MIC-GPU: High-Performance Computing for Medical Imaging on Programmable Graphics Hardware (GPUs)

SPIE Medical Imaging

CUDA Programming Environment

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Setup CUDA

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Compute Unified Device Architecture

- Check hardware compatibility: http://www.nvidia.com/object/cuda_gpus.html
- Driver, Toolkit (4.0) and SDK http://www.nvidia.com/object/cuda_get.html
- Toolkit includes:
  - Compiler
  - Development tools
  - Libraries for scientific computation (CUBLAS, CUFFT, CUSPARSE, CURAND, etc.)
  - User guides and documents

Compilation and Linking

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Any source file containing CUDA language extensions must be compiled with NVCC

NVCC is a compiler

- Compile device code
- Invoking the necessary compilers for host code like, g++, cl, ...

Any executable with CUDA code requires dynamic libraries:

- The CUDA runtime library (`cudart`) OR
- The CUDA core library (`cuda`)

Development Tools

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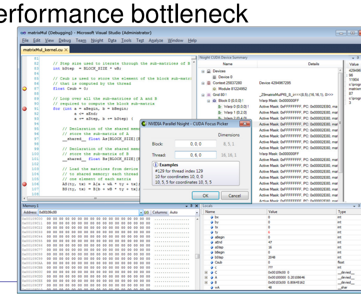
Parallel Nsight (Windows)

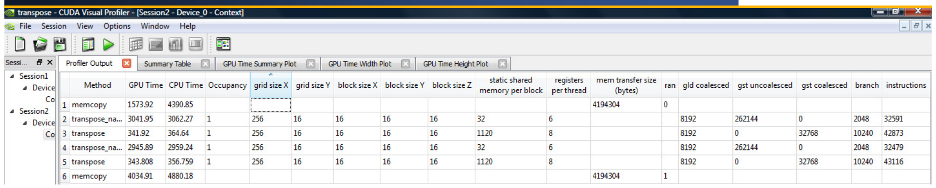
- Visual Studio Based GPU Development Environment
  http://developer.nvidia.com/object/nsight.html
- Debug CUDA C/C++ source code directly on the GPU
- Use the familiar Visual Studio Locals, Watches, Memory and Breakpoints windows
- Integrated analysis tool to isolate performance bottleneck

CUDA-GDB debugger

for Linux and MacOS



Visual Profiler



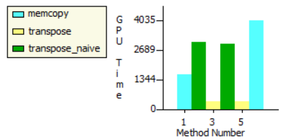
	Method	GPU Time	CPU Time	Occupancy	grid size X	grid size Y	block size X	block size Y	block size Z	static shared memory per block	registers per thread	mem transfer size (bytes)	ran	gld coalesced	gst uncoalesced	gst coalesced	branch	instructions
1	memcopy	1573.92	4390.85									4194304	0					
2	transpose_na...	3041.95	3062.27	1	256	16	16	16	16	32	6			8192	262144	0	2048	32591
3	transpose	341.92	364.64	1	256	16	16	16	16	1120	8			8192	0	32768	10240	42873
4	transpose_na...	2945.89	2959.24	1	256	16	16	16	16	32	6			8192	262144	0	2048	32479
5	transpose	343.808	356.759	1	256	16	16	16	16	1120	8			8192	0	32768	10240	43116
6	memcopy	4034.91	4880.18									4194304	1					

A graphical profiling tool to measure and benchmark performance

tracks events with hardware counters on signals in the chip

Fine Tuning Performance by watching the following metric

- Coalescing
- Occupancy
- Branch diversity
- Instruction throughput
- Computing / Data transfer ratio
- Share memory and register per thread



CUDA Libraries

CUBLAS (BLAS = Basic Linear Algebra Subprograms)

level1 (scalar, vector, vector-vector)

level2 (matrix-vector) , level3 (matrix-matrix)

```
void cublasSsymv(char uplo, int n, float alpha, const float *A, int lda, const
    float *x, int incx, float beta, float *y, int incy)
```

performs the matrix-vector operation where *alpha* and *beta* are single-precision scalars, and *x* and *y* are n-element single-precision vectors. *A* is a symmetric *n*×*n* matrix that consists of single-precision elements and is stored in either upper or lower storage mode

