

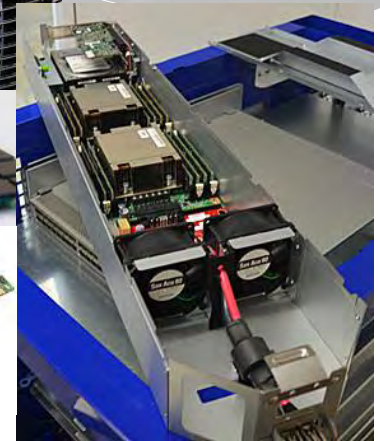
# Cloud Downtime Due to Memory Errors

**A bigger problem than you might think!**

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# Cloud Hardware

- Servers in the Data Center
- Loaded with memory
  - Several DDR3 and soon DDR4 channels per processor
  - Several DIMMs per channel
  - DIMMs becoming denser
- The industry has NO standardized compliance testing
- Price pressures affecting validation budgets



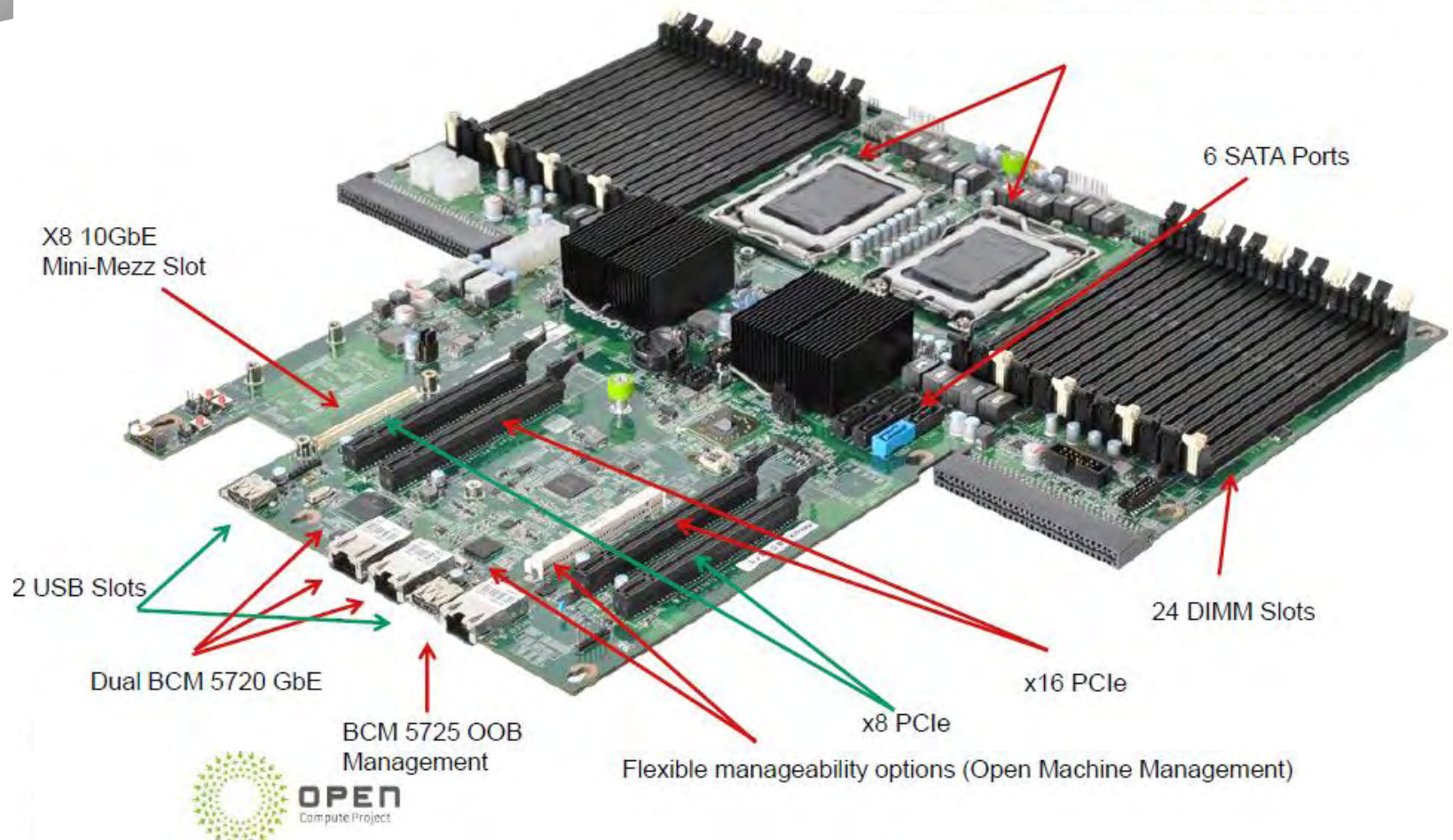
DDR3

**JEDEC**

DDR4

# Cloud Hardware

## *24 total DIMM slots*



# Studies Show: More Errors than Expected

- DRAM Errors in the Wild: A Large-Scale Field Study
- Cosmic Rays Don't Strike Twice: Understanding the Nature of DRAM Errors and the Implications for System Design
- Hard Data on Soft Errors: A Large-Scale Assessment of Real-World Error Rates in GPGPU
- An Empirical Study of Memory Hardware Errors in a Server Farm
