result of a BD operation

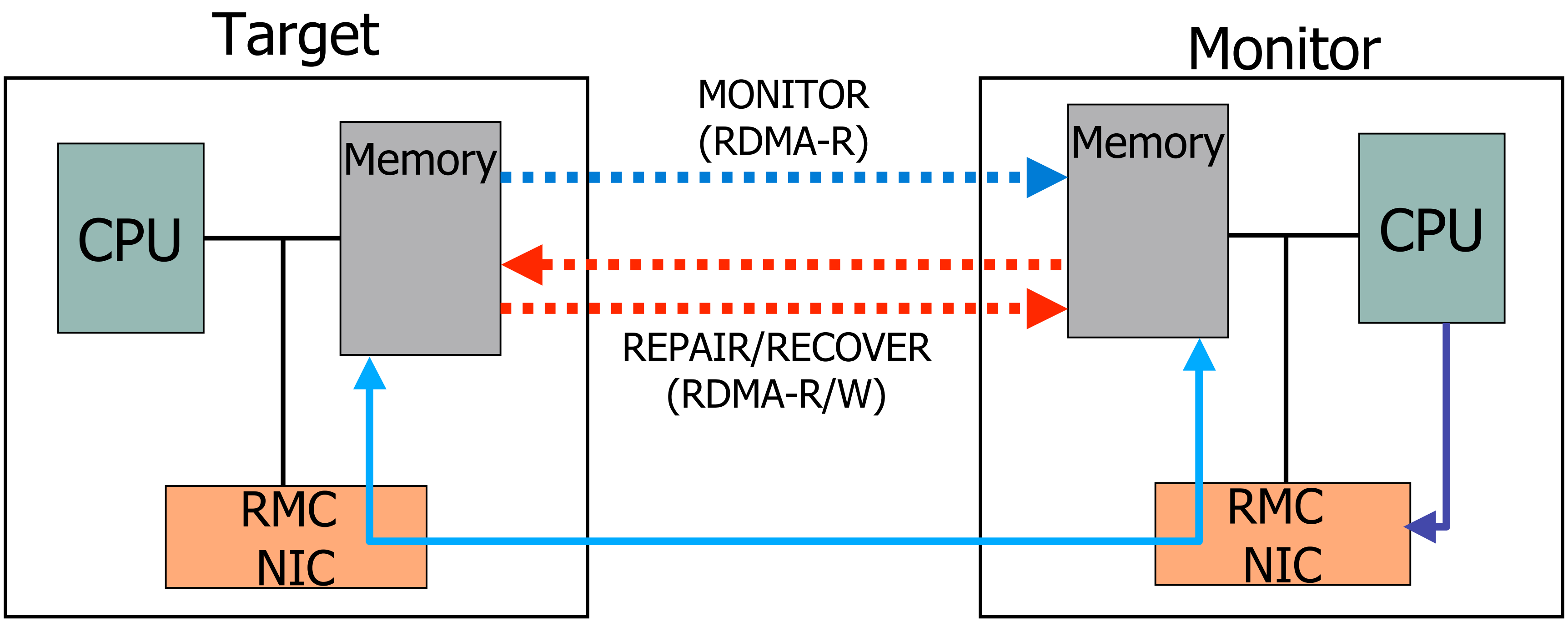
Question: How can we implement Backdoor using existing technologies?

Remote Memory Communication (RMC)



- Remote DMA (RDMA) Read/Write operations
- Remote processor not involved
- RMC-based networking technologies: VIA, InfiniBand, etc.

