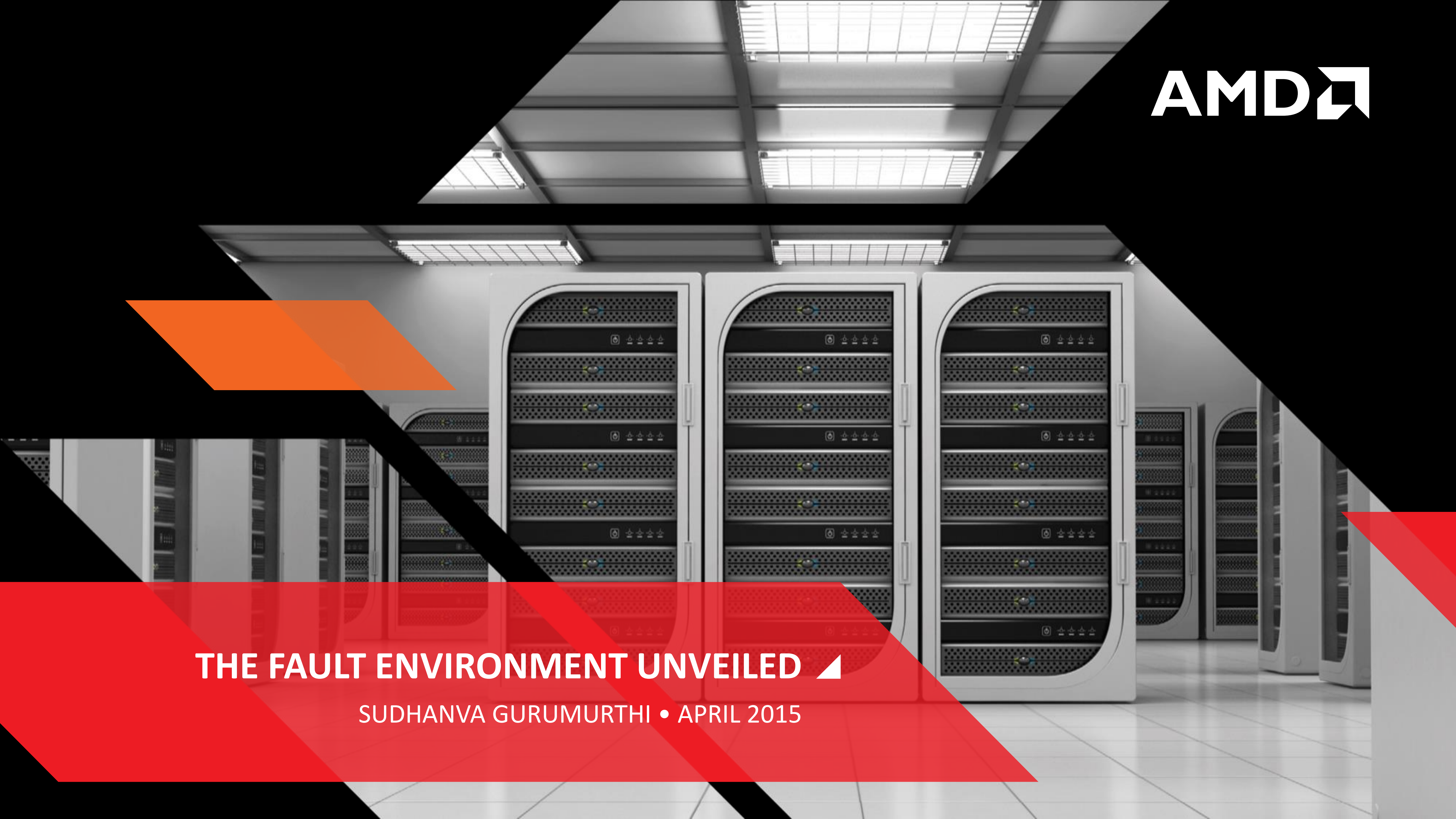

THE FAULT ENVIRONMENT UNVEILED

SUDHANVA GURUMURTHI • APRIL 2015

THE RELIABILITY LANDSCAPE

- Many sources of unreliability in silicon:
  - Particle-induced Transient Faults
  - Permanent Faults
  - Aging
  - Voltage Noise
  - Increased Variability
- Many emerging technologies have reliability problems
- Large systems with high component counts

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Need a deep understanding of faults

STUDY FAULTS FROM REAL SYSTEMS

- Many insights can be gained from field data analyses

- Field studies are beneficial for hardware designers, system integrators, and the operators of the system

- This talk:
  - A look into faults and failures from field studies of supercomputers and other large data centers
  - Implications for resiliency and reliability at scale

ANALYSIS OF FAULTS IN SUPERCOMPUTERS

[SRIDHARAN ET AL., ASPLOS’15] [DEBARDELEBEN ET AL., SELSE’14] [SRIDHARAN ET AL., SC’13]

- Collaboration between AMD and the US Department of Energy National Labs

- **Jaguar system at Oak Ridge National Lab**
  - 18,688x 2-socket 8-core AMD Opteron™ processor nodes
  - 8 DDR-2 DIMMs per node, chipkill ECC
  - 11 months of data
- **Cielo system at Los Alamos National Lab**
  - 8518x 2-socket 12-core AMD Opteron™ processor nodes
  - 8 DDR-3 DIMMs per node, chipkill ECC
  - 16 months of data
- **Hopper system at NERSC / Lawrence Berkeley National Labs**
  - 6000x 2-socket 12-core AMD Opteron™ processor nodes
  - 8 DDR-3 DIMMs per node, chipkill ECC
  - 18 months of data
- **Sufficient data to draw statistically significant conclusions**
  - 500M CPU socket-hours in aggregate
  - 40B DRAM device-hours in aggregate

