DATACUBE
A Scaleable, Fault Tolerant Data Server

Noah Mendelsohn
Lotus Development / IBM
10/27/2000

Agenda

- Project History
- Goals and Hardware Overview
- Software Overview
- Fault Tolerance
- Conclusions

Project History

History

- Milestones:
  - 1986?: Project initiated
  - 1990: Hardware/software simulator
  - 1900-1992: Hardware/software prototype operational
  - July 1992: IBM Cambridge & LA Scientific Centers close, project ends
- Publications
  - ASPLOS work (not) in progress talk, fall 1992
  - Several patents
- Most details of system remain unpublished

Participants

- Sandy Frey
- Joel Gould
- Tom Hancock
- John (Kubi) Kubiatowicz
- Neal Lackritz
- George Linscott
- Noah Mendelsohn
- Ricky Mosteller
- Rip Parmelee
- Jim Perchik
- Ernie Petrides
- Bill Ruh
- Dave Saul
- Jim Sullivan

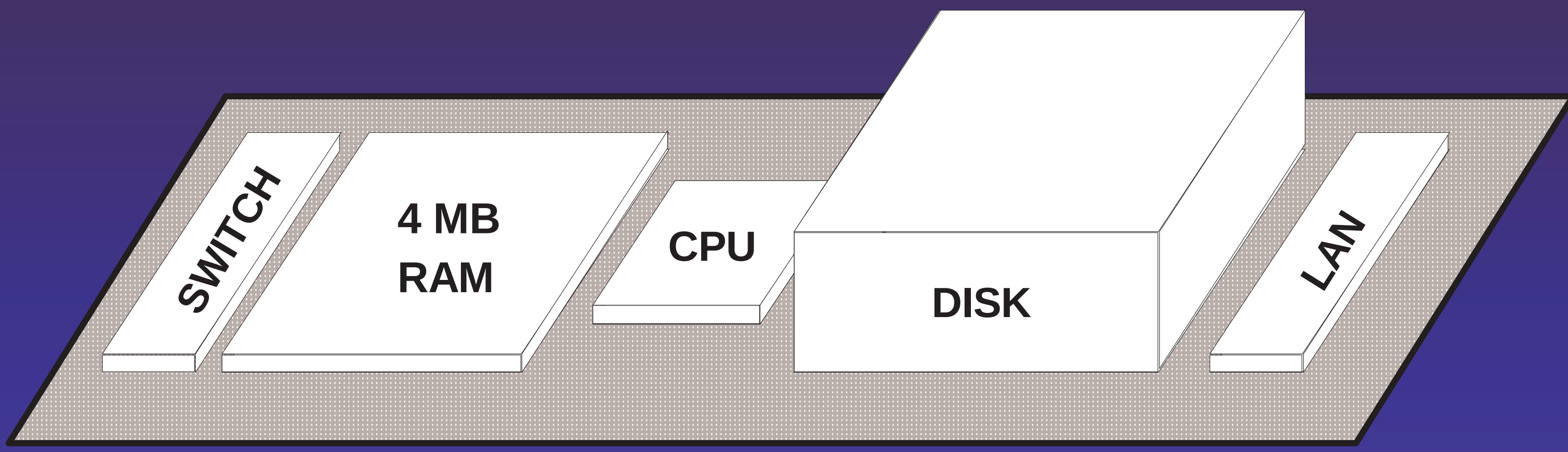
(All participants were regular, part time or contract employees of IBM during their work on the Datacube project.)

