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CUDA Tools for Debugging and Profiling

CUDA Course, Jülich Supercomputing Centre

Andreas Herten, Forschungszentrum Jülich, 3 August 2016

Overview

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What you will learn in this session

- Use `cuda-memcheck` to detect invalid memory accesses
- Use **Nisght Eclipse Edition** to debug a CUDA program
- Use the **NVIDIA Visual Profiler**, use `nvprof`

Contents

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Debugging

cuda-memcheck

Command-line memory access analyzer

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- Memory error detector; similar to Valgrind's `memcheck`
- Has sub-tools, via `cuda-memcheck --tool` *NAME*:
  - `memcheck`: Memory access checking (*default*)
  - `racecheck`: Shared memory hazard checking
  - Also: `synccheck`, `initcheck`
- Remember to compile your program with debug information: add `-g` (host) or `-G` (device)

→ `http://docs.nvidia.com/cuda/cuda-memcheck/`

Example

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Start via `cuda-memcheck` *PROGRAM*

Tasks — herten@zam231 — ..ug-2016/Tasks — -zsh

```
$ cuda-memcheck task1-cuda-memcheck
========= CUDA-MEMCHECK
========= Invalid __global__ write of size 4
=========     at 0x00000138 in /home/aherten/NVAL/Courses/CUDA-Course-2016-Aug/task1-cuda-memcheck.cu:20:set(i
nt, float*, float)
=========     by thread (255,0,0) in block (0,0,0)
=========     Address 0x1305ba23fc is out of bounds
=========     Saved host backtrace up to driver entry point at kernel launch time
=========     Host Frame:/usr/lib64/libcuda.so.1 (cuLaunchKernel + 0x2c5) [0x4745e5]
=========     Host Frame:task1-cuda-memcheck [0x172a1]
=========     Host Frame:task1-cuda-memcheck [0x31ab3]
=========     Host Frame:task1-cuda-memcheck [0x2da9]
=========     Host Frame:task1-cuda-memcheck [0x2cb1]
=========     Host Frame:task1-cuda-memcheck [0x2ce3]
=========     Host Frame:task1-cuda-memcheck [0x2a9d]
=========     Host Frame:/lib64/libc.so.6 (__libc_start_main + 0xf5) [0x21b05]
=========     Host Frame:task1-cuda-memcheck [0x2859]
=========
========= Invalid __global__ write of size 4
=========     at 0x00000138 in /home/aherten/NVAL/Courses/CUDA-Course-2016-Aug/task1-cuda-memcheck.cu:20:set(i
nt, float*, float)
=========     by thread (254,0,0) in block (0,0,0)
```