- A Realistic Evaluation of Memory Hardware Errors and Software System Susceptibility

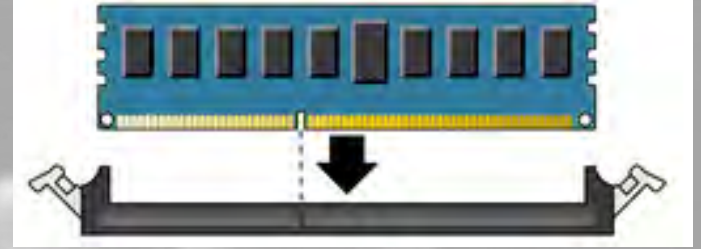
# The Result?

- Band-Aids and work arounds
  - Chip Kill
  - ECC
  - Page Retirement
  - Mirroring
  - Duplication

*You are just rearranging the chairs on the deck of the Titanic....the ship is still going down*



# Memory Standards



- JEDEC [www.JEDEC.com](http://www.JEDEC.com) is the international standards body that governs DRAM Chip Specifications
- JEDEC also specifies DIMM mechanical form factors and electrical properties of the DIMM etch
- Standardizes connector pinout
- Standardizes speeds and properties that promote interoperability
- **However there is NO standardized Compliance Testing**

# How big of a problem is this?

- Studies show: 2-4% error rate
- If Google has a million servers\*\*
- A 4% error rate per year is 40,000 failures a year
- 3,334 failures per month
- 110 failures per day
- 4.6 failures per hour