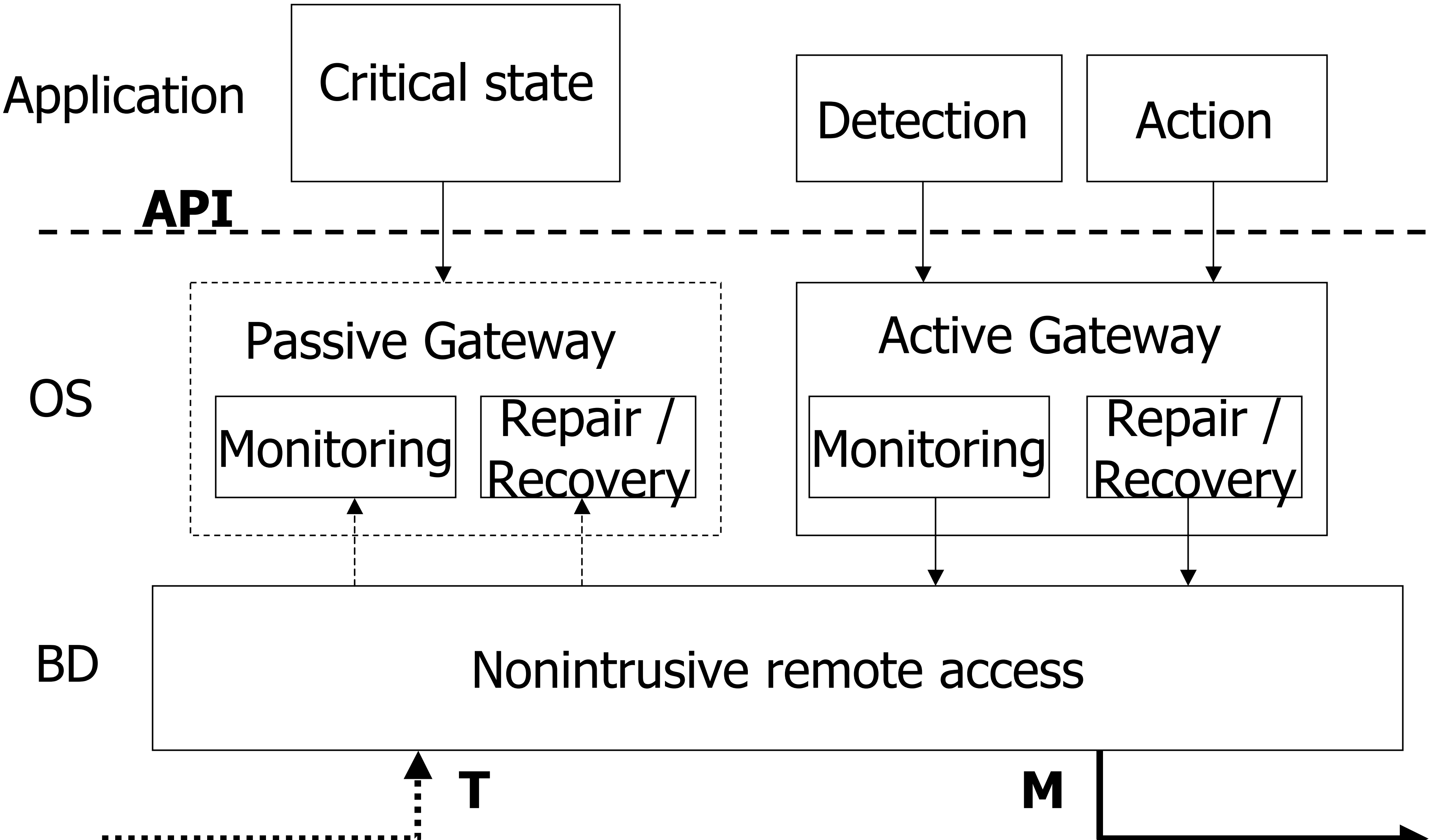
Backdoor with RMC



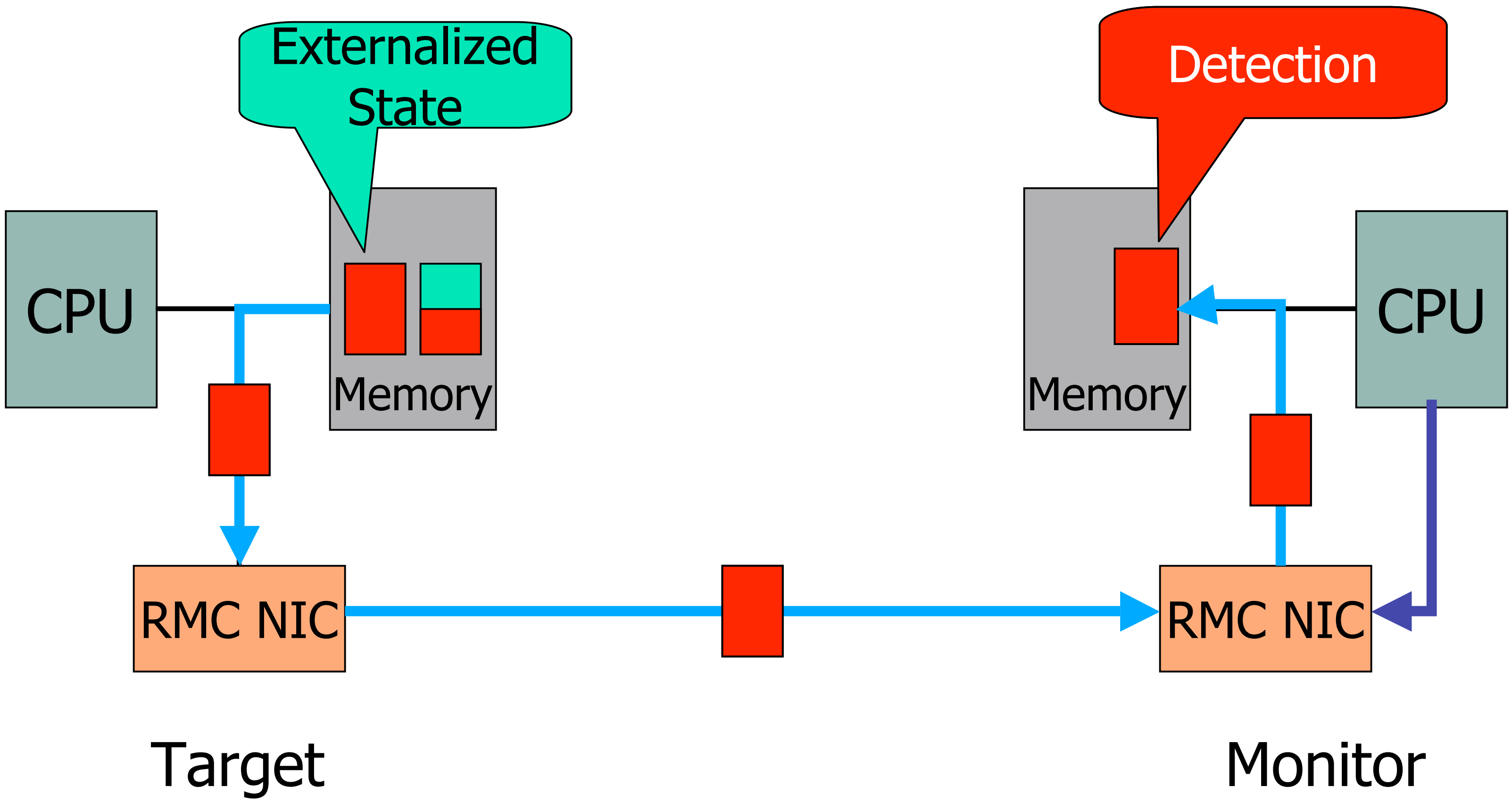
RMC Compliance with BD Principles

Bidirectional access	Y
Remote memory access	Y
Availability	Y
Nonintrusiveness	Y
Transparency	Y?
Access control	Y-
Tamper resistance	Y

