GPU Computing: Past, Present and Future with ATI Stream Technology

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Harnessing the Computational Power of GPUs

- GPU architecture increasingly emphasizes programmable shaders instead of fixed function logic
- Enormous computational capability for data parallel workloads
- New math for datacenters: enables high performance/watt and performance/$
ATI Stream Technology is...

**Heterogeneous:** Developers leverage AMD GPUs and CPUs for optimal application performance and user experience

**Industry Standards:** OpenCL™ and DirectCompute 11 enable cross-platform development

**High performance:** Massively parallel, programmable GPU architecture enables superior performance and power efficiency
ATI Radeon™ HD 3870 Architecture (2007)
GPU Compute Timeline

Folding @Home
Proof of concept achieving >30x speedup over CPUs

ATI Stream SDK v0.9
Open systems approach to drive broad customer adoption (Brook+ & CAL/IL)

ATI Stream SDK v1.0
Enhancements to improve computation performance

ATI Stream SDK v2.0
First production version of OpenCL™ for both x86 CPUs and AMD GPUs

Stream Computing Development Platform
CTM for data parallel programming

AMD FireStream™ 9170
GPU Compute Accelerator
First GPU Stream processor with double-precision floating point

AMD FireStream™ 9250
GPU Compute Accelerator
Breaks the 1 TFLOPS barrier
Up to 8 GFOPS/watt

ATI Radeon™ HD 5870 GPU
2.72 TFLOPS - SP
544 GFLOPS - DP

2006
2007
2008
2009
Enhancing GPUs for Computation

**ATI Radeon™ HD 4870 Architecture (2008)**

- 800 stream processing units arranged in 10 SIMD cores
- Up to 1.2 TFLOPS peak single precision floating point performance; Fast double-precision processing w/ up to 240 GFLOPS
- 115 GB/sec GDDR5 memory interface
- Up to 480 GB/s L1 & 384 GB/s L2 cache bandwidth
- Data sharing between threads
- Improved scatter/gather operations for improved GPGPU memory performance
- Integer bit shift operations for all units – useful for crypto, compression, video processing
- More aggressive clock gating for improved performance per watt
ATI Radeon™ HD 4870 Architecture

- GDDR5 Memory Interface
- Texture Units
- SIMD Cores
- UVD & Display Controllers
- PCI Express Bus Interface
GPU Compute Processing Power Trend

* Peak single-precision performance;
  For RV670, RV770 & Cypress divide by 5 for peak double-precision performance

RV770
ATI RADEON™ HD 4800
ATI FirePro™ V8700
AMD FireStream™ 9250 9270

RV670
ATI RADEON™ HD 3800
ATI FireGL™ V7700
AMD FireStream™ 9170

R600
ATI RADEON™ HD 2900
ATI FireGL™ V7600
V8600 V8650

R580(+)
ATI RADEON™ HD 2900
ATI FireGL™ V7600
V8600 V8650

R520
ATI RADEON™ X19xx
ATI FireStream™

V7200 V7300 V7350

Unified Shaders
Double-precision floating point

OpenCL™ 1.0
DirectX® 11
2.25x Perf. <+18% TDP

GPGPU via CTM

2.5x ALU increase

ATI Stream SDK CAL+IL/Brook+

* For RV670, RV770 & Cypress divide by 5 for peak double-precision performance

GigaFLOPS
3000
2500
2000
1500
1000
500
0

Sep-05 Mar-06 Oct-06 Apr-07 Nov-07 Jun-08 Dec-08 Jul-09
The World’s Most Efficient GPU*

*Based on comparison of consumer client single-GPU configurations as of 12/08/09. ATI Radeon™ HD 5870 provides 14.47 GFLOPS/W and 7.90 GFLOPS/mm² vs. NVIDIA GTX 285 at 5.21 GFLOPS/W and 2.26 GFLOPS/mm².
ATI Radeon™ HD 5870 ("Cypress") Architecture (2009)