\*\* Aug 2011 DataKnowledgeCenter.com reported 900,000

# How is it handled?

## DIMM swaps and system replacement



Source: Google



# What are the causes of these memory errors

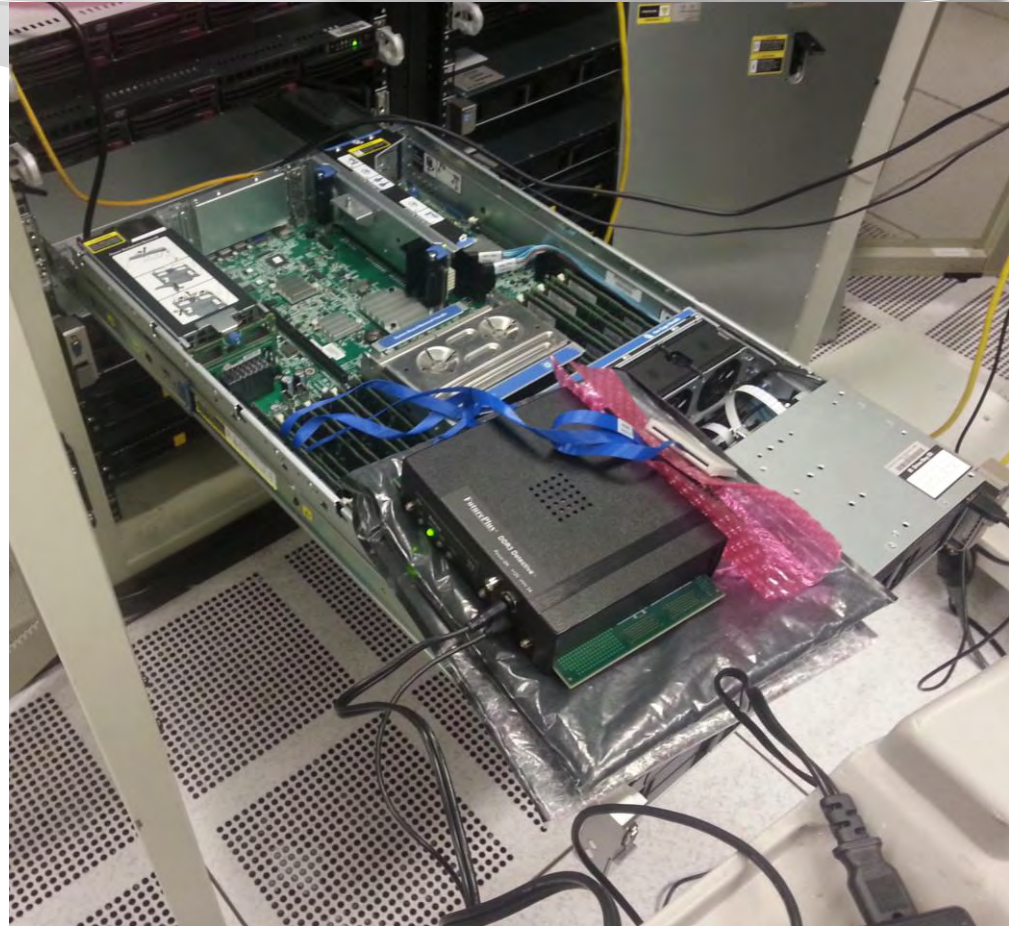
*Other than the Cosmic Rays, Aging and Environmental Issues*

- Motherboard Signal Integrity
- Poor quality Connectors
- Incompatible BIOS Settings
- Protocol Violations by the Memory Controller
- Poor Quality DIMMs

**Design Flaws!**

# Case Study

- Server in the Data Center
- Equipment
  - DDR3 Detective®
  - Google StressAPP test



# Failures

DDR3 Detective (On-Line)

File Windows Help

Run Stop Setup Mode Registers Violations Performance Log File State Listing Eye Detector Setup Wizard

Violations

<p>Violation 1 MRS to MRS (#MRD) and MRS to other command (#MOD)</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 11 Any CS# asserted for more than 1 cycle or CS# to any CS#</p> <p>Main ■ Satellite ■ <b>1397</b></p>	<p>Violation 24 Different rank WR to RD</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 36 PDE followed by non-NOP/DES</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>
<p>Violation 2 ACT To RD or WR (#RCD)</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 12 ACT to PRE</p> <p>R0 ■ R1 ■ R2 ■ <b>1397</b> R3 ■</p>	<p>Violation 26 Different rank WR to WR</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 37 Power Down min time</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>
<p>Violation 3 PRE to ACT in the same bank or ZQCL/ZQCS/MRS or SRE (#RP)</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 13 ACT to PRE, PREA or ACT to AP</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 28 REF to REF over the last 128 intervals is greater than REF1</p> <p>R0 ■ R1 ■ R2 ■ <b>7747</b> R3 ■</p>	<p>Violation 38 Power Down max time</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>
