Anatomy of AMD’s TeraScale Graphics Engine

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Beyond Programmable Shading: Fundamentals
Design Goals

Focus on Efficiency
\[ f(\text{Perf/Watt, Perf/$}) \]

Scale up processing power and AA performance
- Target >2x previous generation

Enhance stream computing capability
- Faster and more flexible

Implement advanced feature set
- DirectX® 10.1, tessellation, UVD2, PCIe® 2.0, and more...
Design Efficiency

- **GigaFlops per Watt**
- **GigaFlops per mm^2**

**4x Performance/w and Performance/mm² in less than a year**

- **ATI RADEON™ HD 4800**
- **ATI RADEON™ HD 3800**
- **ATI RADEON™ X1900**
- **ATI RADEON™ X1800**

*Beyond Programmable Shading: Fundamentals*
Terascale Graphics Engine

- 800 highly optimized stream processing units
- New SIMD core layout
- Optimized texture units
- New texture cache design
- New memory architecture
- Optimized render back-ends for fast anti-aliasing performance
- Enhanced geometry shader & tessellator performance
### ATI Radeon™ HD 4800 Series Architecture

- **10 SIMD cores**
  - Each with 80 32-bit Stream Processing Units (800 total)
- **40 Texture Units**

<table>
<thead>
<tr>
<th></th>
<th>ATI Radeon™ HD 3870</th>
<th>ATI Radeon™ HD 4870</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Die Size</strong></td>
<td>190 mm²</td>
<td>260 mm²</td>
<td>1.4x</td>
</tr>
<tr>
<td><strong>Memory</strong></td>
<td>72 GB/sec</td>
<td>115 GB/sec</td>
<td>1.6x</td>
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<tr>
<td><strong>AA Resolve</strong></td>
<td>32</td>
<td>64</td>
<td>2x</td>
</tr>
<tr>
<td><strong>Z/Stencil</strong></td>
<td>32</td>
<td>64</td>
<td>2x</td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td>16</td>
<td>40</td>
<td>2.5x</td>
</tr>
<tr>
<td><strong>Shader</strong></td>
<td>320</td>
<td>800</td>
<td>2.5x</td>
</tr>
</tbody>
</table>
SIMD Cores

- Each core:
  - Includes 80 scalar stream processing units in total + 16KB Local Data Share
  - Has its own control logic and runs from a shared set of threads
  - Has 4 dedicated texture units + L1 cache
  - Communicates with other SIMD cores via 16KB global data share

- New design allows texture fetch capability to scale with shader power, maintaining 4:1 ALU:TEX ratio
Stream Processing Units

- 40% increase in performance per mm²*
- More aggressive clock gating for improved Performance per Watt *
- Fast double precision processing (240 GigaFLOPS)
- Integer bit shift operations for all units (12.5x improvement *)

* Internal AMD test results comparing ATI Radeon™ HD 4800 series and ATI Radeon™ HD 3800 series
Texture Units

• Streamlined design
  – 70% increase in performance/mm² *

• More performance
  – Double the texture cache bandwidth of the ATI Radeon™ HD 3800 series *
  – 2.5x increase in 32-bit filter rate *
  – 1.25x increase in 64-bit filter rate *
  – Up to 160 fetches per clock *

Peak 32-bit texture fetch rate

ATI Radeon HD 4870: 120 Gtex/s
ATI Radeon HD 3870: 49.6 Gtex/s

* Internal AMD test results comparing ATI Radeon™ HD 4800 series and ATI Radeon™ HD 3800 series
Texture Units

• New cache design
  - L2s aligned with memory channels
  - L1s store unique data per SIMD
    2.5x increase aggregate L1
  - Separate vertex cache
  - Increased bandwidth
    Up to 480 GB/sec of L1 texture fetch bandwidth
    Up to 384 GB/sec between L1 & L2

* Comparing ATI Radeon™ HD 4800 series and ATI Radeon™ HD 3800 series
Render Back-Ends

- Focus on improving AA performance per mm$^2$
  - Doubled peak rate for depth/stencil ops to 64 per clock
  - Doubled AA peak fill rate for 32-bit & 64-bit color
  - Doubled non-AA peak fill rate for 64-bit color

- Supports both fixed function (MSAA) and programmable (CFAA) modes

<table>
<thead>
<tr>
<th>Color</th>
<th>ATI Radeon™ HD 3800 series</th>
<th>ATI Radeon™ HD 4800 series</th>
<th>Difference</th>
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</thead>
<tbody>
<tr>
<td>No MSAA 32-bit</td>
<td>16 pix/clk</td>
<td>16 pix/clk</td>
<td>1x</td>
</tr>
<tr>
<td>2x/4x MSAA 32-bit</td>
<td>8 pix/clk</td>
<td>16 pix/clk</td>
<td>2x</td>
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<tr>
<td>8x MSAA 32-bit</td>
<td>4 pix/clk</td>
<td>8 pix/clk</td>
<td>2x</td>
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<tr>
<td>No MSAA 64-bit</td>
<td>8 pix/clk</td>
<td>16 pix/clk</td>
<td>2x</td>
</tr>
<tr>
<td>2x/4x MSAA 64-bit</td>
<td>8 pix/clk</td>
<td>16 pix/clk</td>
<td>2x</td>
</tr>
<tr>
<td>8x MSAA 64-bit</td>
<td>4 pix/clk</td>
<td>8 pix/clk</td>
<td>2x</td>
</tr>
<tr>
<td>Depth/stencil only</td>
<td>32 pix/clk</td>
<td>64 pix/clk</td>
<td>2x</td>
</tr>
</tbody>
</table>