Nsight Eclipse Edition

The CUDA IDE

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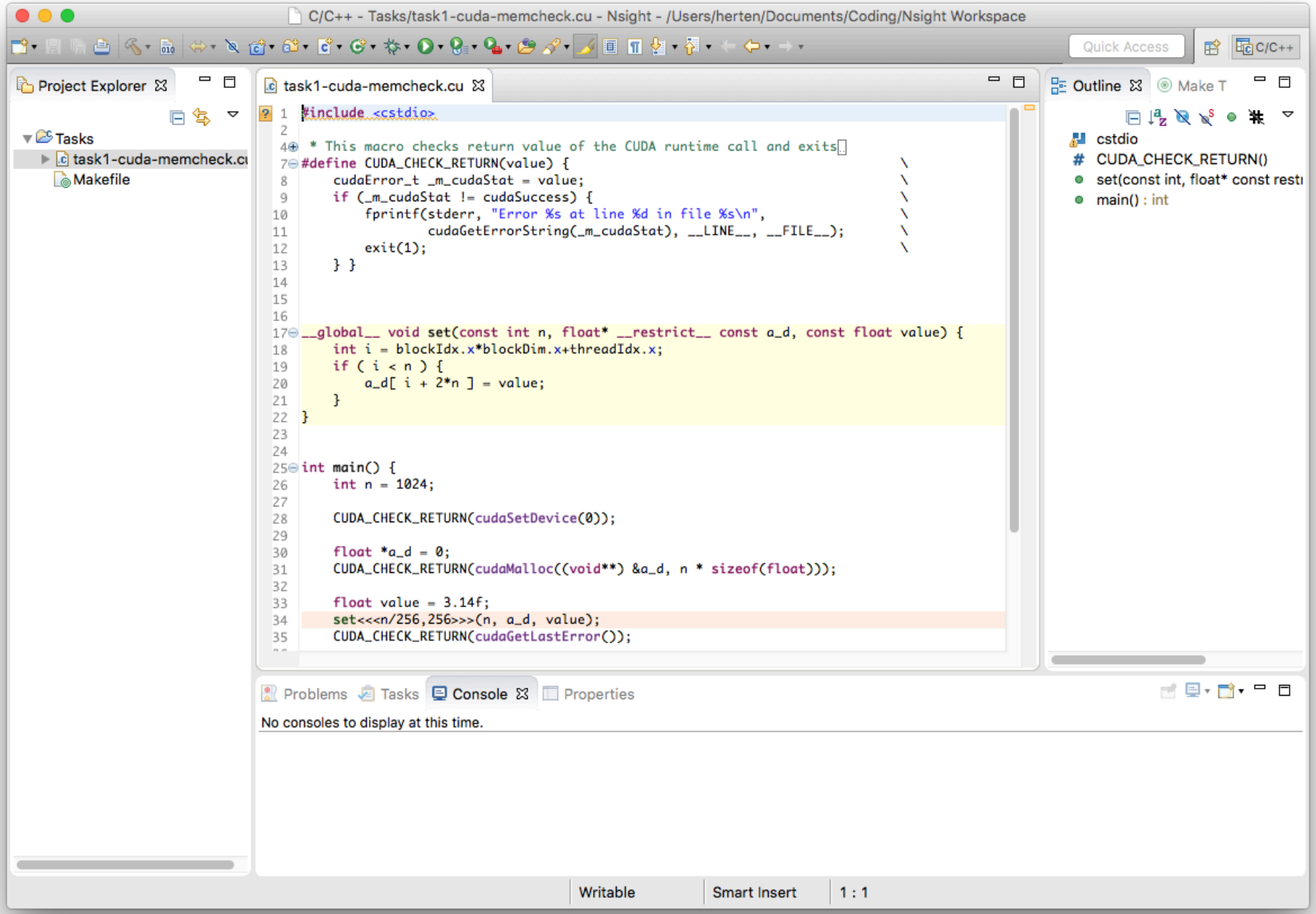
- Full-fledged IDE for CUDA development; based on Eclipse
  - Source code editor with CUDA C / C++ highlighting
  - Project / file management with integration of version control
  - Build system
  - Remote capabilities
  - Graphical interface for debugging heterogeneous applications (command line utility: `cuda-gdb`)
  - Integrated NVIDIA Visual Profiler
- Also: Nsight Visual Studio Edition (*only Windows*)

→ `https://developer.nvidia.com/nsight-eclipse-edition/`


C/C++ - Tasks/task1-cuda-memcheck.cu - Nsight - /Users/herten/Documents/Coding/Nsight Workspace
Quick Access
C/C++
Project Explorer
Tasks
task1-cuda-memcheck.cu
Makefile
task1-cuda-memcheck.cu
#include <cstdio>
* This macro checks return value of the CUDA runtime call and exits
#define CUDA_CHECK_RETURN(value) {
cudaError_t _m_cudaStat = value;
if (_m_cudaStat != cudaSuccess) {
fprintf(stderr, "Error %s at line %d in file %s\n",
cudaGetErrorString(_m_cudaStat), __LINE__, __FILE__);
exit(1);
} }
__global__ void set(const int n, float* __restrict__ const a_d, const float value) {
int i = blockIdx.x*blockDim.x+threadIdx.x;
if (i < n) {
a_d[i + 2*n] = value;
}
}
int main() {
int n = 1024;
CUDA_CHECK_RETURN(cudaSetDevice(0));
float *a_d = 0;
CUDA_CHECK_RETURN(cudaMalloc((void**) &a_d, n * sizeof(float)));
float value = 3.14f;
set<<<n/256,256>>>(n, a_d, value);
CUDA_CHECK_RETURN(cudaGetLastError());
Outline
Make T
cstdio
CUDA_CHECK_RETURN()
set(const int, float* const resti
main() : int
Problems
Tasks
Console
Properties
No consoles to display at this time.
Writable
Smart Insert
1 : 1