IDENTIFYING FAULT TYPES IN THE FIELD

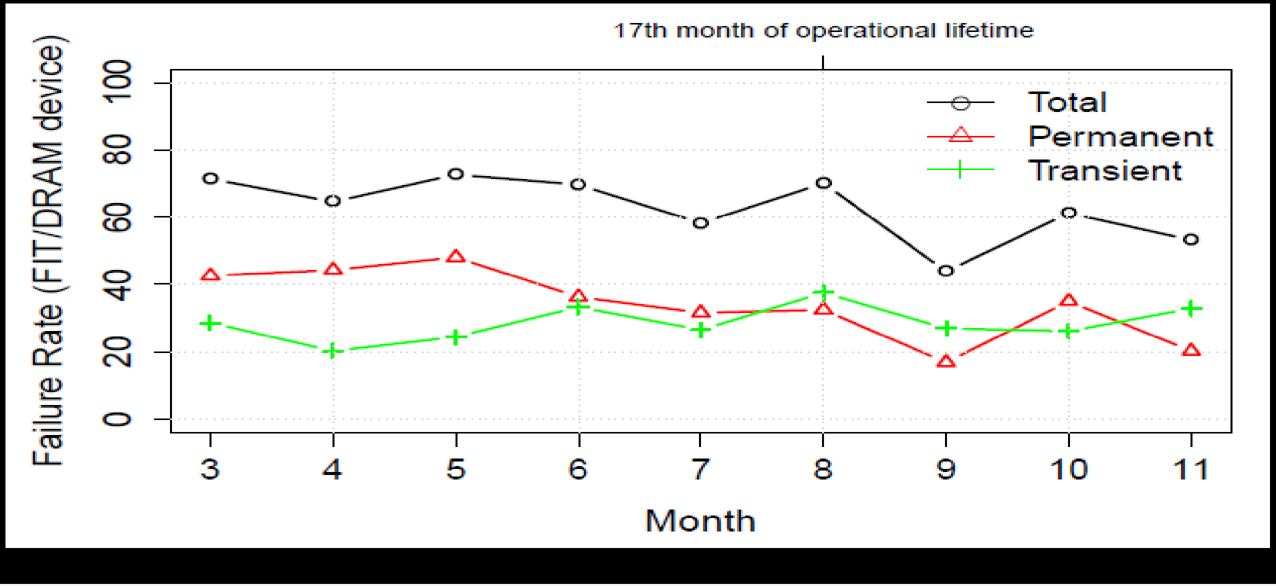
◢ **Data collection**

- Hardware logs errors in hardware error registers
- OS periodically samples error registers and logs corrected errors to the console
- Console log is a *sample* of all errors that occurred in the system
- Can infer fault type based on error log characteristics

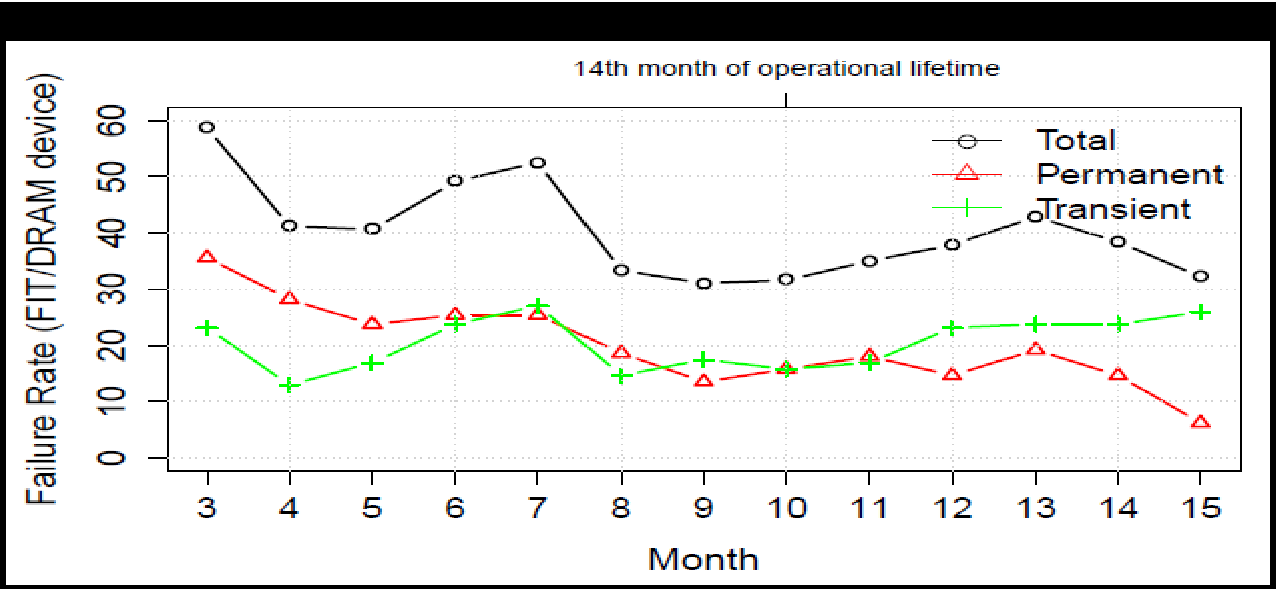
◢ **Scrubber (L2 and L3 caches, DRAM)**

- Periodically reads each memory location, corrects any errors found, writes corrected data back to memory
- Errors in multiple scrub intervals ➔ permanent fault
- Errors in one interval ➔ transient fault (bound)

DRAM: FAULT RATE AND FAULT TYPES



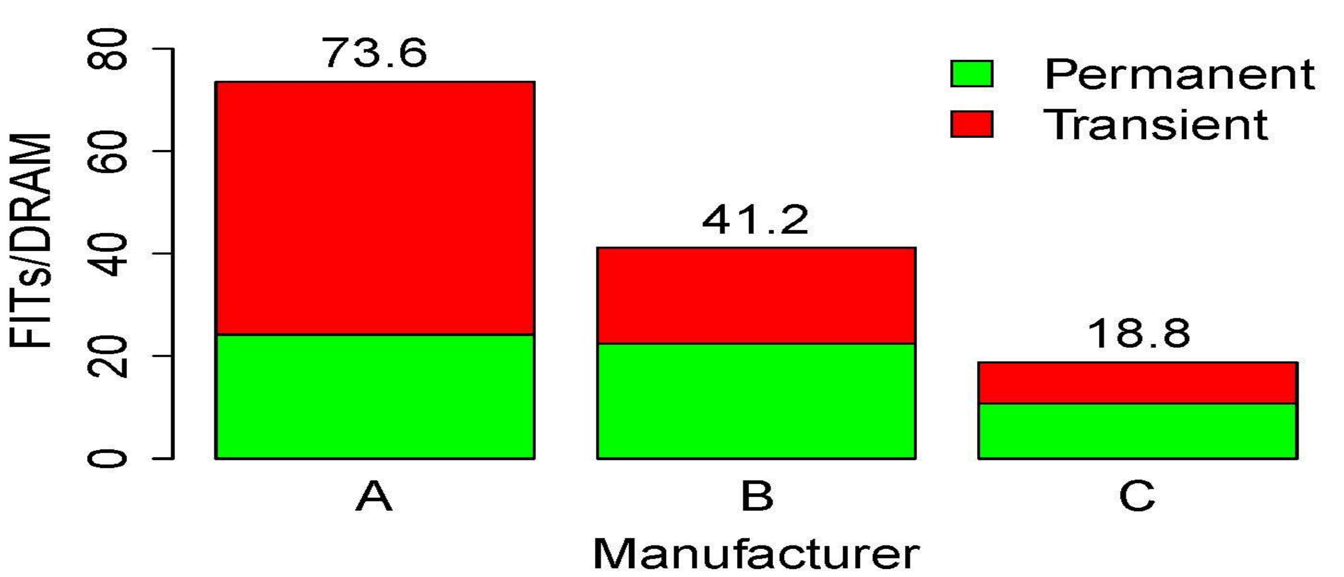
Jaguar (DDR-2)



Cielo (DDR-3)

