OpenCL for NVIDIA GPUs

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NVIDIA

Outline

- OpenCL on NVIDIA GPUs
- Best Practices
- Demos

OpenCL on NVIDIA GPUs

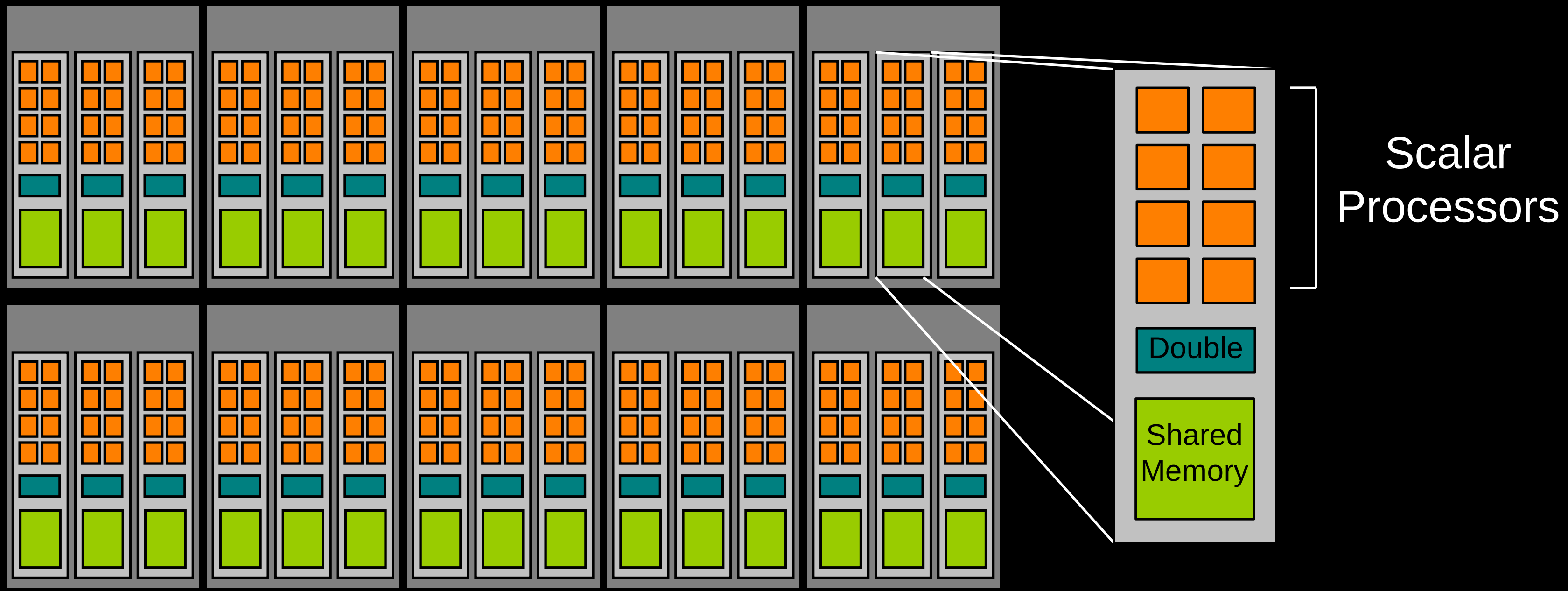
- **OpenCL is a great match**
  - **Direct correlation to the HW execution model**
  - **Direct correlation to the HW memory model**
  - **Direct correlation to the HW synchronization model**

- **Based on NVIDIA's mature GPU computing infrastructure**
  - **Compiles to PTX ISA**
  - **Profiling signals and instrumentation**
  - **Drivers and full SDK available since May**
  - **Available to all professional developers/researchers today**

- **Supported on hundreds of millions of CUDA-enabled GPUs already in the market**

NVIDIA 10-Series Architecture

- 240 Streaming Processor (SP) cores execute HW threads
- 30 Streaming Multiprocessors (SMs) each of which contain:
  - 8 multi-threaded streaming processors
  - 2 Special Function Units (SFUs)
  - 1 double precision unit
  - Shared memory that enables work-item cooperation