Remote Healing Architecture

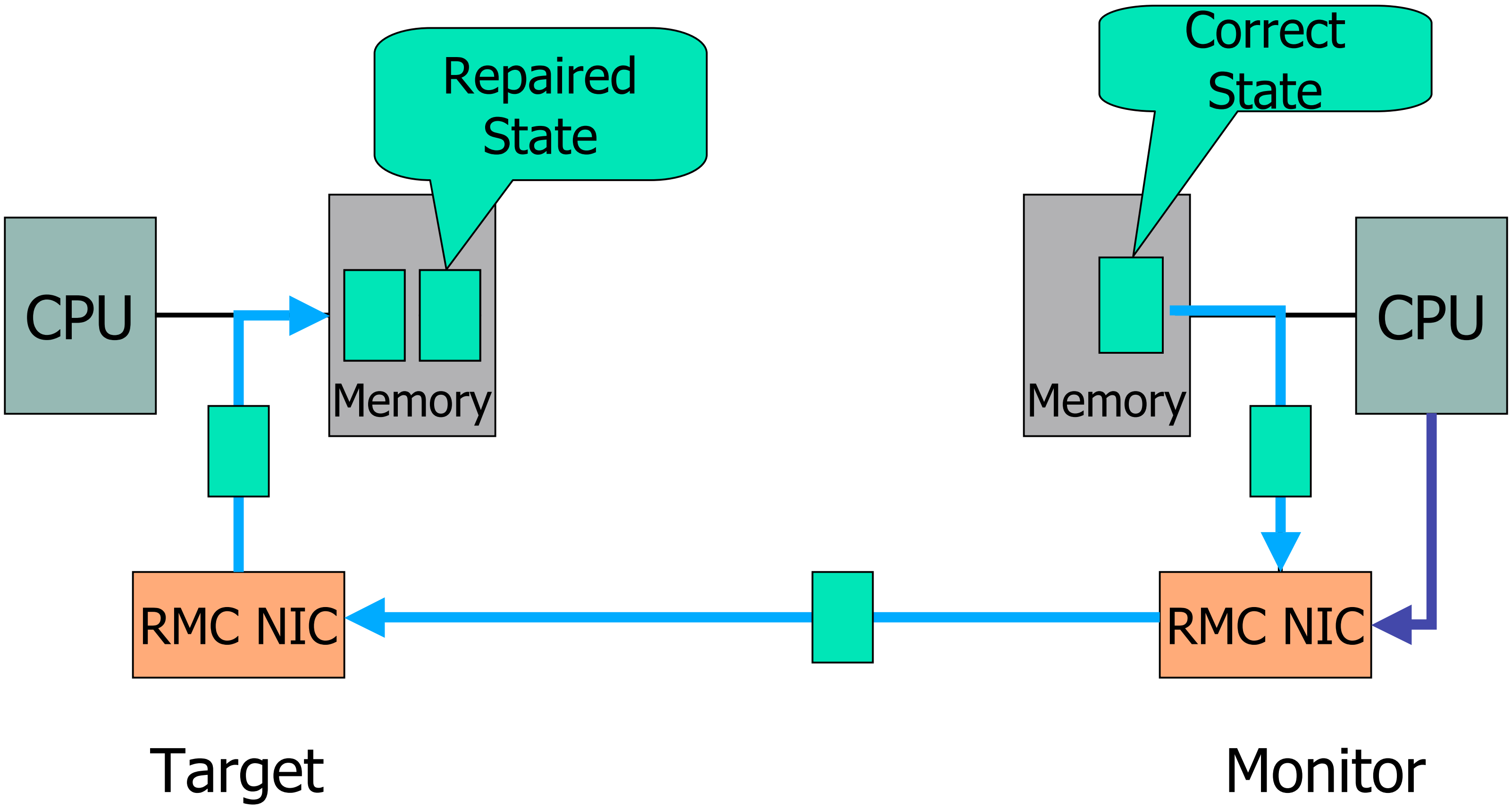


Monitoring over RMC-BD

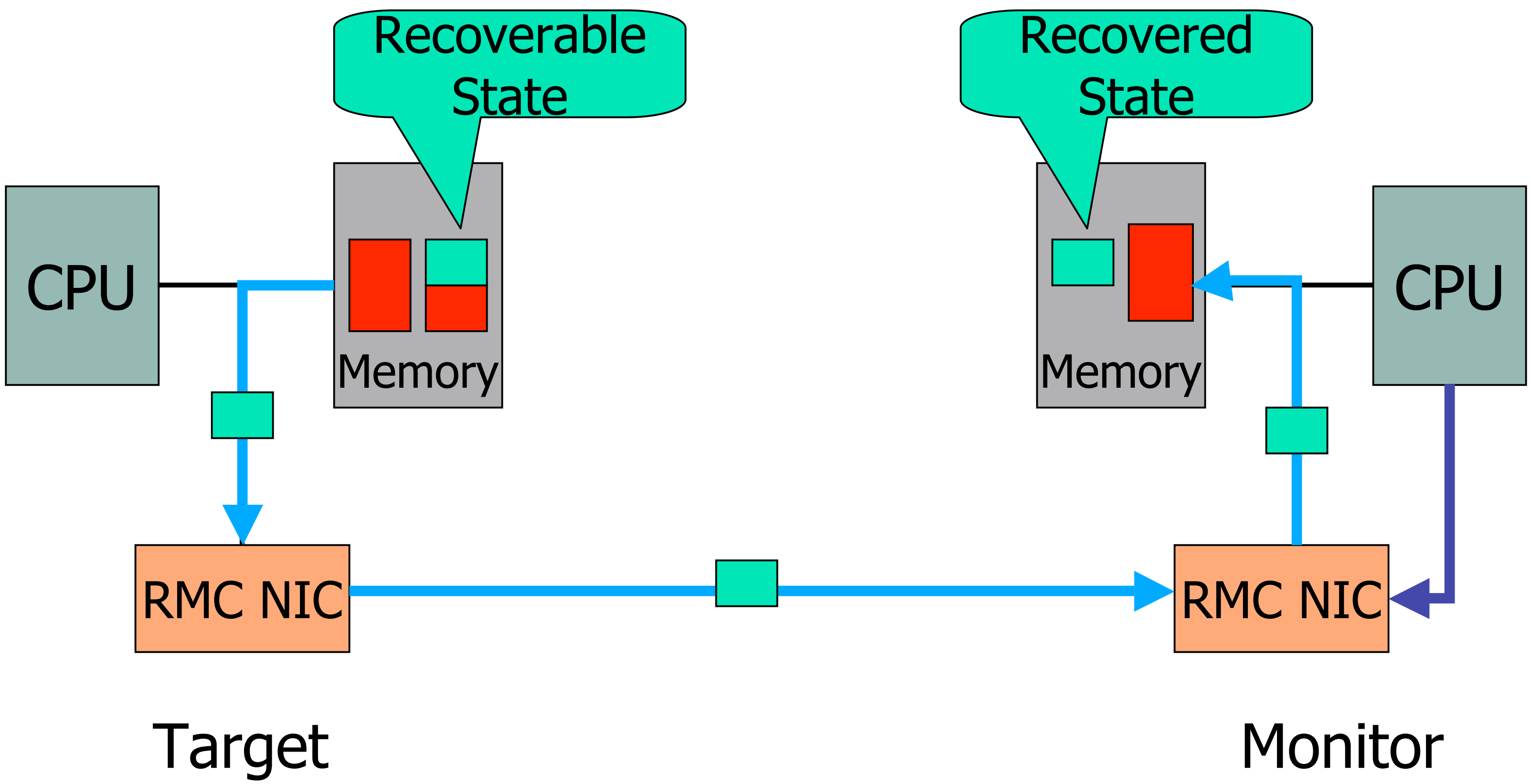


Monitor: progress, anomalous events, integrity constraints, etc.

Repair over RMC-BD



Recovery over RMC-BD



And Possibly More…

- Remote control of I/O devices
  - access state in peripheral devices, e.g., OS swap space
- Dynamically inject code/data in a live system
  - test, diagnosis, repair handlers
  - fast system reboot through OS memory overlay
  - fast restart of application components (micro-reboot)
- Monitor for intrusion/attack detection

Case Study: Recovery In Internet Services