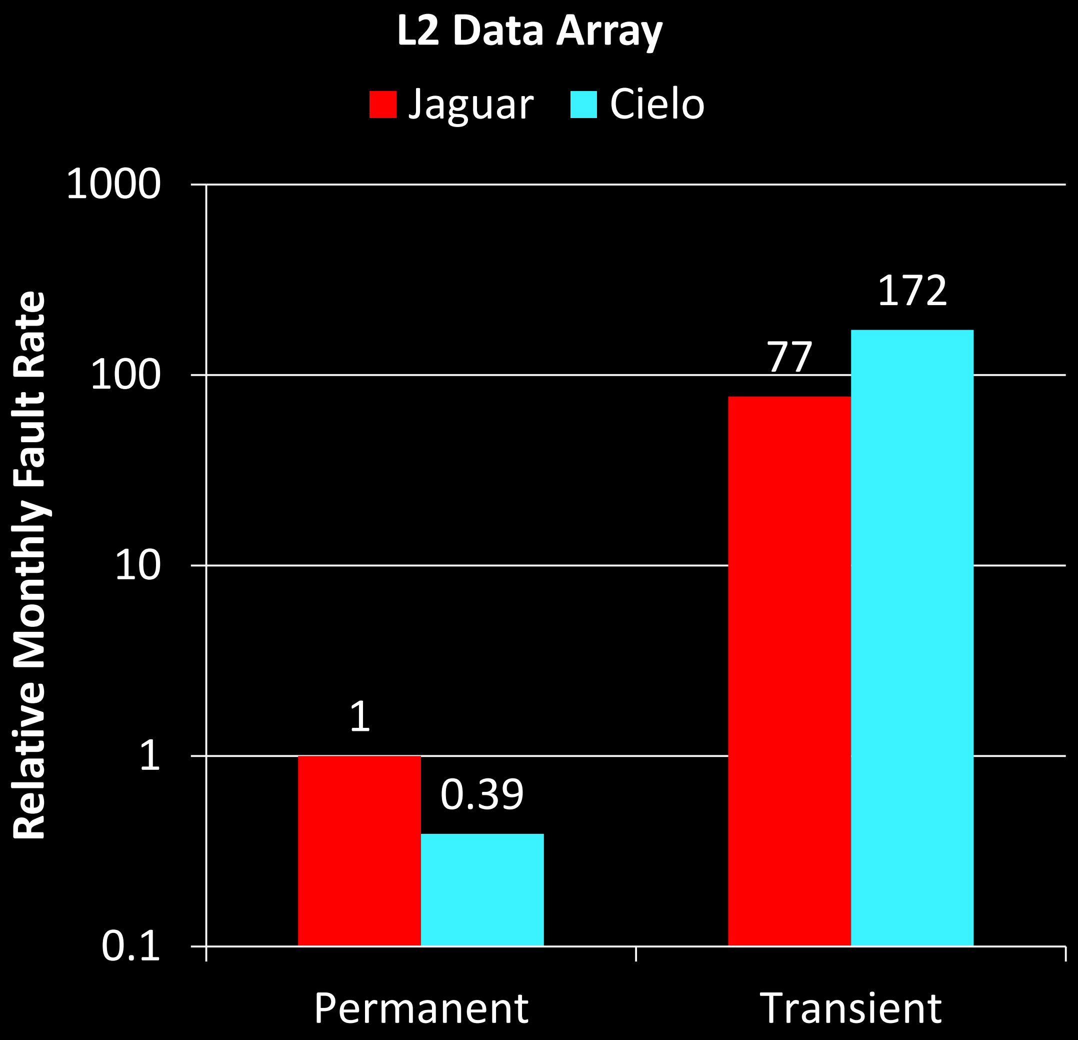
DRAM FAULT MODES

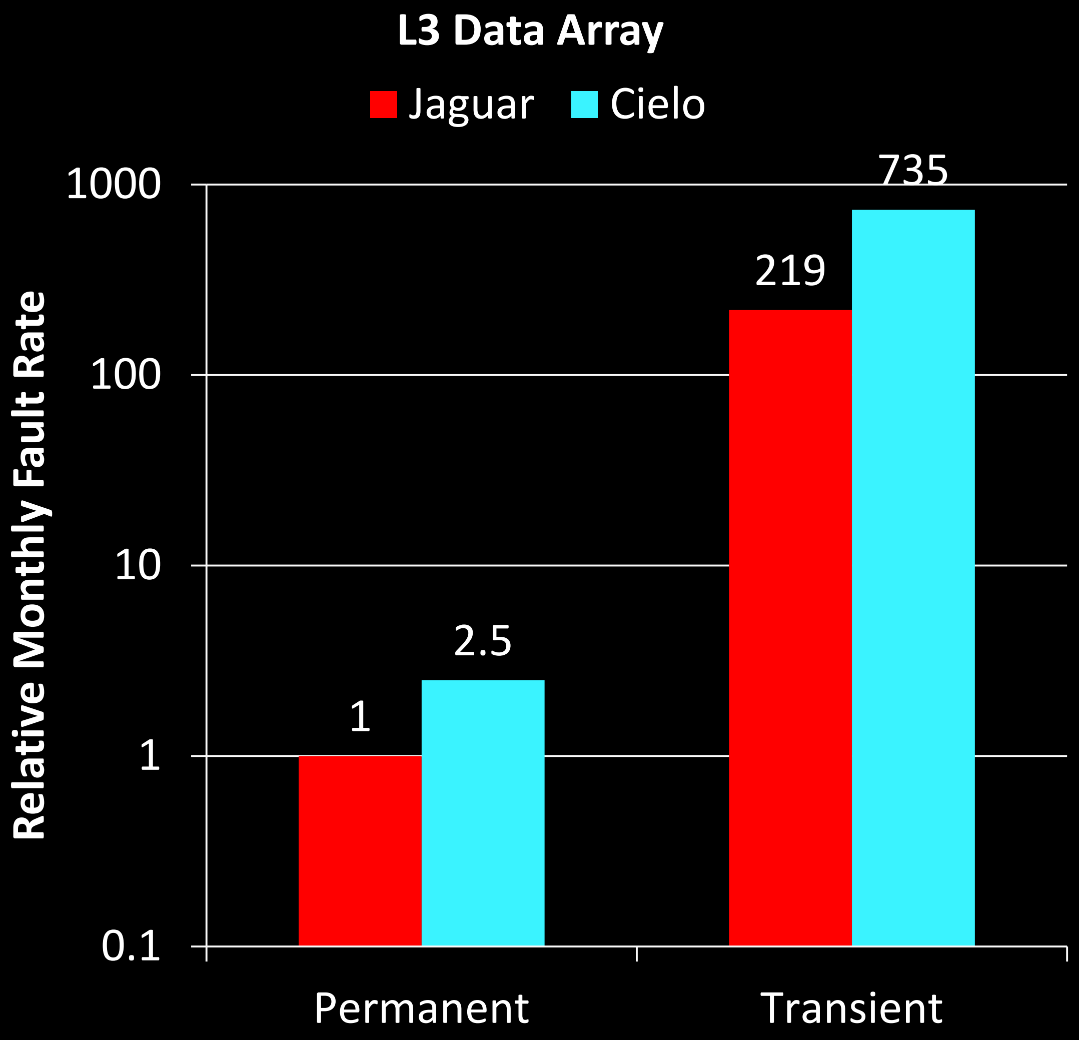
Fault Mode	Vendor A	Vendor B	Vendor C
Single-bit	64.6%	69.5%	58.4%
Single-word	0%	0.3%	0%
Single-column	8.7%	8.8%	11.9%
Single-row	12.2%	10.6%	14.9%
Single-bank	13.5%	7.8%	9.9%
Multiple-bank	1.3%	0.7%	2.0%
Multiple-rank	1.3%	3.0%	3.0%



