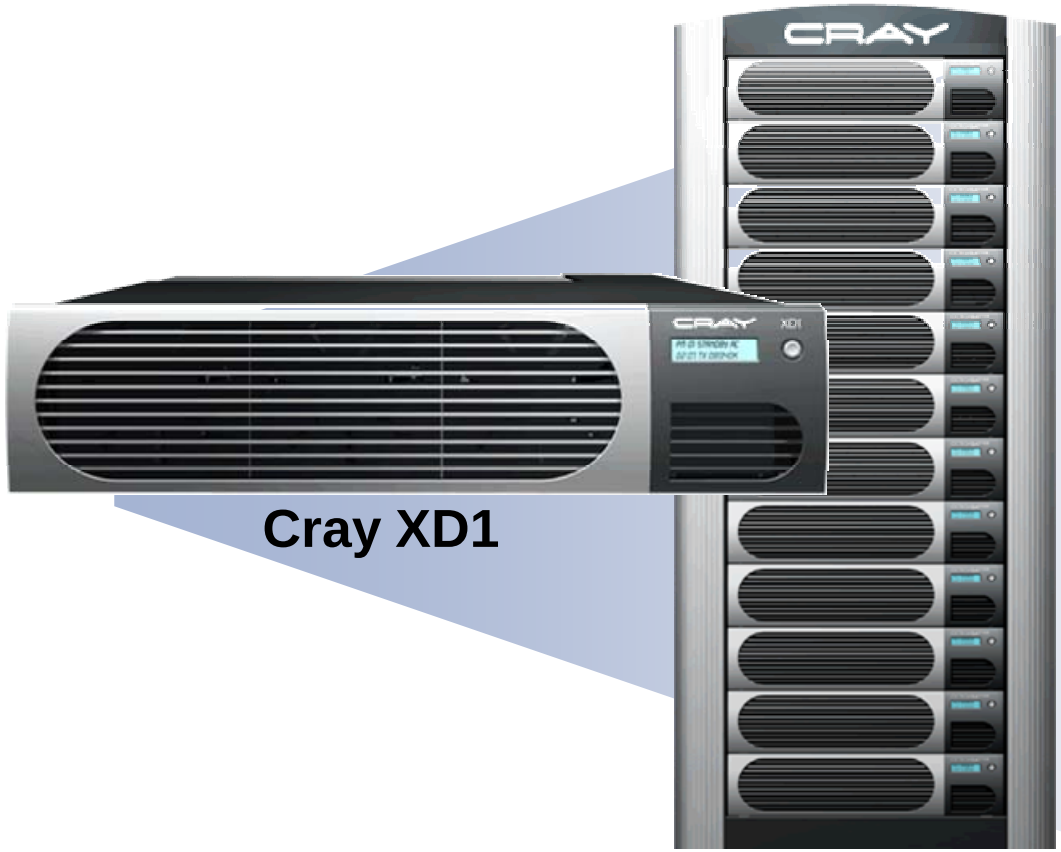
The Cray XD1

Technical Overview

Amar Shan, Senior Product Marketing Manager

The Cray XD1



Cray XD1

- Built for price performance
- 30 times interconnect performance
- 2 times the density
- High availability
- Single system command & control

Purpose-built and optimized for high performance workloads

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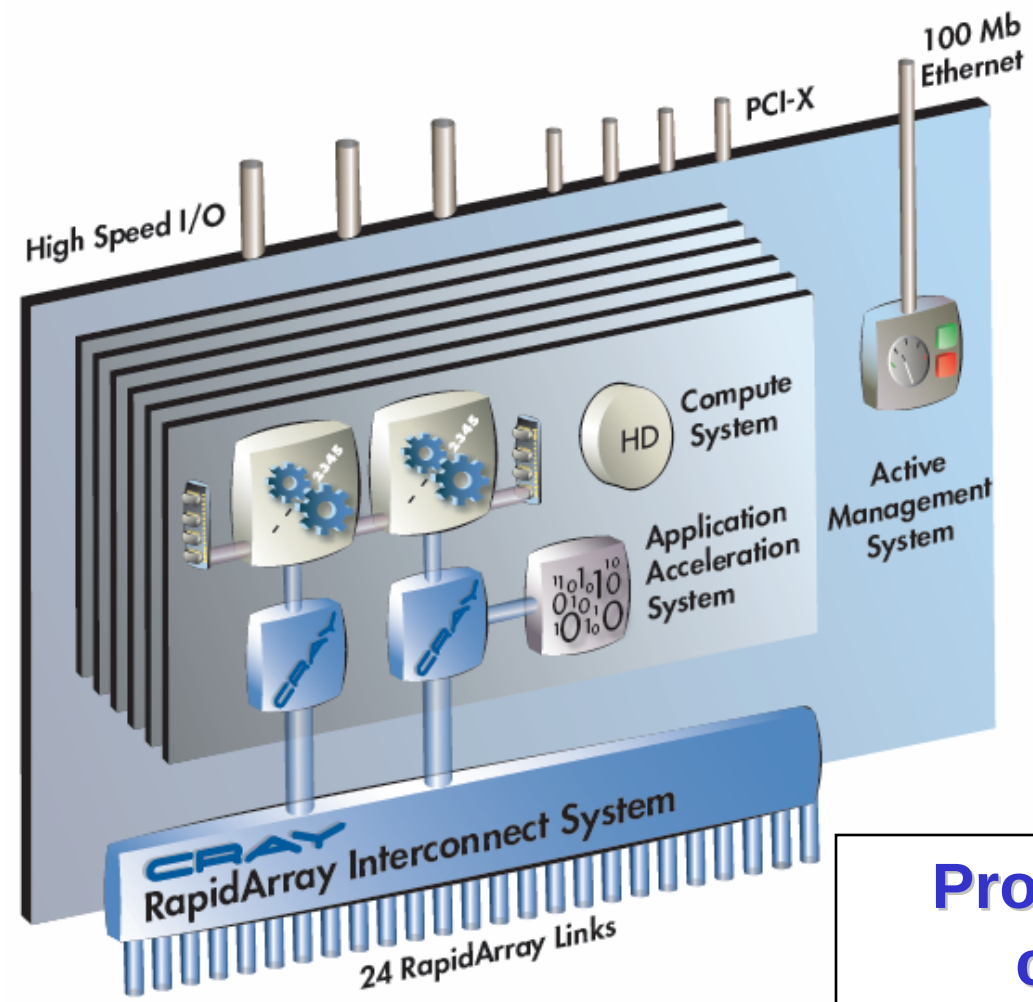
Cray XD1 System Architecture



Compute

- 12 AMD Opteron 32/64 bit, x86 processors
- High Performance Linux

RapidArray Interconnect

- 12 communications processors
- 1 Tb/s switch fabric

Active Management

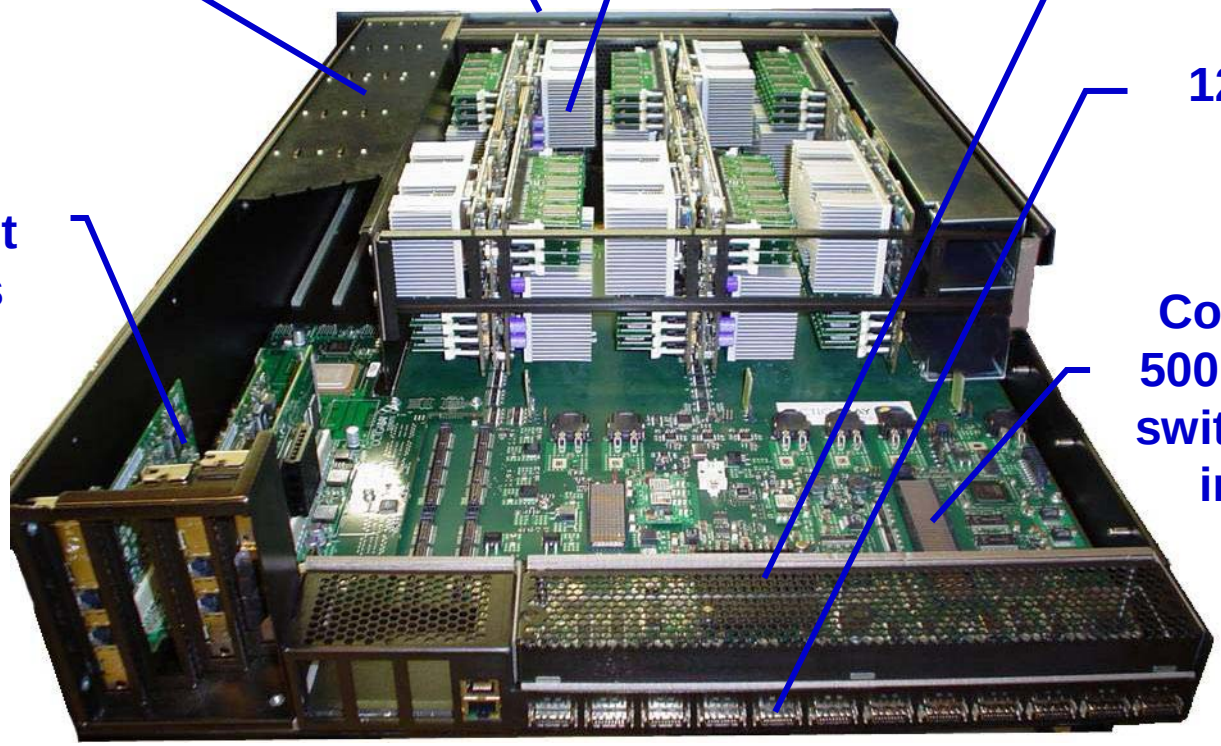
- Dedicated processor

Application Acceleration

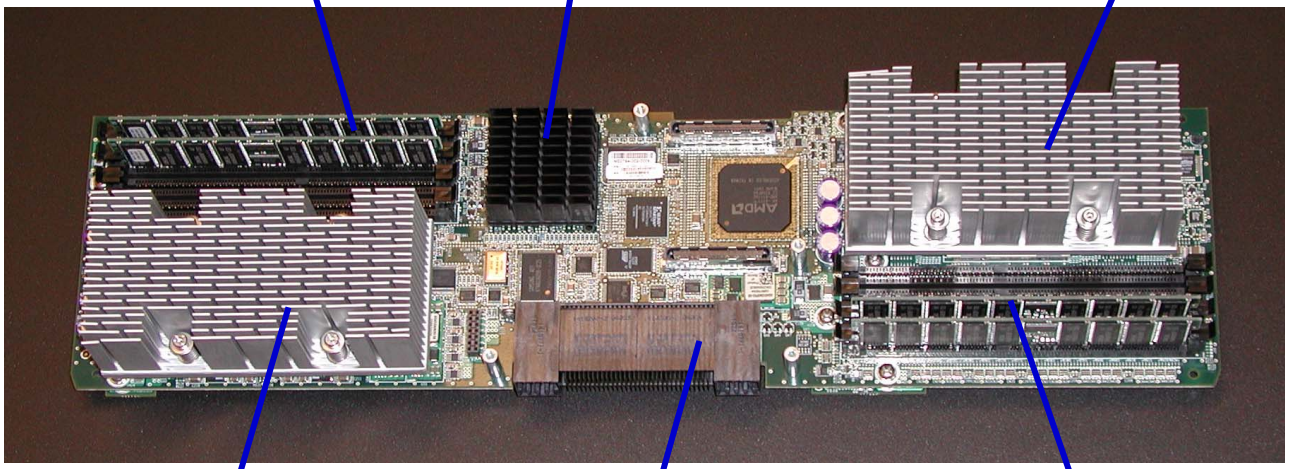
- 6 co-processors

Processors directly connected via integrated switch fabric

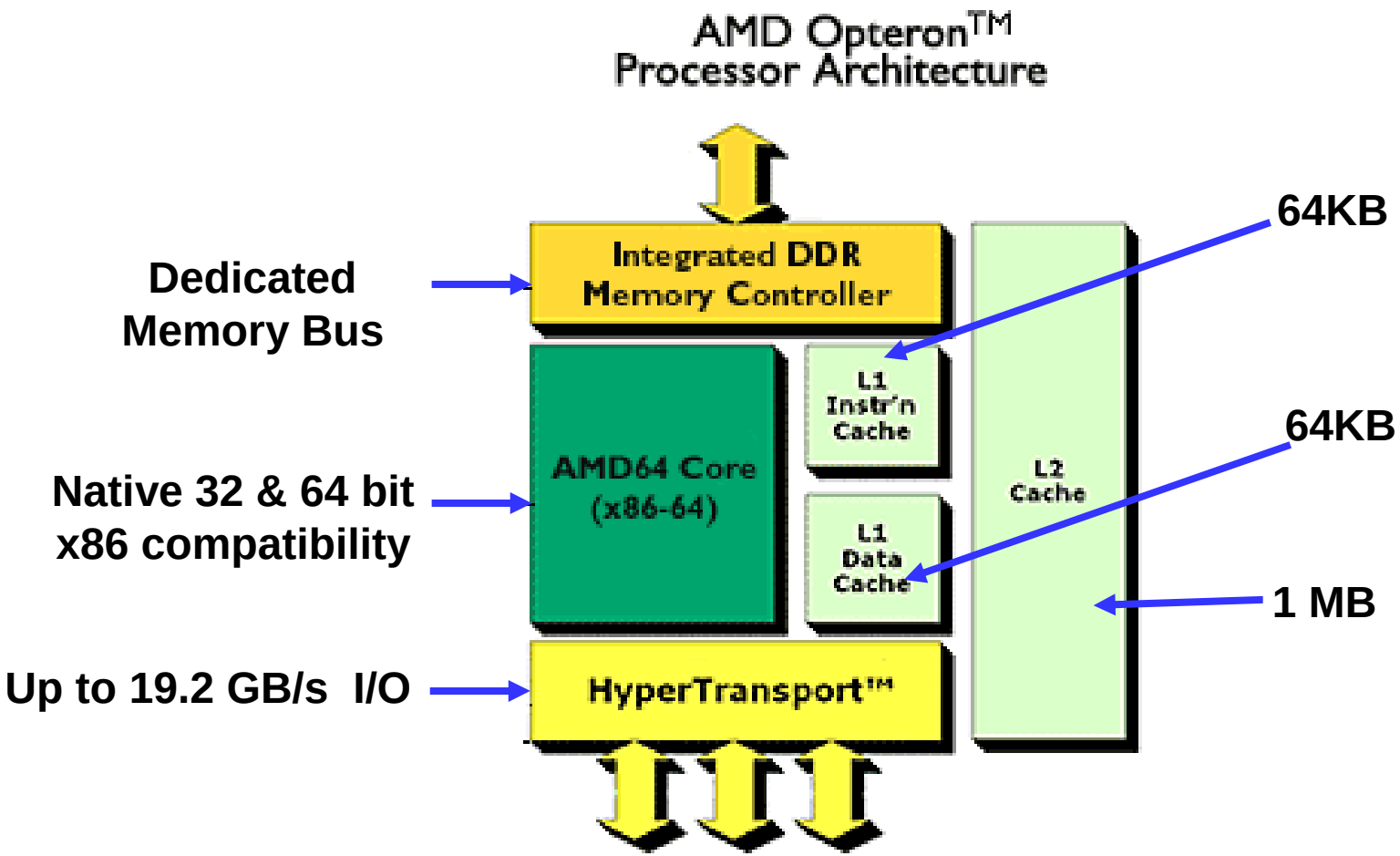
Under the Covers



Compute Blade



The AMD Opteron Processor



Cray Innovations

Cray XD1

Balanced Interconnect

Active Management

Application Acceleration

Performance and Usability

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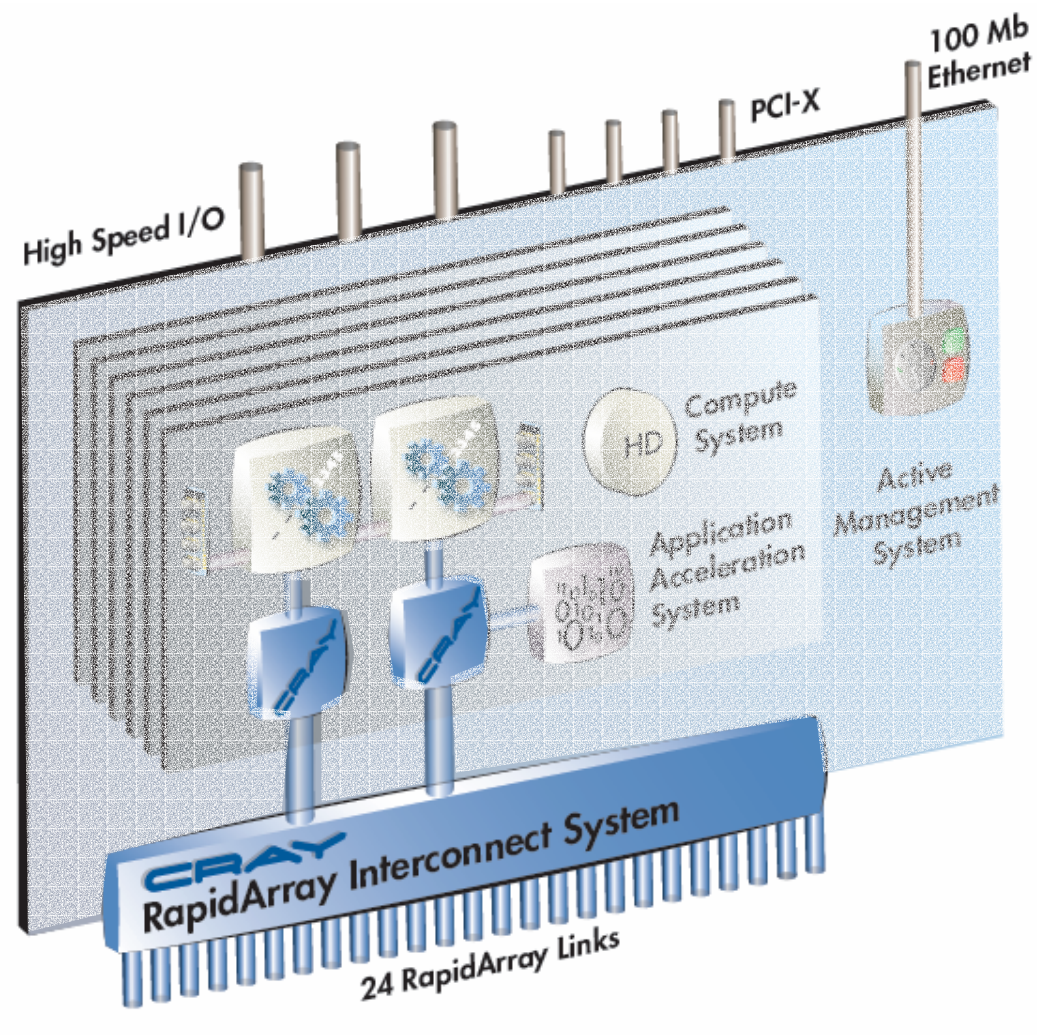
Interconnect