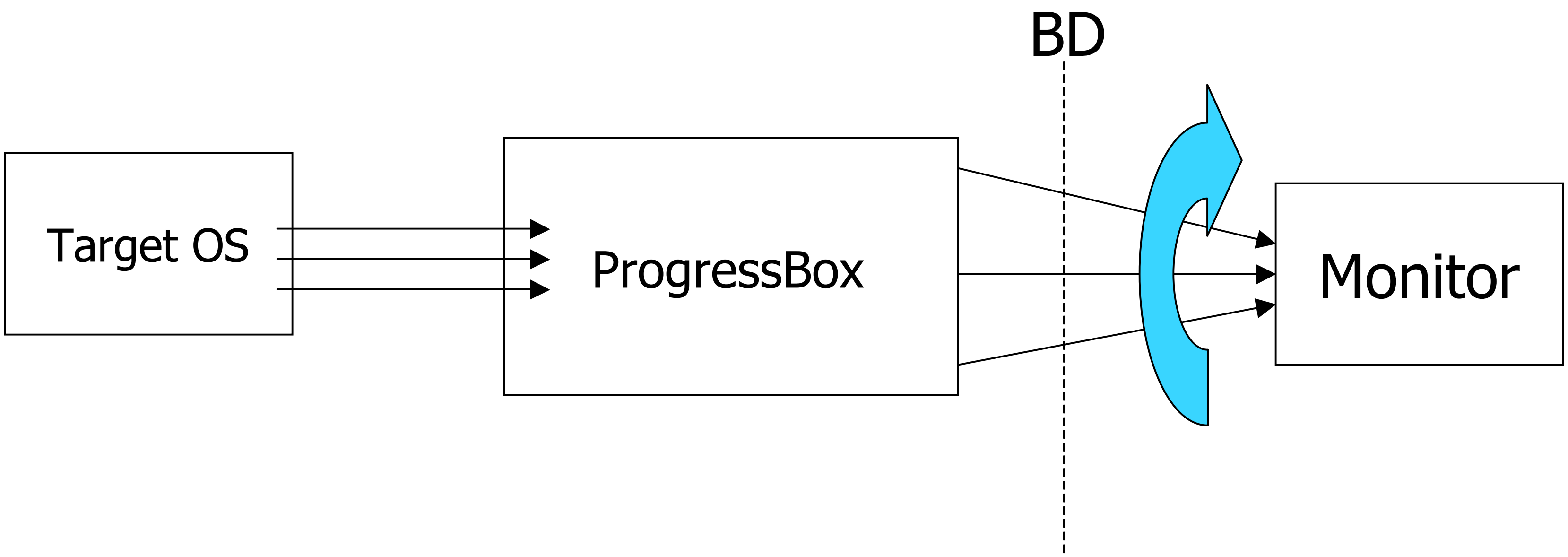
- Remote healing is not just RMC!
  - RMC provides just a way of access
- Requires OS support
  - Failure Detection
  - Session Recovery

OS Support

- Monitoring: Progress Box (PB)
  - progress counter: {scalar value, update deadline}
  - PB = set of progress counters in OS memory
  - API to allocate and update progress counters in PB
  - monitor reads PB, checks counters, detects stalls
- Recovery: State Box (SB)
  - encapsulates per-session server state
  - API to export/import application state to/from SB
  - backup node reads SB, reinstates session, resumes service