Goals and Hardware Overview

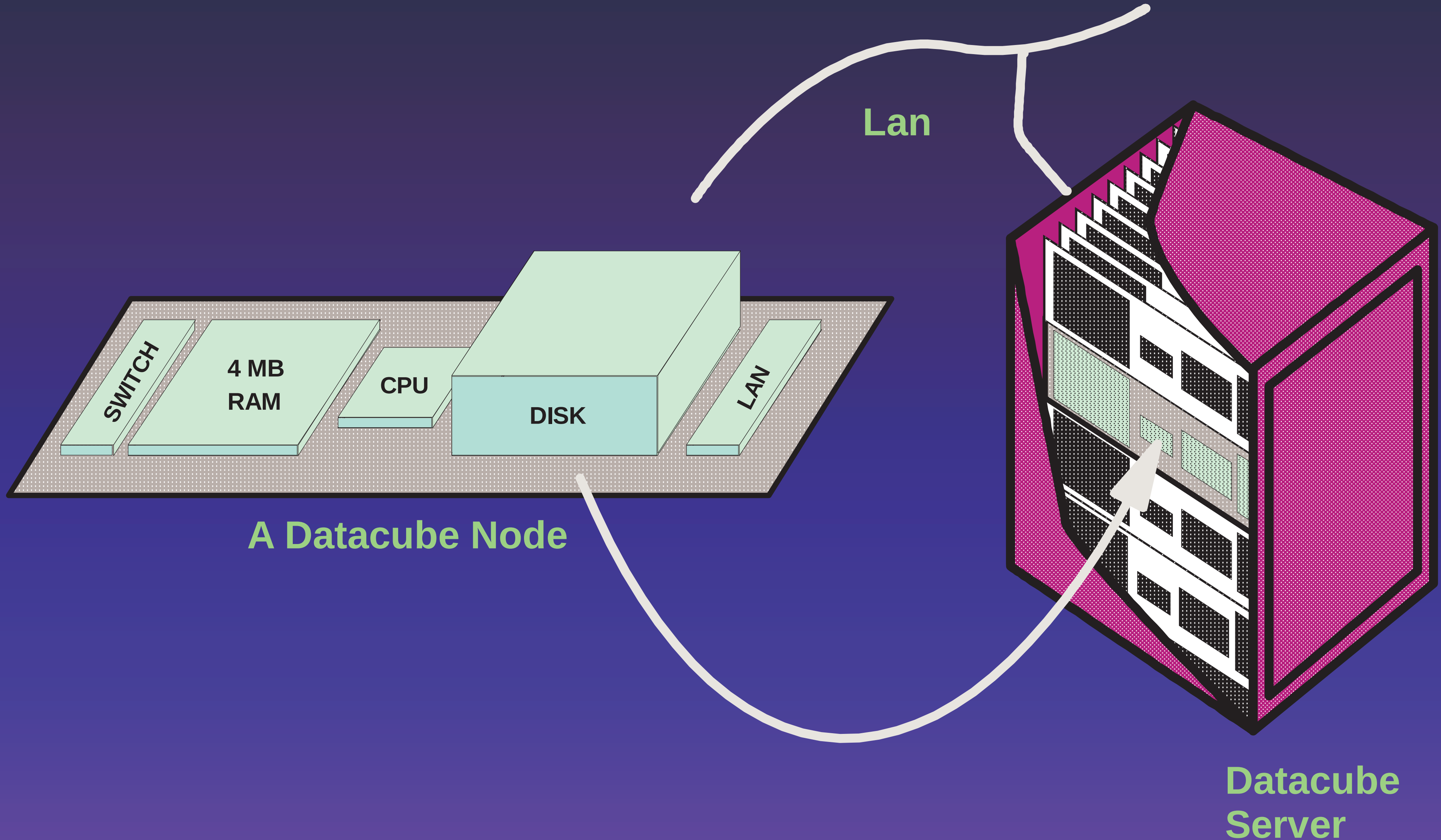
Project Goals

- Investigate massively parallel *business system* architectures
- Strong focus on fault tolerance
- Investigate design & performance of required software
- Scaleable, fault tolerant, continuously available, hardware interconnect
- Focus on realistic maintenance and deployment issues

A DATACUBE NODE



The DATACUBE Parallel Data Server



Datacube System Overview

- Message passing MIMD computer (shared nothing) each node has:
  - Inexpensive processor
  - RAM
  - Disk
  - Switch
  - NVRAM (optional)
  - LAN attach (optional)
- Fault tolerant, adaptive, 4-D torus, distributed switch
- All elements of system scale together

Switch Hardware

- 4 dimensional Taurus
- Distributed routing hardware (on nodes)
- Adaptive real-time path search in hardware
- 3.6 Mbyte/sec/node full duplex, approx 60 usec latency (Xilinx prototype)
- 10x improvement projected for inexpensive single chip VLSI