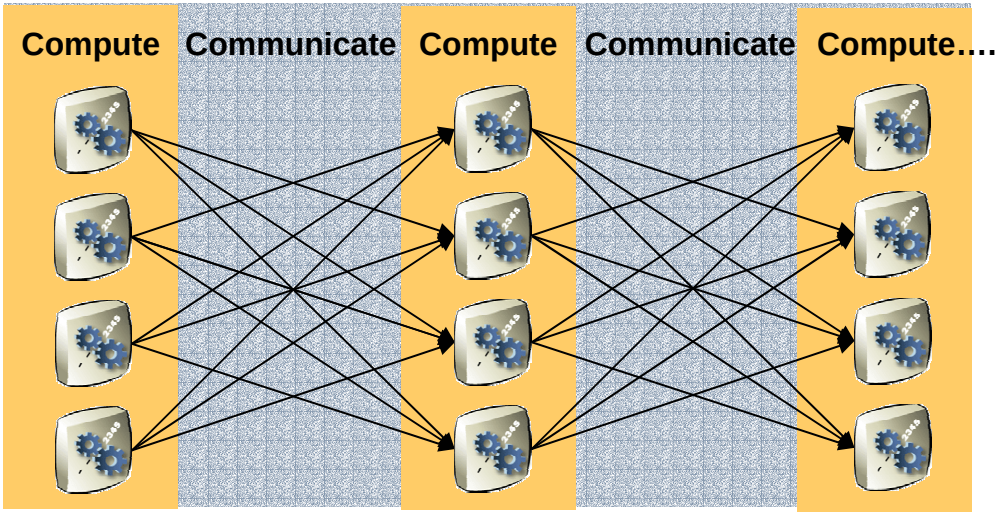
Cray XD1 Interconnect System



RapidArray

- **Interconnect processors**
- **Switch fabric**
- **Communications software**

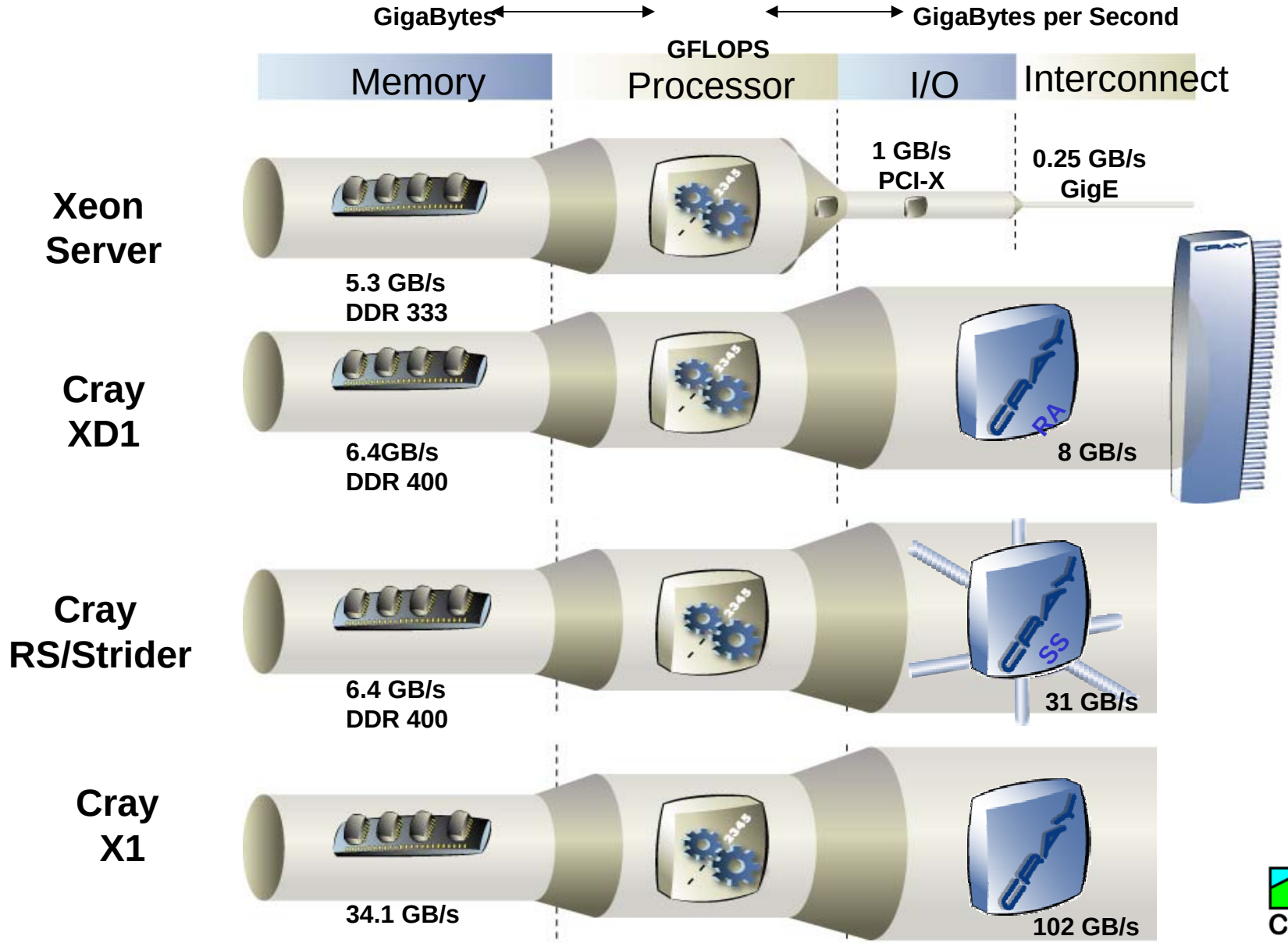
Typical HPC Application



- **HPC applications exhibit intense compute/ communicate cycles**
- **20% - 60% of time, CPUs sit idle, stalled by communications**
- **Application performance is very sensitive to latency and bandwidth**

Interconnect Drives System Performance

Removing the Communications Bottleneck



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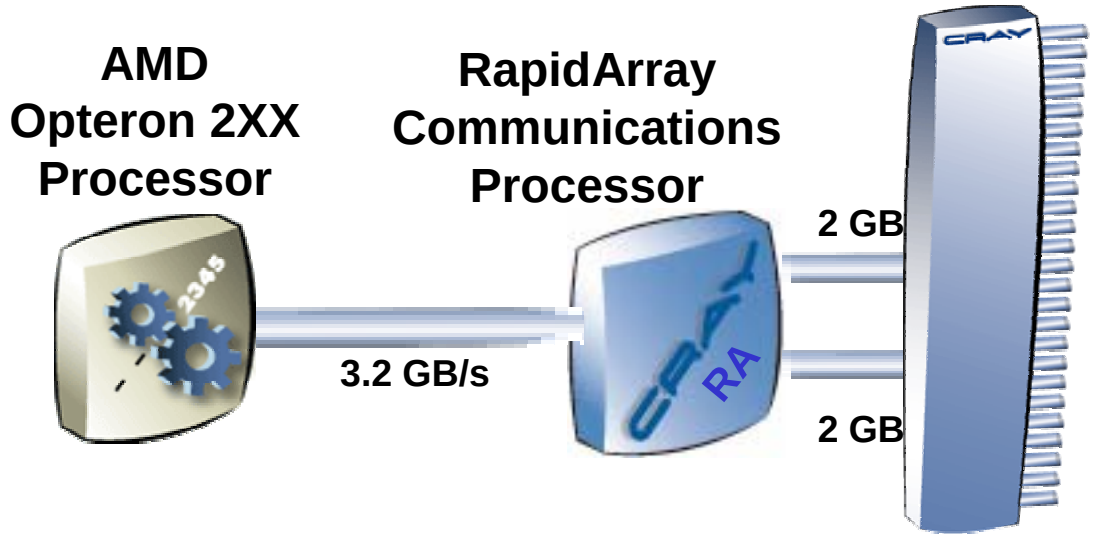
HPC Communications Optimizations

Cray Communications Libraries

- MPI 1.2 library
- TCP/IP
- PVM
- Shmem
- Global Arrays
- System-wide process & time synchronization

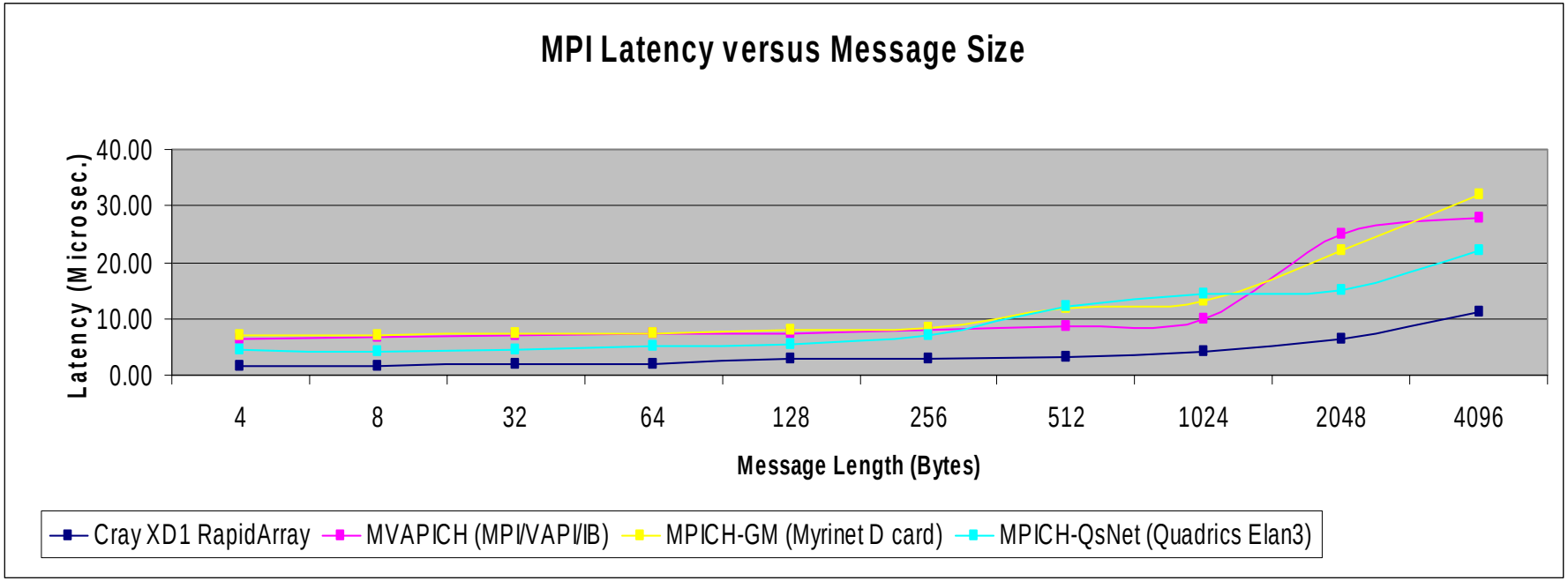
RapidArray Communications Processor

- HT/RA tunnelling with bonding
- Routing with route redundancy
- Reliable transport
- Short message latency optimization
- DMA operations
- System-wide clock synchronization



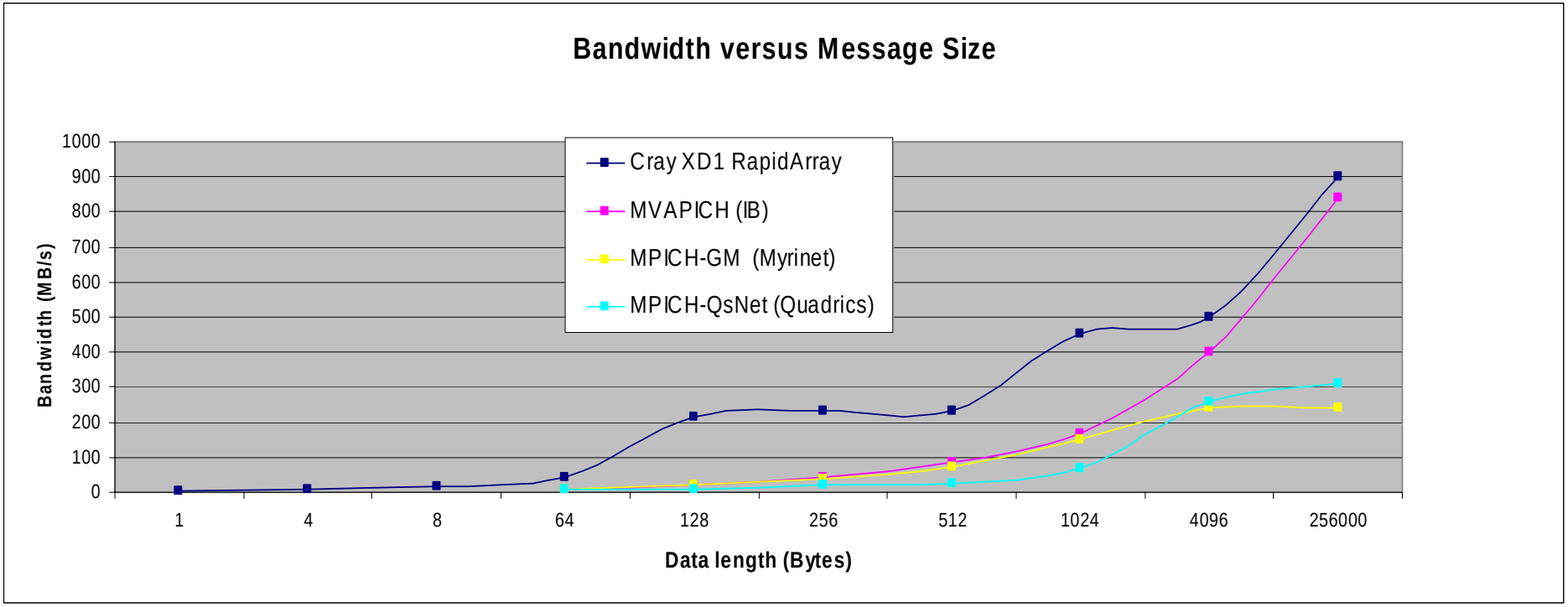
Direct Connected Processor Architecture

Interconnect Benchmarks (MPI Latency)



4 times lower latency than Myrinet (small message).
The Cray XD1 has sent 1 KB before others have sent a single byte.