<p>Violation 4 RD to PRE in the same bank (#RTP)</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 14 Same rank RD To WR</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 29 ZQCS to Non-NOP/DES and ODT &lt; ZQOper</p> <p>R0 ■ R1 ■ R2 ■ <b>13335</b> R3 ■</p>	<p>Violation 39 PDX Fast Ext</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>
<p>Violation 5 WR to WR Cmd in the same bank (#CCD)</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 15 WR to PRE or PREA</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 30 WR w/AP to XXX</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	
<p>Violation 6 REF to an Non NOP/DES (#RFC)</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 16 Same rank WR to RD</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 31 More than 4 ACTs in less than tFAW</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	
<p>Violation 7 SRX followed by non-NOP/DES (#XS)</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 17 Active bank check(s)</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 32 RD/WR to CKE low or MRS violation</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	
<p>Violation 8 REF time is less than tCKE</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 19 Same rank RD to RD</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 33 MR0 DLL reset followed by RD or ODT</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	
<p>Violation 9 SRX followed by RD, ODT or CKE Low within tXSDLL</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 20 Different rank RD to RD</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 34 WR with Synchron/Dynamic ODT assert time</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	
<p>Violation 10 ACT To ACT (#RRD)</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 22 Different rank RD to WR</p> <p>R0 ■ R1 ■ R2 ■ <b>0</b> R3 ■</p>	<p>Violation 35 CKE Assert Time</p> <p>CKE0 ■ CKE1 ■ <b>0</b></p>	