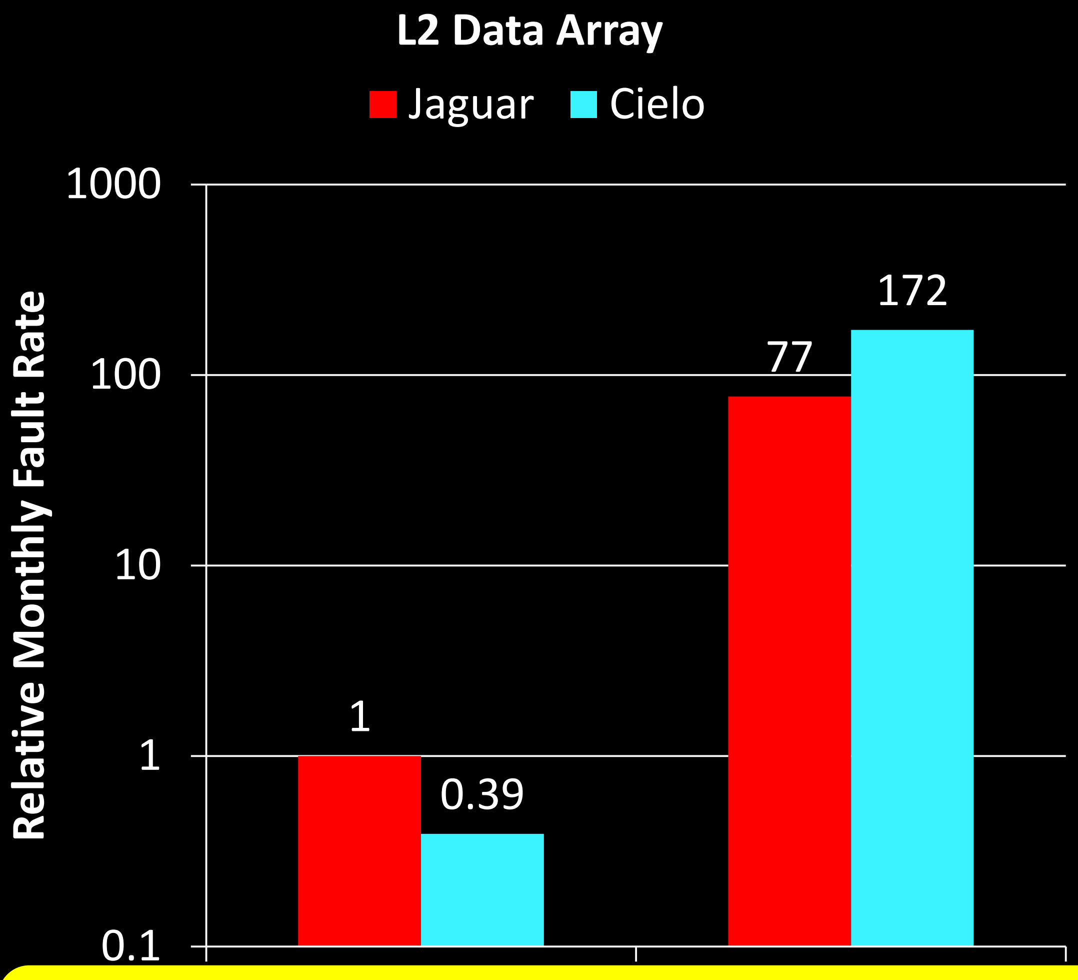
Overall fault rate per vendor

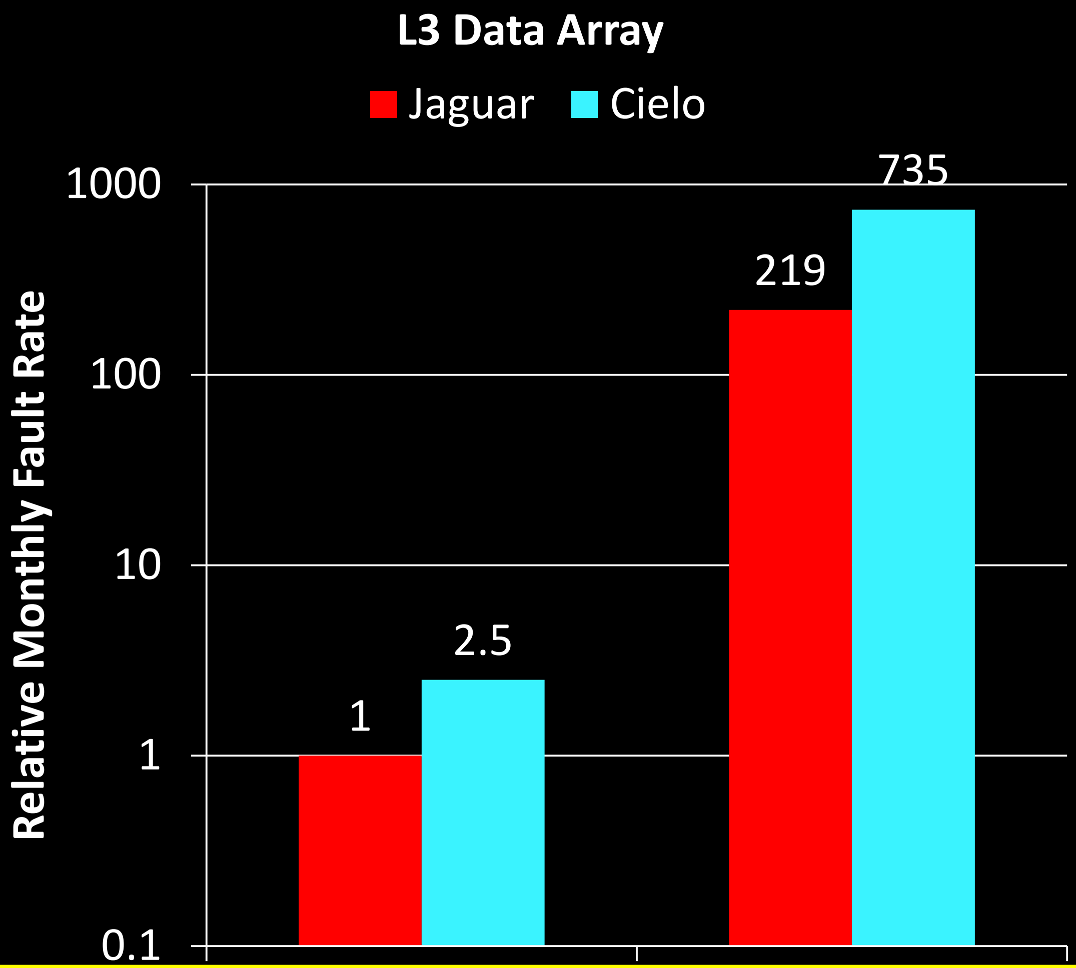
SRAM FAULTS


L2 Data Array
Jaguar
Cielo
Relative Monthly Fault Rate
1000
100
10
1
0.1
1
0.39
77
172
Permanent
Transient


L3 Data Array
Jaguar
Cielo
Relative Monthly Fault Rate
1000
100
10
1
0.1
1
2.5
219
735
Permanent
Transient

