Thursday, Feb. 23:

Matrix Multiplication

N-Body Simulations

Friday, Feb. 24:

Histograms (from Jason Sanders' book; see our webpage link)

Using Tensor Cores in CUDA (only preview)

Timing and Debugging

Wrap-Up of CUDA

Before we start…

Some nice ideas:

/home/Tit4/lecture60/gpu-course/00_error/

(ERR_CHECK instead of HANDLE_ERROR)

/home/Tit4/lecture60/gpu-course/4_dot/dot-special-new.cu

(dynamic vector size allocation in kernel through <<<n,m,size>>>)

Recap of 6: dot_perfect.cu :

Fat Threads! New variable gridDim.x !

Use of gridDim.x * blockDim.x to get size of grid,

Relation to <<<n,m>> in kernel launch

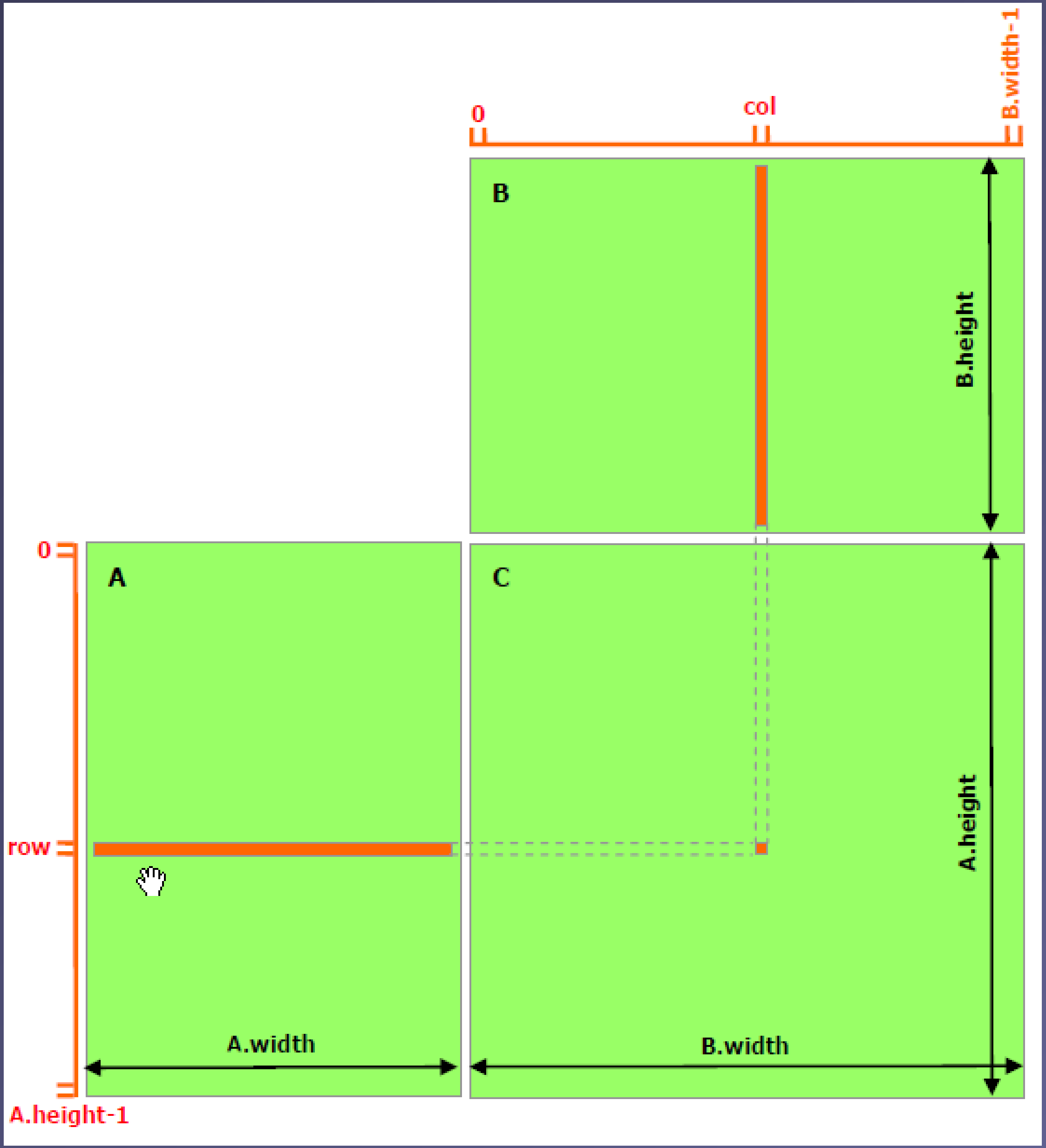
Block Reduction on Host instead of AtomicAdd!