Debug CUDA Program with Nsight EE

Setup

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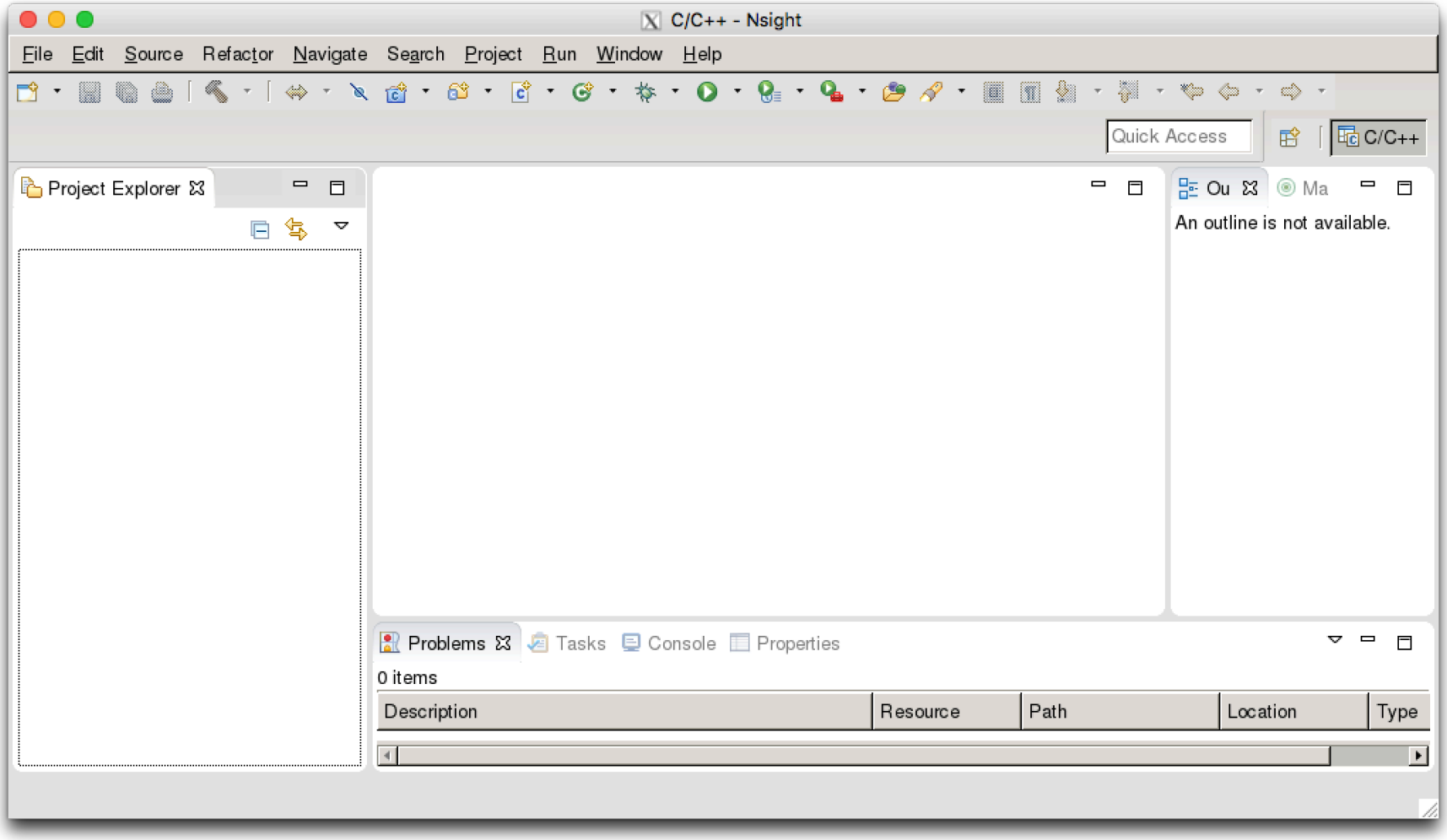
Start `nsight`



