Opteron and AMD64
A Commodity 64 bit x86 SOC

Fred Weber
Vice President and CTO
Computation Products Group
Advanced Micro Devices
Opteron/AMD64 Launch – Today!

• Official Launch of AMD64 architecture and Production Server/Workstation CPUs
  – Series 200 (2P) available today
  – Series 800 (4P+) available later in Q2

• Oracle, IBM-DB2, Microsoft, RedHat, SuSe software support
  – And many others

• Dozens of server system vendors
  – System builder availability this quarter
  – IBM systems available 3Q03

• Lots of public benchmarks
Before AMD64:
Computing & infrastructure islands on either side of the wall

Yesterday’s environment isolates 32-bit and 64-bit computing into incompatible islands.

- Requires new infrastructure – cooling, power, enclosures, etc.
- Requires new software, since x86 applications are incompatible or only run in “emulation mode”
- Steep learning curve for end user and support staff – lowering ROI, increasing TCO
- Wastes significant people-hours of work and billions of dollars in research and development
### AMD’s Industry Vision:
Compatible systems that bridge from 32- to 64-bit

#### AMD: Single Platform

<table>
<thead>
<tr>
<th>32-Bit Application (3 GB limit)</th>
<th>32-Bit Application (4GB limit)</th>
<th>64-Bit Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>32-Bit O/S</td>
<td>64-Bit O/S</td>
<td>64-Bit O/S</td>
</tr>
<tr>
<td>32-Bit Software Drivers</td>
<td>64-Bit Software Drivers</td>
<td>64-Bit Software Drivers</td>
</tr>
</tbody>
</table>

- **Leverages existing infrastructure**
  - thermal, enclosures, power, and **BIOS**
- **Runs existing 32-bit applications natively with unsurpassed performance**
  - >20% increase clock-for-clock compared to AMP Athlon™ processor
  - No tools or O/S work needed
- **Runs existing 32-bit applications on 64-bit O/S**
  - Take full advantage of 4GB local memory
- **Allows customers to migrate to 64-bit performance according to their schedule**
- **Low learning curve for users and support staff**
AMD64 Programmer’s Model

- **RAX**
  - `0` to `31`
  - `63`
  - `15`, `7`, `0`

- **EAX**
  - `AH`, `AL`

- **XMM0**
  - `SS` to `0`

- **XMM7**
  - `SS` to `0`

- **XMM8**
  - `SS` to `0`

- **XMM15**
  - `SS` to `0`

- **EIP**
  - `79`, `0`
Opteron SOC Architecture Overview

• First AMD64 based processor
• Aggressive out-of-order, 9-issue superscalar processor
• Integrated DDR memory controller
• Leading performance in integer, floating point and multimedia
  – AMD64, x87, MMX™, 3DNow!™, SSE, SSE2
• Glueless multiprocessing through HyperTransport
• Expandable IO through HyperTransport
AMD Opteron™ Processor Technology Overview

- **Processor Core Overview**
  - Support for AMD’s 64-bit technology
  - 12-stage int, 17-stage fp pipelines
  - Enhanced TLB structures
  - TLB flush filter
  - Enhanced branch prediction
  - Large L2 cache (up to 1MB)
  - ECC protection

- **Memory Controller Overview**
  - Dual-channel DDR memory
  - PC2700, PC2100, or PC1600 DDR memory support
  - Registered or Unbuffered DIMMs
  - ECC and Chip Kill
  - High bandwidth (up to \(6.4\text{GB/s}\))

- **HyperTransport™ Technology Overview**
  - One, two, or three links
  - 2, 4, 8, 16, or 32-bits full duplex
  - Up to 6.4 GB/s bandwidth per link
  - \(19.2\text{ GB/s}\) aggregate external bandwidth

\(HT = \text{HyperTransport™ technology}\)
"Glueless Multiprocessing"

- No chipset logic needed to connect processors
- HyperTransport™ technology links with \(\sim 6.4\)GBytes/sec bandwidth
- Memory BW and capacity and I/O capacity designed to grow with \# CPUs
**AMD Opteron™ processor-based 4P Server**