Interconnect Benchmarks (MPI Throughput)



The Cray XD1 is 5X throughput of Quadrics at 1KB messages

Processor Interaction

The Case of the Missing Supercomputer Performance:
Achieving Optimal Performance on the 8,192 Processors of ASCI Q

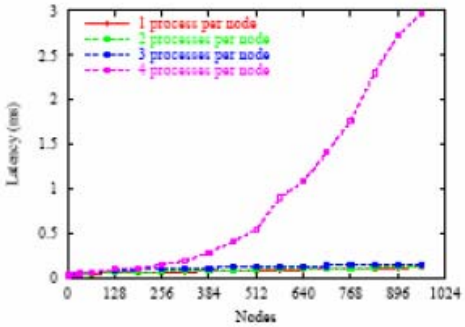
Fabrizio Petrini Darren J. Kerbyson Scott Pakin

Performance and Architecture Laboratory (PAL)
Computer and Computational Sciences (CCS) Division
Los Alamos National Laboratory
Los Alamos, New Mexico, USA

{fabrizio,djk,pakin}@lanl.gov

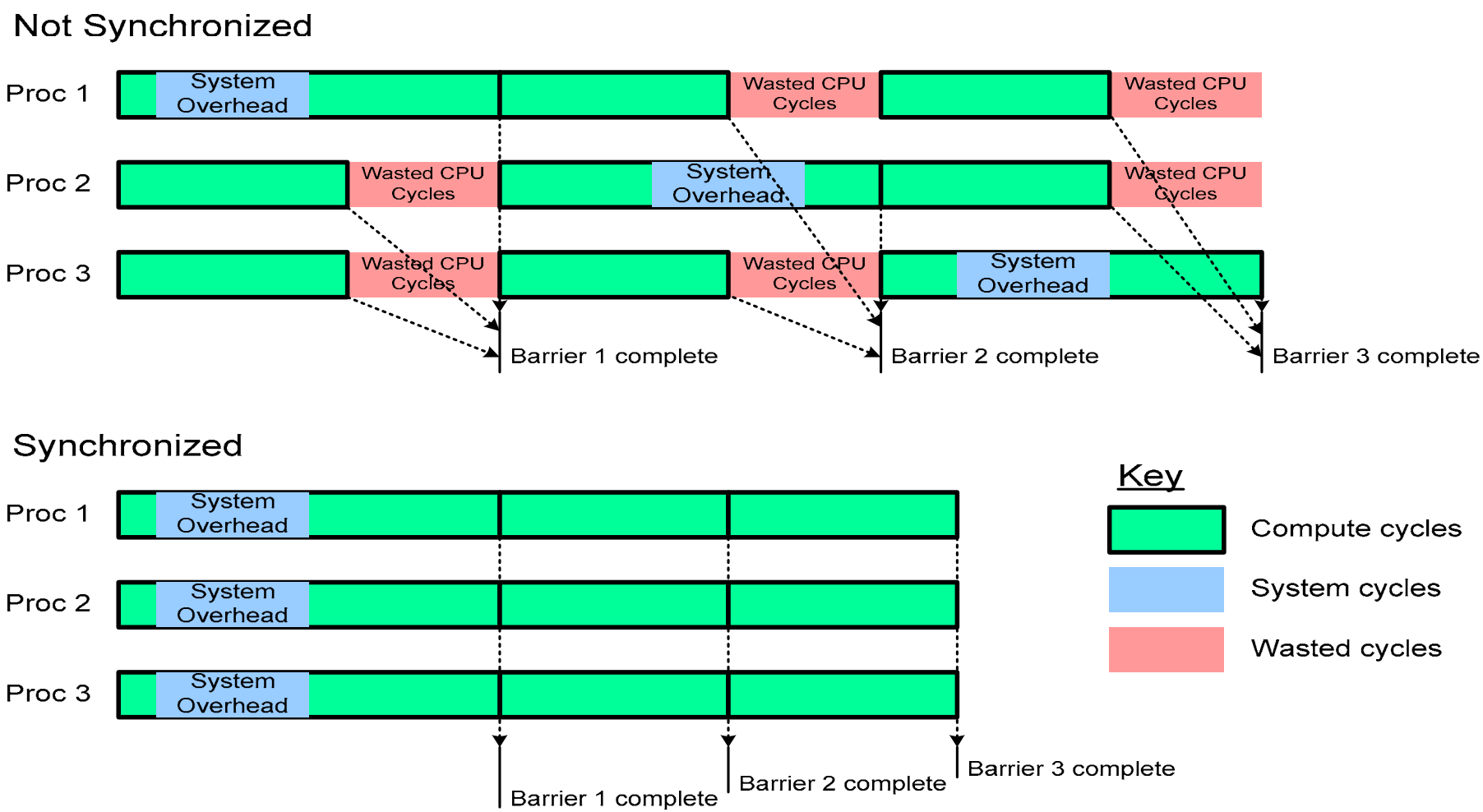
Abstract

In this paper we describe how we improved the effective performance of ASCI Q, the world's second-fastest supercomputer, to meet our expectations. Using an arsenal of performance-analysis techniques including analytical models, custom microbenchmarks, full applications, and simulators, we succeeded in observing a serious—but previously undetected—performance problem. We identified the source of the problem, eliminated the problem, and "closed the loop" by demonstrating up to a factor of 2 improvement in application performance. We present our methodology and provide insight into performance analysis that is immediately applicable to other large-scale supercomputers.



How to Double Application Performance

Synchronized Linux Scheduler



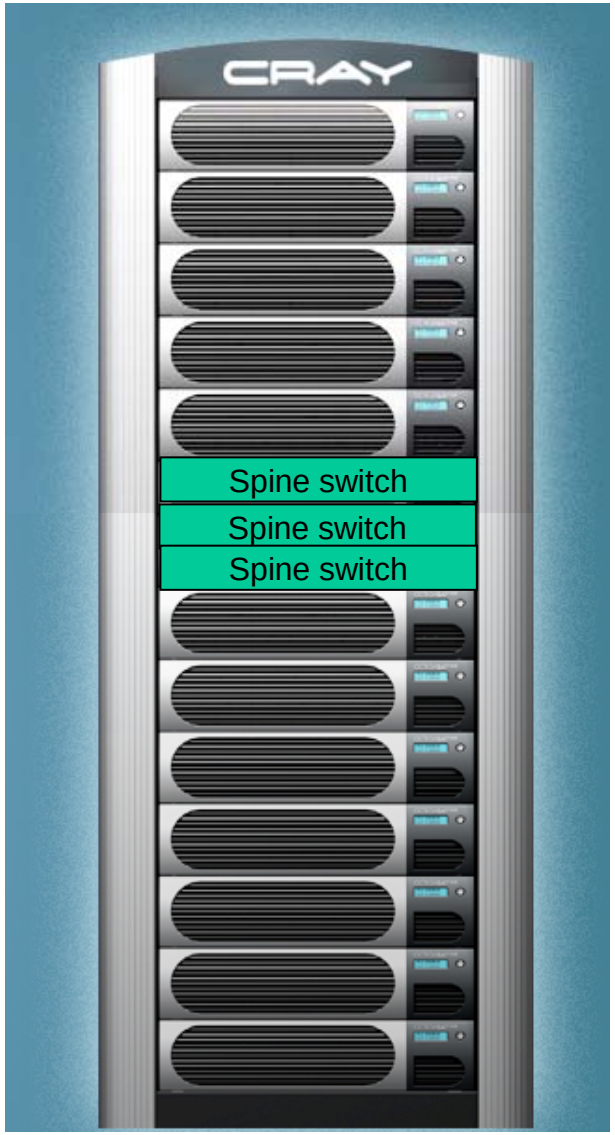
Direct Connect Topology

1 Cray XD1 Chassis
12 AMD Opteron Processors
53 GFLOPS
8 GB/s between SMPs
1.6 µsec interconnect
Integrated switching

3 Cray XD1 Chassis
36 AMD Opteron Processors
158 GFLOPS
8 GB/s between SMPs
1.8 µsec interconnect
Integrated switching

25 Cray XD1 Chassis, two racks
300 AMD Opteron Processors
1.3 TFLOPS
2 - 8 GB/s between SMPs
1.8 µsec interconnect
Integrated switching

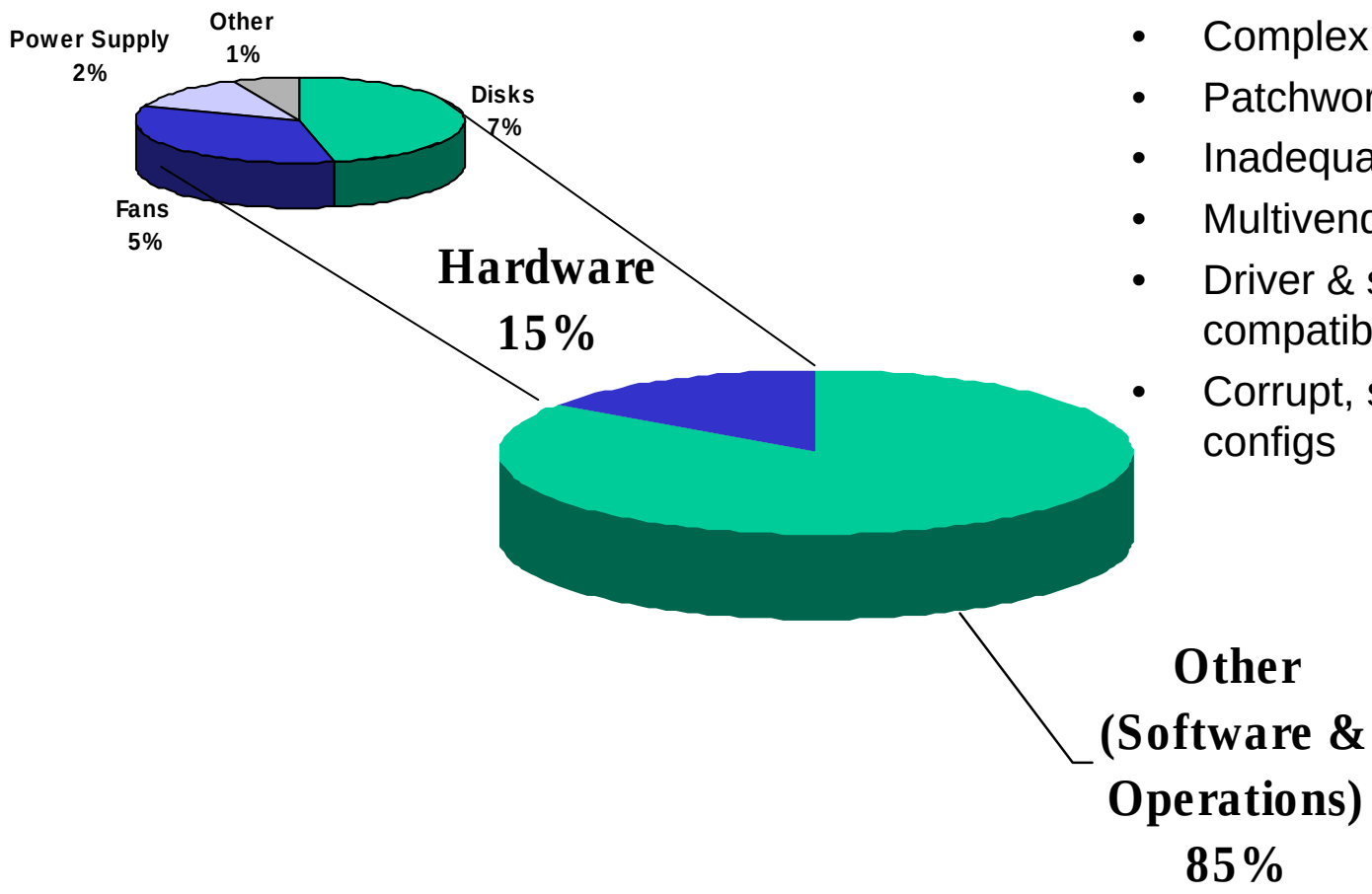
Fat Tree Topology



- **12 Cray XD1 chassis**
- **144 AMD Opteron Processors**
- **633 GFLOPS**
- **4/8 GB/s between SMPs**
- **1.9 μsec interconnect**
- **Fat tree switching, integrated first & third order**
- **6/12 RapidArray spine switches (24-ports)**

Management

Causes of System Outages

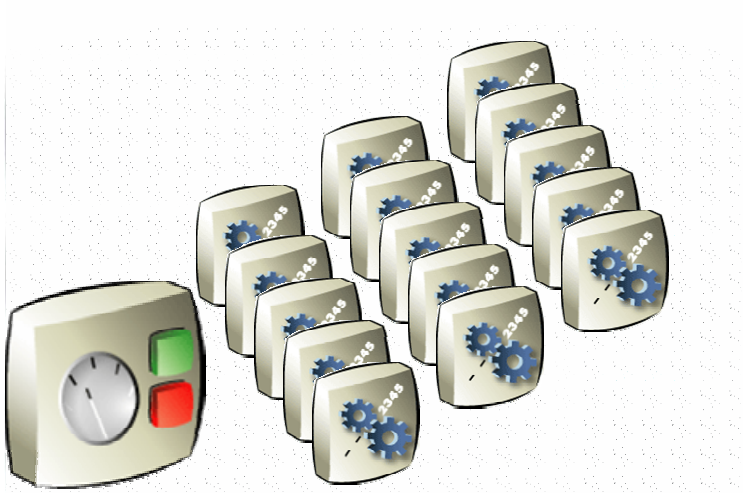


- Most problems occur during:
  - **Upgrades,**
  - **Problem diagnosis,**
  - **Configuration**
- Complex systems
- Patchwork software
- Inadequate tools
- Multivendor h/w, s/w
- Driver & software compatibility
- Corrupt, stale software & configs

Source: UC Berkeley

Active Manager System

CLI and Web Access



Active Management Software

Usability

- Single System Command and Control

Resiliency

- Dedicated management processors, real-time OS and communications fabric.
- Proactive background diagnostics with self-healing.

Automated management for exceptional reliability, availability, serviceability

FCAPS

	FUNCTION	Active Manager Features
Fault	• Maintain health of the system • Monitor, report on and automatically heal or • Allow operator intervention to resolve problems	• System monitoring • Hardware management • Alarm management
Configuration	• Define, monitor and change operational parameters of the system • Provide administrators with a real-time view of total system configuration and • Automate configuration tasks to minimize effort and inconsistencies	• Commission, upgrade, and expand system • Software management • Network configuration management • Manage users • Partition Management
Accounting	• Monitor system resources and usage • Support cost accounting or bill back	• Quotas • Usage tracking – per job, user, department • Reporting • Resource and Queue Management
Performance	Allow administrators to fine tune system operation to improve job and system performance	• Job management • File system management • System performance analysis
Security	Control access to • the system • system resources and to • specific functions within the system	• User privilege management • Data backups

Active Manager GUI: SysAdmin Portal

GUI provides quick access to status info and system functions

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Active Manager Command Line Interface

```
Adam Lorant@Adam ~
$ lspart
Name                  Login JobExec  State  SMPs  Load  JobsR  JobsQ  AlarmCnt
-----------------------------------------------------------------------------
Ab_Initio_Project     No    Yes      open   10    59.46 13     20
Chemistry             Yes   Yes      open   33    50.26 17     0      1
Diagnostic-Staging    No    No       N/A    3     0.84  0      0
File-Server           No    No       N/A    2     0.91  0      0
Front_End_Partition   Yes   No       open   4     1.1   0      0
Physics               No    Yes      open   8     58.2  5      44

Adam Lorant@Adam ~
$ qstat
Job Id      Job Name        Owner          CPU      State    Partition
-----------------------------------------------------------------------
157         amar_job.sh     amar           1057     running  Chemistry
63          paul_job.sh     paul           0        queued   Physics
143         pat_job.sh      pat            1802     running  Ab_Initio_Project
94          adam_job.sh     adam           0        queued   Physics
67          adam_job.sh     adam           0        queued   Physics
136         paul_job.sh     paul           1938     running  Chemistry
125         pat_job.sh      pat            2405     running  Ab_Initio_Project
86          steve_job.sh    steve          19504    running  Chemistry
167         adam_job.sh     adam           331      running  Ab_Initio_Project
145         paul_job.sh     paul           0        queued   Physics
96          john_job.sh     john           0        queued   Physics
95          steve_job.sh    steve          0        queued   Ab_Initio_Project
69          john_job.sh     john           0        queued   Physics
126         ron_job.sh      ron            0        queued   Physics
43          pat_job.sh      pat            0        queued   Physics
76          adam_job.sh     adam           0        queued   Ab_Initio_Project
144         ron_job.sh      ron            0        queued   Physics
79          pat_job.sh      pat            0        queued   Ab_Initio_Project
152         pat_job.sh      pat            0        queued   Physics
155         auji_job.sh     auji           0        queued   Ab_Initio_Project
44          ron_job.sh      ron            0        queued   Physics
117         paul_job.sh     paul           2498     running  Chemistry
90          paul_job.sh     paul           0        queued   Physics
132         steve_job.sh    steve          0        queued   Ab_Initio_P
88          pat_job.sh      pat            0        queued   Physics
149         adam_job.sh     adam           1365     running  Ab_Initio_P
58          adam_job.sh     adam           0        queued   Physics
36          paul_job.sh     paul           0        queued   Ab_Initio_P
59          steve_job.sh    steve          0        queued   Ab_Initio_P
16          pat_job.sh      pat            0        queued   Ab_Initio_P
15          john_job.sh     john           12375    running  Physics
62          ron_job.sh      ron            2797     running  Chemistry
158         adam_job.sh     adam           0        queued   Ab_Initio_Project
161         pat_job.sh      pat            483      running  Ab_Initio_Project
172         paul_job.sh     paul           205      running  Ab_Initio_Project
114         john_job.sh     john           0        queued   Physics
53          ron_job.sh      ron            0        queued   Physics
```