Debug CUDA Program with Nsight EE

Setup

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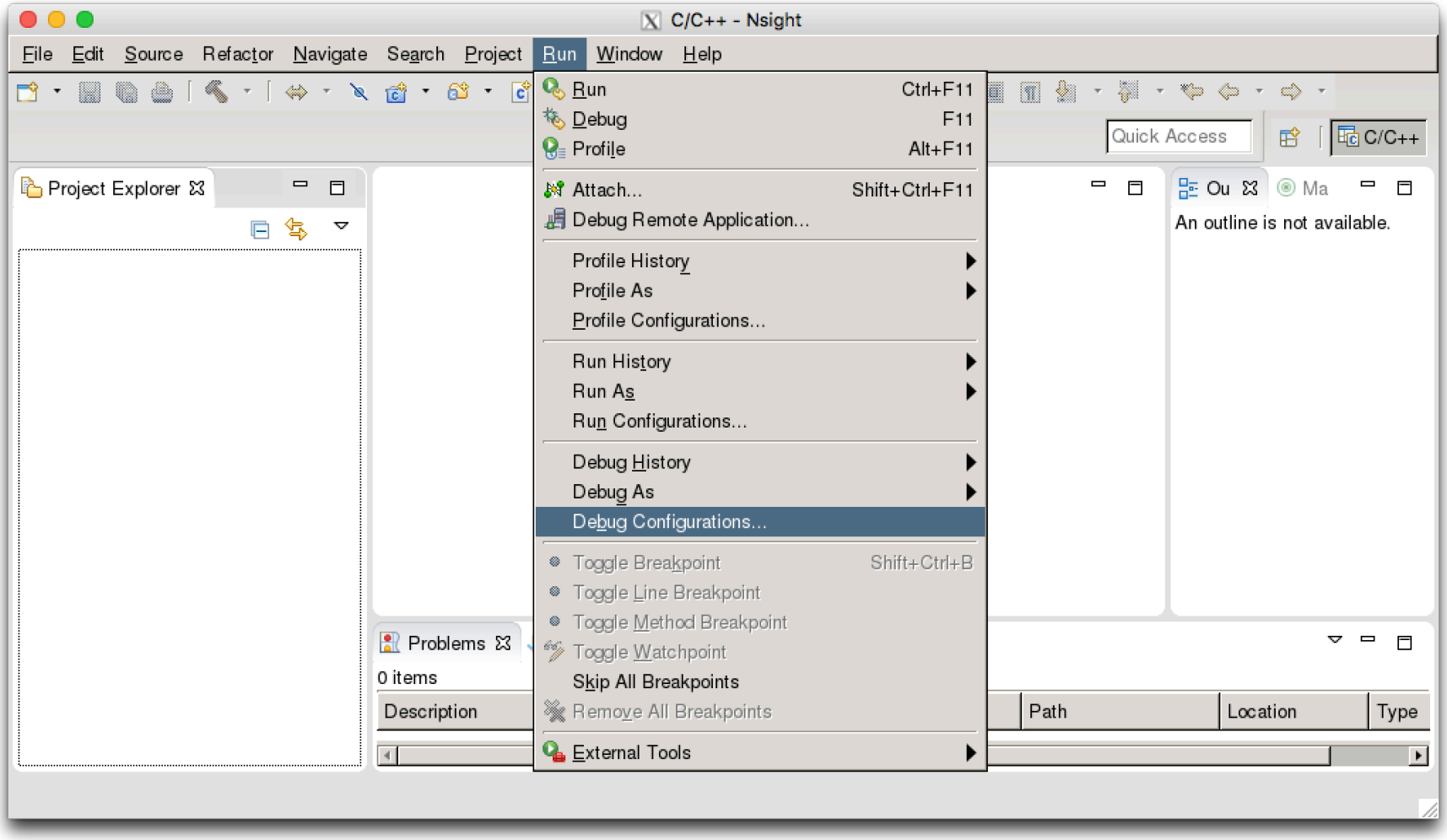
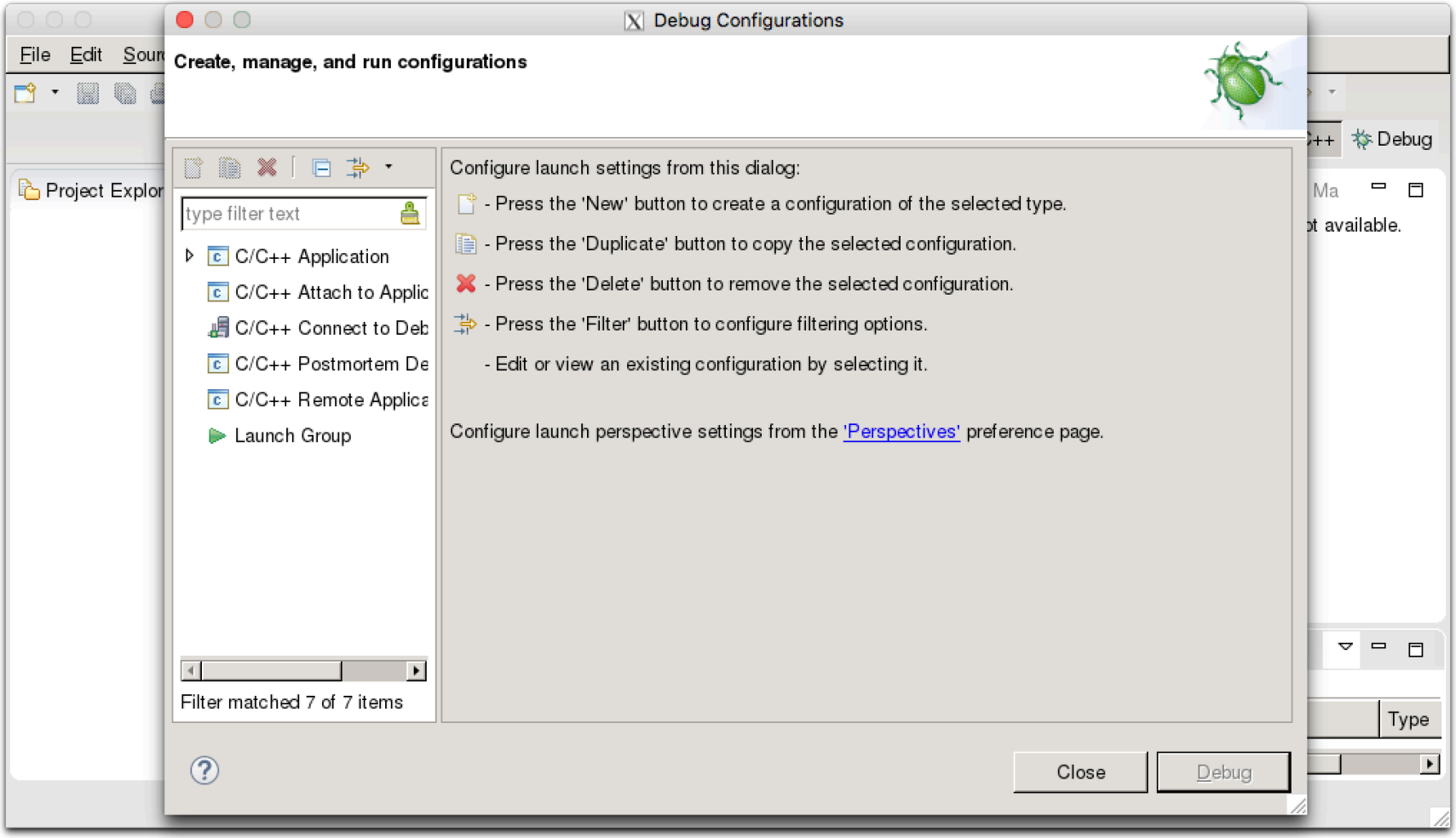
Configure debugging