Also used for histogram later.

Note nice profiling nvprof used in 7_matmul/gpu_script.sh

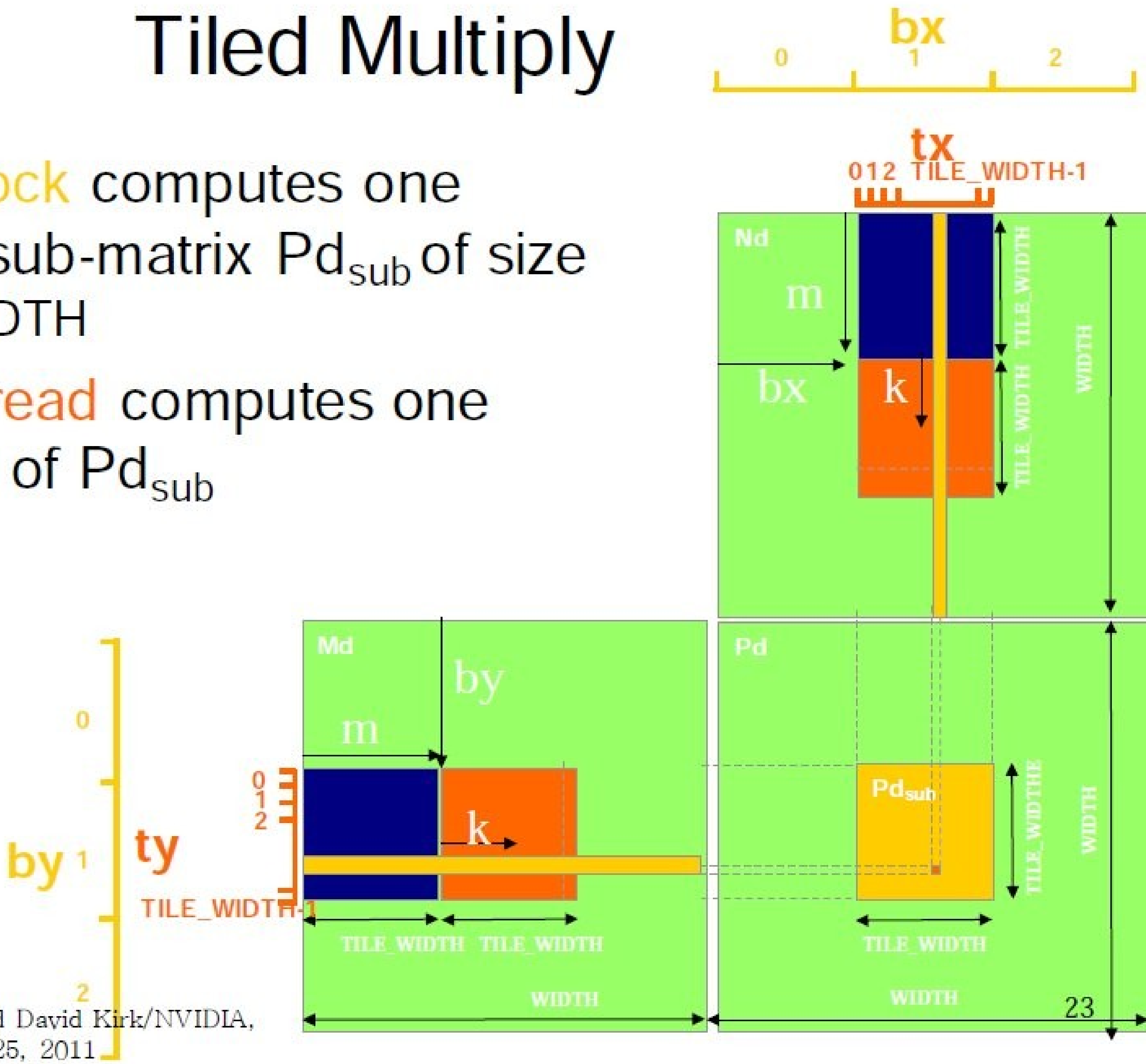
https://docs.nvidia.com/cuda/profiler-users-guide/index.html