Administrators can access Active Manager software and Linux through the CLI

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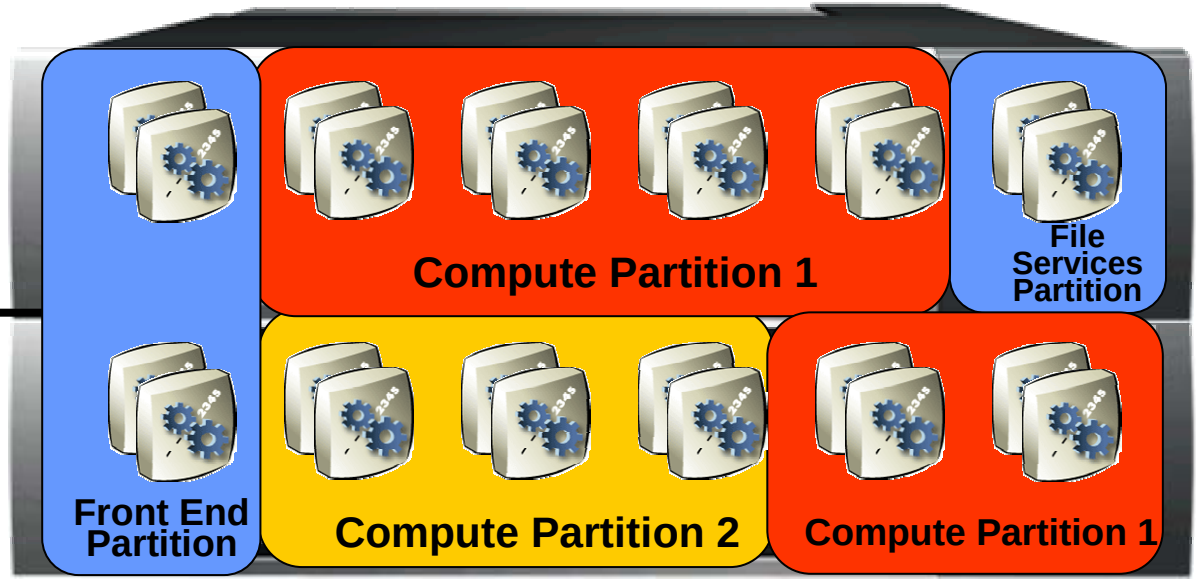
XML Integration Point

```
Adam Lorant@Adam ~
$ lspart --xml
<lspart>
  <partition name="Ab_Initio_Project" login="No" job_execution="Yes" state="open
" smp_count="10" load="61.53" running_jobs="11" queued_jobs="19" alarm_count=" "
/>
  <partition name="Chemistry" login="Yes" job_execution="Yes" state="open" smp_c
ount="33" load="64.19" running_jobs="21" queued_jobs="1" alarm_count=" "/>
  <partition name="Diagnostic-Staging" login="No" job_execution="No" state="N/A"
 smp_count="3" load="1.12" running_jobs="0" queued_jobs="0" alarm_count=" "/>
  <partition name="File-Server" login="No" job_execution="No" state="N/A" smp_co
unt="2" load="0.77" running_jobs="0" queued_jobs="0" alarm_count=" "/>
  <partition name="Front_End_Partition" login="Yes" job_execution="No" state="op
en" smp_count="4" load="1.09" running_jobs="0" queued_jobs="0" alarm_count=" "/>

  <partition name="Physics" login="No" job_execution="Yes" state="open" smp_coun
t="8" load="60" running_jobs="5" queued_jobs="43" alarm_count=" "/>
</lspart>

Adam Lorant@Adam ~
$
```

Simplifies data transfer

System Partitions

Users & Administrators



- **Front End Partition**
- **Compute Partition**
- **Service Partition**
  - **File Services**
  - **Database**
  - **DNS**

Manage multiple processors and copies of Linux as single, unified system

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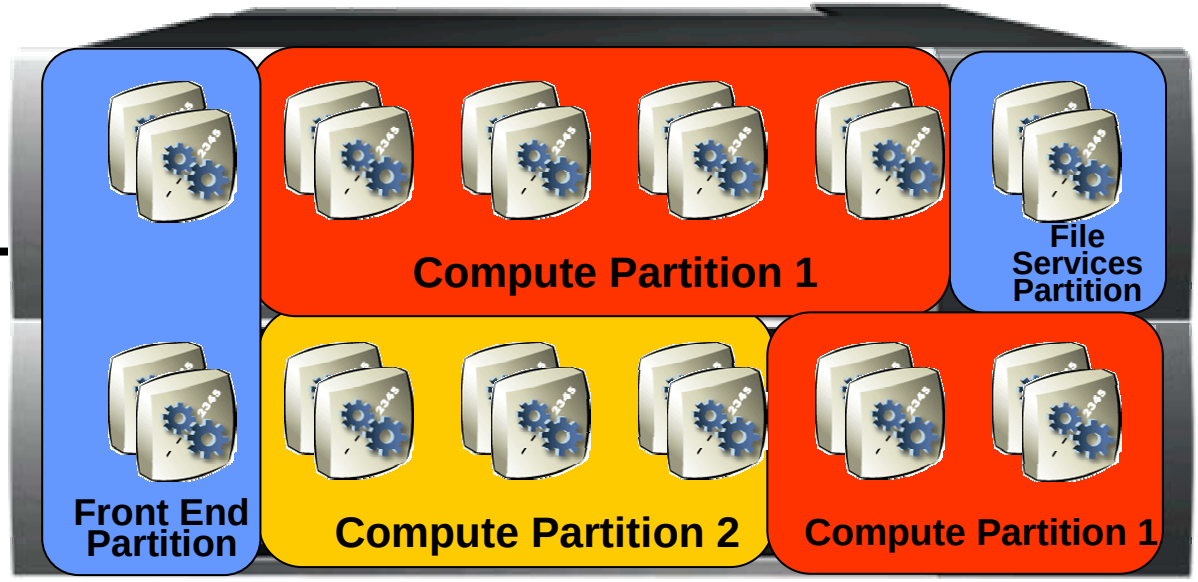
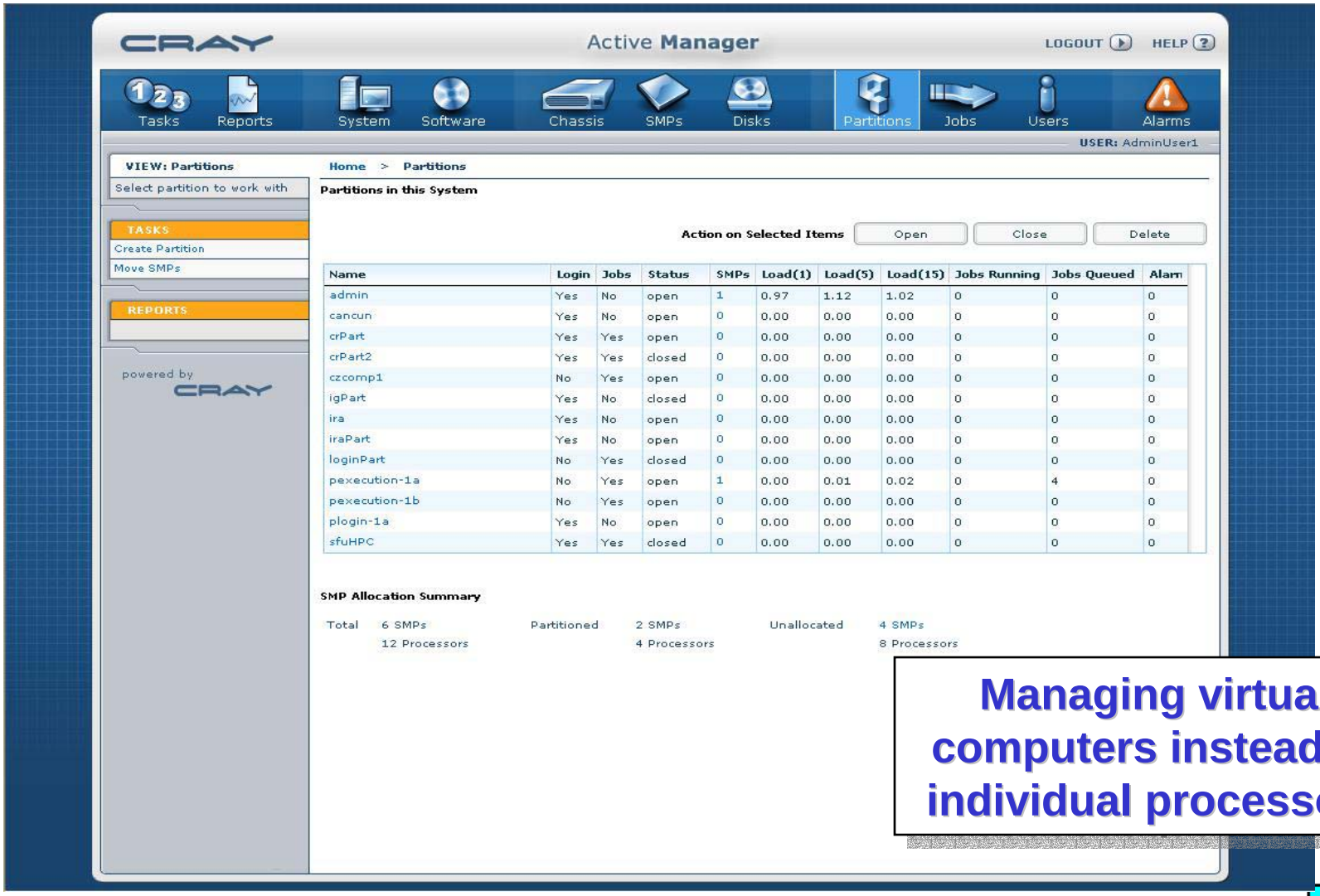
Single System Command and Control

Users & Administrators



- **Partition management**
- **Linux configuration**
- **Hardware monitoring**
- **Software upgrades**
- **File system management**
- **Data backups**
- **Network configuration**
- **Accounting & user management**
- **Security**
- **Performance analysis**
- **Resource & queue management**

Active Manager System/Partition View



Name	Login	Jobs	Status	SMPs	Load(1)	Load(5)	Load(15)	Jobs Running	Jobs Queued	Alarm
admin	Yes	No	open	1	0.97	1.12	1.02	0	0	0
cancun	Yes	No	open	0	0.00	0.00	0.00	0	0	0
crPart	Yes	Yes	open	0	0.00	0.00	0.00	0	0	0
crPart2	Yes	Yes	closed	0	0.00	0.00	0.00	0	0	0
czcomp1	No	Yes	open	0	0.00	0.00	0.00	0	0	0
igPart	Yes	No	closed	0	0.00	0.00	0.00	0	0	0
ira	Yes	No	open	0	0.00	0.00	0.00	0	0	0
iraPart	Yes	No	open	0	0.00	0.00	0.00	0	0	0
loginPart	No	Yes	closed	0	0.00	0.00	0.00	0	0	0
pexecution-1a	No	Yes	open	1	0.00	0.01	0.02	0	4	0
pexecution-1b	No	Yes	open	0	0.00	0.00	0.00	0	0	0
plogin-1a	Yes	No	open	0	0.00	0.00	0.00	0	0	0
sfuHPC	Yes	Yes	closed	0	0.00	0.00	0.00	0	0	0

Managing virtual computers instead of individual processors

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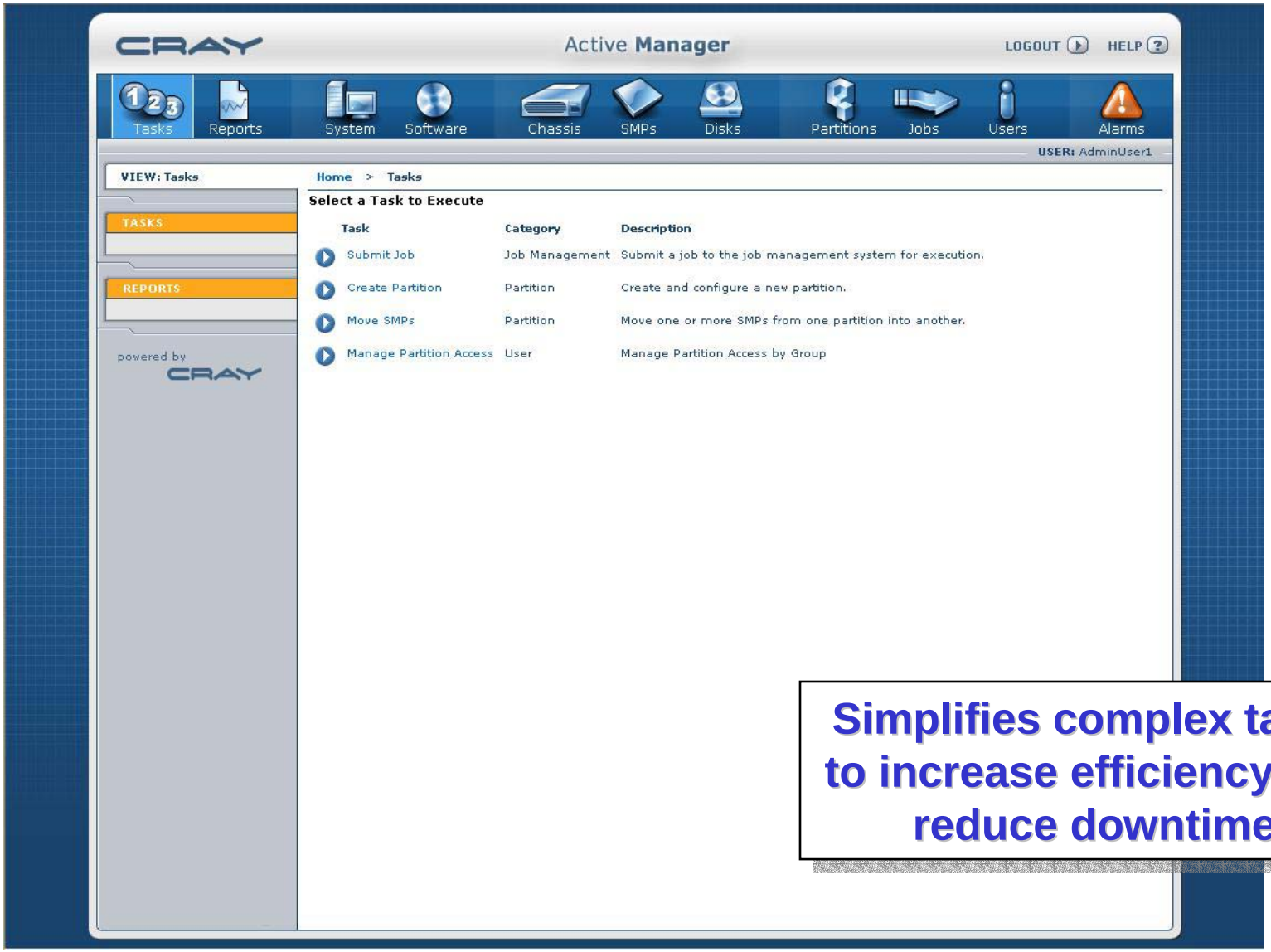
Active Manager Task Wizard