# Violations Found

- Protocol Compliance is correct timing between events on the DDR memory bus
- What we found on the server
  - Simultaneous access to two DIMMs
  - Opening and Closing DRAM Banks too close together
  - Inadequate Refreshes
  - Incorrect protocol during a Calibrate Command

**All of these can cause the DRAM to lose state  
thus resulting in Data Corruption**

# Response from the System Vendor

- Thanks for telling us that. It's a BIOS Setting
- Its ok only a few clocks off on the Refreshes
- We tie ODT high and disable that feature in the Mode Registers
- Really?

# Smoking Gun

DDR3 Detective (Off-Line) - [State Listing]

File Windows Help

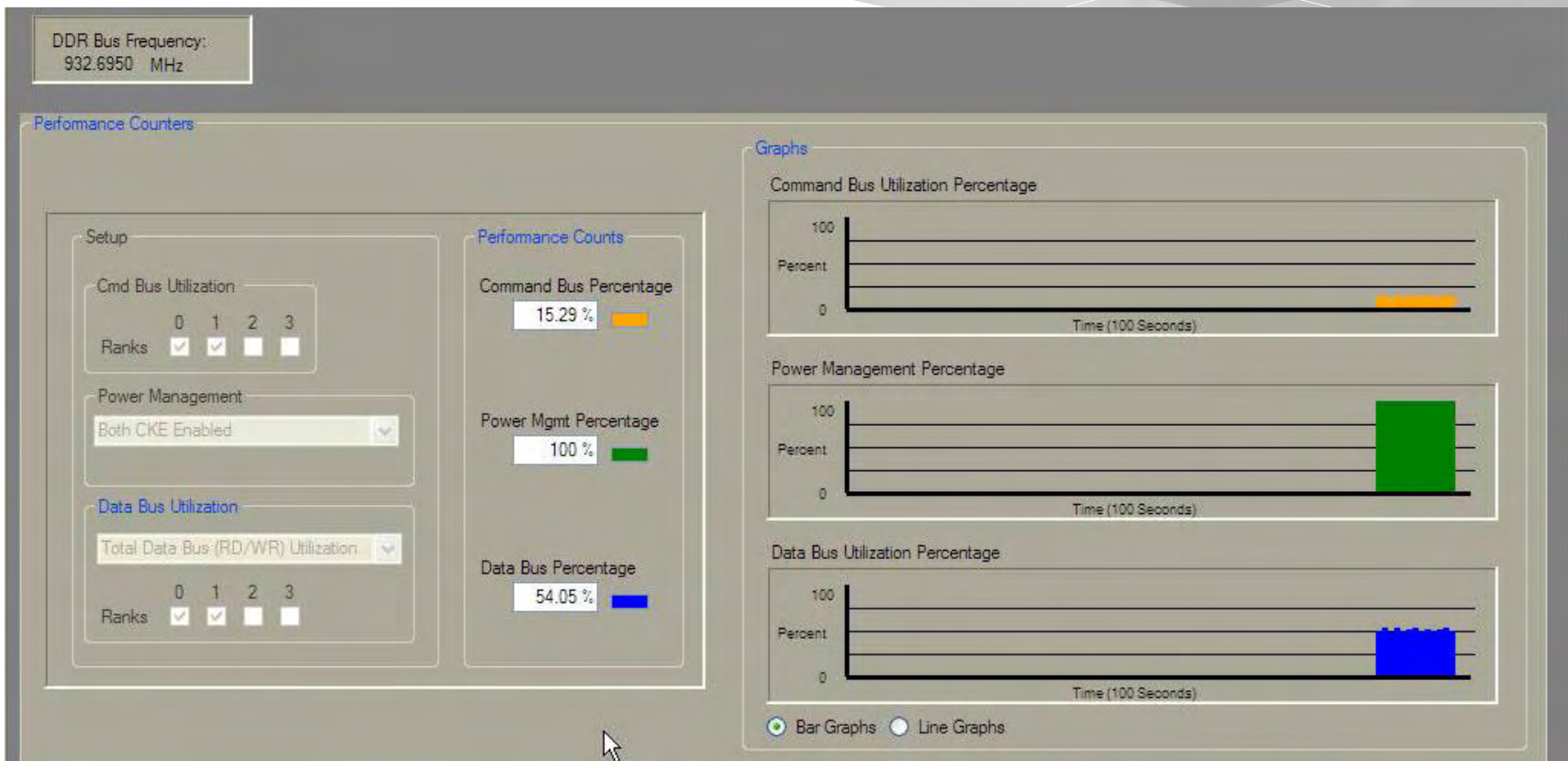
Run Stop Setup Mode Registers Violations Performance Log File State Listing Eye Detector Setup Wizard