2.72 Teraflops Single Precision, 544 Gigaflops Double Precision

- Full Hardware Implementation of DirectCompute 11 and OpenCL™ 1.0
- IEEE754-2008 Compliance Enhancements
- Additional Compute Features:
  - 32-bit Atomic Operations
  - Flexible 32kB Local Data Shares
  - 64kB Global Data Share
  - Global synchronization
  - Append/consume buffers
SIMD Cores

Each core:

- Includes 80 scalar stream processing units in total + 32KB Local Data Share
- Has its own control logic and runs from a shared set of threads
- Has dedicated fetch unit w/ 8KB L1 cache
- Communicates with other SIMD cores via 64KB global data share
Thread Processors

2.7 TeraFLOPS Single Precision
233 GigaFLOPS Double Precision

- 7x more than Nvidia Tesla C1060*

Increased IPC
- More flexible dot products
- Co-issue MUL & dependent ADD in a single clock
- Sum of Absolute Differences (SAD)
  - 12x speed-up with native instruction
  - Used for video encoding, computer vision
  - Exposed via OpenCL extension
- DirectX 11 bit-level ops
  - Bit count, insert, extract, etc.
- Fused Multiply-Add
- Improved IEEE-754 FP compliance
  - All rounding modes
  - FMA (Cypress only)
  - Denorms (Cypress only)
  - Flags

Each Thread Processor includes:
- 4 Stream Cores + 1 Special Function Stream Core
- Branch Unit
- General Purpose Registers

* Based on published figure of 78 GigaFLOPS
Memory Hierarchy

Optimized memory controller area

EDC (Error Detection Code)
- CRC Checks on Data Transfers for Improved Reliability at High Clock Speeds

GDDR5 Memory Clock temperature compensation
- Enables Speeds Approaching 5 Gbps

Fast GDDR5 Link Retraining
- Allows Voltage & Clock Switching on the Fly without Glitches

Increased texture bandwidth
- Up to 68 billion bilinear filtered texels/sec
- Up to 272 billion 32-bit fetches/sec

Increased cache bandwidth
- Up to 1 TB/sec L1 texture fetch bandwidth
- Up to 435 GB/sec between L1 & L2

Doubled L2 cache
- 128kB per memory controller

New DirectX 11 texture features
- 16k x 16k max resolution
- New 32-bit and 64-bit HDR block compression modes (BC6/7)
OpenCL™: Game-Changing Development
Enabling Broad Adoption of GP-GPU Capabilities

- **Industry standard API**: Open, multiplatform development platform for heterogeneous architectures
- **The power of Fusion**: Leverages CPUs and GPUs for balanced system approach
- **Broad industry support**: Created by architects from AMD, Apple, IBM, Intel, Nvidia, Sony, etc.
- **Fast track development**: Ratified in December 2008; AMD is the first company to provide a complete OpenCL solution
- **Momentum**: Enormous interest from mainstream developers and application ISVs

More stream-enabled applications across all markets
ATI Stream SDK v2.01: OpenCL™ For Multicore x86 CPUs and GPUs

The Power of Fusion: Developers leverage heterogeneous architecture to enable superior user experience

- **First complete OpenCL™ development platform**
- **Certified OpenCL™ 1.0 compliant by the Khronos Group**
- Write code that can scale well on multi-core CPUs and GPUs
- AMD delivers on the promise of support for OpenCL™, with both high-performance CPU and GPU technologies
- Available for download now – includes documentation, samples, and developer support


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1 Conformance logs submitted for the ATI Radeon™ HD 5800 series GPUs, ATI Radeon™ HD 5700 series GPUs, ATI Radeon™ HD 4800 series GPUs, ATI FirePro™ V8700 series GPUs, AMD FireStream™ 9200 series GPUs, ATI Mobility Radeon™ HD 4800 series GPUs and x86 CPUs with SSE3.
Anatomy of OpenCL™