Simplifies complex tasks to increase efficiency and reduce downtime

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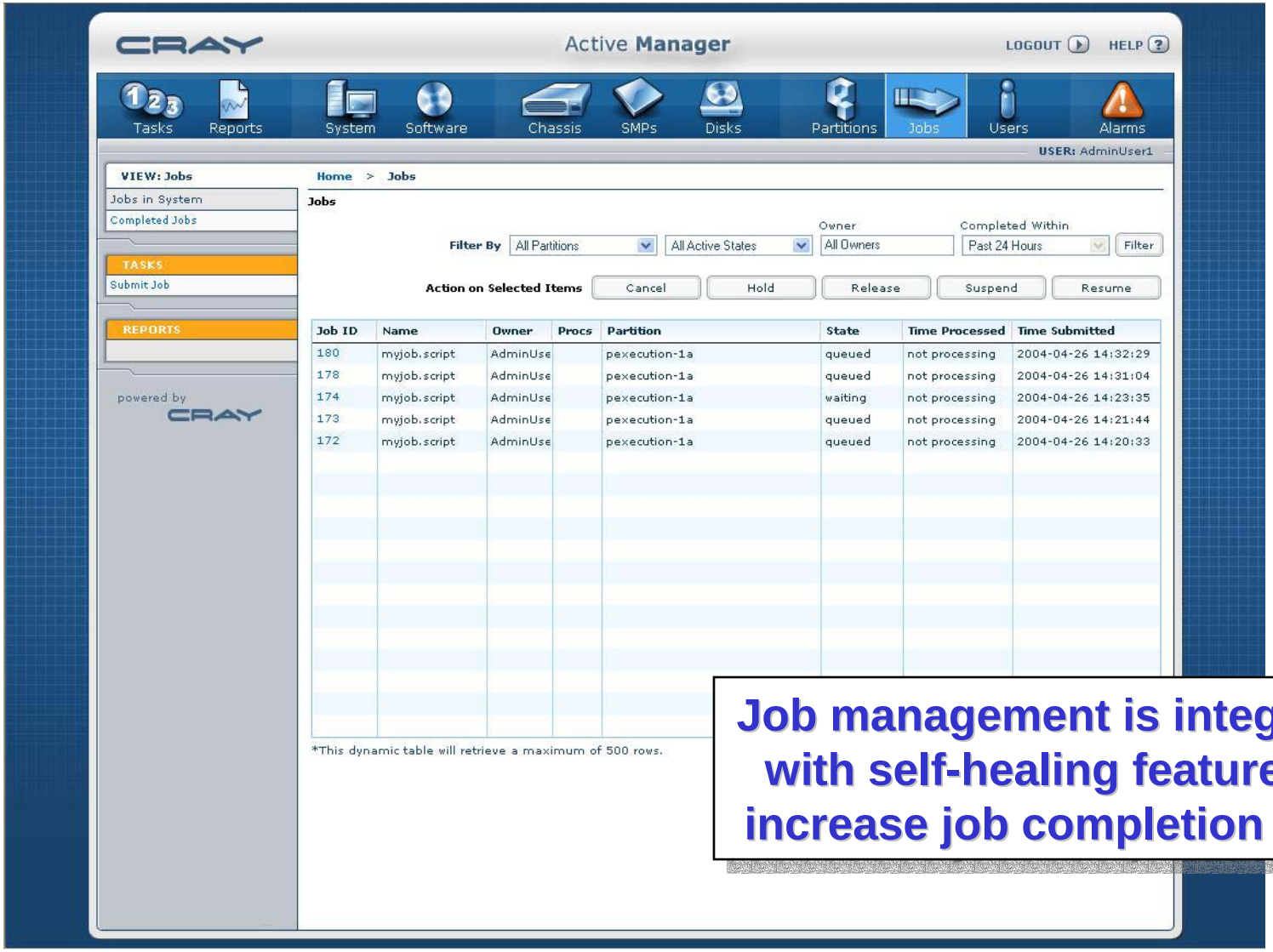
Active Manager Job Scheduler



Job management is integrated with self-healing features to increase job completion rates

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Active Manager User Portal

Intuitive user access for job submission and status lets users focus on applications, not computing

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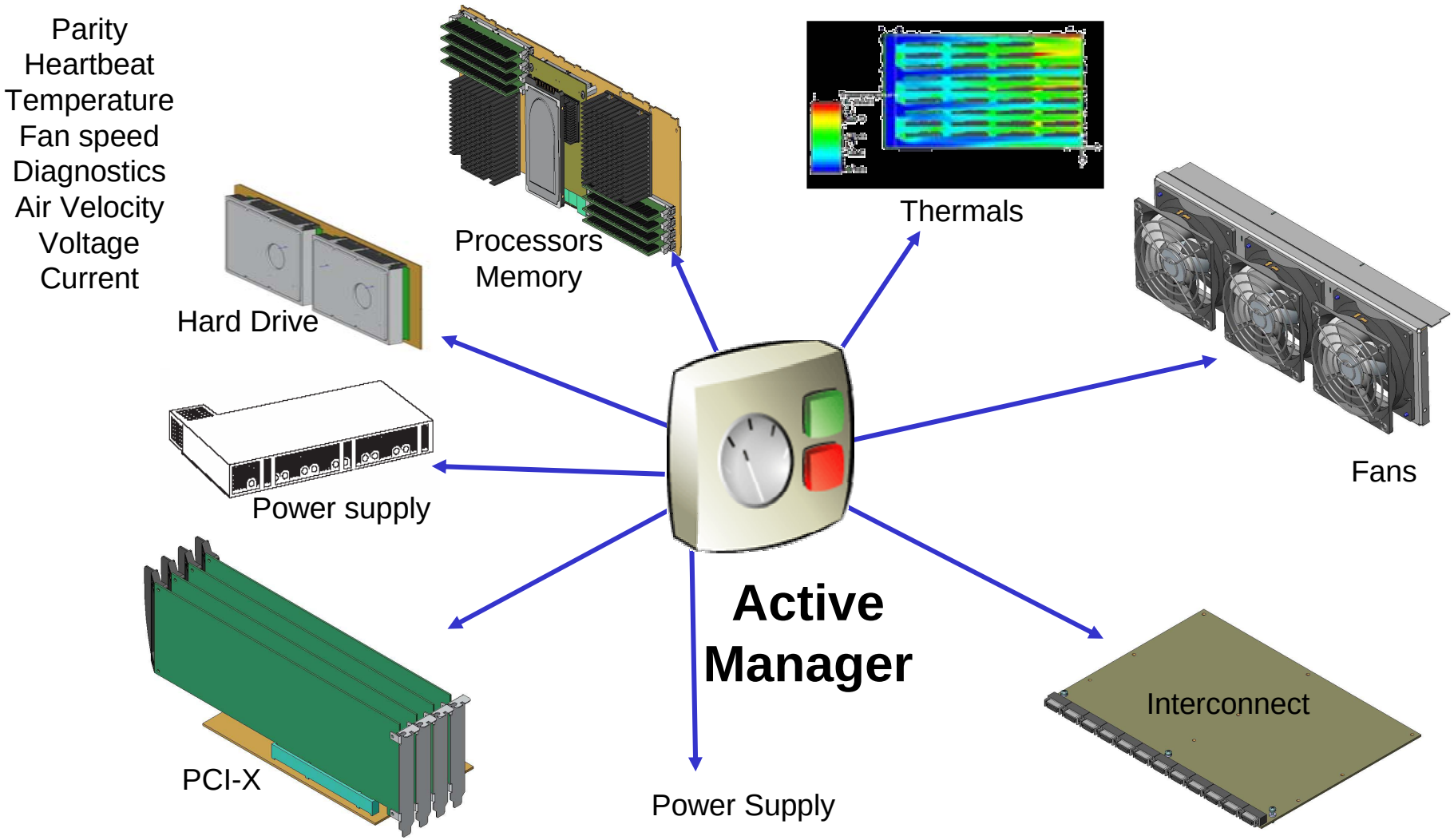
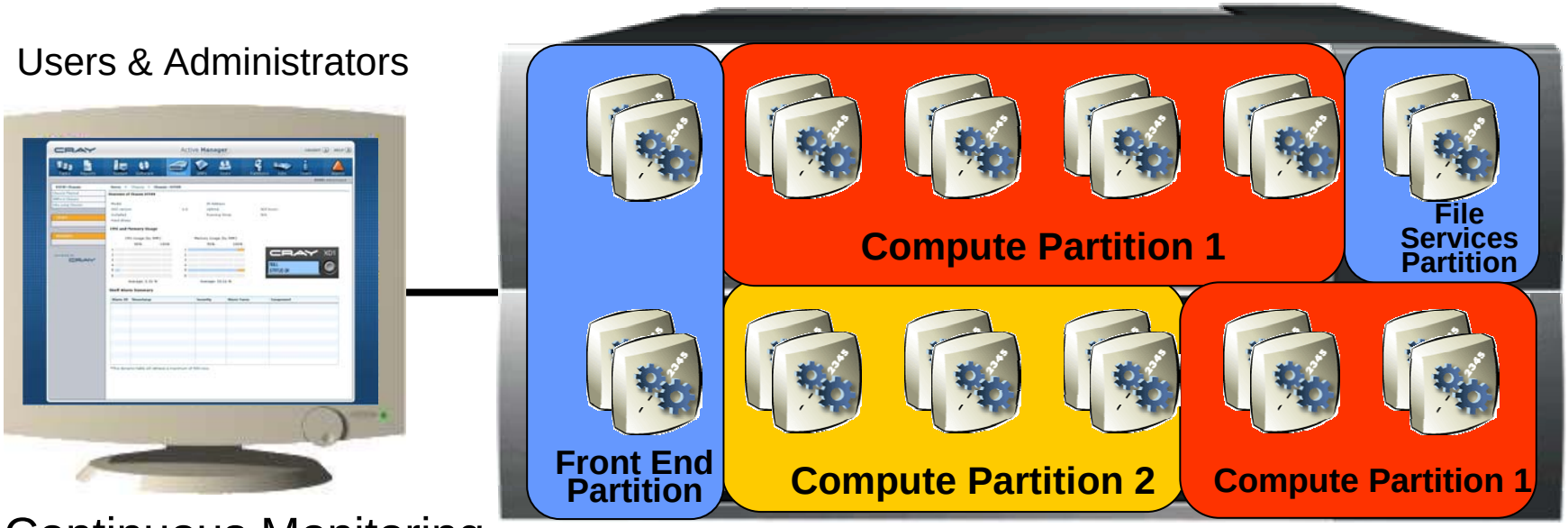
Self-Monitoring



Dedicated Management Processor, OS, Fabric

Self-Healing

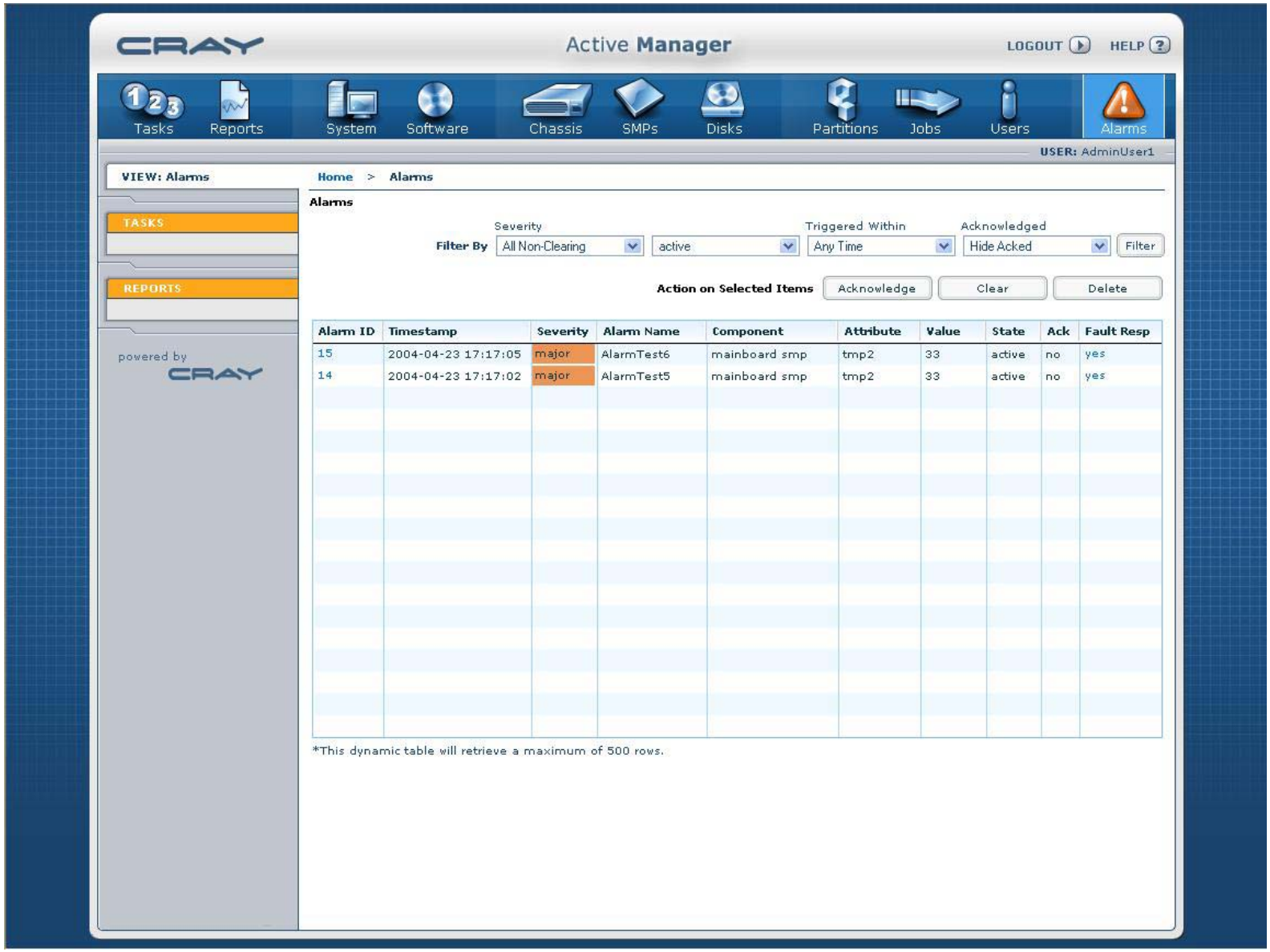


- Continuous Monitoring
- Detect (Future) Failure
- Attempt reset
- Isolate failed component
- Re-allocate resources (N+1 sparing or policy-based)