CUBLAS Example

Compute a vector's L2 norm $\|\mathbf{x}\| := \sqrt{x_1^2 + \cdots + x_n^2}$

- Single precision

```
float cublasSnrm2 (int n, const float *x, int incx)
```

- Double precision

```
double cublasDnrm2 (int n, const double *x, int incx)
```

```
cublasInit();
float *h_A;
h_A = (float*)malloc(n * sizeof(h_A[0]));
…
cublasAlloc(n, sizeof(d_A[0]), (void**)&d_A);
cublasSetVector(n, sizeof(h_A[0]), h_A, 1, d_A, 1);
float norm2result=cublasSnrm2 (n, d_A, 1);
cublasFree(d_A); free(h_A);
cublasShutdown();
```

initialize library

initialize vector

data transfer

compute norm

Wrap-up

CUDA Libraries (3rd party)

MAGMA (porting from LAPACK to GPU+multicore architectures)

CULA (3rd party implementation of LAPACK)

PyCUDA (CUDA via Python)

Thrust (C++ template for CUDA, open source)

Jasper for DWT (Discrete wavelet transform)

OpenViDIA for computer vision

CUDPP for radix sort

Thrust: Introduction

Offers

- STL compatible containers (vector, list, map)
- ~50 algorithm (reduction, prefix sum, sorting)
- Rapid prototyping

Container

- Hides cudaMalloc & cudaMemcpy
- Iterators behave like pointer

Thrust Example: Sorting

```
thrust::host_vector<int> h_vec(16*1024*1024);      // generate 16M random numbers on the host

thrust::generate(h_vec.begin(), h_vec.end(), rand);

thrust::device_vector<int> d_vec = h_vec;          // transfer data to the device

thrust::sort(d_vec.begin(), d_vec.end());          // sort data on the device

thrust::copy(d_vec.begin(), d_vec.end(), h_vec.begin());   // transfer data back to host
```


Thrust: Operators

```
thrust::device_vector<int>   i_vec = ...           // declare storage
thrust:: device_vector<float> f_vec = ...

thrust:: reduce(i_vec.begin(), i_vec.end());       // sum of integers (equivalent calls)
thrust:: reduce(i_vec.begin(), i_vec.end(),   0, thrust:: plus<int>());

thrust:: reduce(f_vec.begin(), f_vec.end());       // sum of floats (equivalent calls)
thrust:: reduce(f_vec.begin(), f_vec.end(), 0.0f, thrust:: plus<float>());

thrust:: reduce(i_vec.begin(), i_vec.end(),   0, thrust:: maximum<int>());   // maximum of integers
```


Thrust Example: Vector L2 Norm

More like C++

$$|\mathbf{x}\| := \sqrt{x_1^2 + \cdots + x_n^2|}$$

```
template <typename T> struct square
{ __host__ __device__                              // define transformation f(x) -> x^2
T operator()(const T& x) const {
        return x * x;      }
};
 square<float>     unary_op;                       // setup arguments
plus<float> binary_op;
float init = 0;
                                                   // initialize vector
device_vector<float>  A(3);
A[0] = 20;  A[1] = 30;  A[2] = 40;                 // compute norm
float norm = sqrt( transform_reduce(A.begin(), A.end(),  unary_op, init, binary_op));
```

To Probe Further

NVIDIA CUDA Zone:

- http://www.nvidia.com/object/cuda_home.html
- Lots of information and code examples
- NVIDIA CUDA Programming Guide

GPGPU community:

- http://www.gpgpu.org
- User forums, tutorials, papers
- Good source: conference tutorials http://www.gpgpu.org/developer/index.shtml#conference-tutorial

Course Schedule

1:30 – 1:45:	Introduction
1:45 – 2:00:	Parallel programming primer
2:00 – 2:15:	GPU hardware
2:15 – 3:00:	CUDA API, threads level optimization
	Coffee Break
3:30 – 4:00:	CUDA memory optimization
4:00 – 4:15:	CUDA programming environment
4:15 – 4:45:	Parallelism in medical image (Klaus)
4:45 – 5:25:	CT reconstruction examples (Eric + Ziyi)
5:25 – 5:30:	Closing remarks (Klaus)