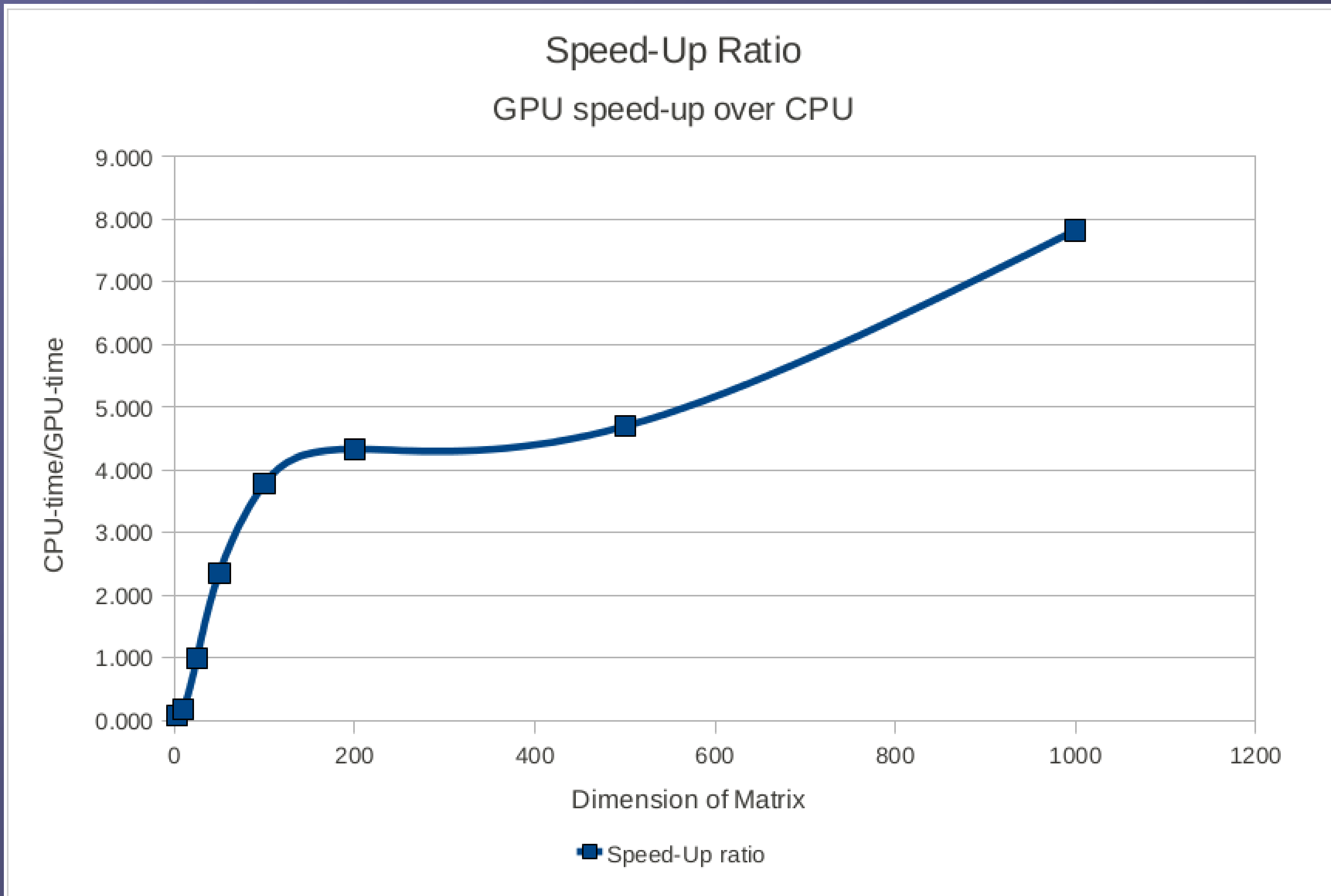
Matrix Intuitive Multiply



Tiled Multiply

- Each block computes one square sub-matrix Pd_{sub} of size TILE_WIDTH
- Each thread computes one element of Pd_{sub}