Failure Detection with PB

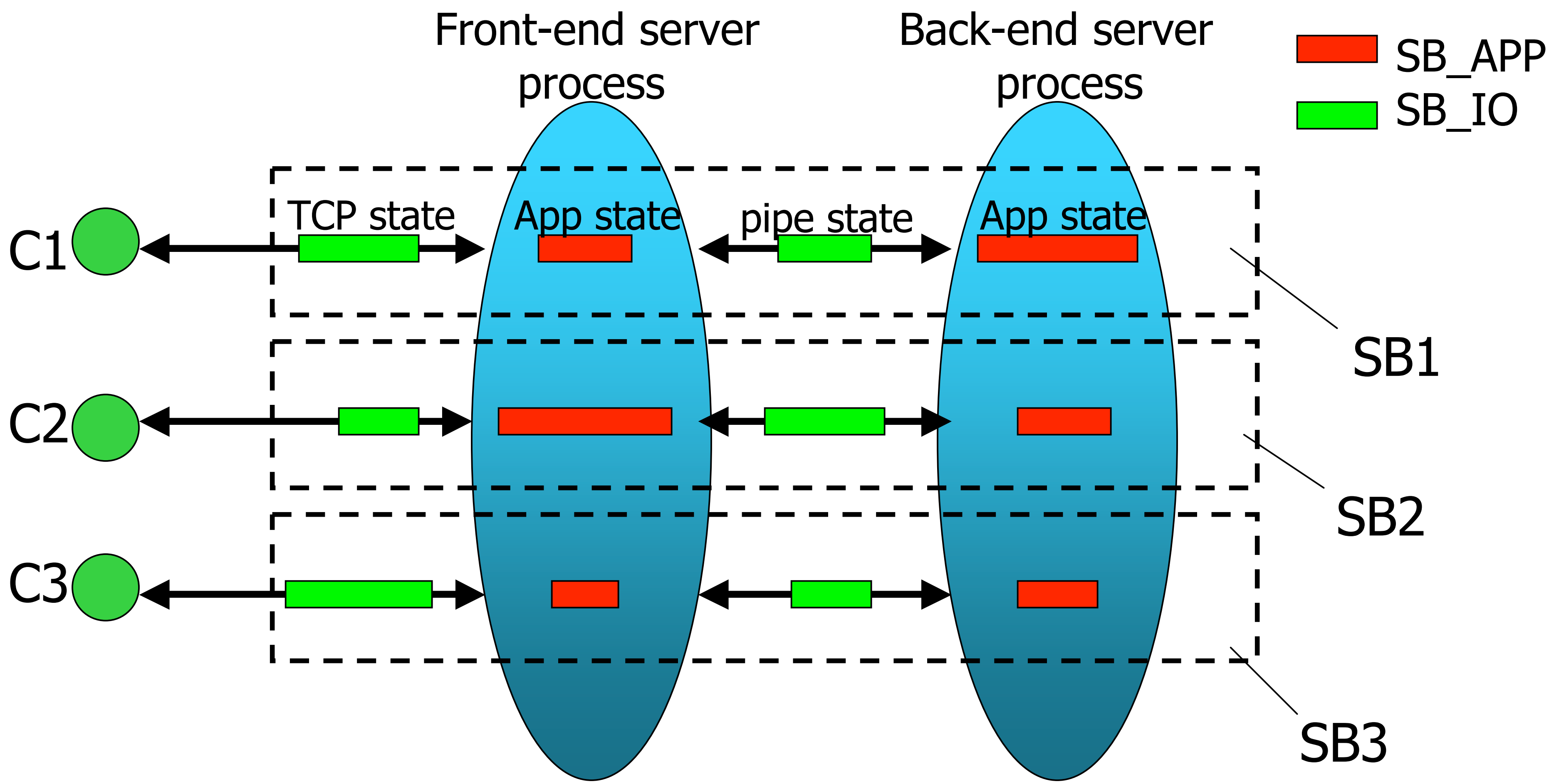
- Target system updates progress counters in PB
  - Examples: interrupts (global, per-device), context switches, connections accepted, etc.
- Monitor process
  - scans remote PB, checks counters, detects stalls



Recovery With SB

- Fine-grained, essential service state
- Application-specific components (SB_APP)
  - E.g., document name, offset in document, etc.
- OS-specific components (SB_IO)
  - E.g., send/receive TCP buffers
- An SB can be distributed over multiple processes (multi-tier servers)
- Backup node extracts SB from a failed node and reinstates it locally

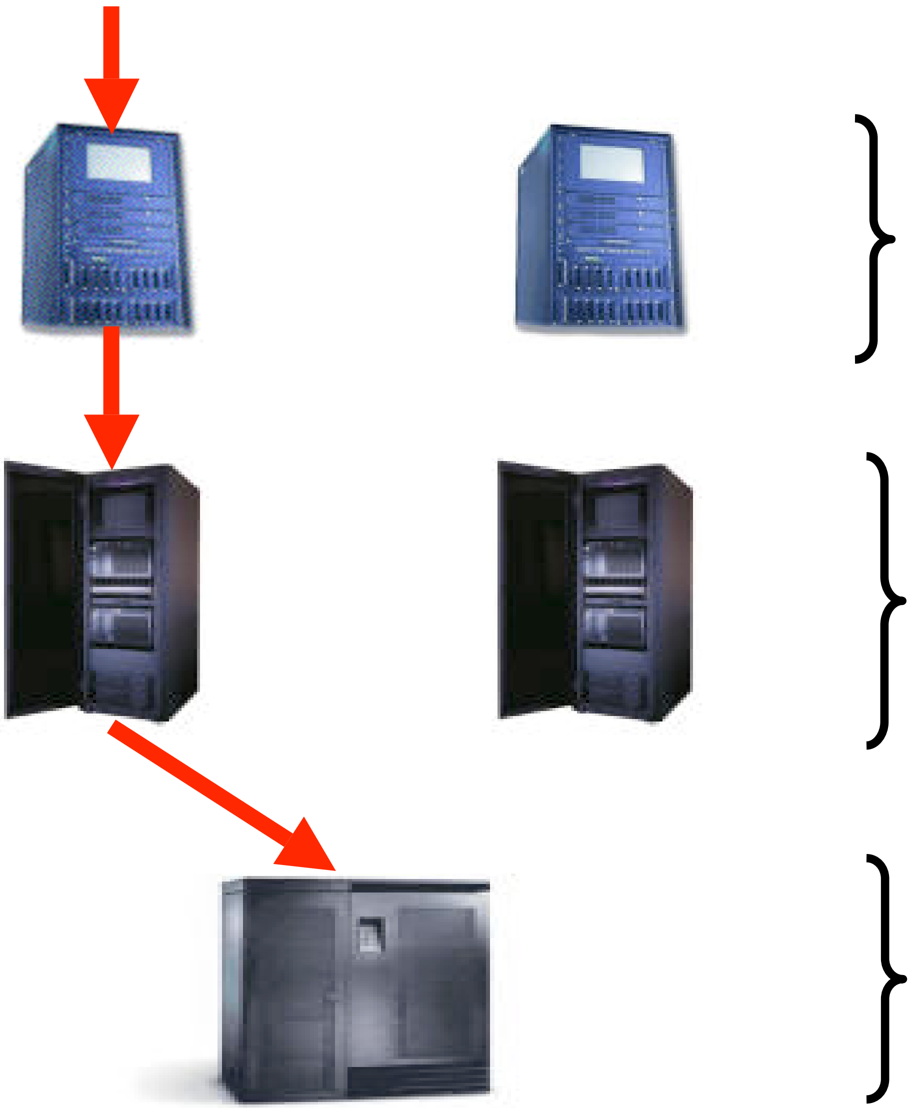
SB Structure



Backdoors Prototype

- Implemented using Myrinet NICs with modified firmware
  - remote Read/Write DMA
  - remote OS locking (syscalls, interrupt handlers)
- Modified FreeBSD kernel
  - Progress Box
  - State Box
- Modified server applications