OpenCL Execution Model on NVIDIA

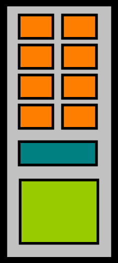
Software | **Hardware**

Work-item

Scalar Processor

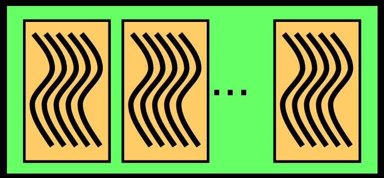
- Work-items are executed by streaming processors
- Maps directly to HW managed threads

Work-group

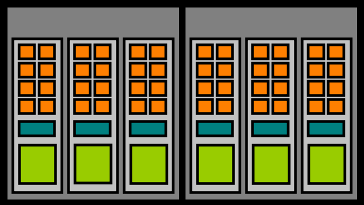


Multiprocessor

- Work-groups are executed on multiprocessors
- They do not migrate
- Several concurrent work-groups can reside on one multiprocessor - limited by multiprocessor resources



NDRange



Device

- A kernel is launched as an N-D Range of work-groups
- Work-groups are dynamically load-balanced by HW scheduler

OpenCL Memory Model on NVIDIA

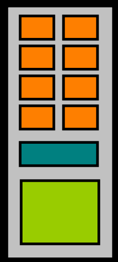
Software | **Hardware**

__private

Scalar Processor

• Each hardware thread has a dedicated __private region for stack

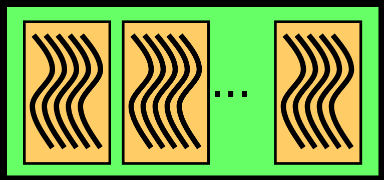
__local and __constant



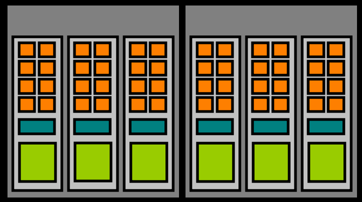
Multiprocessor

• Each multiprocessor has dedicated storage for __local memory and __constant caches

• Work-items running on a multiprocessor can communicate through __local memory



__global



Device

• All work-groups on the device can access __global memory

• Atomic operations allow powerful forms of global communication

OpenCL Synchronization on NVIDIA

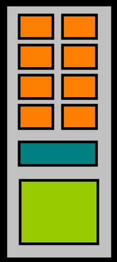
Software | **Hardware**

mem_fence()
atom_*()

Scalar Processor

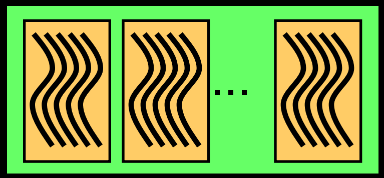
- Independent atomic operations and memory system control
- Write collective operations in a familiar C-style

barrier()
work_group_copy()

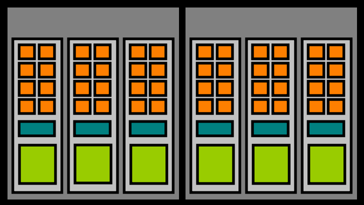


Multiprocessor

- Single instruction fast barrier support directly in HW
- Collective operations leverage the entire multi-processor



EnqueueNDRange
cl_event



Device

- Direct HW support for scheduling NDRange grids
- Direct HW support for scheduling enqueued commands using cl_events

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Scalar Architecture

- NVIDIA GPUs have a scalar architecture
  - Use vector types in OpenCL for convenience, not performance
  - Generally want more work-items rather than large vectors per work-item

- Optimize performance by overlapping memory accesses with HW computation
  - High arithmetic intensity programs (i.e. high ratio of math to memory transactions)
  - Many concurrent work-items

Take Advantage of __local Memory

- Hundreds of times faster than __global memory

- Work-items can cooperate via __local memory
  - barrier() only needs CLK_LOCAL_MEM_FENCE, which is much lower overhead

- Use it to manage locality
  - Stage loads and stores in shared memory to optimize reuse