Language Specification

- C-based cross-platform programming interface
- Subset of ISO C99 with language extensions - familiar to developers
- Well-defined numerical accuracy - IEEE 754 rounding behavior with defined maximum error
- Online or offline compilation and build of compute kernel executables
- Includes a rich set of built-in functions

Platform Layer API

- A hardware abstraction layer over diverse computational resources
- Query, select and initialize compute devices
- Create compute contexts and work-queues

Runtime API

- Execute compute kernels
- Manage scheduling, compute, and memory resources
OpenCL™ Programming Model

**Execution Model**
- *Compute kernel* is basic unit of execution
- Execution can occur in-order or out-of-order
- Kernel can be *data-parallel* (GPU) or *task-parallel* (CPU)
- N-dimensional *execution domain* for kernels
- Ability to group *work-items* into *work-groups* for sync/comm

**Memory Model**
- Multi-level memory model: *private, local, constant* and *global*
OpenCL™ Memory space on AMD GPU

- Registers/LDS
- Thread Processor Unit
- SIMD
- Local Data Share
- Board Mem/Constant Cache
- Board Memory

Global Memory

Local Memory

Private Memory

Work Item 1

Compute Unit 1

Compute Unit N

Global / Constant Memory Data Cache

Compute Device Memory
Example Walk Through – Kernel

```c
__kernel void vec_add (__global const float *a,
    __global const float *b,
    __global float *c)
{
    int gid = get_global_id(0);
    c[gid] = a[gid] + b[gid];
}
```
Example Walk Through – Host Code (Init)

// create the OpenCL context on a GPU device
cl_context = clCreateContextFromType(0, CL_DEVICE_TYPE_GPU,
                               NULL, NULL, NULL);

// get the list of GPU devices associated with context
clGetContextInfo(context, CL_CONTEXT_DEVICES, 0, NULL, &cb);
devices = malloc(cb);
clGetContextInfo(context, CL_CONTEXT_DEVICES, cb, devices, NULL);

// create a command-queue
cmd_queue = clCreateCommandQueue(context, devices[0], 0, NULL);

// allocate the buffer memory objects
memobjs[0] = clCreateBuffer(context, CL_MEM_READ_ONLY |
                              CL_MEM_COPY_HOST_PTR,
                              sizeof(cl_float)*n, srcA, NULL);
memobjs[1] = clCreateBuffer(context, CL_MEM_READ_ONLY |
                              CL_MEM_COPY_HOST_PTR,
                              sizeof(cl_float)*n, srcB, NULL);
memobjs[2] = clCreateBuffer(context, CL_MEM_WRITE_ONLY,
                              sizeof(cl_float)*n, NULL, NULL);
Example Walk Through – Host Code (Compile)

// create the program
program = clCreateProgramWithSource(context, 1, &program_source,
                                      NULL, NULL);

// build the program
err = clBuildProgram(program, 0, NULL, NULL, NULL, NULL);

// create the kernel
kernel = clCreateKernel(program, "vec_add", NULL);
Example Walk Through – Host Code (Run)

// set the args values
err = clSetKernelArg(kernel, 0, (void *)&memobjs[0], sizeof(cl_mem));
err |= clSetKernelArg(kernel, 1, (void *)&memobjs[1], sizeof(cl_mem));
err |= clSetKernelArg(kernel, 2, (void *)&memobjs[2], sizeof(cl_mem));

// set work-item dimensions
global_work_size[0] = n;

// execute kernel
err = clEnqueueNDRangeKernel(cmd_queue, kernel, 1, NULL, 
                               global_work_size,
                               NULL, 0, NULL, NULL);

// read output array
err = clEnqueueReadBuffer(context, memobjs[2], CL_TRUE, 0, 
                          n*sizeof(cl_float),
                          dst, 0, NULL, NULL);
OpenCL™ Development Directions

Khronos Group is working to evolve specification to support future architectural models and features

- Moving compute-oriented optional features into the core specification
  - Double Precision, Atomics
- Developing extensions to support specific applications
  - Video, Physics, etc.
- Improving cross-platform interoperability
- Tightening mathematical precisions
- Developing more advanced scheduling models
OpenCL™ Backend for HMPP

(Scheduled to be released)

- A compiler integrating OpenCL™ stream generator
  - Build portable CPU and GPU hardware specific computations
- C & Fortran programming directives
  - High level programming interface for scientific applications
- Runtime library
  - Ease application deployment on multi-GPUs systems
Comparing OpenCL™ and DirectX® 11 DirectCompute

How will developers choose between OpenCL™ and DirectX® 11 DirectCompute?