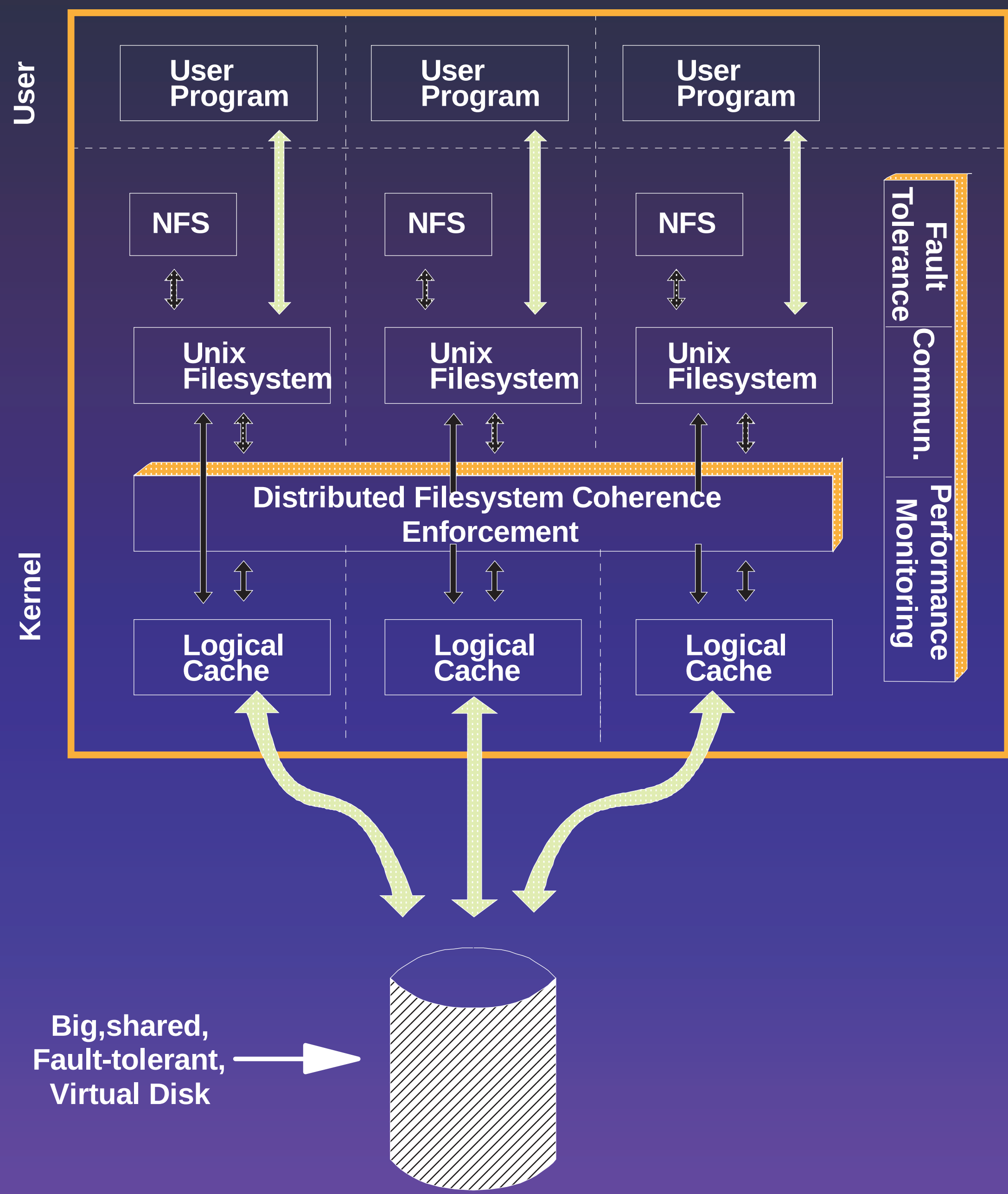
Remember, this was ~1988

Software Overview

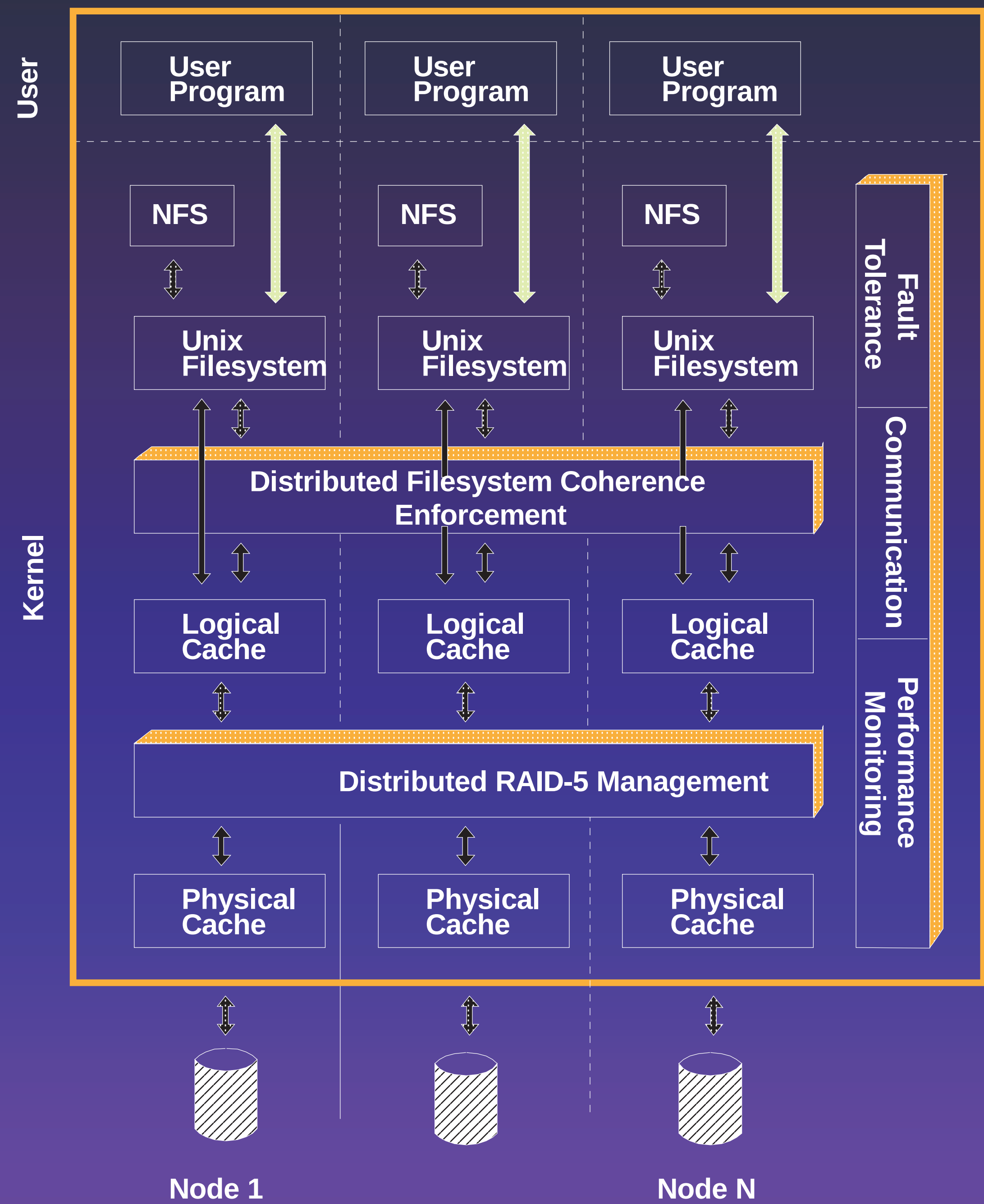
The Datacube Prototype: Software Features

- Unix kernel-based prototype
- Communications
  - Communication/disk buffer integration: zero copy disk cache update & access
  - IP packet switching
- RAID-1 (mirror) and RAID-3&5 virtual disk
  - Appears as large, common disk at all nodes
  - Optimized for 1:1 interleave...adaptive RAID 5/RAID 3
  - Faults hidden from surviving nodes
  - Distributed caching
- Distributed Unix filesystem
- Scaleable distributed reconfiguration algorithms