SRAM FAULTS

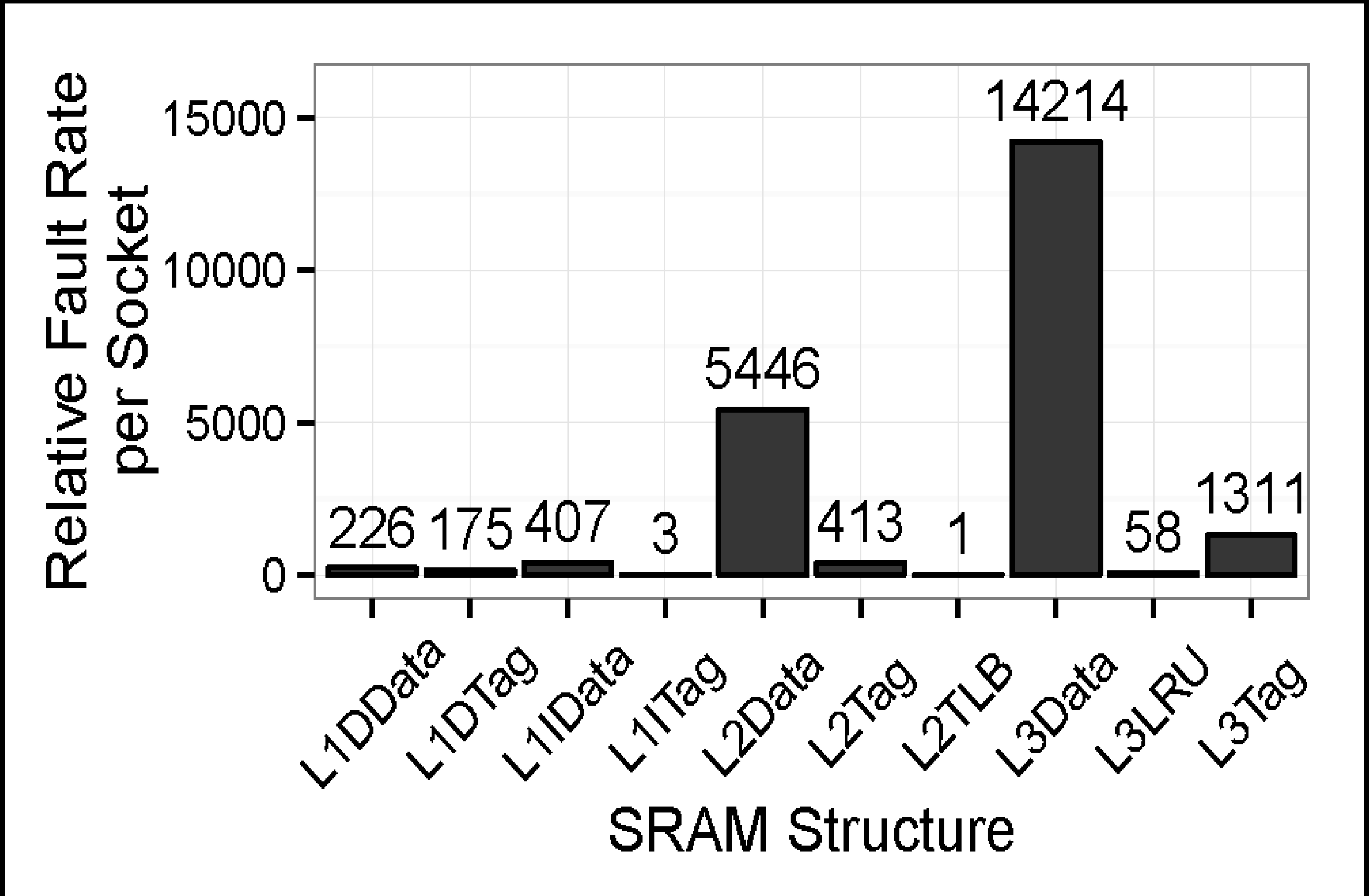




Most SRAM faults are transient, especially in mature process technologies

MANY SRAM STRUCTURES EXPERIENCE FAULTS

- Most faults are in L2 and L3 caches
  - Largest on-chip structures
- Even small structures see faults
  - TLB, tag arrays
- Exascale systems will:
  - Have 4-5x the number of compute sockets
  - Have much more SRAM per socket