Debug CUDA Program with Nsight EE

Setup

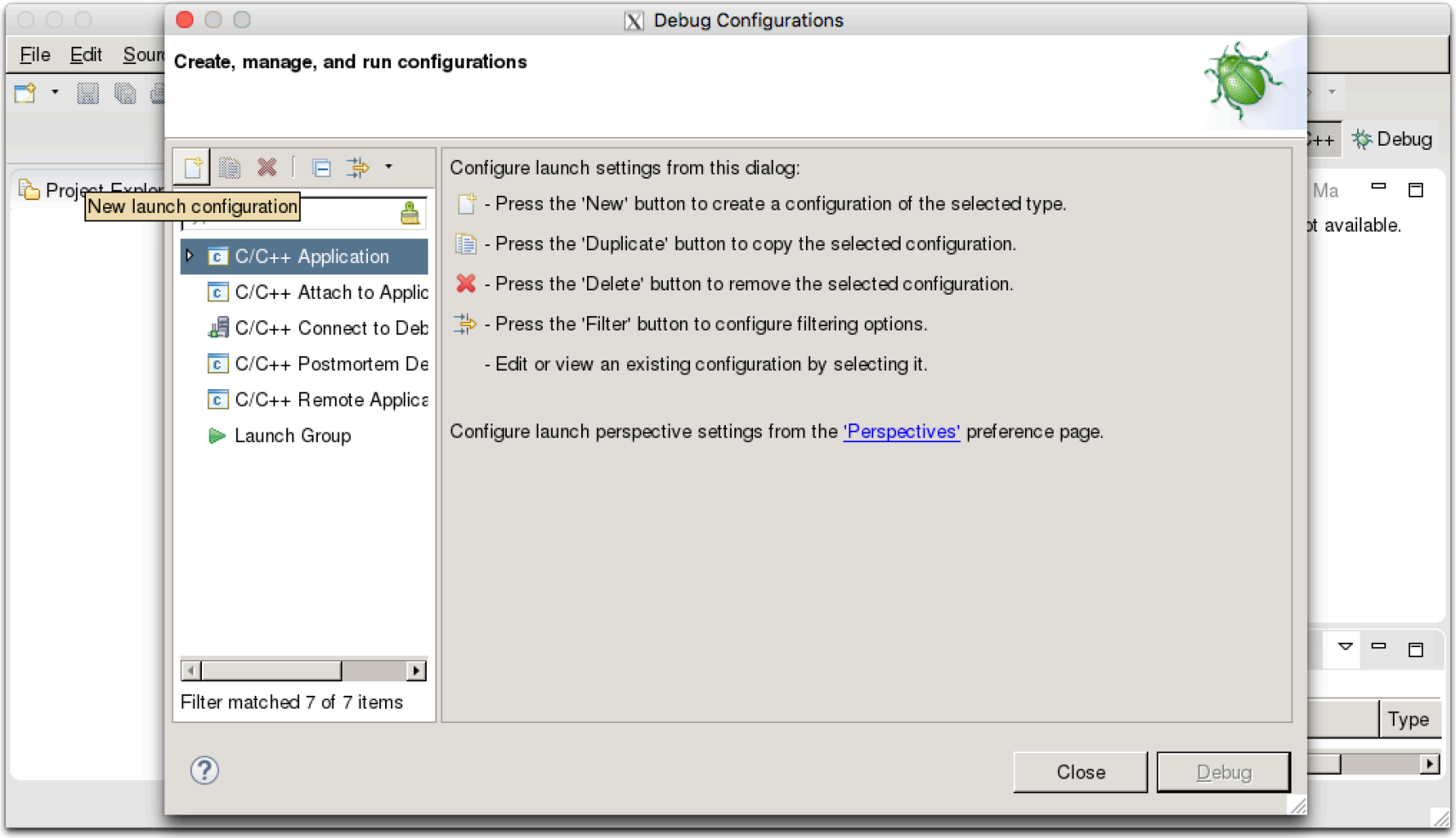
Choose *C/C++ Application*



Debug CUDA Program with Nsight EE

Setup

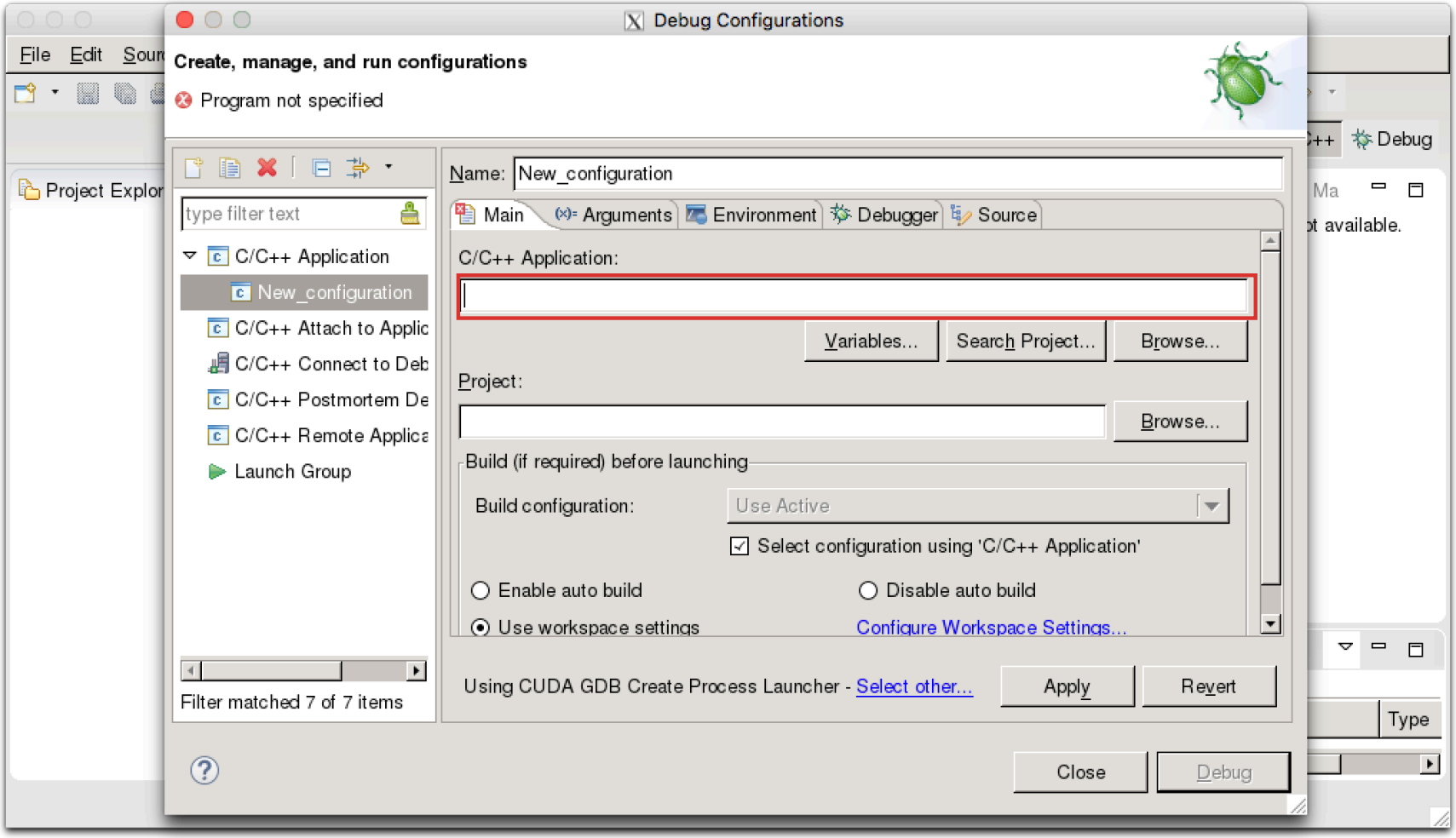