- **200-333MHz 144-Bit Reg DDR**
- **AMD Opteron 940 mPGA**
- **16x16 coherent HyperTransport™ @ 1600MT/s**
- **200-333MHz 144-Bit Reg DDR**
- **AMD Opteron 940 mPGA**
- **16x16 HyperTransport™ @ 1600MT/s**
- **200-333MHz 144-Bit Reg DDR**
- **AMD Opteron 940 mPGA**
- **8x8 HyperTransport™ @ 400MT/s**
- **AMD-8111™ Southbridge**
- **Legacy PCI**
- **PCI Graphics**
- **VGA**
- **USB AC97**
- **UDMA100 10/100 Ethernet**
- **Gbit Ethernet**
- **Zircon BMC**
- **LPC**
- **FLASH**
- **SIO**
- **100 BaseT Management LAN**
4P, 32GB AMD Opteron™ Processor System
4U, 4P AMD Opteron™ processor System
AMD64 Code Quality

• GCC port alpha quality since Feb ‘01
  – Compiler generating alpha quality code in 50 man-months
  – Linux kernel ported in 60 man-months
  – Tool chain was straightforward port

• SpecInt2000 code quality, 64bits vs. 32 bits (using GCC 3.1.1)
  – average instruction length increased to 3.8 from 3.4 bytes
  – dynamic instruction count decreased by 10%
  – dynamic load count decreased by 26%
    • number of loads forwarded from recent stores substantially reduced
  – dynamic store count decreased by 36%
  – back to back register dependencies decreased by 10%
GCC SPECint
FORTRAN Compiler Support

- AMD and STMicroelectronics are working together to bring The Portland Group Compiler Technology to AMD64

• Support will include
  - F90 & F77
    • Some F95 extensions also included
    • SPECcpu2000 explicitly supported
  - Optimized 32-bit and 64-bit code generation
  - Linux and Windows
  - OpenMP support
  - Full debugging support

• STMicro will also be developing C and C++ compilers based on same code generation technology

• Beta now, Production quality in 1H03
The Rewards of Good Plumbing

**High Bandwidth**
- 2P system is designed to achieve 7 GB/s aggregate memory Read bandwidth
- 4P system is designed to achieve 10 GB/s aggregate memory Read bandwidth
  - With data spread uniformly across the nodes

**Low Latency**
- Average 2P unloaded latency (page hit) is designed to be < 120 ns
- Average 4P unloaded latency (page hit) is designed to be < 140 ns
- Latency under load increases slowly due to excess Interconnect Bandwidth
- Latency shrinks quickly with increasing CPU clock speed and HyperTransport link speed
Integrated Memory Controller
Latency (Local Memory Access, Registered Memory, CAS2)

Read Latency Accessing Local Memory, PC2100

- PageHit 0 Hop
- PageMiss 0 Hop
- Prb Miss 1 Hop (2 node case)
- Prb Miss 2 Hop (4 node case)
Memory Bandwidth

![Graph showing memory bandwidth for different processors and types of RAM. The x-axis represents the processors and the y-axis represents the bandwidth in MB/s. The processors include Opteron 844 8xPC2700 CL2.5, Opteron 244 4xPC2700 CL2.5, Opteron 144 2xPC2700 CL2.5, Intel 865 2xPC3200 CL2 DDR, Intel 850E 2xPC1066 CL2 RDRAM, Intel 7205 2xPC2100 CL2 DDR, and Intel 845PEPC2700 CL2 DDR. The bars for bandwidth are shown for both integer (SSE2) and floating-point (SSE2) operations.]
## Integer Performance

### SPECint®_peak2000 Performance (Uniprocessor)

<table>
<thead>
<tr>
<th>Processor</th>
<th>SPECint®_peak2000</th>
<th>Integer Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD Opteron™ 144</td>
<td>1170</td>
<td>104%</td>
</tr>
<tr>
<td>Xeon 3.06GHz</td>
<td>1130</td>
<td>100%</td>
</tr>
<tr>
<td>Itanium 2 1.0GHz</td>
<td>719</td>
<td>164%</td>
</tr>
</tbody>
</table>