Automated Recovery Reduces MTTR from hours to minutes

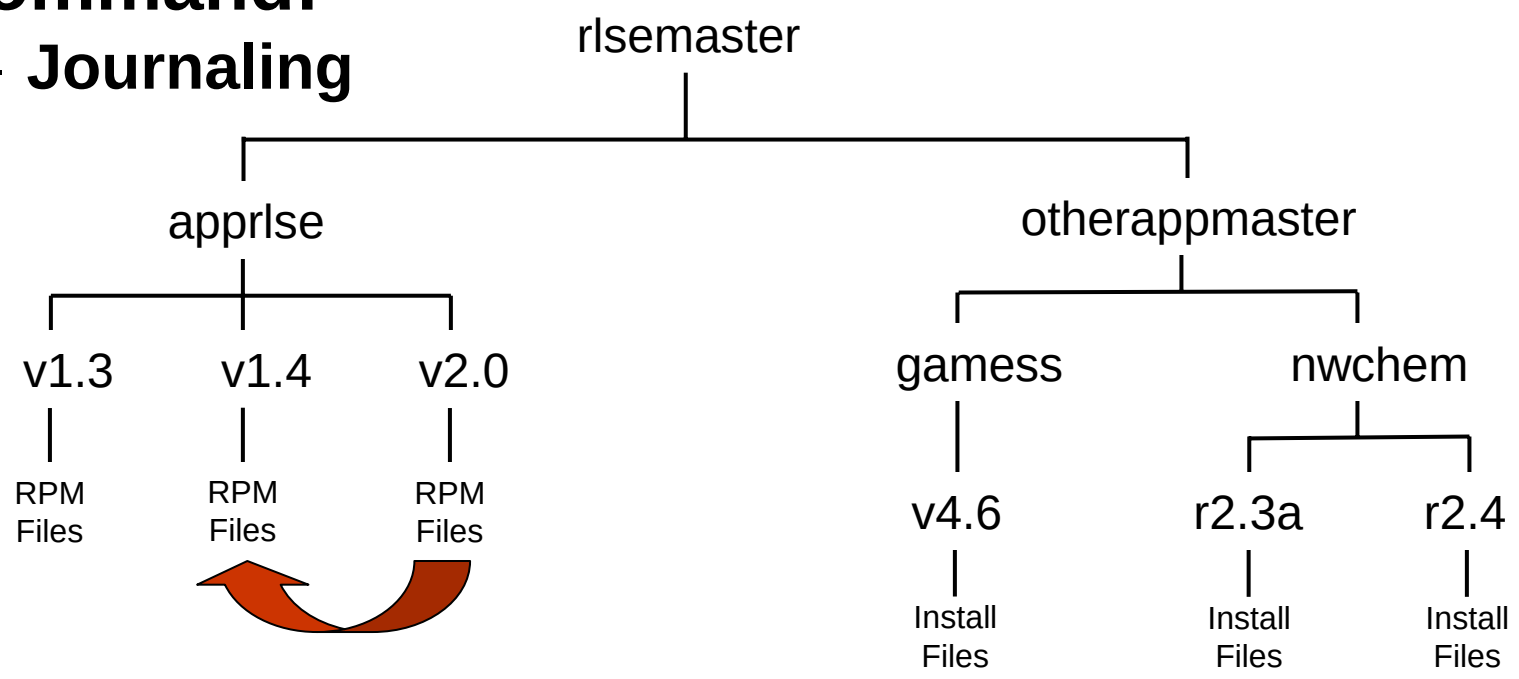
Active Manager Thermal Management

Active Manager Alarm Management



Roll back

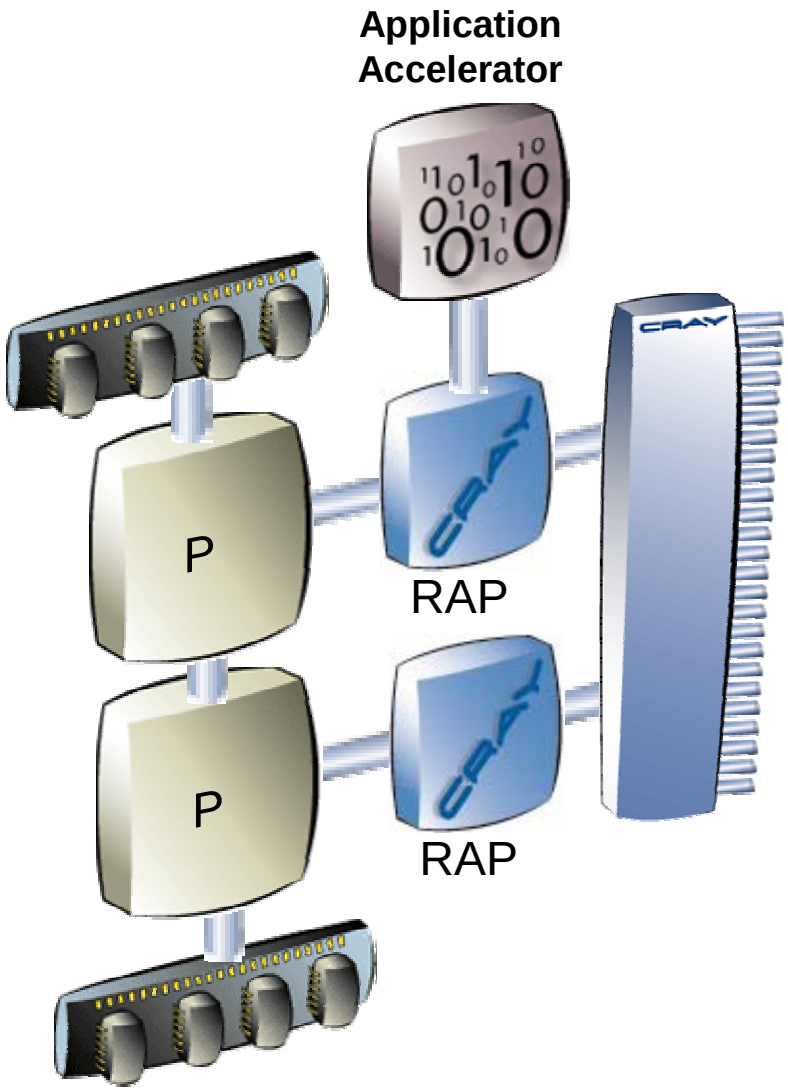
- **Undo command:**
  - **Journaling**



Quick Rollback Reduces MTTR from hours to minutes

Application Acceleration FPGA

Application Acceleration

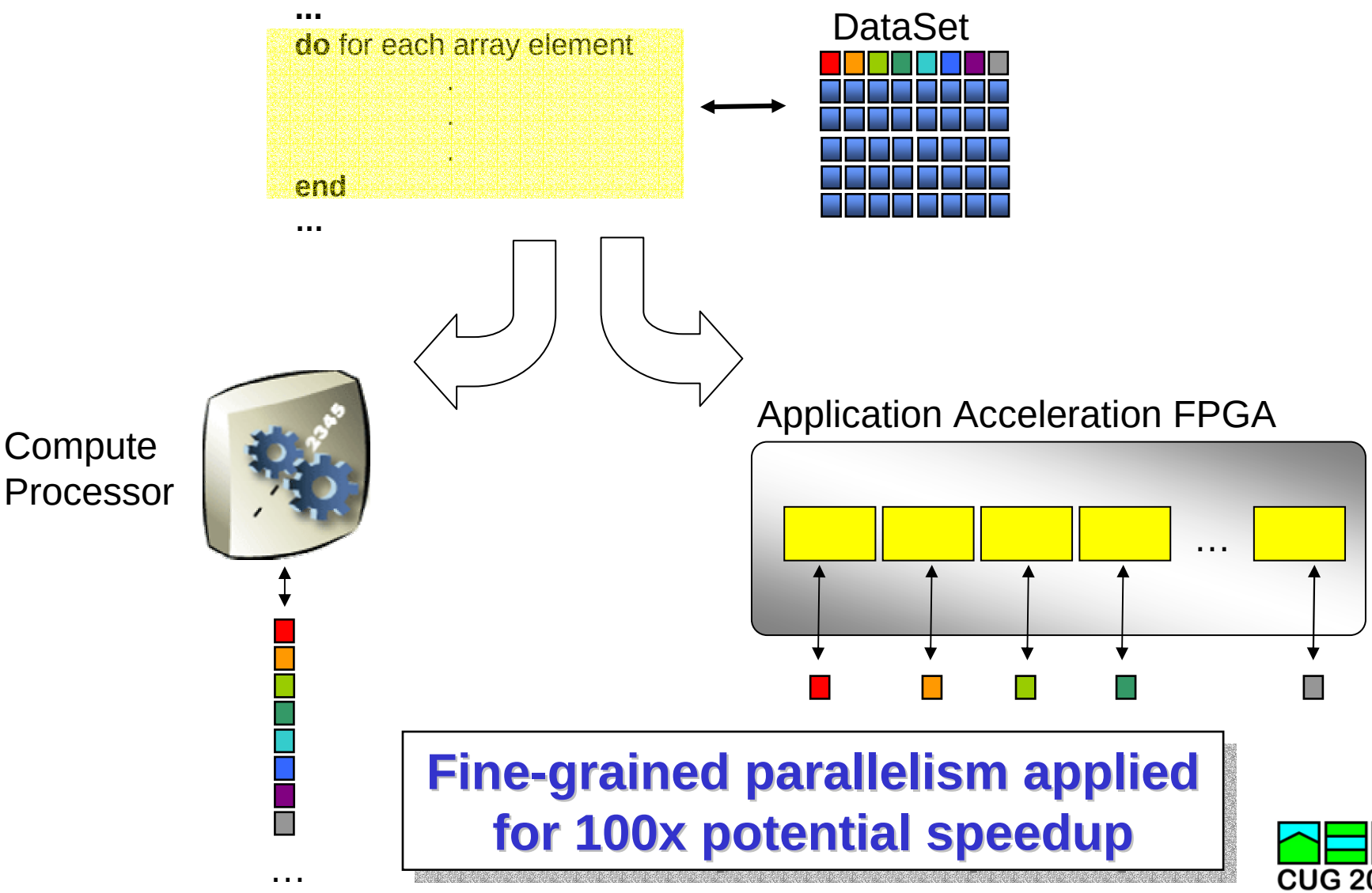


Application Acceleration

- *Reconfigurable Computing*
- Tightly coupled to Opteron
- FPGA acts like a programmable co-processor
- Well-suited for:
  - Searching, sorting, signal processing, audio/video/image manipulation, error correction, coding/decoding, packet processing, random number generation.

SuperLinear speedup for key algorithms

Application Acceleration FPGA



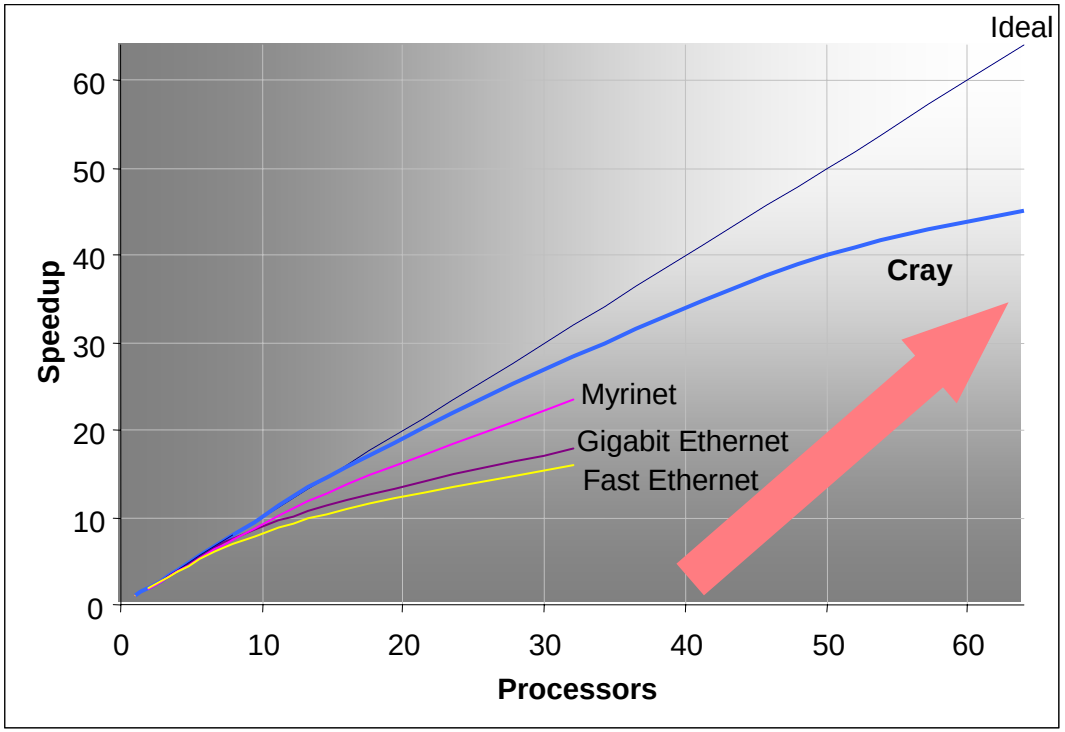
Fine-grained parallelism applied for 100x potential speedup

FPGA and Vector Processors

Vector Processors	FPGAs
• SIMD – instruction level parallelism	• MIMD – code fragments are replicated
• Mature Development Environment (C, Fortran)	• Emerging Development Tools (mostly HW tools – VHDL, Verilog)
• Integer or Floating Point	• Integer or Fixed Point
• Suited to matrix operations: BLAS, LAPACK, …	• Suited to pre-processing (signal processing, sorting/searching, error correction, coding/decoding, packet processing)

Cray XD1: Built for Performance

Faster interconnect throughput
Lower interconnect latency
System-wide process synchronization



Greater Efficiency
Greater Scalability
Faster Performance

Increasing application efficiency and scalability for breakthrough performance gains

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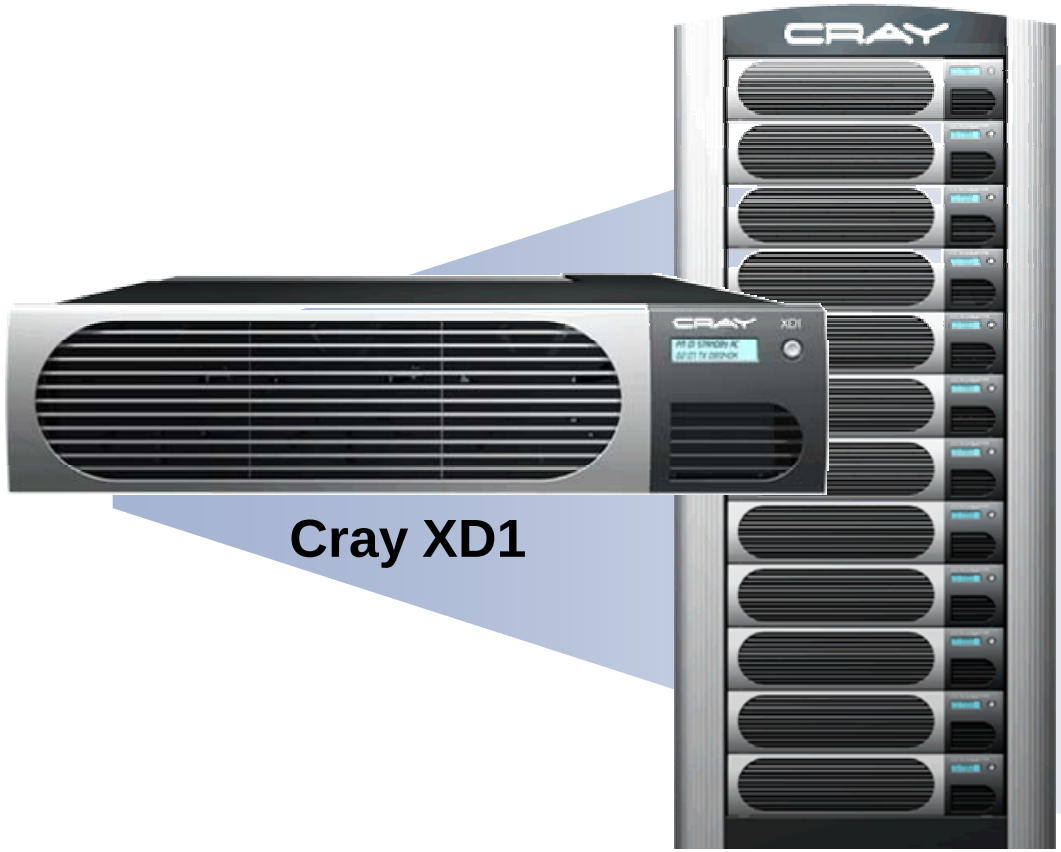
The Cray XD1



Cray XD1

- Built for price/performance
  - Interconnect bandwidth/latency
  - System-wide process synchronization
  - Application Acceleration FPGAs
- Standards-based
  - 32/64-bit X86, Linux, MPI
- High resiliency
  - Self-configuring, self-monitoring, self-healing
- Single system command & control
  - Intuitive, tightly integrated management software

Purpose-built and optimized for high performance workloads

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Questions?

Amar Shan, Senior Product Marketing Manager

shan@cray.com

Additional Slides

Cray System Portfolio

Cray X1

- 1 to 50+ TFLOPS
- $3 M - $10 M+
- Vectorized apps
- Cray MSP/UNICOS/mp

RS/Strider

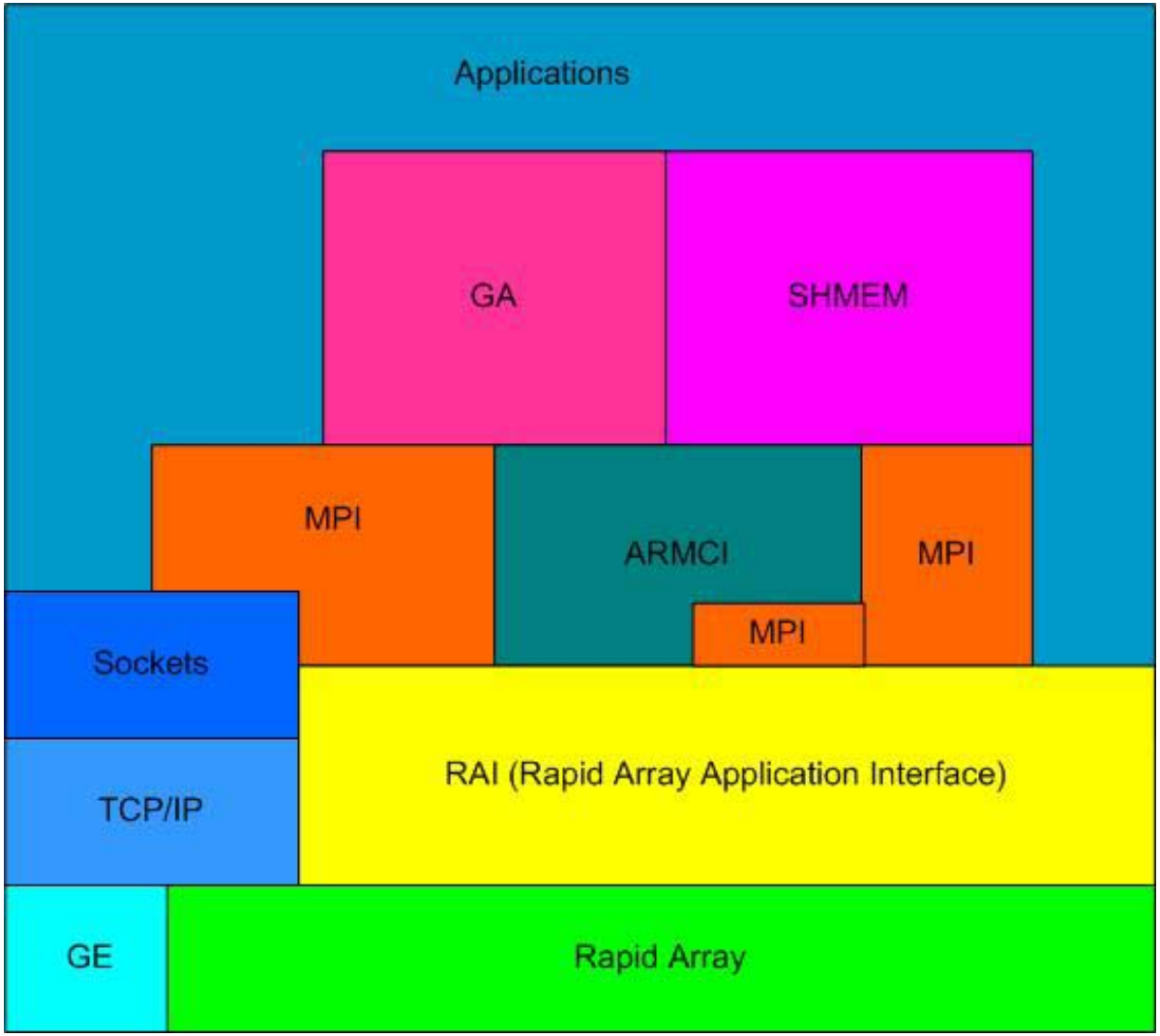
- 1 to 50+ TFLOPS
- 256 – 10,000+ processors
- $1 M - $5 M+
- Opteron/Linux/Catamount