Optimize Memory Access

- **Assess locality of __global memory access patterns**
  - **HW coalescing of accesses within 128-byte memory blocks**
  - **1st Order performance effect**

- **Optimize for spatial locality of accesses in cached texture memory (OpenCL Images)**
  - **Image reads may benefit from processing as 2D blocks**
  - **Experiment with work-group aspect ratio to discover what's best**

- **Let OpenCL allocate memory optimally**
  - **CL_MEM_ALLOC_HOST_PTR**
  - **The implementation can optimize alignment and location**
  - **Can still get access for the host via clEnqueueMap{Buffer|Image}**

Transfer/Compute Overlap

- **Separate command queues can always overlap**
  - **Can use this to overlap transfer and compute**
  - **Generally best when transfer and compute time is balanced**
  - **Most useful when data has high reuse**
- **Or directly pass ALLOC_HOST memory to kernel**
  - **Uses GPUs latency hiding to ensure maximal bus usage**
  - **Generally best when data has low/no reuse**
  - **No events needed to synchronize between copy and kernel**

Use Parallelism Efficiently

- **Partition your computation to keep the GPU multiprocessors equally busy**
  - **Many work-items, many work-groups**
  - **work-groups >> number of Compute Units**
  - **256-512 work-items per work-group a good target**

- **Keep resource usage low enough to support multiple active work-groups per multiprocessor**
  - **Registers, __local memory can reduce available parallelism**
  - **Use Occupancy Calculator tool to help estimate**

Math Library and Compiler

- **Use native_* and half_* math functions where possible**
  - **Many have a direct mapping to hardware ISA**
  - **Can be orders of magnitude faster than higher precision variants**
  - ***Note that half_* functions do not mean the FP16 type extension***

- **Use the -cl-mad-enable compiler option**
  - **Permits use of FMADs, which can lead to large performance gains**

- **Investigate using the -cl-fast-relaxed-math compiler option**
  - **enables many aggressive compiler optimizations**

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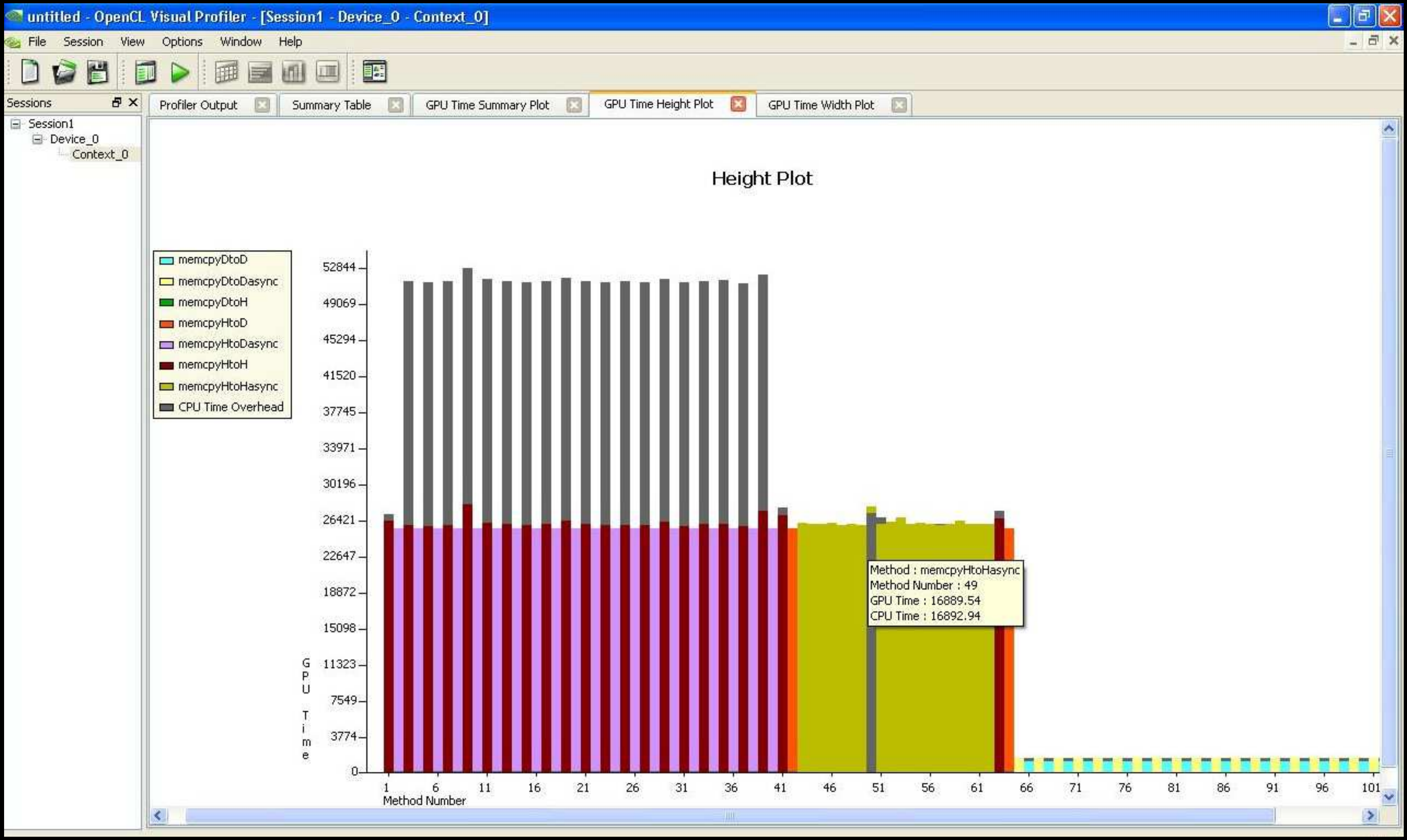
OpenCL Profiler Overview