Datacube Software



Datacube Software



Fault Tolerance

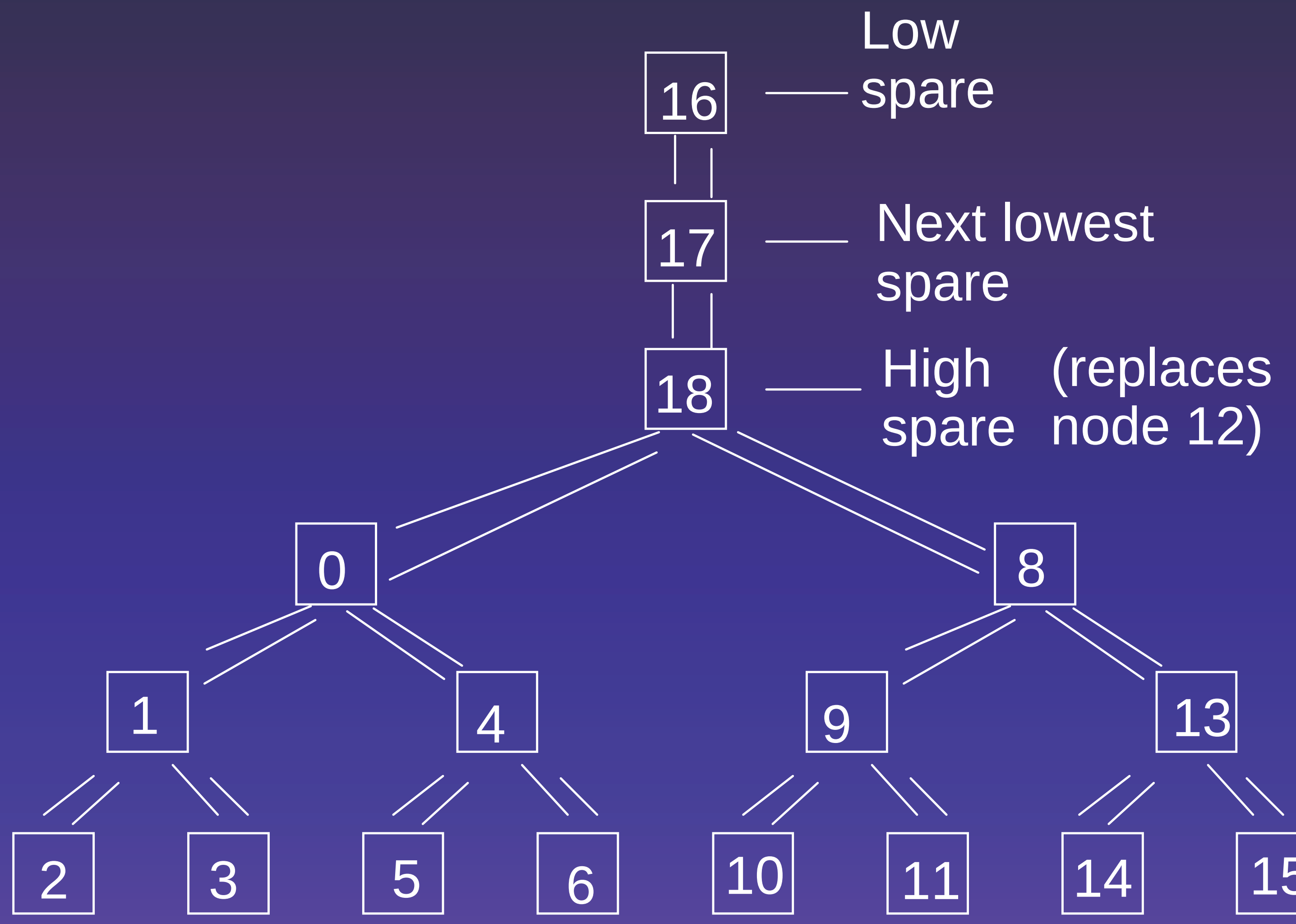
Fault tolerance model

- Hardware
  - ► Hot pluggable nodes, redundant power, etc.
  - ► Passive backplane (power, ground, torus wiring)
  - ► Hardware provides fault tolerant message routing
  - ► Failstop on all errors
- Software
  - ► Nodes fail and are replaced by warm standby spares
  - ► Distributed reconfiguration algorithms
  - ► Raid (1,3,5) reconstruction of disk, nvram

Reconfiguration software

- Simulates stable virtual node space
  - Spares replace failed nodes, routing tables updated
  - Nodes appear to pause for ~2 seconds on failure
  - Performance degraded during RAID reconstruction, filesystem token resync, etc.
- Anticipates realistic failure statistics (almost any 2 nodes at a time)
- Correctly rejects old nodes that reappear including after reboot
- Distributed algorithm simulated on thousands of nodes, tested on hardware