Cray XD1

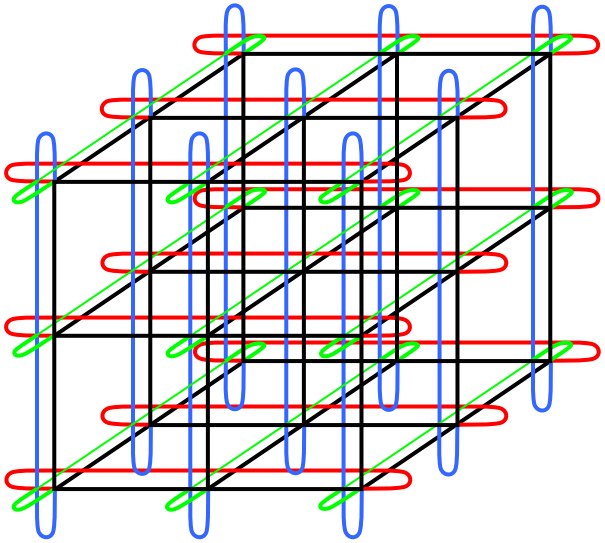
- 48 GFLOPS - 1.2+ TFLOPS
- 12 – 288+ processors
- $50 K - $2 M+
- AMD Opteron/Linux

Purpose-Built High Performance Computers

Communications Protocols



Switchless Toroid Topology



3D torus

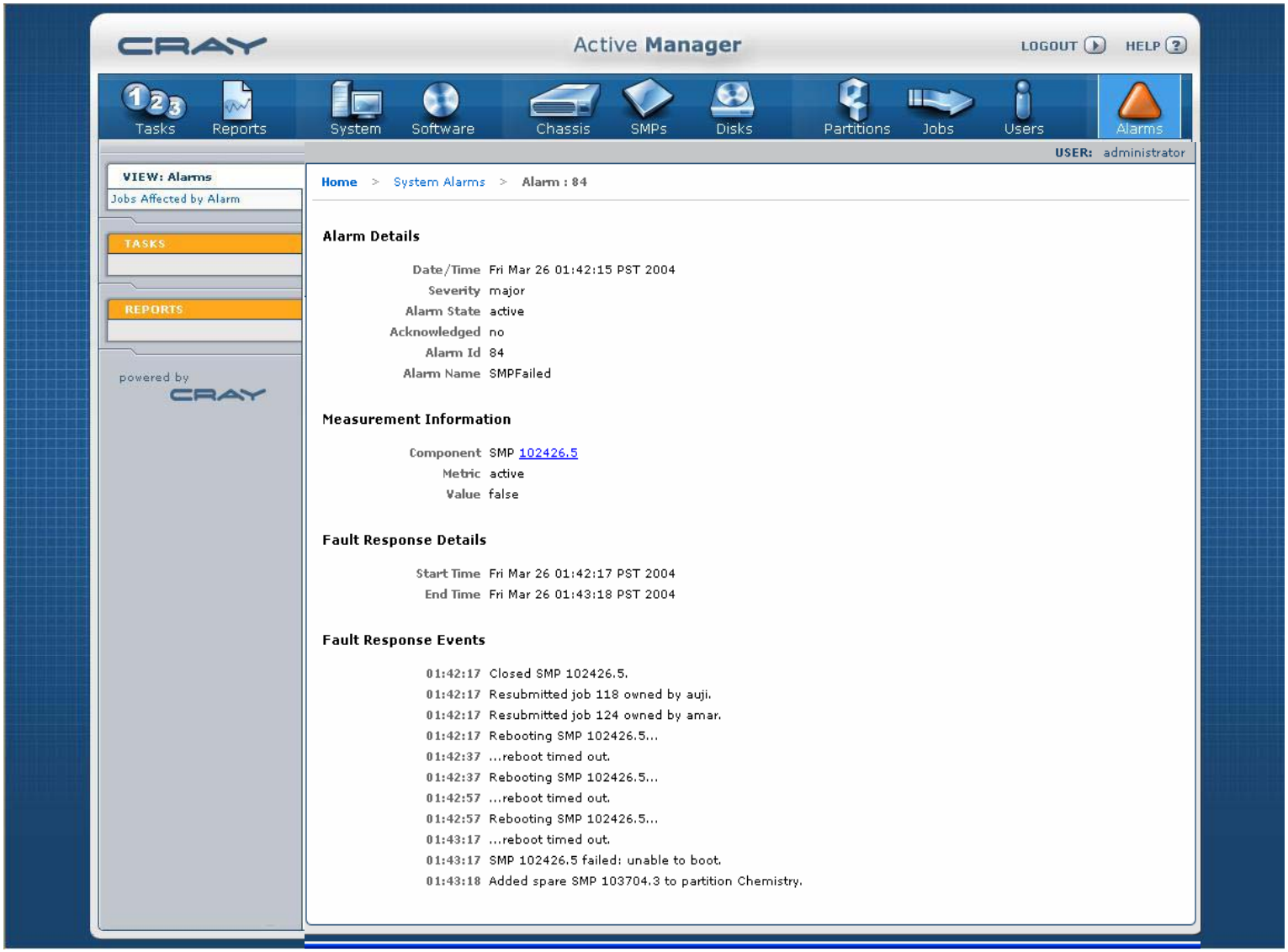
27 chassis, 324 Processors
1.4 TFLOP
3x3x3 Toroid

Nearest Neighbor
- 4-8 GB/s bandwidth per SMP
- 1.8 µsec latency

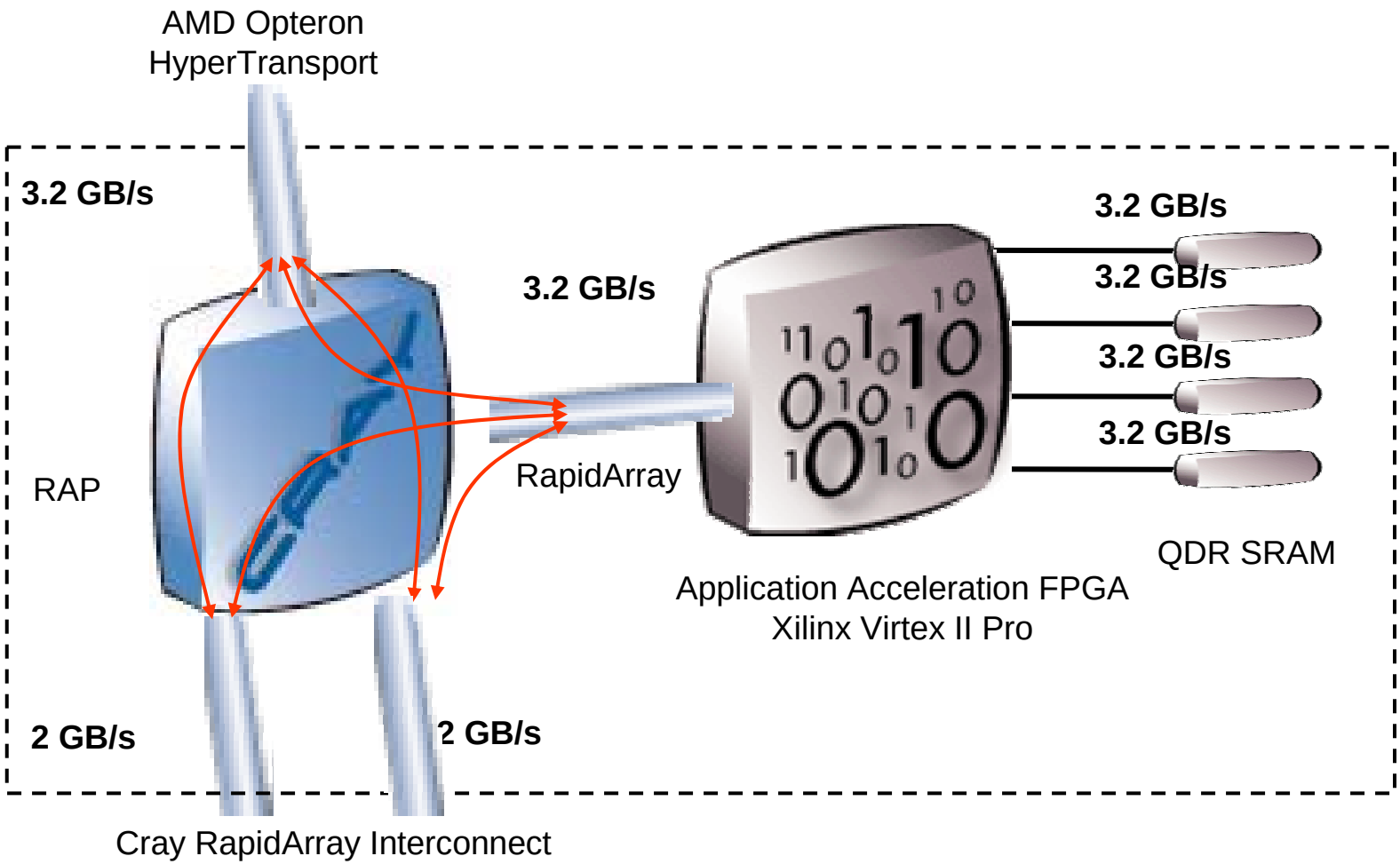
Worst case: 6 Hops, 2.8 µsec

Well-Suited for Nearest Neighbor Problems

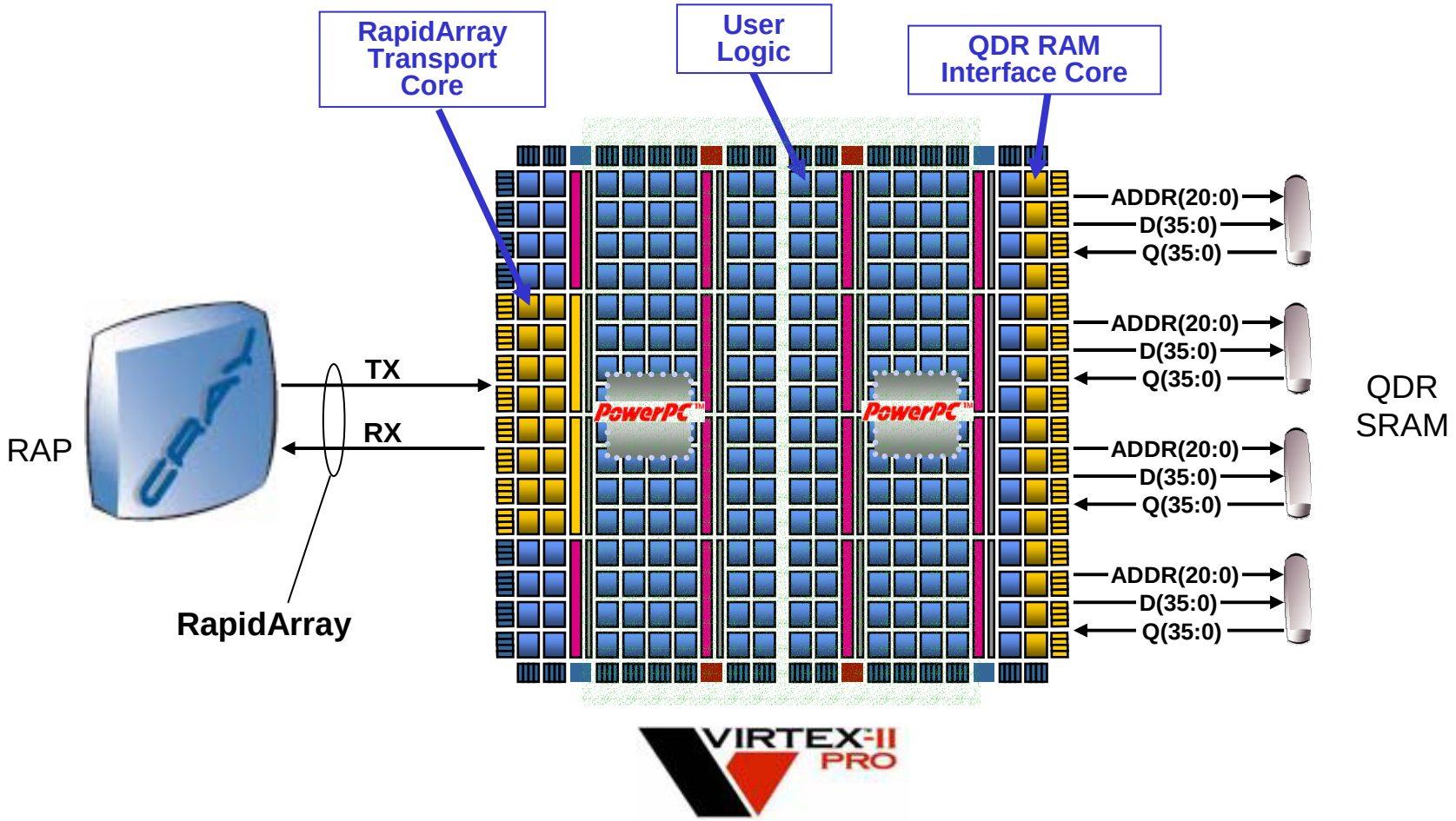
Active Manager Self Healing Policies



Application Acceleration Co-Processor



Application Acceleration Interface



- XC2VP30 running at 200 MHz.
- 4 QDR II RAM with over 400 HSTL-I I/O at 200 MHz DDR (400 MTransfers/s).
- 16 bit simplified HyperTransport I/F at 400 MHz DDR (800 MTransfers/s.)
- QDR and HT I/F take up <20 % of XC2VP30. The rest is available for user applications.

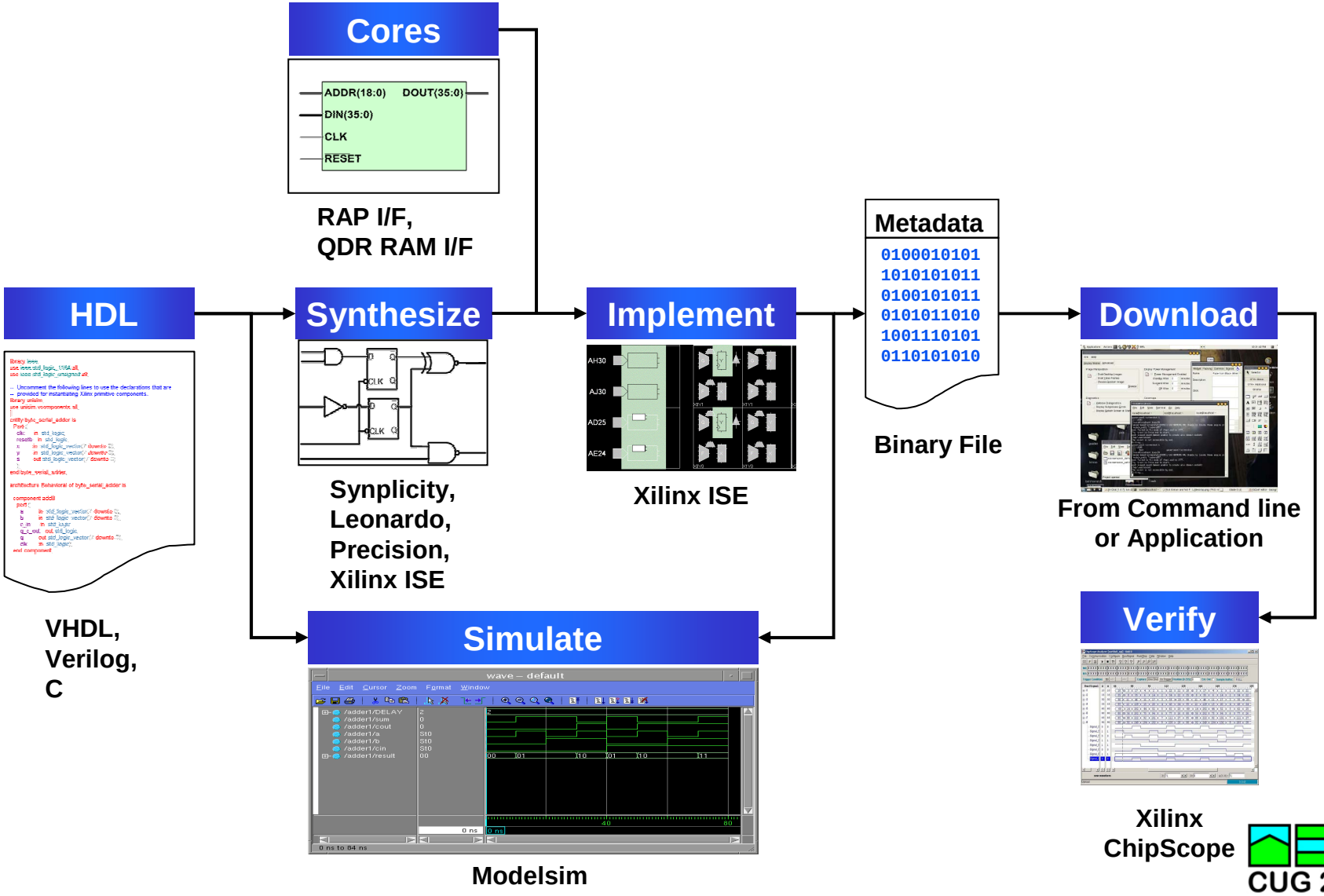
Application Acceleration Variants

A variety of Application Acceleration variants can be manufactured by populating different pin compatible FPGAs and QDR II RAMs.