Columns M2 28 Clks

State	ODT1	ODT0	TIME	BA	Addr	DDR3	PV	PC	CKE0	CKE1	CS3n	CS2n	CS1n
-15	1	0	244.9958ns	0	0400	PREA Rank 1	0		0	1	1	1	0
-14	1	0	144.9975ns	0	0400	PREA Rank 1	0		0	1	1	1	0
-13	1	0	19.9997ns	0	0020	PDE CKE1	0		0	0	1	1	1
-12	1	0	79.9986ns	0	0000	SRX Or PDX CKE1	0		0	1	1	1	1
-11	1	0	1.2500ns	0	0000	SRX Or PDX CKE0	0		1	1	1	1	1
-10	1	0	7.4999ns	0	0C78	MRS Rank 0	0		1	1	1	1	1
-9	1	0	6.2499ns	0	0C78	MRS Rank 1	0		1	1	1	1	0
-8	1	0	287.4951ns	0	0400	PREA Rank 1	0		1	1	1	1	0
-7	1	0	242.4958ns	0	0400	PREA Rank 1	0		1	1	1	1	0
-6	1	0	327.4944ns	0	0400	PREA Rank 1	0		1	1	1	1	0
-5	1	0	19.9997ns	4	03E0	PDE CKE0	0		0	0	1	1	1
-4	1	0	174.9970ns	0	0000	SRX Or PDX CKE0	0		1	1	1	1	1
-3	1	0	329.9943ns	0	0400	PREA Rank 1	0		1	1	1	1	0
-2	1	0	242.4958ns	0	0400	PREA Rank 1	0		1	1	1	1	0
M2 -1	1	0	249.9957ns	2	F7FB	ACT Rank 0 Bank=2 Addr=F7FB	0		1	1	1	1	1
T 0	1	0	34.9994ns	0	0400	PREA Rank 0	1	V12	1	1	1	1	1
1	1	0	14.9997ns	0	0400	PREA Rank 1	0		1	1	1	1	0
2	1	0	17.4997ns	0	1C78	MRS Rank 0	0		1	1	1	1	1
3	1	0	6.2499ns	0	1C78	MRS Rank 1	0		1	1	1	1	0
4	1	0	18.7497ns	2	F7FB	ACT Rank 0 Bank=2 Addr=F7FB	0		1	1	1	1	1
5	1	0	13.7498ns	2	089A	RD Rank 0 Bank=2 Row=F7FB Column=3a	0		1	1	1	1	1
6	1	0	66.2489ns	6	43E2	PDE CKE1	0		1	0	1	1	1
7	1	0	29.9985ns	0	4020	SRX Or PDX CKE1	0		1	1	1	1	1
8	1	0	17.4997ns	0	0400	PREA Rank 0	0		1	1	1	1	1
9	1	1	19.9997ns	0	00E8	PDE CKE0	0		0	1	1	1	1
10	1	0	188.7468ns	0	0020	SRX Or PDX CKE0	0		1	1	1	1	1
11	1	0	6.2499ns	2	F7FB	ACT Rank 0 Bank=2 Addr=F7FB	0		1	1	1	1	1
12	1	0	13.7498ns	2	0380	RD Rank 0 Bank=2 Row=F7FB Column=38	0		1	1	1	1	1
13	1	0	113.7480ns	0	0400	PREA Rank 0	0		1	1	1	1	1
14	1	0	19.9997ns	4	02A0	PDE CKE0	0		0	1	1	1	1
15	1	0	58.7490ns	0	4020	SRX Or PDX CKE0	0		1	1	1	1	1
16	1	0	6.2499ns	2	F7FB	ACT Rank 0 Bank=2 Addr=F7FB	0		1	1	1	1	1
17	1	0	14.9997ns	2	0808	RD Rank 0 Bank=2 Row=F7FB Column=8	0		1	1	1	1	1
18	1	0	4.9999ns	2	0800	RD Rank 0 Bank=2 Row=F7FB Column=0	0		1	1	1	1	1
19	1	0	44.9992ns	0	0400	PREA Rank 1	0		1	1	1	1	0
20	1	1	117.4980ns	2	0000	PRE Rank 0 Bank=2	0		1	1	1	1	1
21	1	0	97.4985ns	0	0400	PREA Rank 0	0		1	1	1	1	1
22	1	0	19.9997ns	4	02A0	PDE CKE0	0		0	1	1	1	1
23	1	0	122.4979ns	0	0400	PREA Rank 1	0		1	1	1	1	0
24	1	0	19.9997ns	4	0220	PDE CKE1	0		0	0	1	1	1
25	1	0	81.2486ns	0	0000	SRX Or PDX CKE0	0		1	1	1	1	1
26	1	0	7.4999ns	0	0C78	MRS Rank 0	0		1	1	1	1	1
27	1	0	6.2499ns	0	0C78	MRS Rank 1	0		1	1	1	1	0
28	1	0	21.2496ns	4	03E0	PDE CKE0	0		0	0	1	1	1
29	1	0	6.2499ns	2	0021	SRX Or PDX CKE0	0		1	1	1	1	1
30	1	0	319.9945ns	0	0000	REF Rank 0	0		1	1	1	1	1
31	1	0	49.9991ns	0	0000	REF Rank 1	0		1	1	1	1	0
32	1	0	301.2448ns	0	1C78	MRS Rank 0	0		1	1	1	1	1
33	1	0	6.2499ns	2	1C78	MRS Rank 1	0		1	1	1	1	0
34	1	0	18.7497ns	2	F7FB	ACT Rank 0 Bank=2 Addr=F7FB	0		1	1	1	1	1
35	1	0	13.7498ns	2	081A	RD Rank 0 Bank=2 Row=F7FB Column=1a	0		1	1	1	1	1
36	1	0	114.9980ns	0	0400	PREA Rank 0	0		1	1	1	1	1
37	1	0	19.9997ns	4	03E0	PDE CKE0	0		0	1	1	1	1

Ready

# Performance



# Summary

- Its Cloudy with a chance of Errors
- Ask your vendor about their validation strategy
- Don't fill your data center with problems!
- The DDR3 Detective can help
  - Prequalification before purchase
  - Measure effectiveness of your software
  - Validate that BIOS changes are compatible with your DIMMs



# FuturePlus Systems

Computer System Validation experts for over 20 years!

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