### SPECint®_rate2000 Performance (Peak, 2P)

<table>
<thead>
<tr>
<th>Processor</th>
<th>SPECint®_rate2000</th>
<th>Integer Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD Opteron™ 244</td>
<td>26.8</td>
<td>137%</td>
</tr>
<tr>
<td>AMD Opteron 242</td>
<td>24</td>
<td>122%</td>
</tr>
<tr>
<td>AMD Opteron 240</td>
<td>21.2</td>
<td>108%</td>
</tr>
<tr>
<td>Xeon 2.8GHz</td>
<td>19.6</td>
<td>100%</td>
</tr>
<tr>
<td>Itanium 2 900MHz</td>
<td>15.5</td>
<td>79%</td>
</tr>
</tbody>
</table>
Floating-Point Performance

<table>
<thead>
<tr>
<th>SPECfp®_peak2000 Performance (Uniprocessor)</th>
<th>SPECfp®_rate2000 Performance (Peak, 2P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Itanium 2 1.0GHz</td>
<td>Itanium 2 1.0GHz 30.7 209%</td>
</tr>
<tr>
<td>AMD Opteron™ 144</td>
<td>AMD Opteron™ 244 26.7 182%</td>
</tr>
<tr>
<td>Xeon 3.06GHz</td>
<td>AMD Opteron 242 25.1 171%</td>
</tr>
<tr>
<td></td>
<td>AMD Opteron 240 22.7 150%</td>
</tr>
<tr>
<td></td>
<td>Xeon 2.8GHz 14.7 100%</td>
</tr>
</tbody>
</table>

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### SPECfp®_rate2000 Performance

<table>
<thead>
<tr>
<th>Processor Type</th>
<th>SPECfp®_rate2000</th>
<th>Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Itanium 2 1.0GHz</td>
<td>49.3</td>
<td>244%</td>
</tr>
<tr>
<td>AMD Opteron™ 844</td>
<td>49.2</td>
<td>244%</td>
</tr>
<tr>
<td>AMD Opteron 842</td>
<td>45</td>
<td>223%</td>
</tr>
<tr>
<td>AMD Opteron 840</td>
<td>40.7</td>
<td>201%</td>
</tr>
<tr>
<td>Xeon 2.0GHz</td>
<td>20.2</td>
<td>100%</td>
</tr>
</tbody>
</table>

### SPECfp®_rate2000 Performance and Scalability

<table>
<thead>
<tr>
<th>Processor Type</th>
<th>SPECfp®_rate2000</th>
<th>Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Itanium 2 1.0GHz (4P)</td>
<td>49.3</td>
<td>161%</td>
</tr>
<tr>
<td>Itanium 2 1.0GHz (2P)</td>
<td>30.7</td>
<td>100%</td>
</tr>
<tr>
<td>AMD Opteron™ 844 (4P)</td>
<td>49.2</td>
<td>184%</td>
</tr>
<tr>
<td>AMD Opteron 244 (2P)</td>
<td>26.7</td>
<td>100%</td>
</tr>
<tr>
<td>Xeon MP 2.0GHz (4P)</td>
<td>20.2</td>
<td>146%</td>
</tr>
<tr>
<td>Xeon MP 2.0GHz (2P)</td>
<td>13.8</td>
<td>100%</td>
</tr>
</tbody>
</table>
### Web Server Performance

#### SPECweb®99 Performance

**(2P Servers, Red Hat CA2)**

<table>
<thead>
<tr>
<th>Processor</th>
<th>SPECweb®99 Score</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD Opteron™ 244</td>
<td>6250</td>
<td>116%</td>
</tr>
<tr>
<td>AMD Opteron 242</td>
<td>5800</td>
<td>108%</td>
</tr>
<tr>
<td>Xeon 3.06 GHz</td>
<td>5373</td>
<td>100%</td>
</tr>
<tr>
<td>AMD Opteron 240</td>
<td>5181</td>
<td>96%</td>
</tr>
<tr>
<td>Itanium 2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