FPGA	Speed	Logic Elements	PowerPC	18x18 Multipliers
XC2VP30	-6	30,816	2	136
XC2VP50	-7	53,136	2	232

RAMs	Speed	Dimensions	Quantity	Total Size
K7R643682	**200 MHz**	**1M x 36**	**4**	**16 MByte**

FPGA Development Flow



FPGA Linux API

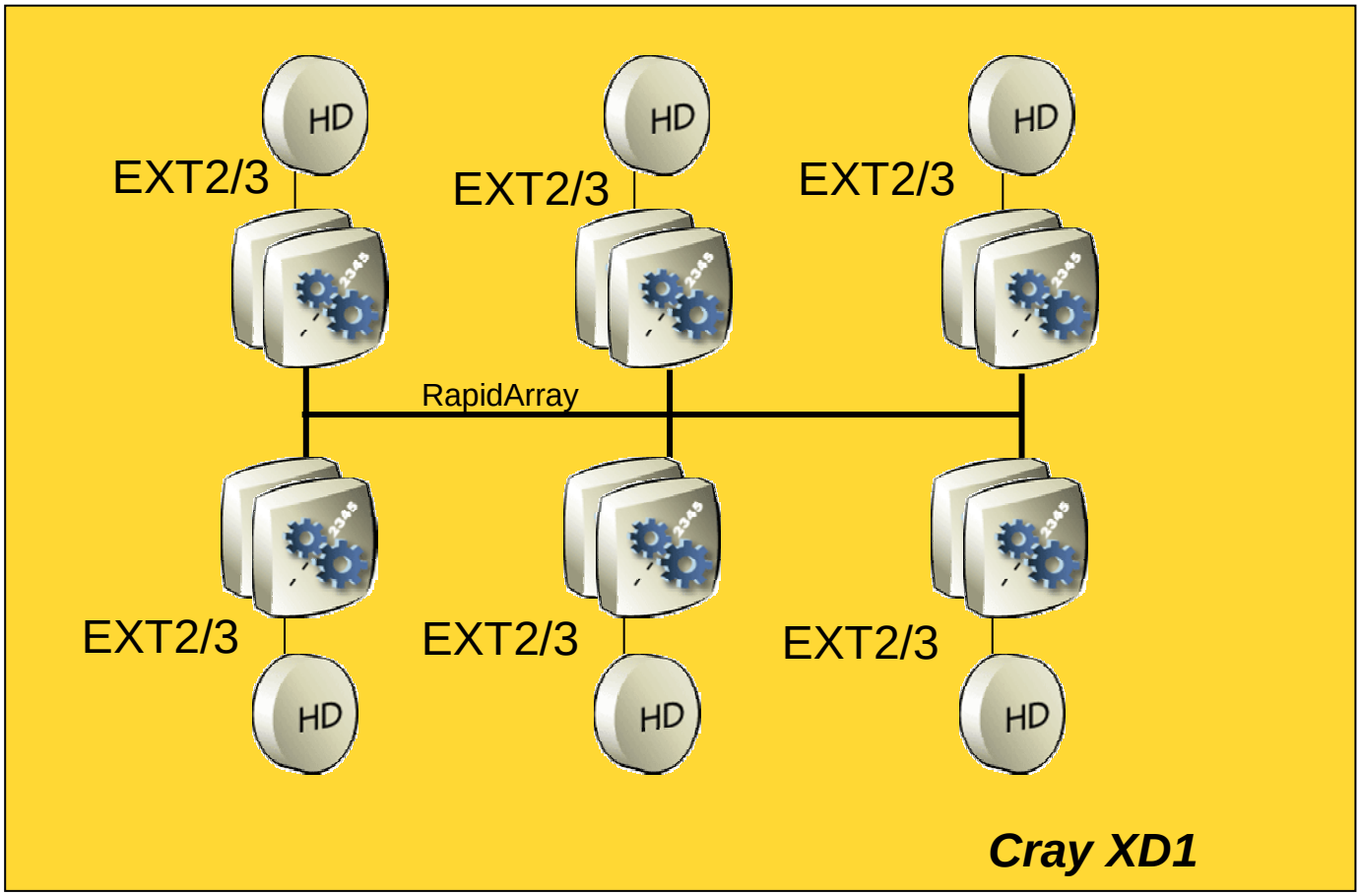
- Admininstration Commands
  - fpga_open – allocate and open fpga
  - fpga_close – close allocated fpga
  - fpga_load – load binary into fpga
- Control Commands
  - fpga_start – start fpga (release from reset)
  - fpga_stop – stop fpga
- Status Commands
  - fpga_status – get status of fpga
- a
  ram

Programmer sees get/put and message passing programming model

Storage Strategy

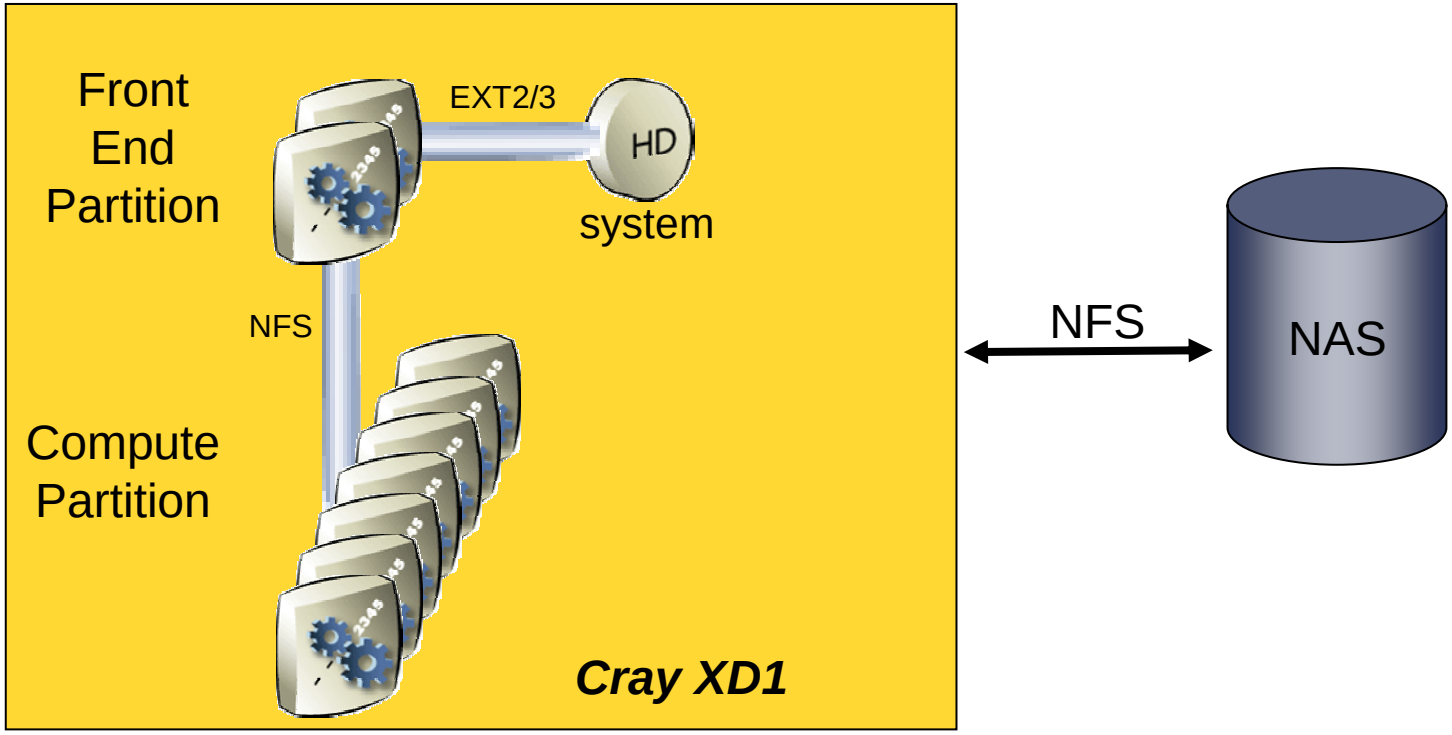
File Systems: Local Disks

One S-ATA HD per SMP; Local Linux directory per HD



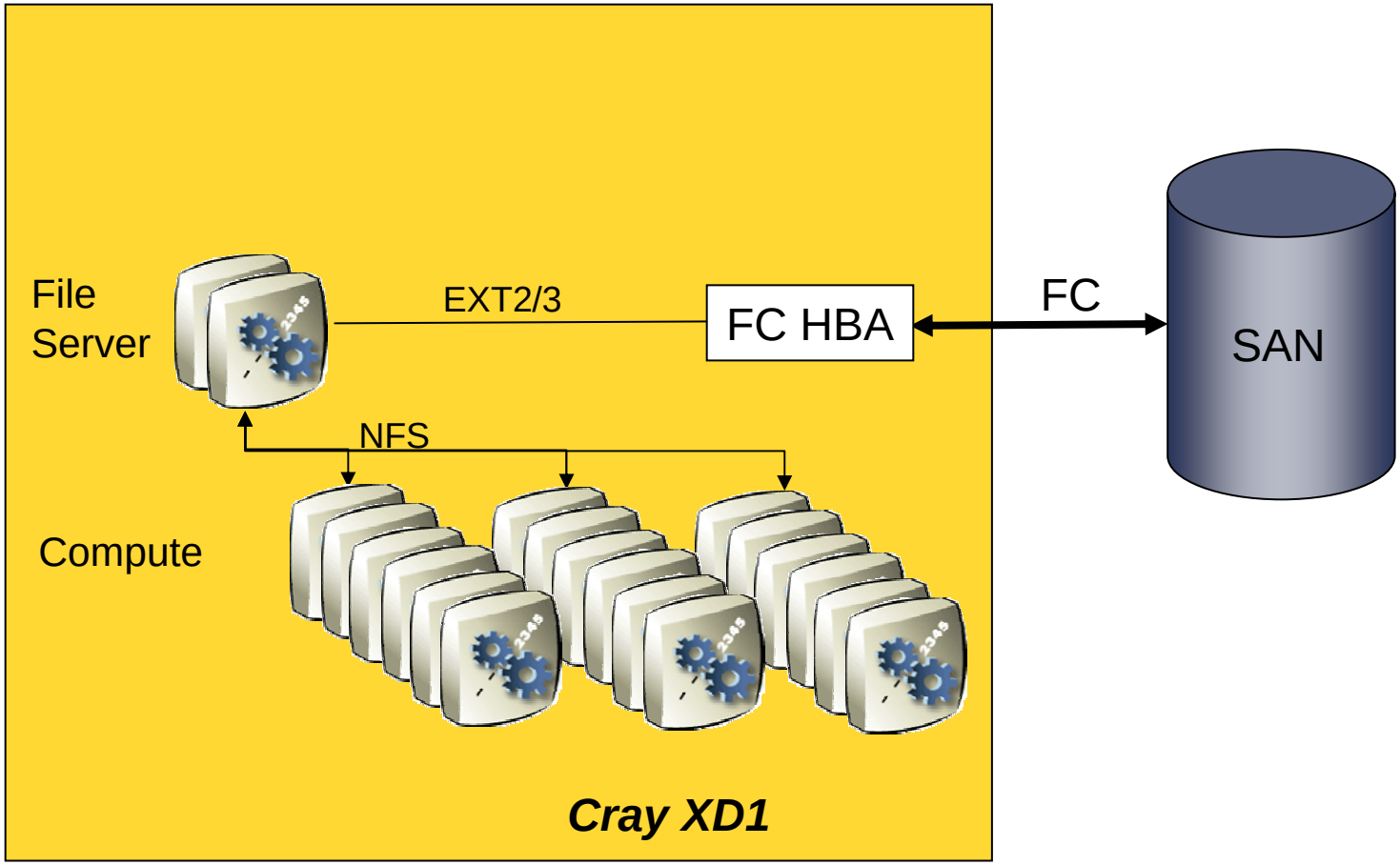
File Systems: Diskless compute nodes

Single Boot Disk for System, External NAS for User Data



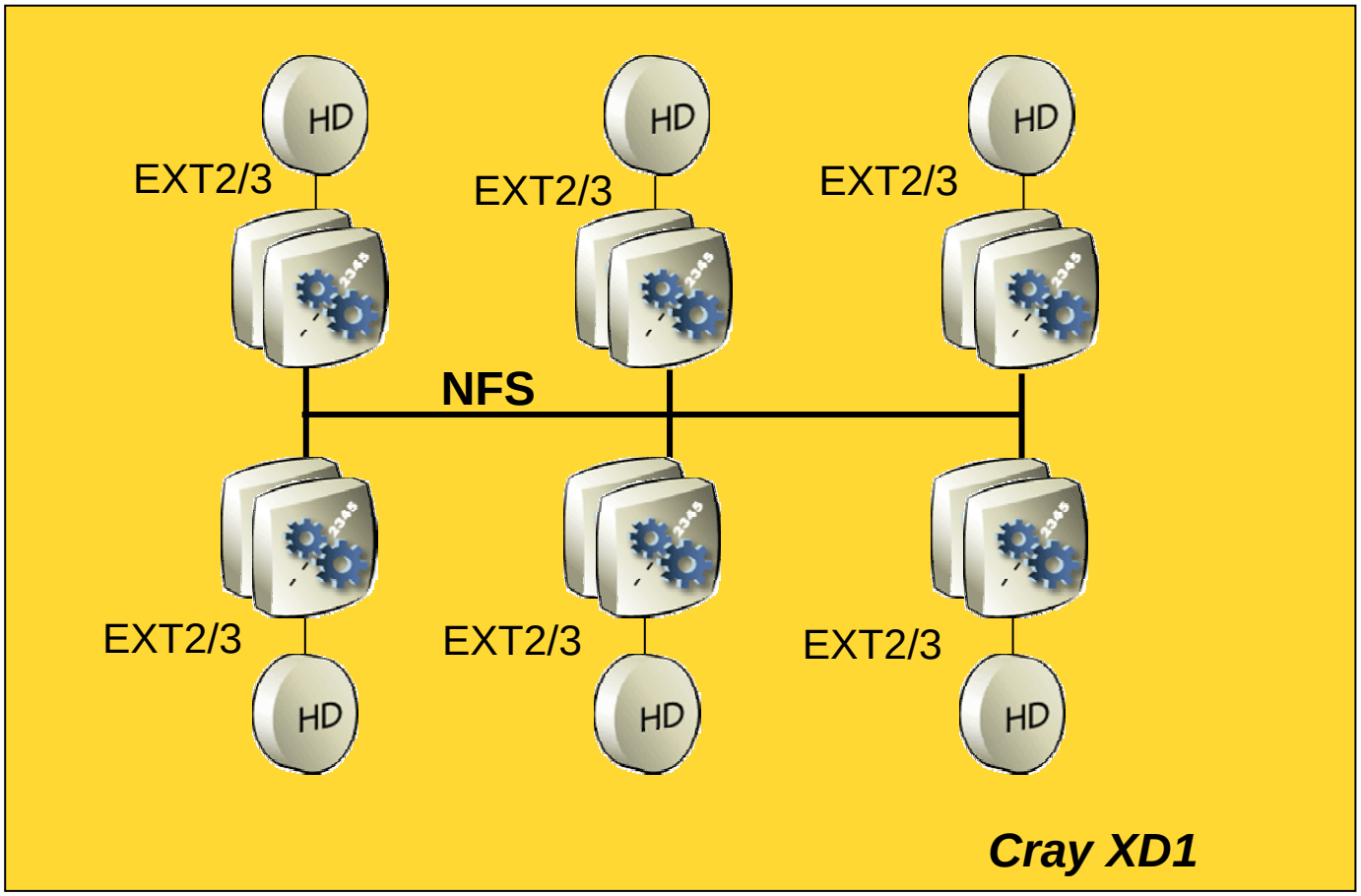
File Systems: SAN

SMP acting as a File Server for the SAN



File Systems: Local Disk per Compute Node

One disk per SMP; NFS Cross-mounting; External NAS Optional



Designed for High Availability

Fewer Failures

- **Stateless Hardware**
- **Reduced Variability**
- **Self-Configuring**

Faster Recovery

- **Self-Monitoring**
- **Self-Healing**
- **Software Rollbacks**

Today

99% Availability

- **100 minutes downtime / week**
- **1 failure / week**

Target

99.99% Availability

- **53 minutes downtime / year**
- **1 failure of 5 minutes/month**
- **No incremental cost**

One vendor
One phone call
Fully integrated and tested