- Feature set is similar in both APIs

DirectX® 11 DirectCompute

- Easiest path to add compute capabilities to existing DirectX® applications
- Windows Vista® and Windows® 7 only

OpenCL™

- Ideal path for new applications porting to the GPU for the first time
- True multiplatform: Windows®, Linux®, MacOS
- Natural programming without dealing with a graphics API
ATI Stream Technology
Enabled Multimedia Applications

CyberLink
MediaShow 5
MediaShow Espresso
PowerDirector 8
PowerDirector 7

ArcSoft
SimHD™ Plug-in for TotalMedia Theatre

ROXIO
Roxio Creator™ 2010
Roxio Creator™ 2010 Pro
GPU Acceleration in Technical Applications

Tomographic Reconstruction: Alain Bonissent, Centre de Physique des Particules de Marseille
- Reporting 42-60x* speedups
- This image: 7 minutes in optimized C++; 10 seconds in Brook+

EDA Simulation: ACCIT
- Currently beta testing applications and reporting >10x speedup**

Seismic Processing: Brown Deer
- Achieving 120x speedup vs CPU on 3D 2nd order finite-difference time-domain (FDTD) seismic processing algorithm

Options Trading: Scotia Capital:
- Reported a 28x speedup over a quad-core CPU.

Neural Networks: Neurala
Developing Neurala Technology Platform for advanced brain-based machine learning applications
- Report achieving 10-200x speedups on biologically inspired neural models
Distributed.net provides a distributed model allowing users to donate compute cycles to large compute-intensive projects.

RC5-72 – Cryptography algorithm that searches for encryption keys.

Application Acceleration

ACML GPU Accelerated DGEMM Performance

• AMD FireStream™ 9270 on AMD Phenom™ X4 9950/790FX/4GB DDR2 running RHEL 5.1 x86_64
• AMD FireStream measured performance includes transfer of operand and result matrices
• Quad-Core peak theoretical performance quoted for 3.2GHz Nehalem processor
• C1060 peak theoretical performance derived from published specifications
• ACML-GPU library freely available from: http://developer.amd.com/gpu/acmlgpu
NUDT’s Tianhe-1

1.206 Pflops peak - 563.1 Tflops LINPACK
6,144 Intel CPUs - 5,120 ATI RV770 GPUs
Hybrid Parallel Gas Dynamics in OpenCL™
LANL, IBM, AMD, NVIDIA Booths at SC09

- SC09 demos on
  - x86 CPU – Opteron
  - x86 CPU – Xeon
  - GPU – NVIDIA
  - GPU – AMD
  - Power6
  - PowerXCell
A New Era of Processor Performance

Single-Core Era
Constrained by:
- Power
- Complexity

Multi-Core Era
Constrained by:
- Power
- Parallel SW availability
- Scalability

Heterogeneous Systems Era
Enabled by:
- Abundant data parallelism
- Power efficient GPUs
Constrained by:
- Programming models

Targeted Application Performance

Single-thread Performance

Throughput Performance

Targeted Application Performance

Time

Time (Data-parallel exploitation)

Time (No of processors)

we are here

we are here

we are here
A New Era of Processor Performance

**Microprocessor Advancement**

- Single-Core Era
- Multi-Core Era
- Heterogeneous Systems Era

**Heterogeneous Computing**

- System-level programmable
  - OpenCL™/DirectX® driver-based programs
  - Graphics driver-based programs