#### SPECweb®99 Performance

**(4P Servers, Red Hat CA2)**

<table>
<thead>
<tr>
<th>Processor</th>
<th>SPECweb®99 Score</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD Opteron™ 844</td>
<td>10135</td>
<td>151%</td>
</tr>
<tr>
<td>AMD Opteron 842</td>
<td>9396</td>
<td>140%</td>
</tr>
<tr>
<td>AMD Opteron 840</td>
<td>8800</td>
<td>131%</td>
</tr>
<tr>
<td>Xeon MP 2.0 GHz</td>
<td>6700</td>
<td>100%</td>
</tr>
<tr>
<td>Itanium 2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Processor</th>
<th>SPECweb®99_ssl Performance (2P Servers)</th>
<th>SPECweb®99_ssl Performance (4P Servers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD Opteron™ 244 (64-bit app/64-bit OS)</td>
<td>1783 (155%)</td>
<td>3498 (213%)</td>
</tr>
<tr>
<td>AMD Opteron 244 (32-bit app/32-bit OS)</td>
<td>1760 (153%)</td>
<td>3344 (204%)</td>
</tr>
<tr>
<td>Itanium 2 1.5GHz (64-bit app/64-bit OS)</td>
<td>1750 (152%)</td>
<td>3270 (199%)</td>
</tr>
<tr>
<td>Xeon 2.8GHz (32-bit app/32-bit OS)</td>
<td>1149 (100%)</td>
<td>1643 (100%)</td>
</tr>
</tbody>
</table>

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### Email Server Performance

<table>
<thead>
<tr>
<th></th>
<th>MMB2 Performance (2P Servers, Windows®)</th>
<th>MMB2 Performance (4P Servers, Windows®)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AMD Opteron™ 244</strong></td>
<td>11000 112%</td>
<td>15520 118%</td>
</tr>
<tr>
<td><strong>Xeon 2.8GHz</strong></td>
<td>9800 100%</td>
<td>13200 100%</td>
</tr>
<tr>
<td>Itanium 2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

[www.amd.com/opteronperformance](http://www.amd.com/opteronperformance)
### Database Server Performance

#### TPC-C Performance
(4P Servers, tpmC, Windows®)

<table>
<thead>
<tr>
<th>CPU Type</th>
<th>Performance</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Itanium 2 1.0GHz (HP rx5670)</td>
<td>87741</td>
<td>113%</td>
</tr>
<tr>
<td>AMD Opteron™ 844 (RackSaver QuatreX-64)</td>
<td>82226.46</td>
<td>106%</td>
</tr>
<tr>
<td>Xeon MP 2.0GHz (HP DL580-G2)</td>
<td>77905</td>
<td>100%</td>
</tr>
<tr>
<td>Xeon MP 2.0GHz (Dell PE6650)</td>
<td>71586.49</td>
<td>92%</td>
</tr>
<tr>
<td>Xeon MP 2.0GHz (IBM xSeries 360)</td>
<td>52587.46</td>
<td>68%</td>
</tr>
</tbody>
</table>

#### TPC-C Price/Performance
(4P Servers, $/tpmC, Windows®)

<table>
<thead>
<tr>
<th>CPU Type</th>
<th>Price/Performance</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD Opteron™ 844 (RackSaver QuatreX-64)</td>
<td>$2.76</td>
<td>52%</td>
</tr>
<tr>
<td>Xeon MP 2.0GHz (IBM xSeries 360)</td>
<td>$4.31</td>
<td>81%</td>
</tr>
<tr>
<td>Itanium 2 1.0GHz (HP rx5670)</td>
<td>$5.03</td>
<td>95%</td>
</tr>
<tr>
<td>Xeon MP 2.0GHz (Dell PE6650)</td>
<td>$5.10</td>
<td>96%</td>
</tr>
<tr>
<td>Xeon MP 2.0GHz (HP DL580-G2)</td>
<td>$5.32</td>
<td>100%</td>
</tr>
</tbody>
</table>
## Linpack – Hot off the press

<table>
<thead>
<tr>
<th>AMD Opteron™ system</th>
<th># P</th>
<th>Rmax (GFlops)</th>
<th>Nmax (order)</th>
<th>N1/2 (order)</th>
<th>Rpeak (GFlops)</th>
<th>GFLOPs/Proc</th>
<th>Rmax Gflops / Cycle</th>
<th>RPEAK/Proc</th>
<th>Peak Gflops / Cycle</th>
<th>Rmax/Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>4P Melody Opteron 1.8GHz 2GB/proc PC2700 8GB Total</td>
<td>4</td>
<td>11.99</td>
<td>28000</td>
<td></td>
<td>14.4</td>
<td>3.00</td>
<td>1.665</td>
<td>3.60</td>
<td>2.00</td>
<td>83.3%</td>
</tr>
<tr>
<td>2P Melody Opteron 1.8GHz 2GB/proc PC2700 4GB Total</td>
<td>2</td>
<td>6.009</td>
<td>19320</td>
<td>616</td>
<td>7.2</td>
<td>3.00</td>
<td>1.669</td>
<td>3.60</td>
<td>2.00</td>
<td>83.5%</td>
</tr>
<tr>
<td>1P Melody Opteron 1.8GHz 2GB PC2700</td>
<td>1</td>
<td>3.042</td>
<td>14000</td>
<td></td>
<td>3.6</td>
<td>3.04</td>
<td>1.690</td>
<td>3.60</td>
<td>2.00</td>
<td>84.5%</td>
</tr>
</tbody>
</table>
CPU Design Clusters – From RISC to AMD64