- Profiler facilitates analysis and optimization of OpenCL programs by:
  - Reporting hardware counter values:
    - Number of various bus transactions
    - Branches
    - Effective Parallelism
    - Etc.
  - Computing per kernel statistics:
    - Effective instruction throughput
    - Effective memory throughput
  - Visually displaying time spent in various GPU calls
- Requires no instrumentation of the source code

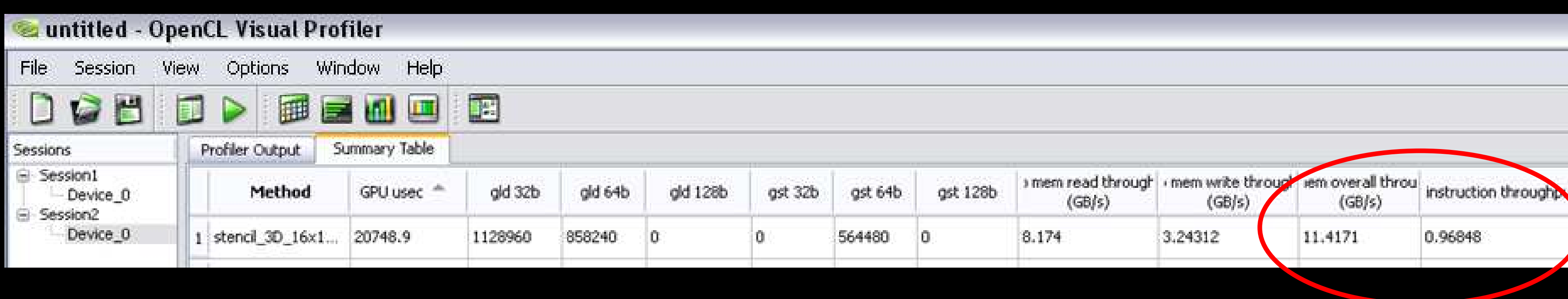
OpenCL Profiler Example

Time profile of GPU operations



OpenCL Profiler Sample Uses

- Determining whether kernel performance is bound by instruction or memory throughput
- Determining whether performance is limited by kernel execution or data transfer times
- Determining percentage of the application time spent in each kernel