Speed-Up Ratio
GPU speed-up over CPU
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
CPU-time/GPU-time
0
200
400
600
800
1000
1200
Dimension of Matrix
Speed-Up ratio

Wrapping Up 1

Exercises (CUDA Lectures in afternoon)

0. hello, device- first kernel call, hello world, GPU properties
1. add - vector addition using one thread in one block only
2. add-index - vector addition using blocks in parallel, one thread per block only.
3. add-parallel - vector addition using all blocks and threads in parallel
4. dot - scalar product using shared memory of one block only for reduction
5. dot-full - scalar product using shared memory and atomic add across blocks
6. dot-perfect - scalar product; fat threads and final reduction on host.

8. histo - histogram using fat threads and atomic add on shared and global memory, timing

7. matmul - matrix multiplication with tiled access shared memory

Wrapping Up 2

Elements of CUDA C learnt:

threadId.x , blockId.x, blockDim.x, gridDim.x	Threads, Blocks
(threadId.y, blockId.y, blockdim.y, gridDim.y	(matmul coming with 2D grids)
kernel<<<n,m>>> (...)	kernel calls
Kernel<<n,m,size>>(…)	kernel call with dyn. alloc. size
kernel<<<dimBlock,dimGrid>>>(…)	dim3 variable type (matmul)
__global__	device code
__shared__	shared memory on GPU
cudaMalloc / cudaFree	manage global memory of GPU
cudaMemcpy / cudaMemset	copy/set to or from memory
cudaGetDeviceProperties	get device properties in program
cudaEventCreate, cudaEventRecord, cudaEventSynchronize, cudaEventElapsedTime, cudaEventDestroy	CUDA profiling
AtomicAdd	atomic functions

Wrapping Up 3

What we have not yet learnt...

__constant__	constant memory on GPU
__device__	functions device to device
Intrinsic Functions (__device__ type)	

https://docs.nvidia.com/cuda/cuda-math-api/group__CUDA__MATH__SINGLE.html#group__CUDA__MATH__SINGLE

__host__	functions host to host
More atomic functions	
cudaBindTexture	using texture memory
fat threads for 2D and 3D stencils	thread coalescence opt.
cudaStreamCreate, cudaStreamDestroy	working with CUDA streams
<<<n,m,size,s>>>	kernel call with streams s
using Tensor Cores	
...	

Matrix Multiply and Histogram

Matrix Multiply: Inspired by Lecture of Wen-mei Hwu

http://whtresearch.sourceforge.net/example.html

On kepler: 7_matmul/

Histo: Chapter in Book of Jason Sanders

https://wwwstaff.ari.uni-heidelberg.de/spurzem/lehre/WS21/cuda/files/cuda-histograms.pdf

(Link on our webpage)

On kepler: 8_histo/

histo.cu (atomic on both shared and global memory)

histo-no-atomic.cu (atomic only on global memory)

Final Remarks

Important Note:

If you do some NBODY research in the future, please contact us (tutors or lecturer); do not use the course code for research it is not fully performant in some respects (openMP).

Remember for course certificate:

* Output files of small experiments on your lecture account (0_hello, 1_add, … , 7-matmul, 8-histo)

* Return two plots, one data file, and a few comments to your tutors
  Deadline? Agree with tutors, no strict deadline, but please NOT one day before you need the certificate! Outputs of the 8 Nbody runs on your lecture account.

* Notice: Student Queues will close Sunday, Mar 6, 23:59 (latest).
  You can run later, but contact me please spurzem@ari.uni-heidelberg.de

This Timing API is used in 8_histo/histo.cu !