• K6 was built entirely on Sparc, PA-RISC and Power machines

• K7/Athlon was built 50% on K6 running Linux
  • Few apps. Mostly only ran in house logic simulators
  – K8/Opteron was built 80% on K7 running Linux
    • Many apps available. Only 64 bit apps conspicuously missing

• Hardware
  • Over 3000 Athlon CPUs doing back-end CAD work in California and Austin
  • Over 1500 Athlon CPUs doing front-end design world-wide
  • Non-AMD machines are used only for applications which require more memory than x86 is capable of addressing

– Software
  • Predominantly Linux based
  • Transitioning away from non-x86 based Unix (Solaris, HP-UX, etc.)
  • 64-bit software is run on non-AMD machines
K9 Tapeout Plan

• K9 will be taped out using **only** AMD Opteron Processors

• Hardware
  - Create a homogenous compute environment
  - Anticipate over **8000** AMD Opteron/Athlon CPUs doing back-end CAD work in Sunnyvale and Austin
  - Anticipate over **2000** AMD Opteron/Athlon CPUs doing front-end design world-wide
  - AMD **will not** use any non-AMD 32-bit or 64-bit hardware

• Software
  - 100% Linux/LSF based throughput cluster
  - 32-bit and 64-bit applications running side by side
  - Large memory applications will scale well on Opteron – **4P = 16-32 GB of RAM**
The AMD64/Opteron Story

• The right instruction set
  – Excellent compatibility
  – Excellent performance future

• The right system architecture
  – Great memory and IO capacity and bandwidth
  – Great memory latency
  – Simple “lego” system configuration

• A strong ecosystem of commodity HW and SW
  – Support chips, Software tools, motherboards

• Millions of 64 bit CPUs in 03

• 10s of millions of 64 bit CPUs in 04
Opteron Implications

• Allow more balanced scale-up/scale-out future
  – Remove 2P/4P cost barrier
  – And eventually 8P, 16P

• Re-create the workstation
  – Constrained by 32 bit x86 on one side and slow RISC processors w/o desktop software on the other
  – 2P, 16GB, 64 bit Workstation that runs Outlook, Powerpoint and Unreal Tournament
    • 64 bit portables in 04

• X86 forever (sorry 😊)
Futures

• Moore’s law continues through the decade (and beyond)
  – 90nm, 65nm, 45nm, 30nm
  – 1 Billion transistors, 4 Billion transistors
  – Vertical integration
    • It will come, first for memory
    • Gigabyte on a die goes a long way to help memory wall

• Power is the biggest issue
  – Cache, Evaporators 😊
  – Metal gate, FinFet, Adiabatic clocks, etc

• CMP is good (and obvious)

• Threading is a mixed bag
  – Latency tolerance vs. Ahmdal’s law and synchronization overhead
    • Long history
  – Certainly not for execution unit utilization
Futures

• Communication barrier
  – More fundamental than memory barrier
  – Even the speed of light doesn’t help (much)
  – 3D helps a lot

• Single Chip Performance (a guess)
  – 2003  5 +/- 1 Gflop   Opteron, P4, iTanium2
  – 2005  12 Gflop       2 * 6GHz
  – 2006  24 Gflop       2P * 2 * 6GHz
  – 2007  36-72 Gflop    4 * 9GHz
  – 2008  144 Gflop      4P * 4 * 9GHz
What Can You Do To Help

• Killer Apps that drive what you want
  – Games
  – Video compression/decompression
  – Face recognition as a ubiquitous app

• Keep the faith on COTS