Dynamic node replacement

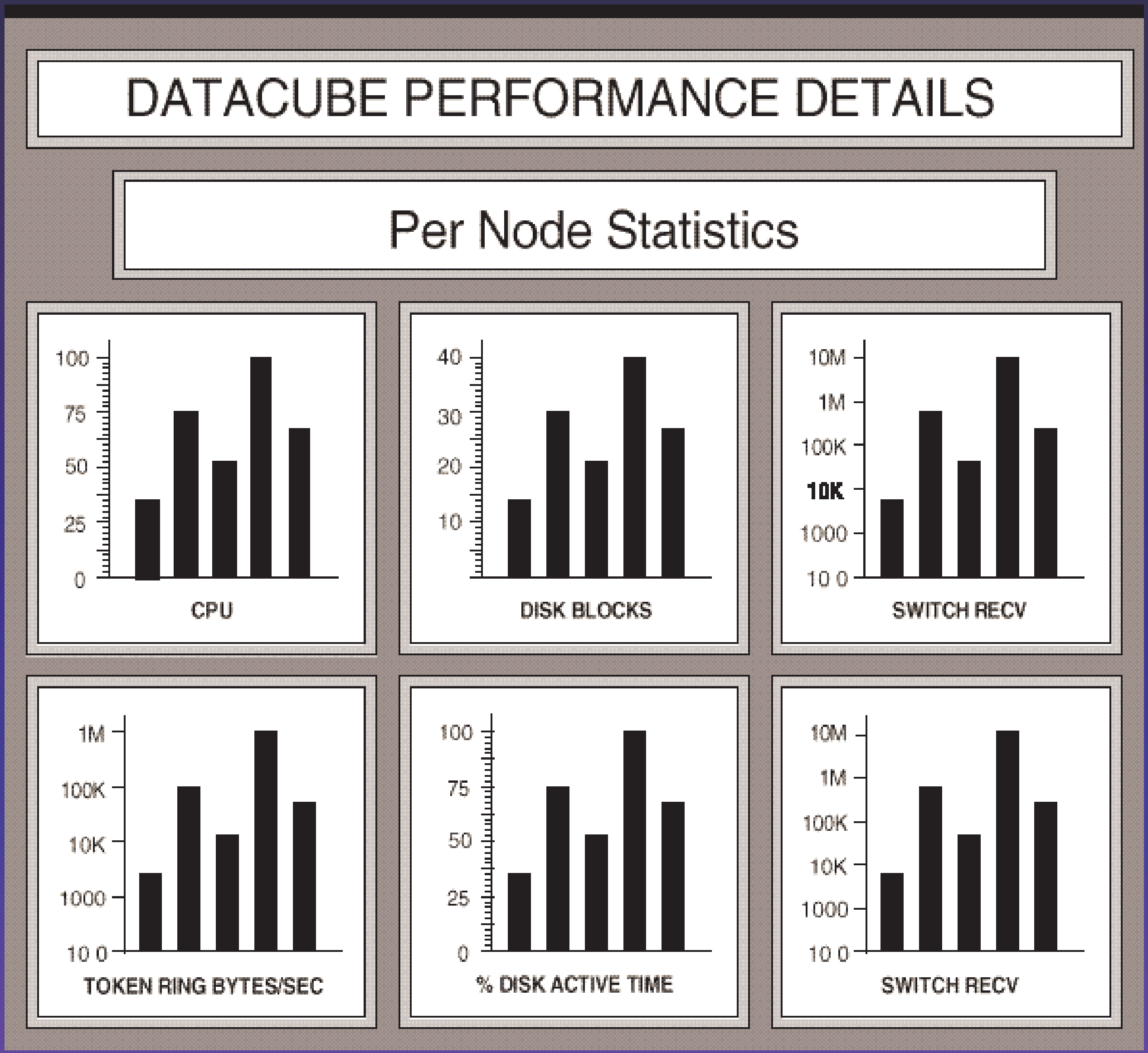


Performance

Performance tools

- Real time displays of low level software instrumentation
- Logging of same
- Kernel event tracing...post-facto clock correlation reproduces virtual time (causality) in face of local clock drift
- Complete software emulator for switch...software stack run on emulator
- Analytical models