Timing with CUDA Event API

```
int main ()
{
    cudaEvent_t start, stop;
    float time;

    cudaEventCreate (&start);
    cudaEventCreate (&stop);

    cudaEventRecord (start, 0);

    someKernel <<<grids, blocks, 0, 0>>> (...);

    cudaEventRecord (stop, 0);
    cudaEventSynchronize (stop);

    cudaEventElapsedTime (&time, start, stop);

    cudaEventDestroy (start);
    cudaEventDestroy (stop);

    printf ("Elapsed time %f sec\n", time*.001);

    return 1;
}
```

CUDA Event API Timer are,

- OS independent
- High resolution
- Useful for timing asynchronous calls

Ensures kernel execution has completed

Standard CPU timers will not measure the timing information of the device.

CUDA – GNU Debugger – CUDA-gdb

http://docs.nvidia.com/cuda/cuda-gdb/index.html

NVIDIA DEVELOPER ZONE CUDA TOOLKIT DOCUMENTATION

Search

CUDA-GDB (PDF) - v7.5 (older) - Last updated September 1, 2015 - Send Feedback -

CUDA-GDB

1. Introduction

This document introduces CUDA-GDB, the NVIDIA® CUDA® debugger for Linux and Mac OS.

1.1. What is CUDA-GDB?

CUDA-GDB is the NVIDIA tool for debugging CUDA applications running on Linux and Mac. CUDA-GDB is an extension to the x86-64 port of GDB, the GNU Project debugger. The tool provides developers with a mechanism for debugging CUDA applications running on actual hardware. This enables developers to debug applications without the potential variations introduced by simulation and emulation environments.

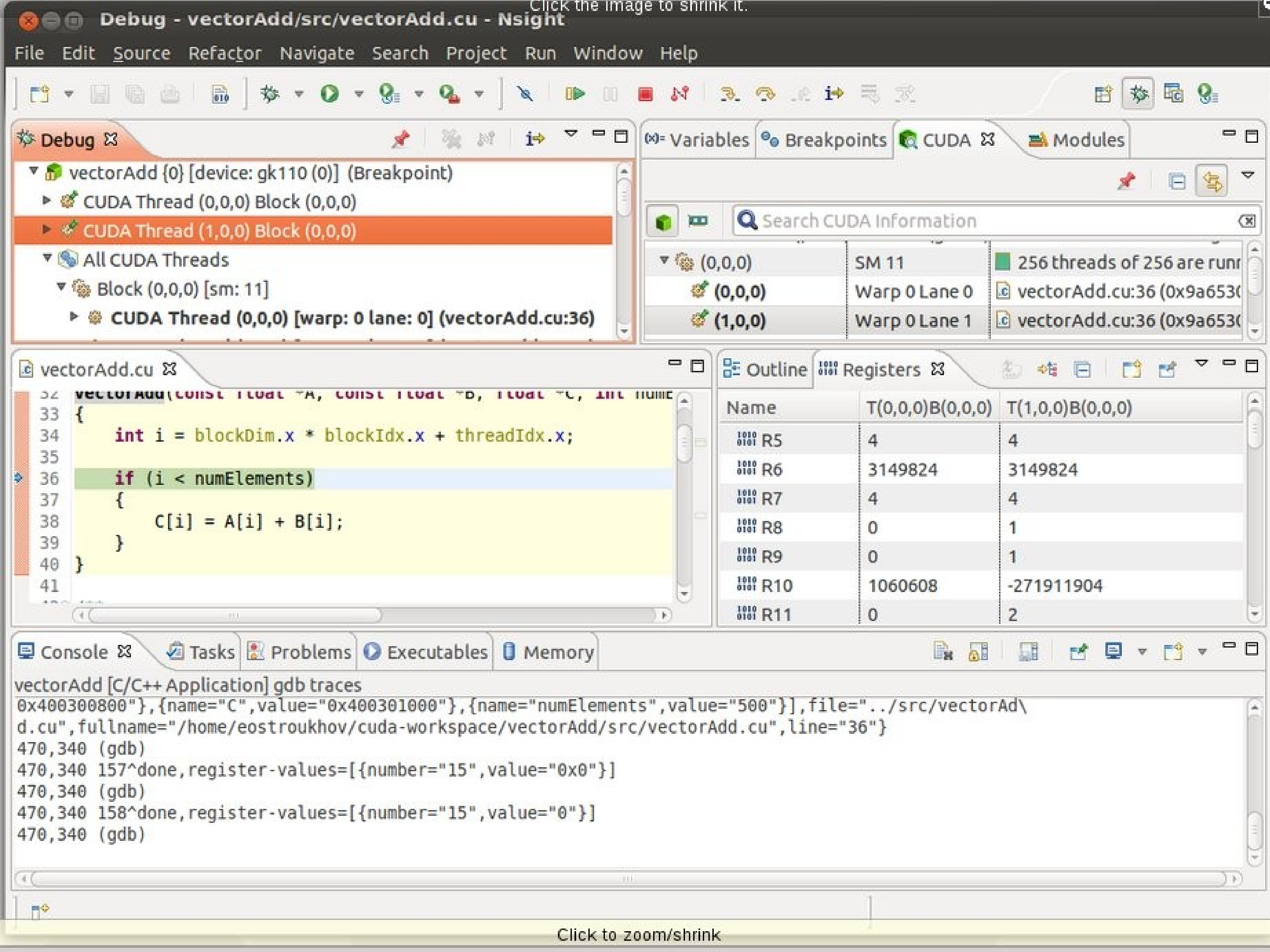
CUDA-GDB runs on Linux and Mac OS X, 32-bit and 64-bit. CUDA-GDB is based on GDB 7.6 on both Linux and Mac OS X.