* Comparing ATI Radeon™ HD 4800 series and ATI Radeon™ HD 3800 series
Edge Detect CFAA Filters

- Enhanced edge-detect filter delivers 12x & 24x CFAA modes
- Avoids blurring by taking additional samples along edges, not across them
- Same memory footprint as 4x & 8x MSAA
- Works with Adaptive AA
Edge Detect CFAA Filters

ATI 8x MSAA

ATI 24x CFAA (Edge Detect)

Images captured from Half-Life 2 by Valve Software
Custom Filter Anti-Aliasing Performance

- Performance benefits greatly from 2x sample generation rate and 2.5x shader resolve rate

- New fast path between render back-end and shader engine provides further improvements

Test settings were 2560x1600 with 8x AF for Call of Duty 4 and Half Life 2, and 1920x1200 with 8xAF for Unreal Tournament 3. Test platform was an AMD Phenom X4 9850, with Catalyst 8.6 driver.
Memory Controller Architecture

- New distributed design with hub
- Controllers distributed around periphery of chip, adjacent to primary bandwidth consumers
- Memory tiling & 256-bit interface allows reduced latency, silicon area, and power consumption
- Hub handles relatively low bandwidth traffic
  - PCI Express, CrossFireX interconnect, UVD2, display controllers, intercommunication)
Geometry Shader & Tessellation

- Enhanced geometry amplification performance over previous generation
  - Allow more GS-generated data to be kept on-chip
  - 4x more GS threads supported

- Improved tessellation unit
  - Instancing support
  - Compatible with DirectX® 10/10.1

Test settings: High Polycount, Heavy Load settings, 640x480 resolution.
Config: Intel Core2 Extreme X9650 processor, using Catalyst 8.5 driver
ATI Radeon™ HD 4800 Series Stream Architecture

- Several enhancements done for stream computing
  - Fast compute vector
  - Local and Global data shares
  - Fast Integer Processing
  - Fast Memexport/Memimport

- Significant increases in performance on many important stream processing workloads

![Graph showing performance improvements](graph.png)

Internal AMD testing, CAL SDK version 1.1, Intel QX6800 CPU, Catalyst version 8.5
ATI Radeon™ HD 4870 Computation Highlights

- >100 GB/s memory bandwidth
  - 256b GDDR5 interface

- Targeted for handling thousands of simultaneous lightweight threads

- 800 (160x5) stream processors
  - 640 (160x4) basic units (FMAC, ADD/SUB, etc.)
    - ~1.2 TFlops theoretical peak
  - 160 enhanced transcendental units (adds COS, LOG, EXP, RSQ, etc.)
  - Support for INT/UINT in all units (ADD/SUB, AND, XOR, NOT, OR, etc.)
  - 64-bit double precision FP support
    - 1/5 single precision rate (~250GFlops theoretical performance)

4 SIMDs -> 10 SIMDs
- 2.5X peak performance increase over ATI Radeon™ 3870
- ~1.2 TFlops FP32 theoretical peak
- ~250 GFlops FP64 theoretical peak

Scratch-pad memories
- 16KB per SIMD (LDS)
- 16KB across SIMDs (GDS)

Synchronization capabilities

Compute Shader
- Launch work without rasterization
- "Linear" scheduling
- Faster thread launch
Dynamic Power Management

- On-chip microcontroller
  - Constantly monitors thermals sensors and activity of various GPU blocks, PCI Express bus
  - Minimal driver overhead

- Controls clock gating, engine/memory clock speeds, voltages, and fan controller

- Enables 2x Perf/W improvement vs. ATI Radeon™ HD 3800

\[\text{Windows Desktop} \quad | \quad \text{3D App} \quad | \quad \text{Windows Desktop}\]

\[\text{Power} \quad | \quad \text{Time}\]

\[\text{No clock gating} \quad | \quad \text{Clock gating}\]

Up to 36% avg. power savings from clock gating

1 Internal AMD test results for ATI Radeon™ HD 4800 series
2 Internal AMD test results comparing ATI Radeon™ HD 4800 series and ATI Radeon™ HD 3800 series
Terascale Graphics Have Arrived

Efficient GPU design
  • Major advances in Performance/Watt, Performance/\$

Improved game performance and image quality
  • >2x increase in AA frame rates

Massive stream compute power
  • Over 1 TeraFLOPS per GPU

Advanced feature set
  • DirectX® 10.1, tessellation, CFAA, GDDR5, PCI Express® 2.0
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