Realtime performance monitor

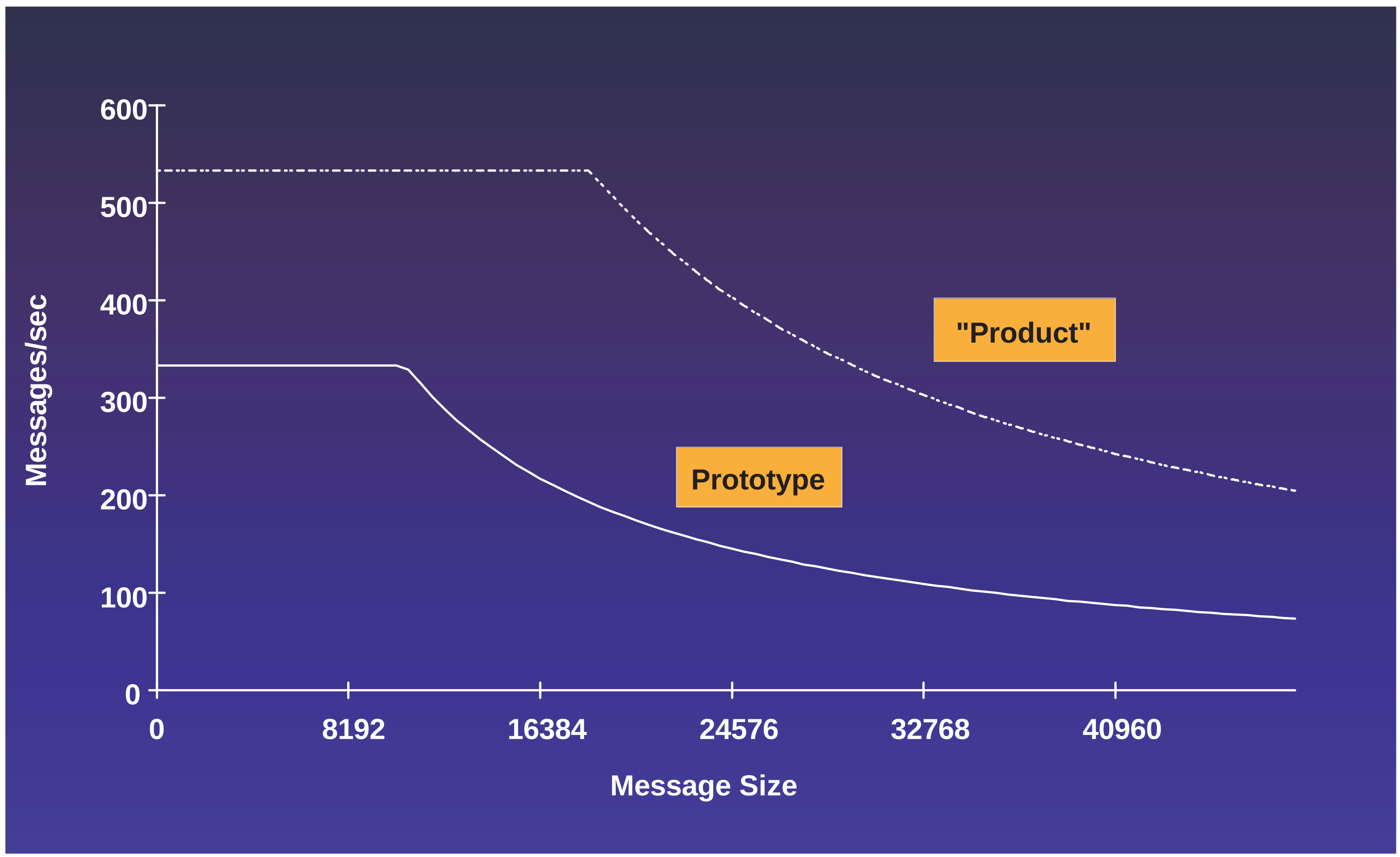


Software Performance

- Message send:
  - 2250 instruction times for full kernel to kernel RPC round-trip (1500 usec at 1.5 Mip, incl. buffer allocation, queueing, interrupts, etc.)
- Parallel Filesystem (4K byte block size):
  - Non cached/sequential access: 630 KBytes/sec/drive = 156 blocks/sec (drive & controller limited, same as single node system)
  - Non caching/random access: 130 Kbytes/sec/drive = 42.5 blocks/sec (drive limited, same as single node system)
  - Cache hits through filesystem & switch: 3.2 Mbyte/sec/filesys-node 800 blocks/sec (cpu limited - 89% of node's switch bandwidth!)