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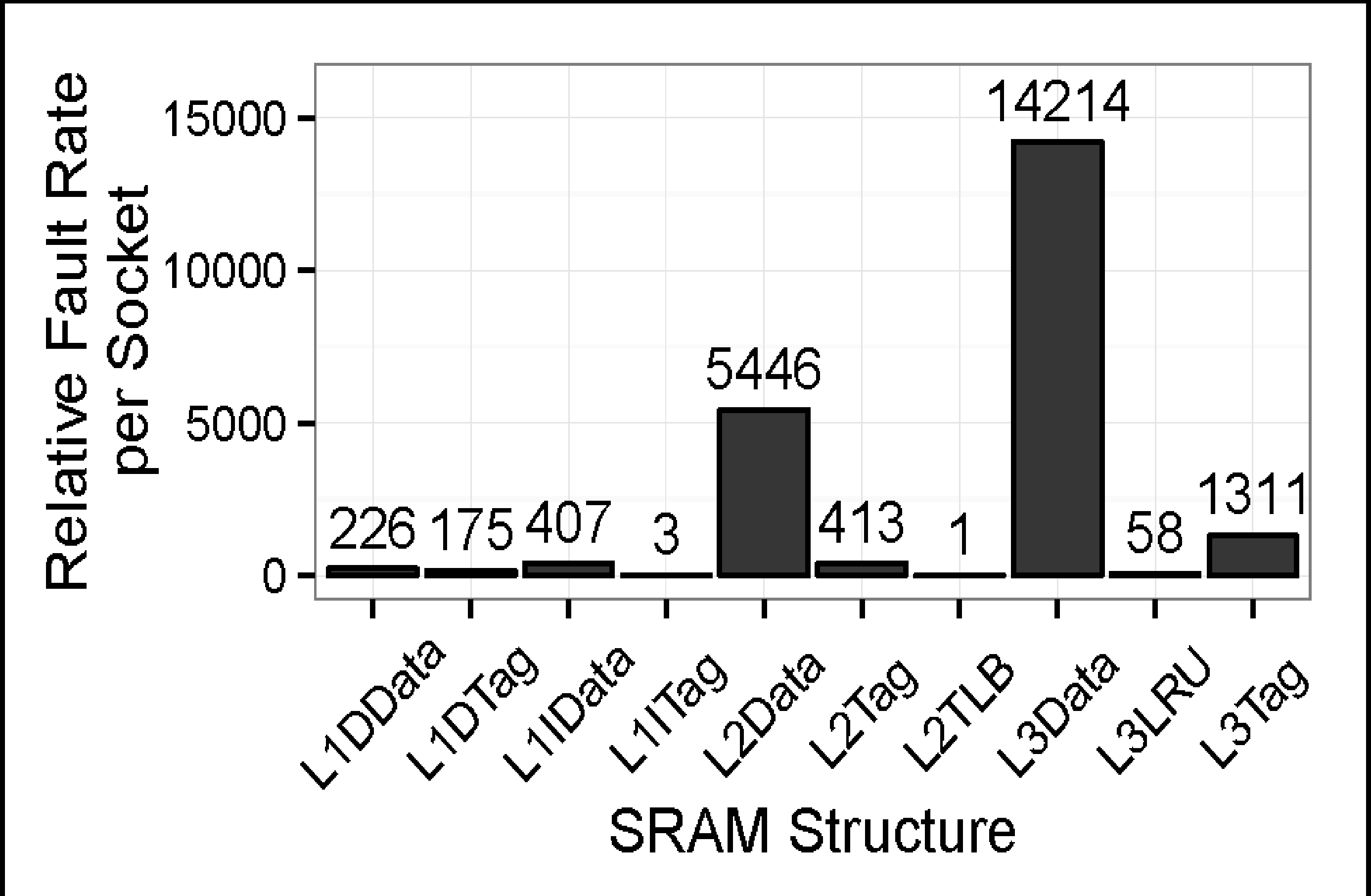
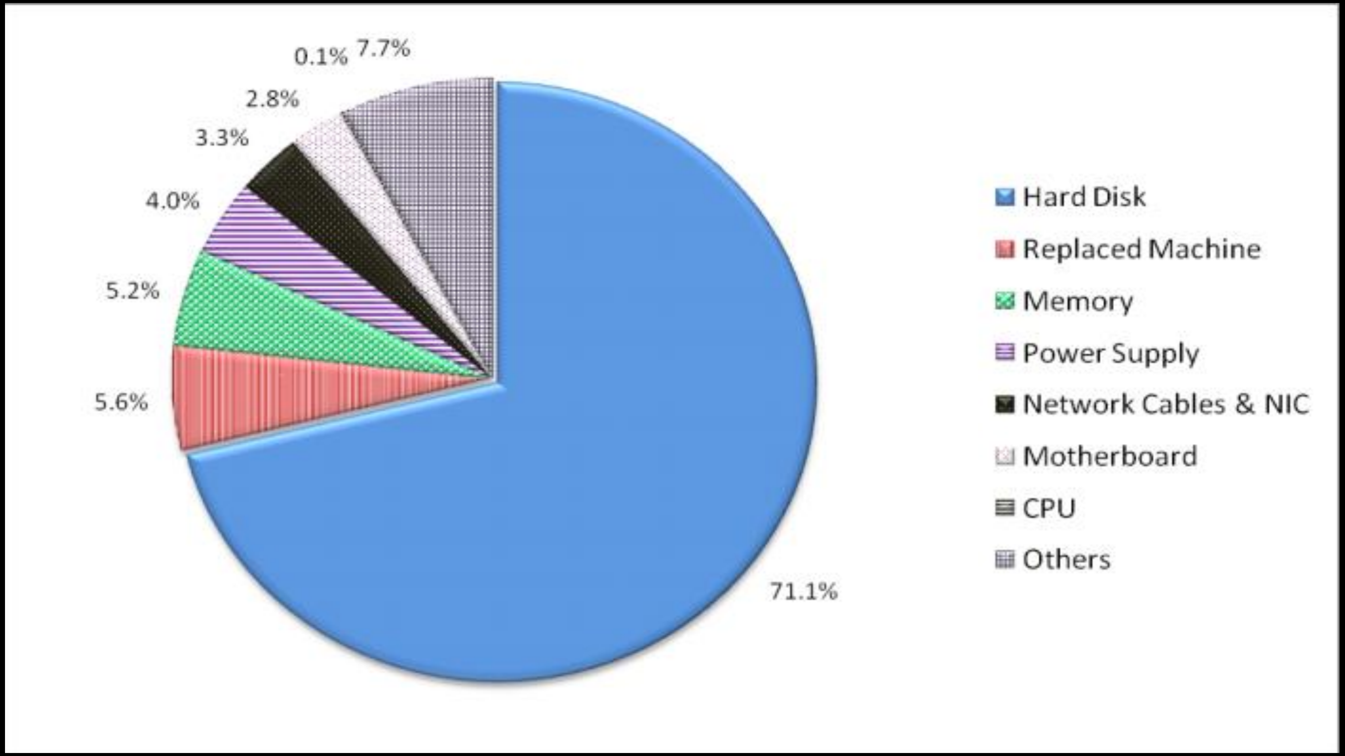


Exascale systems will experience more faults!

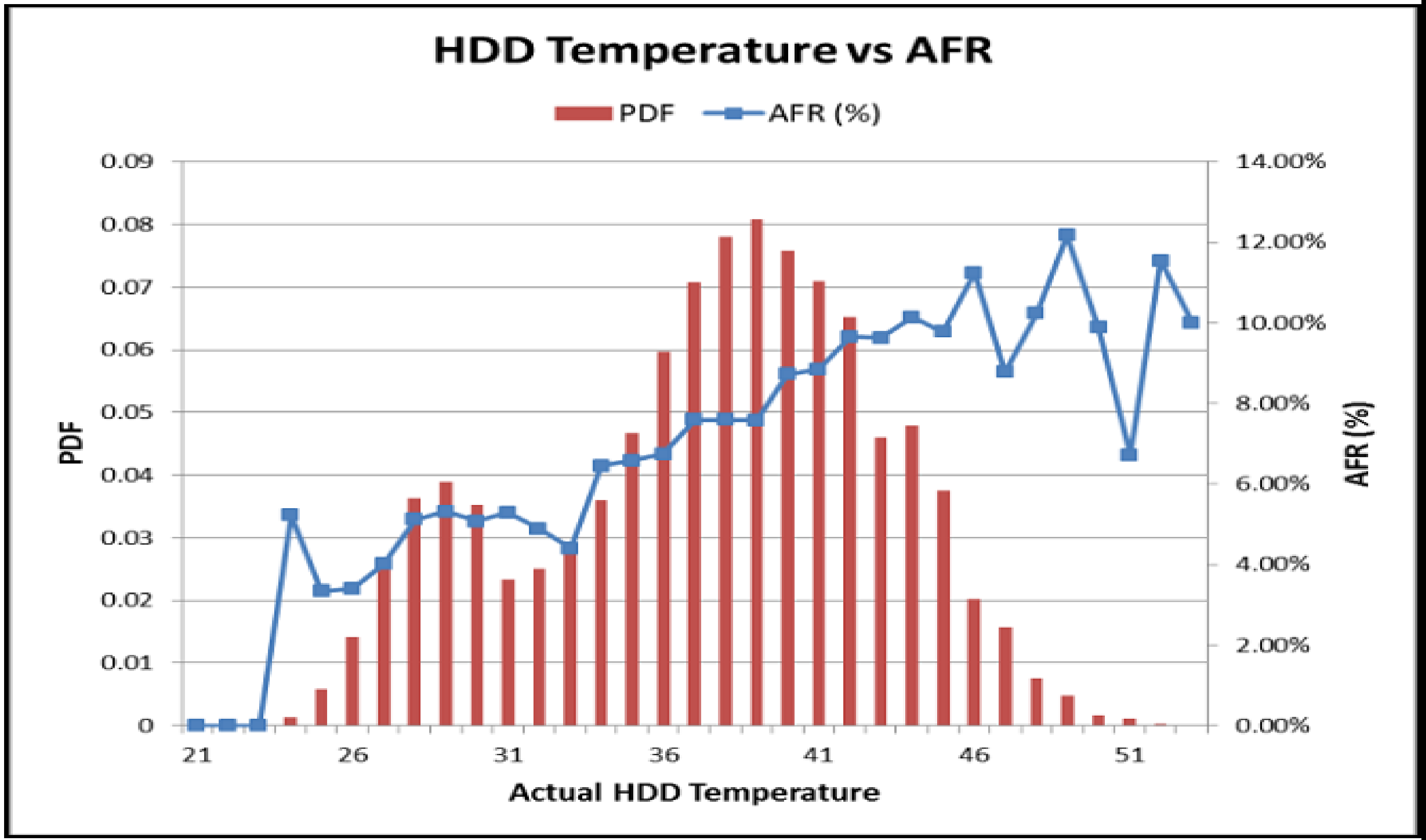
FAILURES IN OTHER NODE COMPONENTS

[SANKAR ET AL., ACM TOS'13]