1.2. Supported Features

CUDA-GDB is designed to present the user with a seamless debugging environment that allows simultaneous debugging of both GPU and CPU code within the same application. Just as programming in CUDA C is an extension to C programming, debugging with CUDA-GDB is a natural extension to debugging with GDB. The existing GDB debugging features are inherently present for debugging the host code, and additional features have been provided to support debugging CUDA device code.

CUDA-GDB supports debugging C/C++ and Fortran CUDA applications. (Fortran debugging support is limited to 64-bit Linux operating system) All the C++ features supported by the NVCC compiler can be debugged by CUDA-GDB.

CUDA-GDB allows the user to set breakpoints, to single-step CUDA applications, and also to inspect and modify the memory and variables of any given thread running on the hardware.


Click the image to shrink it.
Debug - vectorAdd/src/vectorAdd.cu - Nsight
File Edit Source Refactor Navigate Search Project Run Window Help
Debug
vectorAdd {0} [device: gk110 (0)] (Breakpoint)
CUDA Thread (0,0,0) Block (0,0,0)
CUDA Thread (1,0,0) Block (0,0,0)
All CUDA Threads
Block (0,0,0) [sm: 11]
CUDA Thread (0,0,0) [warp: 0 lane: 0] (vectorAdd.cu:36)
Variables Breakpoints CUDA Modules
Search CUDA Information
(0,0,0) SM 11 256 threads of 256 are runn
(0,0,0) Warp 0 Lane 0 vectorAdd.cu:36 (0x9a653
(1,0,0) Warp 0 Lane 1 vectorAdd.cu:36 (0x9a653
vectorAdd.cu
33 {
34 int i = blockDim.x * blockIdx.x + threadIdx.x;
35
36 if (i < numElements)
37 {
38 C[i] = A[i] + B[i];
39 }
40 }
41
Outline Registers
Name T(0,0,0)B(0,0,0) T(1,0,0)B(0,0,0)
R5 4 4
R6 3149824 3149824
R7 4 4
R8 0 1
R9 0 1
R10 1060608 -271911904
R11 0 2
Console Tasks Problems Executables Memory
vectorAdd [C/C++ Application] gdb traces
0x400300800"},{name="C",value="0x400301000"},{name="numElements",value="500"}],file="../src/vectorAd\
d.cu",fullname="/home/eostroukhov/cuda-workspace/vectorAdd/src/vectorAdd.cu",line="36"}
470,340 (gdb)
470,340 157^done,register-values=[{number="15",value="0x0"}]
470,340 (gdb)
470,340 158^done,register-values=[{number="15",value="0"}]
470,340 (gdb)
Click to zoom/shrink