Model: Msg. rate vs. msg. size

Messages per Second

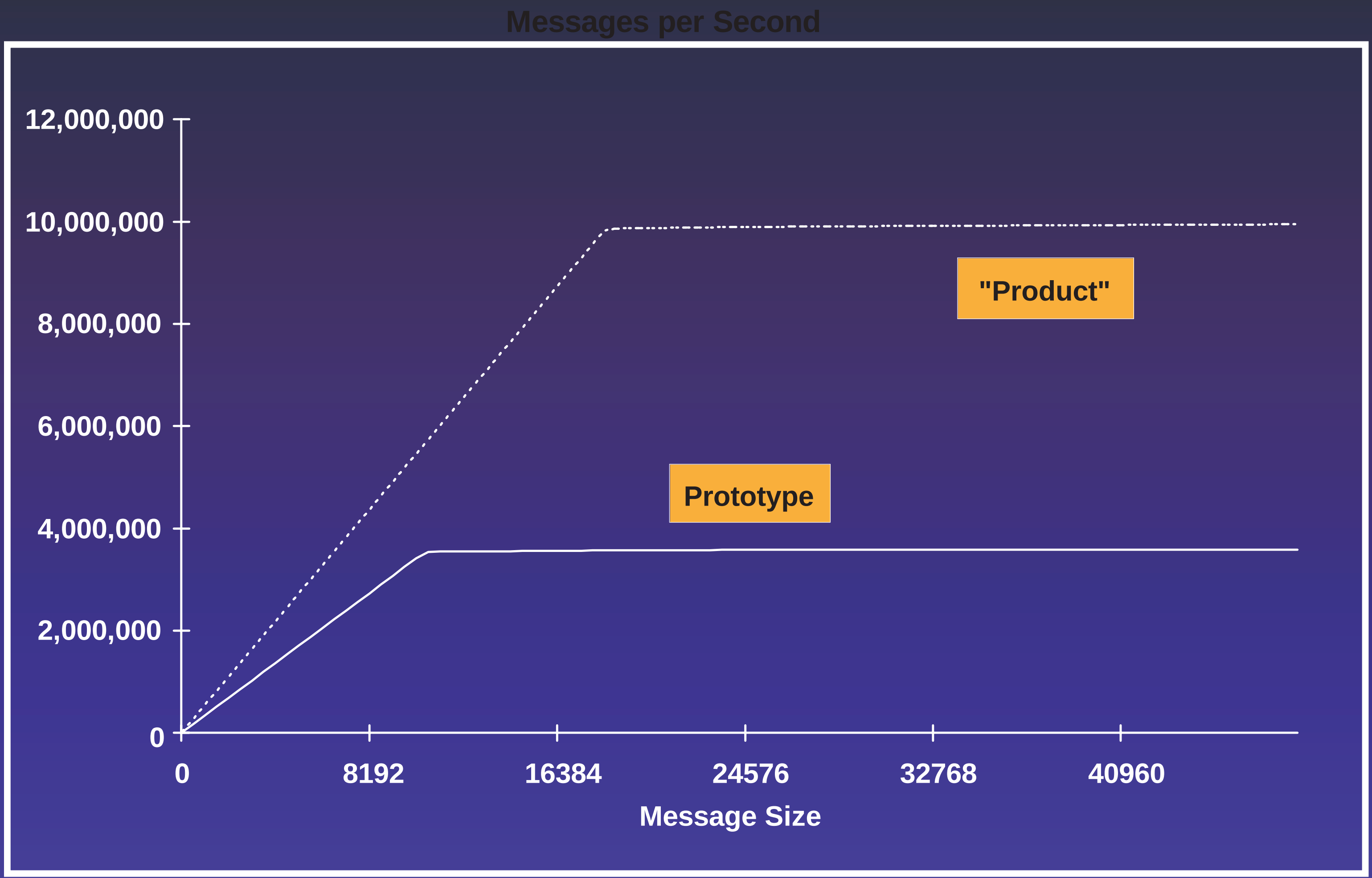


	Switch Speed	Driver Latency	Switch Latency	Max CPU in Switch Driver
Prototype	3.6 MB/sec	750 usec	50 usec	25 %
Product	10 MB/sec	375 usec	26 usec	20 %

Msgs per second = 1 / MAX(Driver Latency/Max CPU, Switch Latency + Message size/Switch Speed)

Bytes per second = Messages per second x Message Size

Model: Bytes/sec vs. msg. size



	Switch Speed	Driver Latency	Switch Latency	Max CPU in Switch Driver
Prototype	3.6 MB/sec	750 usec	50 usec	25 %
Product	10 MB/sec	375 usec	26 usec	20 %

Msgs per second = 1 / MAX(Driver Latency/Max CPU, Switch Latency + Message size/Switch Speed)

Bytes per second = Messages per second x Message Size

Conclusions

- Datacube Successes
  - The Datacube model of fault tolerance has attractive features
  - Specialized hardware/software integrating message passing with disk cache is very effective
  - Datacube style hardware is very easy to engineer and implement
  - Datacube is both scaleable and economical
- Datacube Disadvantages
  - Software is difficult to scale--programming these machines is difficult!
  - Assumption of uniform nodes is unrealistic
  - Specialized architecture--difficult to share hardware and software with general purpose machines

Controversial Ideas!

- Massively parallel systems must be fault tolerant
- We need software tools for parallel system development (you can't write filesystems in FORTRAN-D!)
- Designing message switch interfaces involves the same kind of hardware/software tradeoffs as designing instructions sets