A Realistic Sample Application: Multi-tier Auction Service (RUBiS)



Front-End (FE)

Apache web server

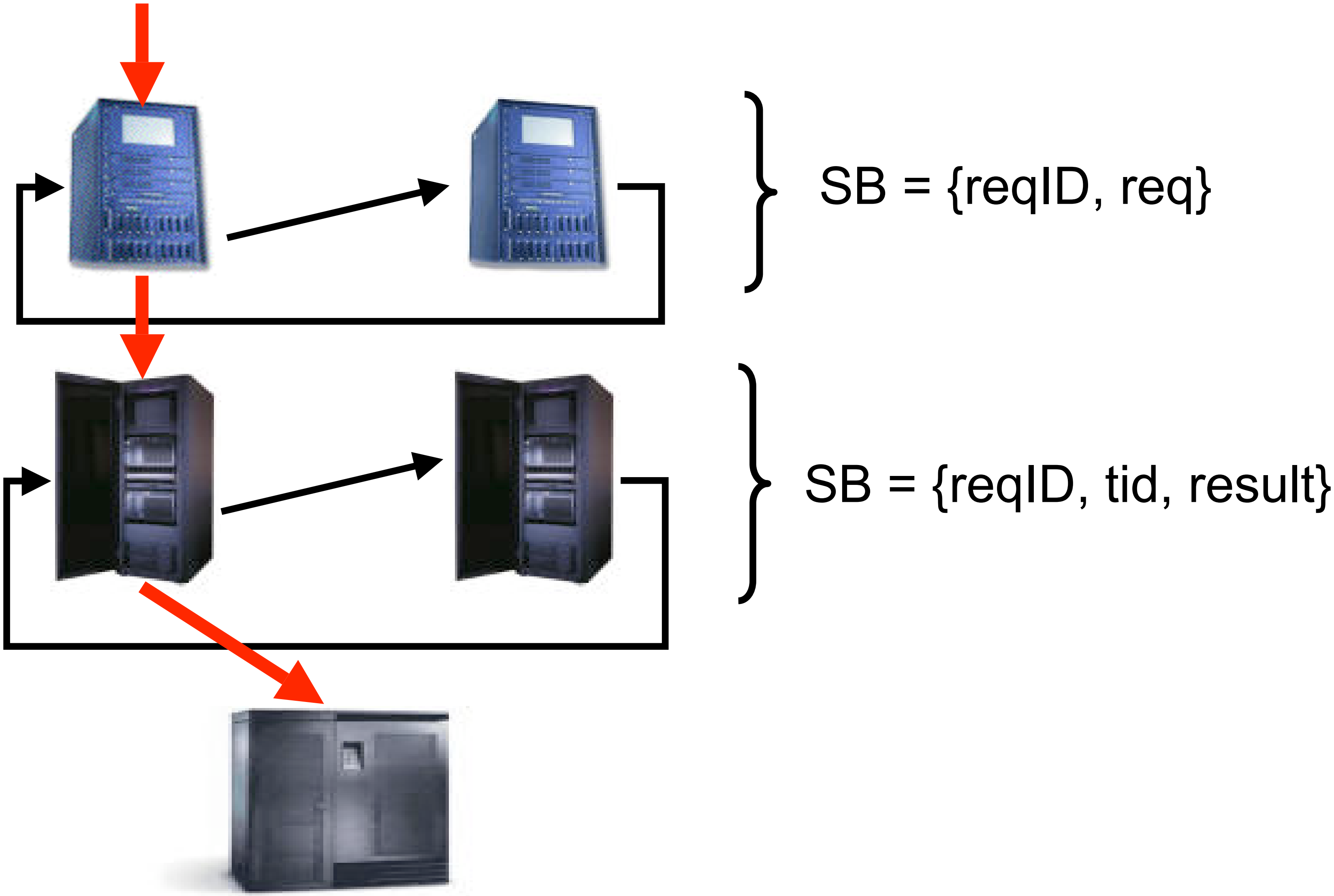
Middle Tier (MT)