**Throughput Performance**

**Homogeneous Computing**

**Programmability**

- CPU
- GPU

**Era Evolution**

- Single-Core Era
- Multi-Core Era
- Heterogeneous Systems Era

**Advancements**

- CPU
  - Microprocessor Advancement
- GPU
  - Advancement
  - Throughput Performance

**ATI Stream Computing Update**

GPU Computing – Past, Present and Future with ATI Stream Technology
AMD Fusion™ APUs Fill the Need

x86 CPU owns the Software World

- Windows®, MacOS and Linux® franchises
- Thousands of apps
- Established programming and memory model
- Mature tool chain
- Extensive backward compatibility for applications and OSs
- High barrier to entry

GPU Optimized for Modern Workloads

- Enormous parallel computing capacity
- Outstanding performance-per-watt-per-dollar
- Very efficient hardware threading
- SIMD architecture well matched to modern workloads: video, audio, graphics
Heterogeneous Computing:
Next-Generation Software Ecosystem

- **Advanced Optimizations & Load Balancing**
  - Load balance across CPUs and GPUs; leverage AMD Fusion™ performance capabilities

- **End-user Applications**
  - High Level Frameworks
  - Middleware/Libraries: Video, Imaging, Math/Sciences, Physics
  - Tools: HLL compilers, Debuggers, Profilers

- **Hardware & Drivers:**
  - AMD Fusion™, Discrete CPUs/GPUs
  - OpenCL™ & DirectX® Compute

- **Ease of application development**
  - Drive new features into industry standards

**Ease of application development**
ONLY AMD!

CPU

GPU

OpenCL

DirectCompute

KHRONOS GROUP

Microsoft

ATI STREAM TECHNOLOGY

The future is fusion

GPU Computing – Past, Present and Future with ATI Stream Technology
Backup Slides
Training and Related Resources

- Training Resources
  - Introductory Tutorial to OpenCL™
  - AMD Developer Inside Track: Introduction to OpenCL™
  - ATI Stream OpenCL™ Technical Overview Video Series
  - Porting CUDA to OpenCL™
  - Image Convolution Using OpenCL™ - A Step-by-Step Tutorial
  - OpenCL™ Tutorial: N-Body Simulation

- Related Resources
  - OpenCL™: The Open Standard for Parallel Programming of GPUs and Multi-core CPUs
  - The Khronos™ Group – OpenCL™ Overview Page
  - ATI Stream Profiler Product Page
  - ACML-GPU Product Page
  - ATI Stream Power Toys Product Page
  - ATI Stream Developer Articles & Publications
  - ATI Stream Developer Showcase
  - ATI Stream Developer Training Resources
  - KB75 - Tips and suggestions for running SiSoftware Sandra 2010 OpenCL™ GPGPU benchmarks

- ATI Stream SDK v2.01 Documentation
## OpenCL™ vs. CUDA

<table>
<thead>
<tr>
<th>Feature</th>
<th>OpenCL™</th>
<th>CUDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compilation Methods</td>
<td>Online + Offline</td>
<td>Offline Only</td>
</tr>
<tr>
<td>Mathematical Precision</td>
<td>Well Defined</td>
<td>Undefined</td>
</tr>
<tr>
<td>Math Libraries</td>
<td>Defined Standard</td>
<td>Proprietary</td>
</tr>
<tr>
<td>CPU Support</td>
<td>OpenCL™ CPU Device</td>
<td>No CPU Support</td>
</tr>
<tr>
<td>Native Host Task Support</td>
<td>Task Parallel Compute Model w/ Ability To Enqueue Native Threads</td>
<td>No Native Thread Support</td>
</tr>
<tr>
<td>Extension Mechanism</td>
<td>Defined Mechanism</td>
<td>Proprietary</td>
</tr>
<tr>
<td>Vendor Support</td>
<td>Industry-Wide Support AMD, Apple, etc.</td>
<td>NVIDIA Only</td>
</tr>
<tr>
<td>C Language Support</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
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