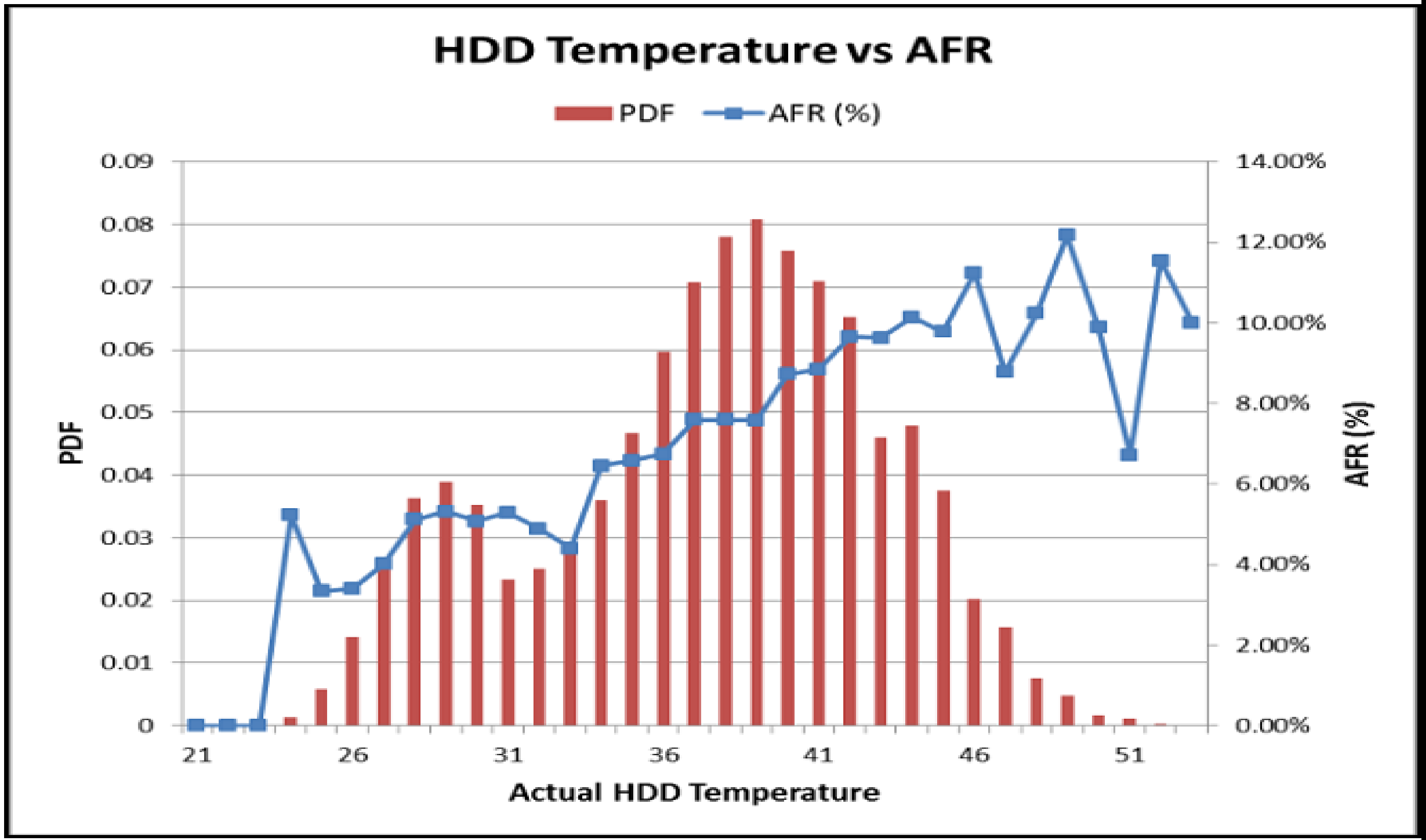
- Work done at the University of Virginia in collaboration with Microsoft
- Hardware component failures observed over two years from data centers with 100,000+ servers

HDD FAILURE RATE HIGHLY CORRELATED WITH TEMPERATURE



- Data contradicts some prior studies on the impact of temperature on HDD failures