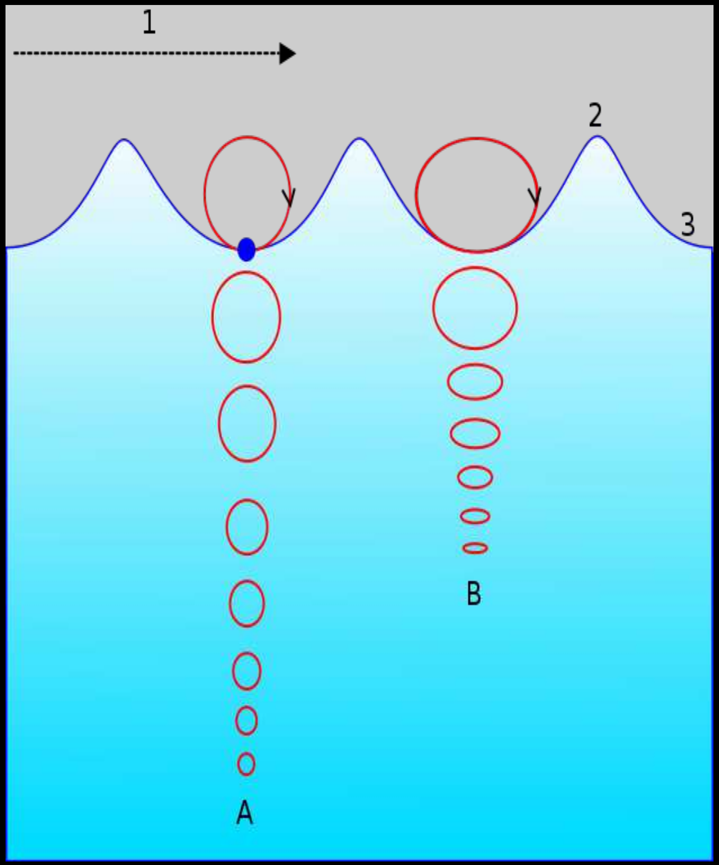
Ocean Simulation Overview

- **Based on Jerry Tenssendorf's paper "Simulating Ocean Water"**
  - **Statistic based, not physics based**
  - **Generate wave distribution in frequency domain, then perform inverse FFT**
  - **Widely used in movie CGIs since 90s, and in games since 2000s**
- **In movie CGI: The size of height map is large**
  - **Titanic, 2048x2048**
  - **Water World, 2048x2048**
- **In games: The size of height map is small**
  - **Crysis, 64x64**
  - **Resistance 2, 32x32**
  - **All simulated on CPU (or Cell SPE)**

The Algorithm: Wave Composition

- The ocean surface is composed by enormous simple waves

- Each sine wave is a hybrid sine wave (Gerstner wave)
  - A mass point on the surface is doing vertical circular motion



Performance Issues

- The simulation is required to generate the displacement map in real-time
- Computing FFT on CPU becomes the bottleneck when the displacement map gets larger
  - Larger texture also takes longer time on CPU-GPU data transfer
  - However, large displacement map is a must-have for detailed wave crests
- GPU computing is really good at FFT
  - Multiple 512x512 transforms can be performed in trivial time on high-end GPUs
  - Demo uses multiple 1024x1024 transforms, clearly affordable for high quality real-time rendering

Ocean Simulation Demo

nvidia.com/opencl

developer.nvidia.com/page/registered_developer_program.html

GPU Technology Conference

Sept 30 – Oct 2, 2009 – The Fairmont San Jose, California

The most significant event in 2009 dedicated to application development on the GPU

- Learn about the seismic shifts happening in computing
- Preview disruptive technologies and emerging applications to stay ahead of imminent trends
- Get tools/techniques to impact mission critical projects now
- Network with experts and peers from across several industries

Opportunities:

- **Call for Submissions** open for talks, tutorials, panels, birds of a feather, posters and moderated roundtables
- **Sponsors / Exhibitors** have a variety of options to reach influential decision makers
- **Startup Showcase** Present your company and technology to potential investors

Event focused on developers, engineers, researchers, senior executives, venture capitalists, press and analysts

nvidia.com/gtc