Tomcat + JBoss

Back-End

MySQL DB

Recoverable RUBiS



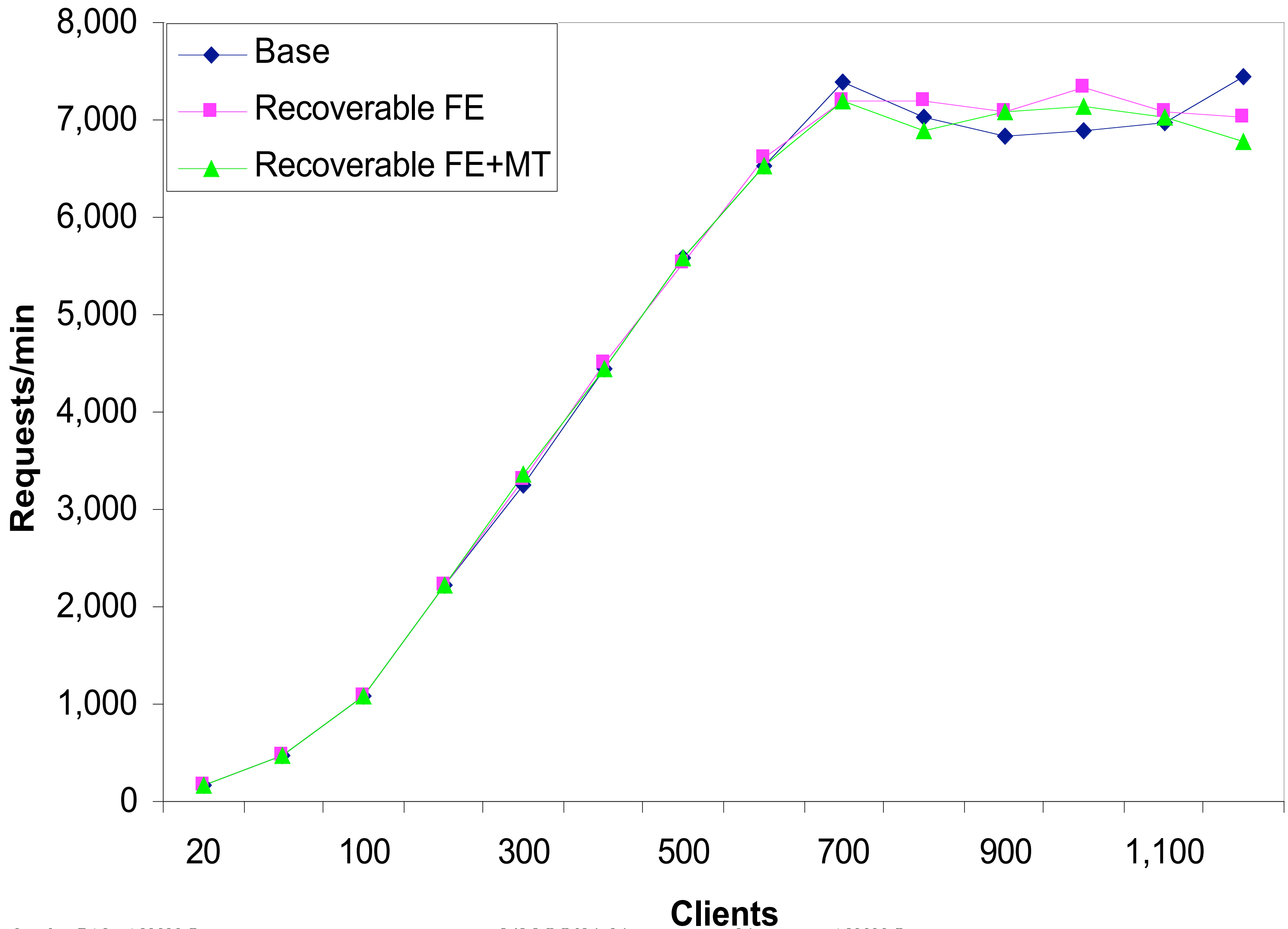
Experimental Evaluation

- 2.4 GHz, 1 GB RAM, 1Gbps Ethernet, Myrinet LanaiX 133 MHz PCI
- Fault injection
  - synthetic freeze: halt CPU, disable device interrupts, disable network interface, trap to kernel debugger
  - emulated crashes in buggy network drivers
- Experiments
  - Microbenchmarks
  - Failover correctness
  - Failover throughput and latency

Microbenchmarks

- Monitor CPU usage, sampling a 100-counter PB
  - 46% worst-case (infinite loop)
  - < 5% @ 10 ms, < 1% @ 100 ms
  - High sampling rates possible
- Low overhead SB API
  - export/import: < 30 us
  - extract + reinstate a 10 KB front-end SB: 358 us

