The Intel® Xeon® Processor E5 Family
Architecture, Power Efficiency, and Performance

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Agenda
1. Architecting Performance
2. Energy Efficiency from the Load Line to the Data Center
3. Measured Performance
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Notice revision #20101101
Foundations of SNB-EP Performance

Start with the Sandy Bridge Core

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Foundations of SNB-EP Performance

Put Eight Cores on a High BW Interconnect: The Ring

**Peak Ring BW Math**

_____ bytes data bus
× _____ directions
× _____ active stops
× _____ GHz
= _____ GB/s
Foundations of SNB-EP Performance

Add an LLC, System Agents, and Power Management

- Power Control Unit
- Intel® QuickPath Interconnect (QPI) Agent
- Integrated I/O
- PCIe __ GBy/sec
- QPI __ GBy/sec
- LLC __ GBy/sec
- iMC __ GBy/sec
- Unit Peak Rates
- not sustainable

SNB Core

Integration of System Agents and Power Management

- Memory Controller
- Home Agent

Peak Rates not sustainable
Intel® Xeon® Processor E5-2600 Product Family

Thurley Platform Review

Single IOH

PCIe*

Tylersburg‡
I/O Caching Agent

Nhms/Wsm EP
CPU Caching Agent

Nhms/Wsm EP
CPU Caching Agent

Dual IOH

PCIe

Tylersburg
I/O Caching Agent

Nhms/Wsm EP
CPU Caching Agent

Nhms/Wsm EP
CPU Caching Agent

+Note: PCH omitted in diagrams
Foundations of SNB-EP Performance

Higher Performance Platform

Topography Performance Changes
- 40 Lanes of 8 GT/s Integrated PCIe
- Dual Inter-processor QPI links
- Four higher speed memory channels

+Note: PCH omitted in diagrams
Foundations of SNB-EP Performance

Focus on I/O Performance

- **PCIe G3: 8 GT/s vs. 4 GT/s**
  - DMI2 (4 GT/s) vs. DMI1 (2 GT/s) (not shown in diagram)

- **I/O capacity scales with sockets** (memory BW)

- **Inherent benefit from Integration:**
  - QPI link to I/O controller replaced with direct ring interconnect reducing latency and increasing BW

- **CPUs and PCIe are a unified Caching Agent**
  - Less resource partitioning
    - More scalable, higher performance
  - Reduces the latency of cacheable traffic
  - PCIe acts under the auspices of and uses the LLC (more later)
Foundations of SNB-EP Performance
Focus on I/O Performance (cont’d)

- **I/O-related Optimizations**
  - Double width data buses in the I/O unit
  - ReadCurrent semantics rather than the Code Read
    - Potentially reduces memory write traffic – maybe a lot
  - Inbound writes
    - Cache line pre-allocated but ownership can be preempted
    - Prefetch of data (for write merging)

- **40 lanes vs. 36 lanes**
- **Physical address range (46b vs. 41b)**
Foundations of SNB-EP Performance
Focus on I/O Performance (cont’d)

- **Intel® Direct Data I/O Technology (Intel® DDIO):** IIO allocates and transfers directly into LLC
  - IIO cache allocating is generally limited to 2 (of 20) ways
    - Can use a line that’s already been allocated by, say, a core
  - Circular buffers of reasonable size (a few to ten MB) can reside in the LLC and, in practice, almost never be written.
  - Making use of this can effectively double the achievable I/O bandwidth of a core and of a socket.
  - Permits practically linear scaling as multiple high bandwidth I/O devices are added (e.g., 10 GbE adapters) with achieving nearly zero read and write bandwidth to memory
    - Saves power, too
Mid-Game Summary

- **Improved performance by improving the parts**
  - Sandy Bridge core
  - On-die interconnect (“Ring”)
  - More and faster memory channels with improved scheduling
  - Faster inter-socket communication (Intel® QPI)
  - Integrating and accelerating I/O

- **Coming Up in the Next Half:**
  
  Performance with Power Efficiency
Energy Efficient Load Line
Energy Efficient Load Line

Server Platform Power versus Workload

- Platform efficiency at low Power
  - CPU and DRAM VR Phase shedding
- Scalable Uncore Power
  - Uncore voltage frequency scaling
- Scalable Memory Power
  - Multi-rank slow CKE

- Processor Power
  - Energy Perf BIAS, Dynamic Switching
- I/O Power management
  - QPI L0p/L1, PCIE ASPM L1

Performance: 45% CAGR
Energy Efficiency: 60% CAGR

Significant Improvement to Proportional Energy

Data from spec.org

Lower is Better

LOWER IS BETTER

Higher Energy Efficiency

HIGHER PERFORMANCE

HIGHER PERFORMANCE

Data from spec.org

Performance:

45% CAGR

Energy Efficiency:

60% CAGR
Dynamic Performance Load Line

PCU dynamically adjusts to OS Power Management Policy

- OS communicates Policy through EPB (Energy Perf BIAS)
- PCU monitors and adjusts autonomous on die power saving engines

PCU automatically adjusts for Performance at high utilization

- Leverages EPB to switch into performance mode when necessary

Optimized across a range of workloads

- Single-threaded workloads
- Multi-threaded workloads

PCU works synergistically with OS Power Policy
Energy Efficiency in the Data Center
Running Average Power Limiting (RAPL)

RAPL gives accurate and stable power limiting than P state control.