Create *New launch configuration*



Debug CUDA Program with Nsight EE

Setup

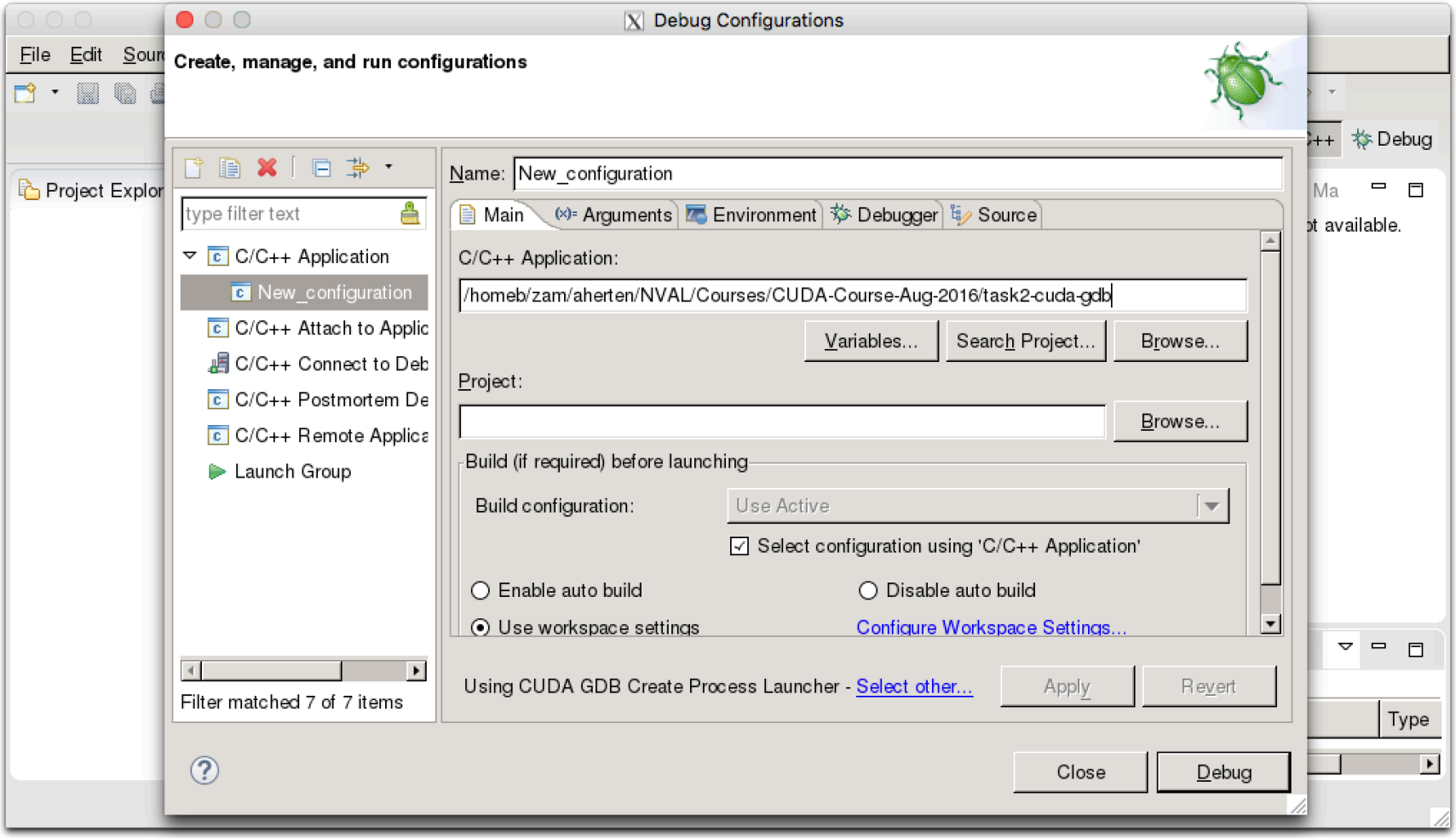
Insert path to executable



Debug CUDA Program with Nsight EE