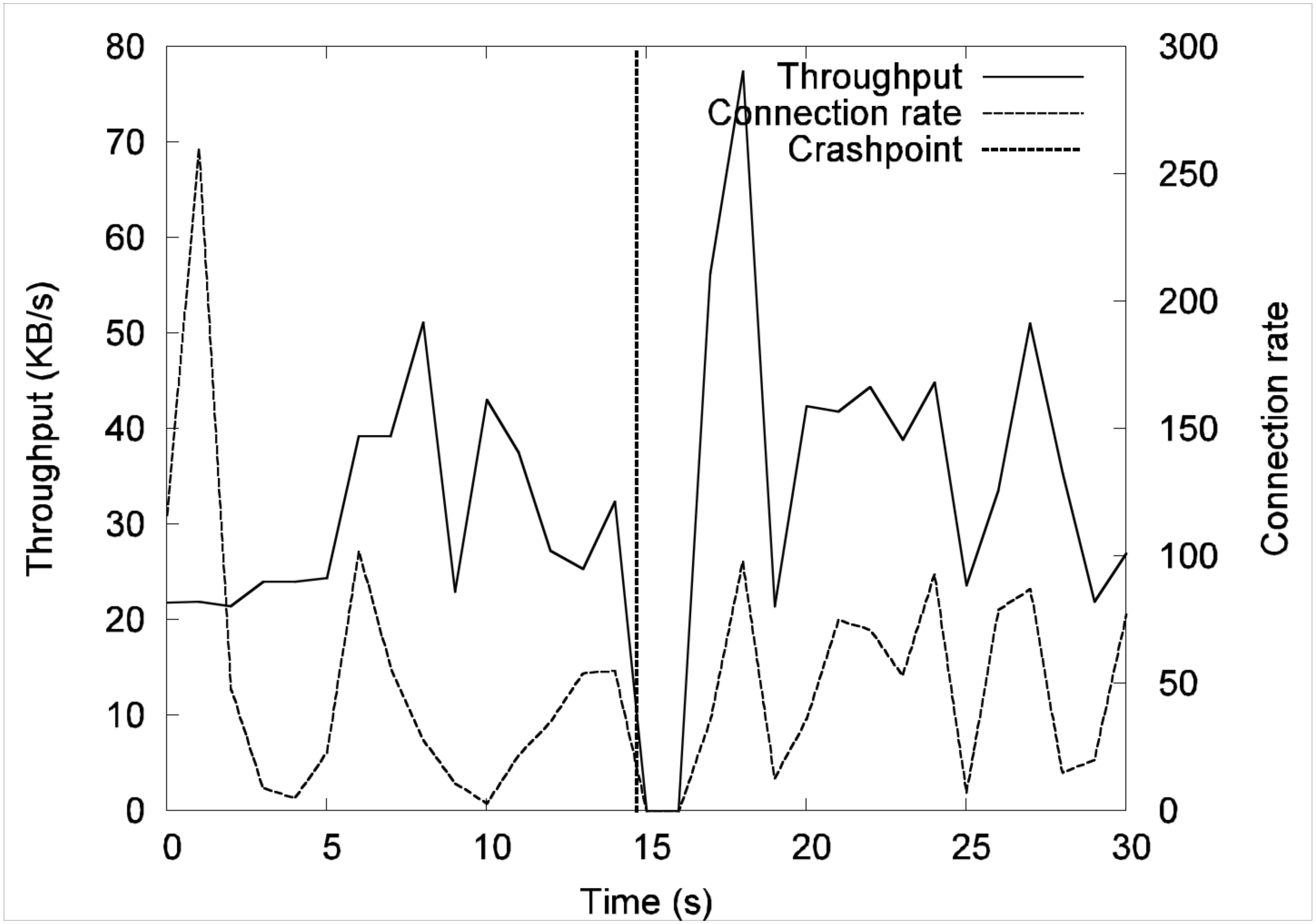
Failure-free Overhead



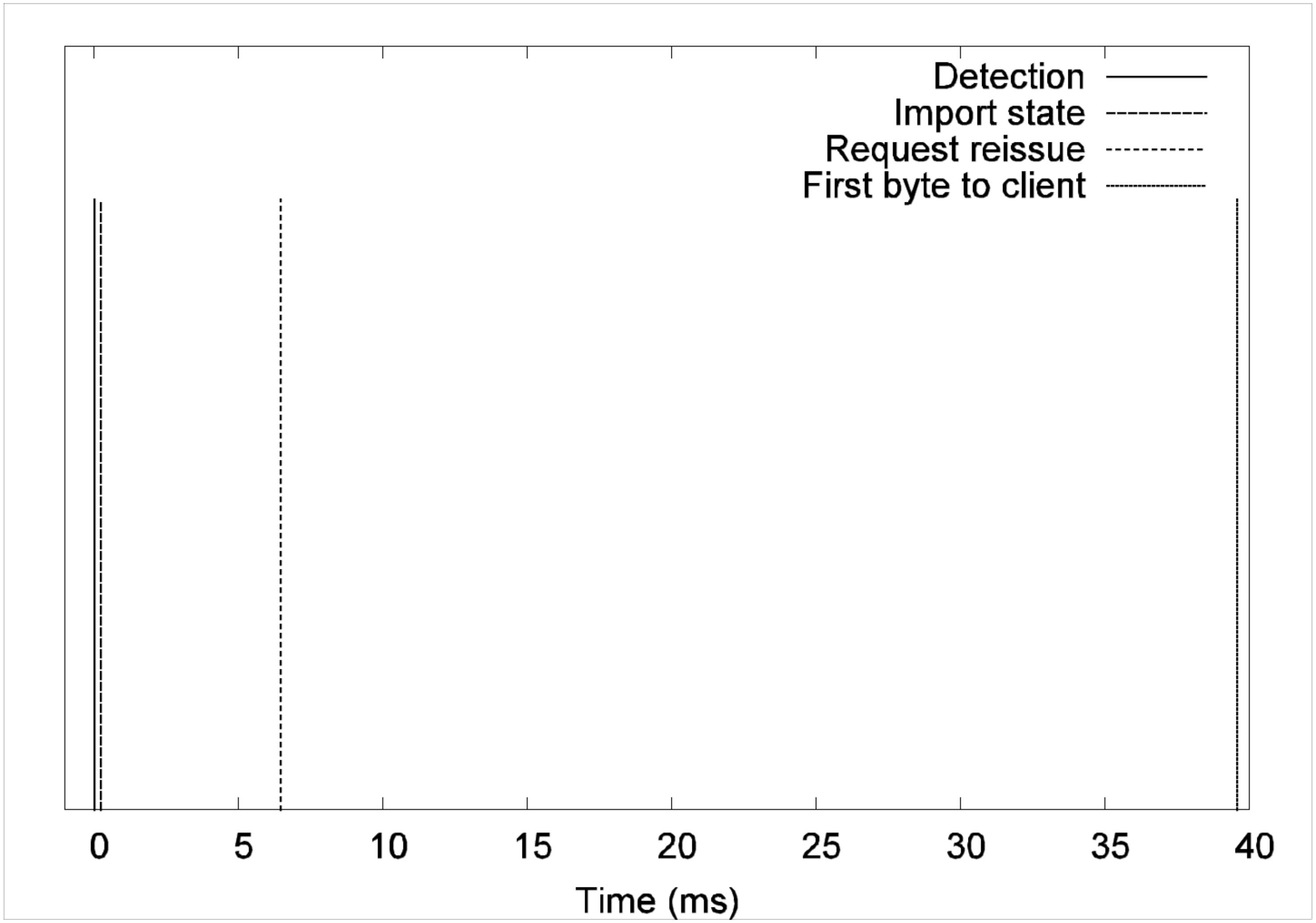
Failover Correctness

- Workload/run: 600 requests from 200 clients
  - request = DB queries + DB table update
- Two correctness tests across crash & recovery
  - End-to-end consistency (crash invisible to client)
  - Database integrity (exactly-once semantics preserved)
- All crash-test runs were validated

Failover Throughput (FE+MT crash)



Failover Latency (FE+MT crash)



Related Work

- DEC WRL Titan system [Mogul ’86]
- Recovery Box [Baker ‘93]
- Rio reliable file cache [Chen ‘96]
- Online OS reconfiguration [Soules ‘03]
- Virtual machines [Bressoud ‘95, Dunlap ‘02]
- Automatic repair of data structures [Demski ‘03]

Conclusions

- Backdoor: system architecture for nonintrusive remote healing
  - monitoring without using processor cycles
  - repair, recovery even when remote processor is not available
- BD prototype for transparent recovery of active service sessions in cluster-based Internet services

Current and Future Work

- Remote repair of OS state
- OS support and API for healing-conscious applications
  - programmer performs application-specific monitoring, repair and recovery
- Securing the BD
  - low-level access control through BD Guard entities implemented in firmware
- Remote control of I/O devices

The People Behind Backdoors

- Aniruddha Bohra
- Stephen Smaldone
- Yufei Pan
- Iulian Neamtiu (Maryland)
- Pascal Gallard (IRISA/INRIA)
- Liviu Iftode

Thank you!

http://discolab.rutgers.edu/bda