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Improved Efficiency with RAPL

No Power Limiting

5kW

600W

8 Servers per Rack

Power limiting w/o RAPL

420W Guard Band

350W

350W

12 Servers per Rack

Power limiting with RAPL

98W

350W

350W

14 Servers per Rack

Max System Power: 600W
Typical System Power: 350W
Rack Power: 5kW

Improved Power Limiting Accuracy Allows for Smaller Guard bands and Increased Rack Density.
Socket RAPL & the Power/Performance Load Line

- Power Clamps effectively limit socket power
- Max possible performance achieved for given power limit
- Efficient Power Scaling across the load line

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Maximum Performance
Memory Latency Optimizations

- Early Snoop
- Dynamic Direct 2 Core
- Uncore Frequency Change
- Dynamic Memory CKE Disable
- New LLC Prefetcher

**Distributed L3**
- Theoretical Peak: ~844GB/s (1s @ 3.3GHz w/ 8 cores)
- Core->L3 Read Throughput: >250GB/s (1s @ 3.3GHz w/ 8 cores)

- **Dual Load Ports on L1 D-Cache**
- **SandyBridge Turbo 2.0**

>2x max bandwidth from Xeon 5600 on read BW
- 3->4 channels (+33%)
- 1333->1600 (+20%) 
- Improved Efficiency (+~40%)

**Benchmark Notes:**
- Intel internal tool for BW and Latency
Intel® Xeon® Processor E5-2600 Product Family

Architecture, Power Efficiency, and Performance

Comparison of 4 core to 8 core Scaling @ 3.3GHz

Integer Throughput Workloads

Floating Point Throughput Workloads

- Core sensitive apps in both INT and FP show excellent performance scaling
- Memory sensitive apps show less scaling (as expected shown in red)

Internal Testing – Estimate
4c: SNB E5-2643 w/out Turbo (1 DPC, DDR 1600)
8c: SNB E5-2690 w/ Turbo (2 DPC, DDR 1600)
ICC 12.1 / RHEL 6.1 / 2.6.32.131

Apps highlighted in Red are Memory Bandwidth sensitive

Intel® Xeon® E5 uncore provides significant core Scaling

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Configuration Details for Foil #25

For the SPEC benchmarks, please see [http://www.spec.org](http://www.spec.org) for more information

**Configuration Details:** As of 31 May 2012

**SAP** SD 2-tier

2x Intel Xeon processor X5690 (12M cache, 3.46GHz, 6.40GT/s Intel QPI) score 5220 SD users. Certification #2011005. Source: [http://download.sap.com/download.epd?context=40E29D5E0E00EEF74B29992CE278ECD5166ED276FF20DF78759DC5B1E5F79](http://download.sap.com/download.epd?context=40E29D5E0E00EEF74B29992CE278ECD5166ED276FF20DF78759DC5B1E5F79);

2x Intel Xeon processor E5-2690 (20M cache, 2.9GHz, 8.0GT/s Intel QPI) score 7865 SD users. Source: [http://download.sap.com/download.epd?context=40E29D5E0E00EEF74B29992CE278ECD5166ED276FF20DF78759DC5B1E5F79](http://download.sap.com/download.epd?context=40E29D5E0E00EEF74B29992CE278ECD5166ED276FF20DF78759DC5B1E5F79)

**SPECvirt_sc**

2x Intel® Xeon® processor X5690 (6C, 12M, 3.46GHz) score 1367 @ 84 VMs. Source: [http://www.spec.org/virt_sc2010/results/res2011q1/virt_sc2010-20110209-00022-perf.html](http://www.spec.org/virt_sc2010/results/res2011q1/virt_sc2010-20110209-00022-perf.html);

2x Intel® Xeon® processor E5-2690 (8C, 2.9GHz, C0) score 2,388 @ 150 VMs. Source: [http://www.spec.org/virt_sc2010/results/res2012q2/virt_sc2010-20120403-00045-perf.html](http://www.spec.org/virt_sc2010/results/res2012q2/virt_sc2010-20120403-00045-perf.html)

**SPECpower_ssj**

metrics for SPECpower are efficiency based and expressed as ssj_ops/watt.