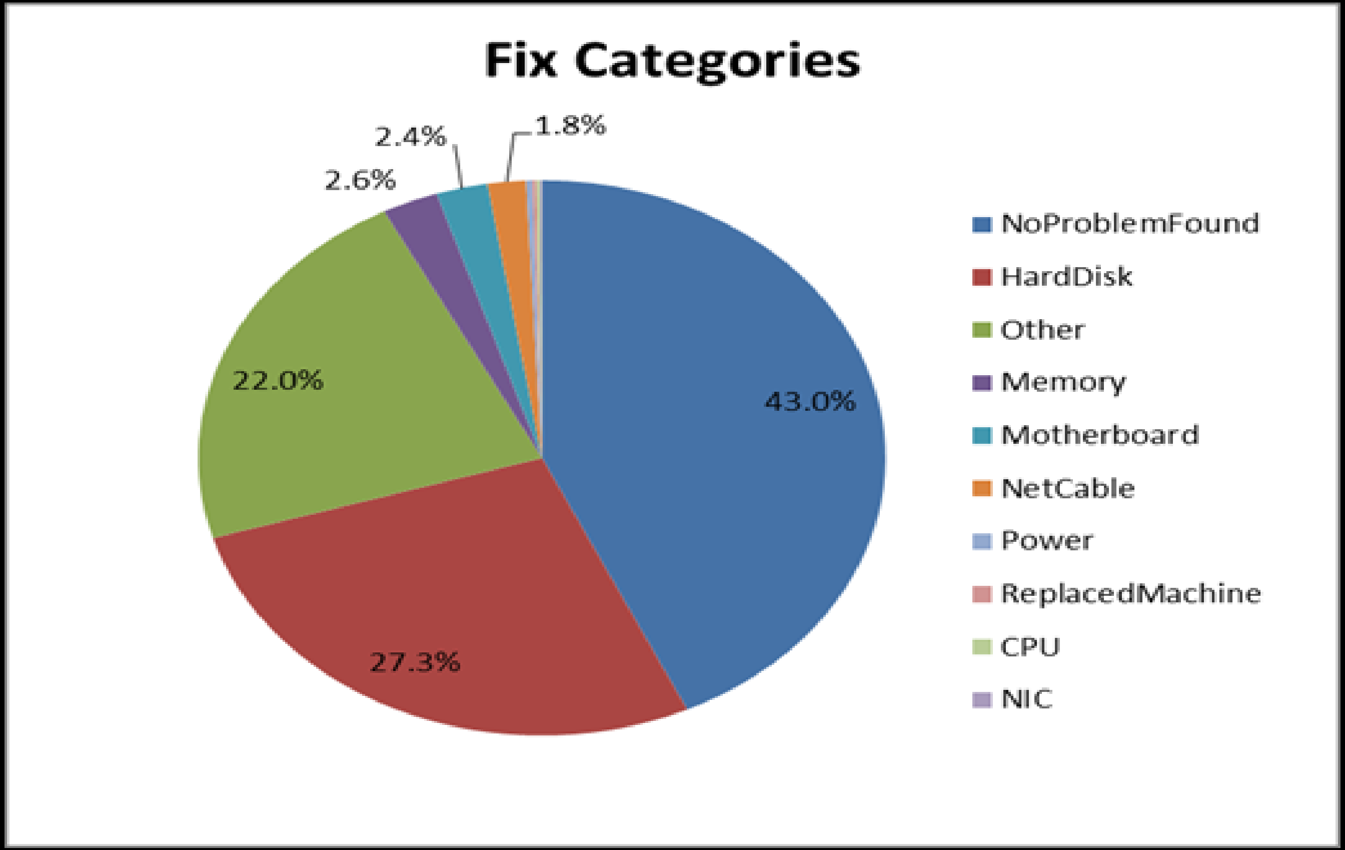
HDD FAILURE RATE HIGHLY CORRELATED WITH TEMPERATURE



Need more field studies!

“NO PROBLEM FOUND” (NPF) FAILURES

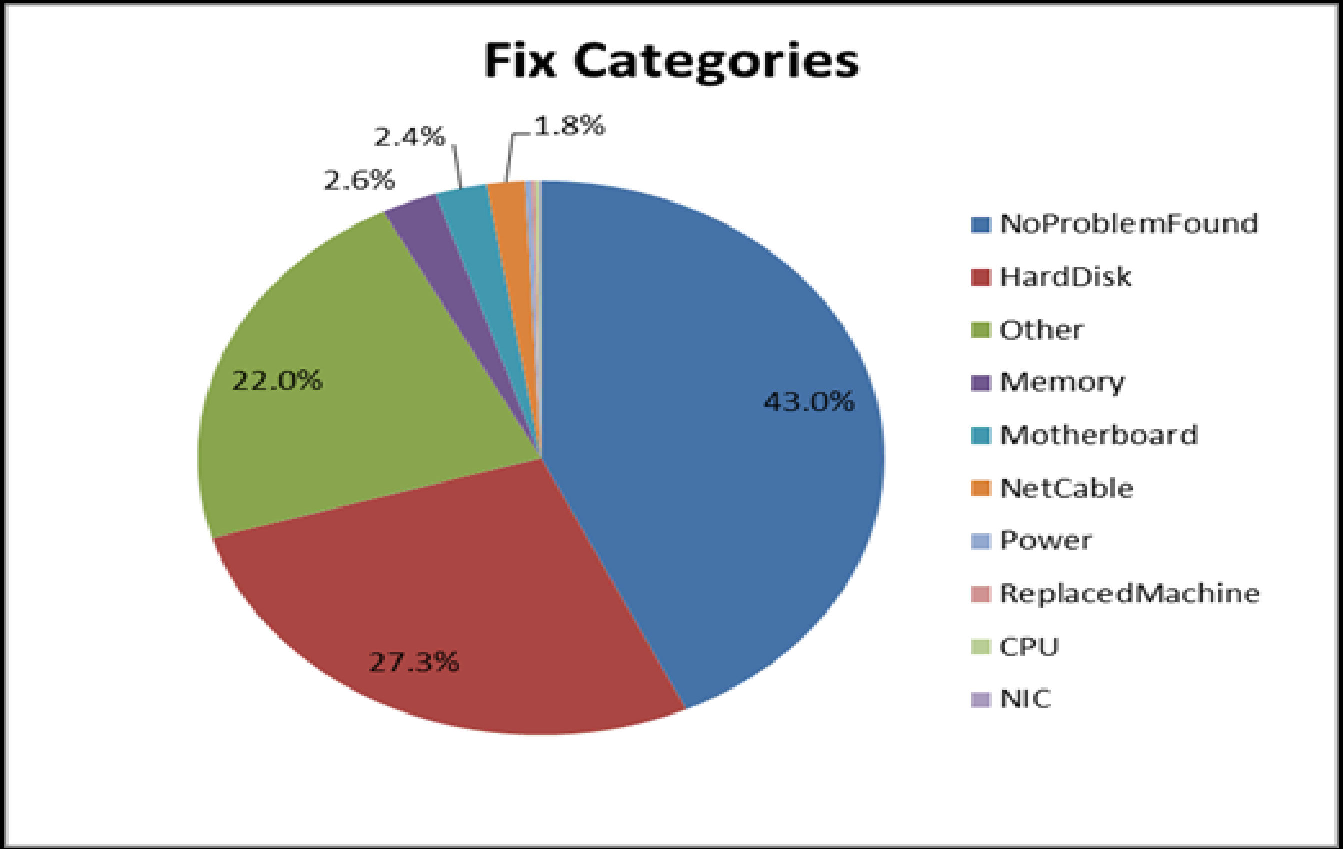
[SANKAR ET AL., IEEE CAL’14]



- Machines report a failure but no hardware failure detected
- Hard power-cycling, reseating HDDs, cables, etc. sometimes fix the problem
- Takes a long time to diagnose and hence affects service availability and quality

"NO PROBLEM FOUND" (NPF) FAILURES

[SANKAR ET AL., IEEE CAL'14]



- Machines report a failure but no hardware failure detected

Need better root cause analysis and failure prediction capabilities

SUMMARY

ANALYZE

COLLABORATE

SHARE

RELATED PUBLICATIONS

- V. Sridharan, N. DeBardeleben, S. Blanchard, K. Ferreira, J. Stearley, J. Shalf, S. Gurumurthi, Memory Errors in Modern Systems: The Good, The Bad, and the Ugly, International Conference on Architectural Support for Programming Languages and Operating Systems (ASPLOS), 2015.
- N. DeBardeleben, S. Blanchard, V. Sridharan, S. Gurumurthi, J. Stearley, K. Ferreira, Extra Bits on SRAM and DRAM Errors - More Data from the Field, IEEE Workshop on Silicon Errors in Logic - System Effects (SELSE), 2014.
- V. Sridharan, J. Stearley, N. DeBardeleben, S. Blanchard, S. Gurumurthi, Feng Shui of Supercomputer Memory - Positional Effects in DRAM and SRAM Faults, Supercomputing (SC), 2013.
- S. Sankar, S. Gurumurthi, Soft Failures in Large Datacenters, IEEE Computer Architecture Letters (CAL), 2014.
- S. Sankar, M. Shaw, K. Vaid, S. Gurumurthi, Datacenter Scale Evaluation of the Impact of Temperature on Hard Disk Drive Failures, ACM Transactions on Storage (TOS), 2013.

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