2x Intel Xeon processor E5-2660 (20M cache, 2.2GHz, 8.0GT/s Intel QPI, C1) score 5,088. Source: [http://www.spec.org/power_ssj2008/results/res2012q2/power_ssj2008-20120427-00454.html](http://www.spec.org/power_ssj2008/results/res2012q2/power_ssj2008-20120427-00454.html)

**TPC-E**

2x Intel Xeon processor X5690 (12M Cache, 3.46GHz, 2P/12C/24T) referenced as published at 1,284.14 tpsE, $250 USD/tpxE, available 5/4/11. Source: [http://www.tpc.org/tpce/results/tpce_result_detail.asp?id=111050403](http://www.tpc.org/tpce/results/tpce_result_detail.asp?id=111050403);

Intel: 2x Intel Xeon processor E5-2690 (20M cache, 2.9GHz, 2P/16C/32T) referenced as published at 1,863.23 tpsE, $207.85 USD/tpxE, available 3/6/12. Source: [http://www.tpc.org/tpce/results/tpce_result_detail.asp?id=112030601](http://www.tpc.org/tpce/results/tpce_result_detail.asp?id=112030601)

**VMmark**


**SPECjbb**


**SPECint_rate_base2006**


2x Intel Xeon processor E5-2690 (20M cache, 2.9GHz, 8.0GT/s Intel QPI) baseline score 671. Source: [http://www.spec.org/cpu2006/results/res2012q1/cpu2006-20120307-19618.html](http://www.spec.org/cpu2006/results/res2012q1/cpu2006-20120307-19618.html)

**SPECjEnterprise**


2x Intel Xeon processor E5-2690 (20M cache, 2.9GHz, 8.0GT/s Intel QPI) score 8,310.19 EjOPS. Source: [http://www.spec.org/jEnterprise2010/results/jEnterprise2010.html](http://www.spec.org/jEnterprise2010/results/jEnterprise2010.html)

**SPECfp_rate_base2006**

2x Intel Xeon processor X5690 (12M cache, 3.45GHz, 6.40GT/s Intel QPI) baseline score 271. Source: [http://www.spec.org/cpu2006/results/res2012q1/cpu2006-20111219-19195.html](http://www.spec.org/cpu2006/results/res2012q1/cpu2006-20111219-19195.html);

2x Intel Xeon processor E5-2690 (20M cache, 2.9GHz, 8.0GT/s Intel QPI) baseline score 496. Source: [http://www.spec.org/cpu2006/results/res2012q1/cpu2006-20120307-19617.html](http://www.spec.org/cpu2006/results/res2012q1/cpu2006-20120307-19617.html)

**STREAM**

2x Intel Xeon processor X5690 (12M cache, 3.45GHz, 6.40GT/s Intel QPI) TRIAD score 42GB/s. Source: Intel TR#1241

2x Intel Xeon processor E5-2690 (20M cache, 2.9GHz, 8.0GT/s Intel QPI, C1) score 79.5 GB/s. Source: Intel TR#1241

**Linpack**

2x Intel Xeon processor X5690 (12M cache, 3.45GHz, 6.40GT/s Intel QPI) score 159.4. Source: Intel TR#1236

2x Intel Xeon processor E5-2690 (20M cache, 2.9GHz, 8.0GT/s Intel QPI, C1) score 347.7. Source: Intel TR#1236

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Intel® Xeon® Processor E5-2600 Product Family
Generational Performance Summary

Intel® Xeon® Processor E5-2690 (8C, 2.9GHz, 135W) vs. Intel® Xeon® Processor X5690 (6C, 3.46GHz, 130W)

Relative Performance (Normalized to 1.0 Baseline of Intel® Xeon® processor X5690)

Enterprise

- OLTP Warehouse Database (TPC®-C)
- OLTP Brokerage Database (TPC®-E)
- Virtualized Consolidation 2.0 (VMmark® 2)
- Enterprise Resource Planning (SAP®-SD® 2T)
- Energy Efficiency (SPECpower_ssj® 2008 single-node)
- Java App Server (SPECjEnterprise® 2010)
- Integer Throughput (SPECint_rate_base2006)
- Middle-Tier Java (SPECjbb® 2005, IBM J9® JVM)
- Virtualized Consolidation 1.0 (SPECvirt_base2010)
- Floating Point Throughput (SPECfp_rate_base2006)

Energy Efficiency (SPECpower_ssj® 2008 single-node)

Technical Computing

- Enterprise Resource Planning (SAP®-SD® 2T)
- Enterprise Resource Planning (SAP®-SD® 2T)
- Memory Bandwidth (STREAM MP Triad, SMT Disabled, Non-temporal writes)
- Matrix Multiplication (Linpack)

Intel® Xeon® processor E5-2690 delivers performance gains up to 2X

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Linpack performance may vary based on thermal solution.
Configuration Details: Please reference fol 24 for details.
For more information go to http://www.intel.com/performance

Turbo Enabled
High is better

E5-2660 vs. X5675

Best Published