Setup

Insert path to executable



Debug CUDA Program with Nsight EE

Setup

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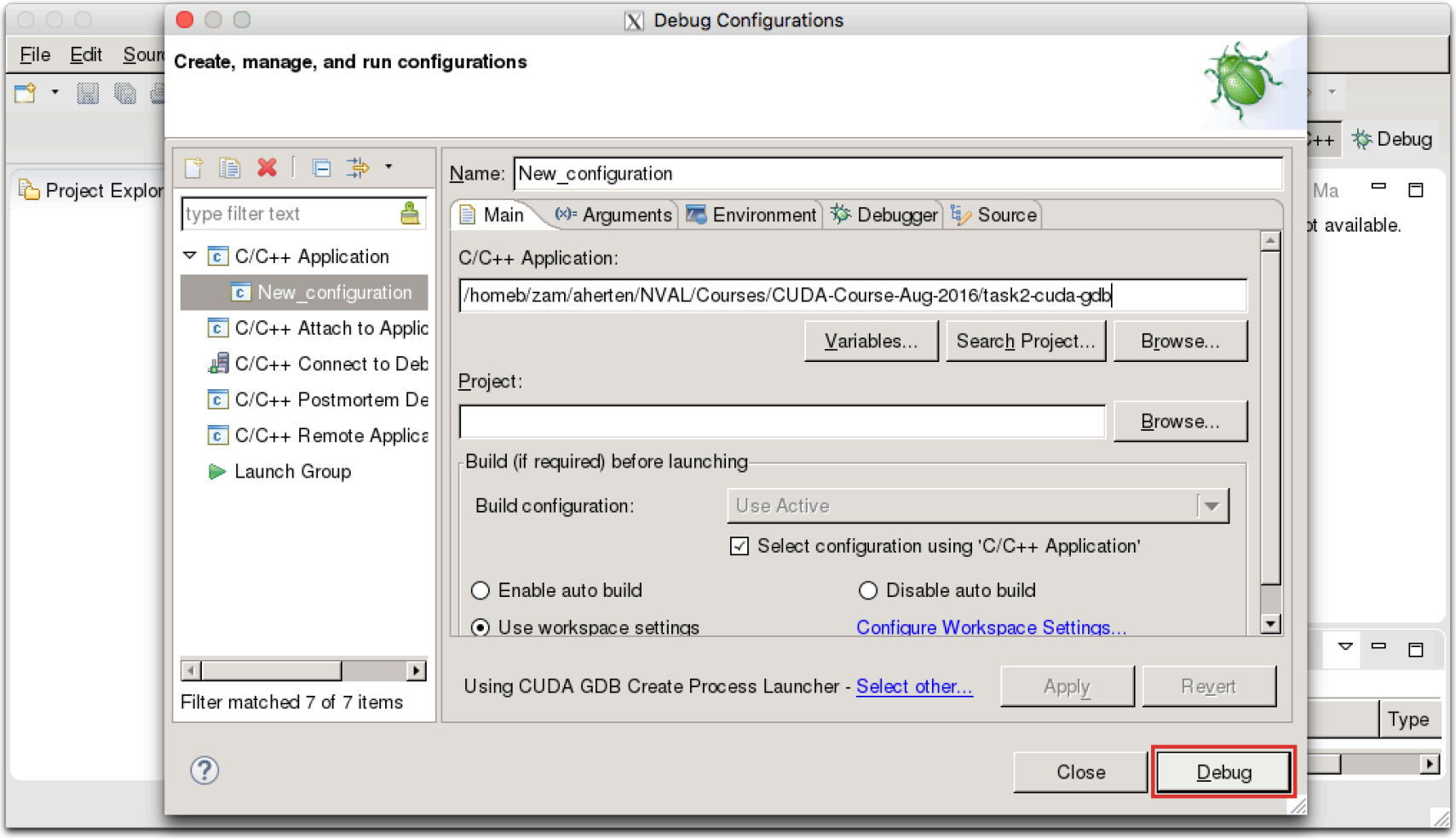
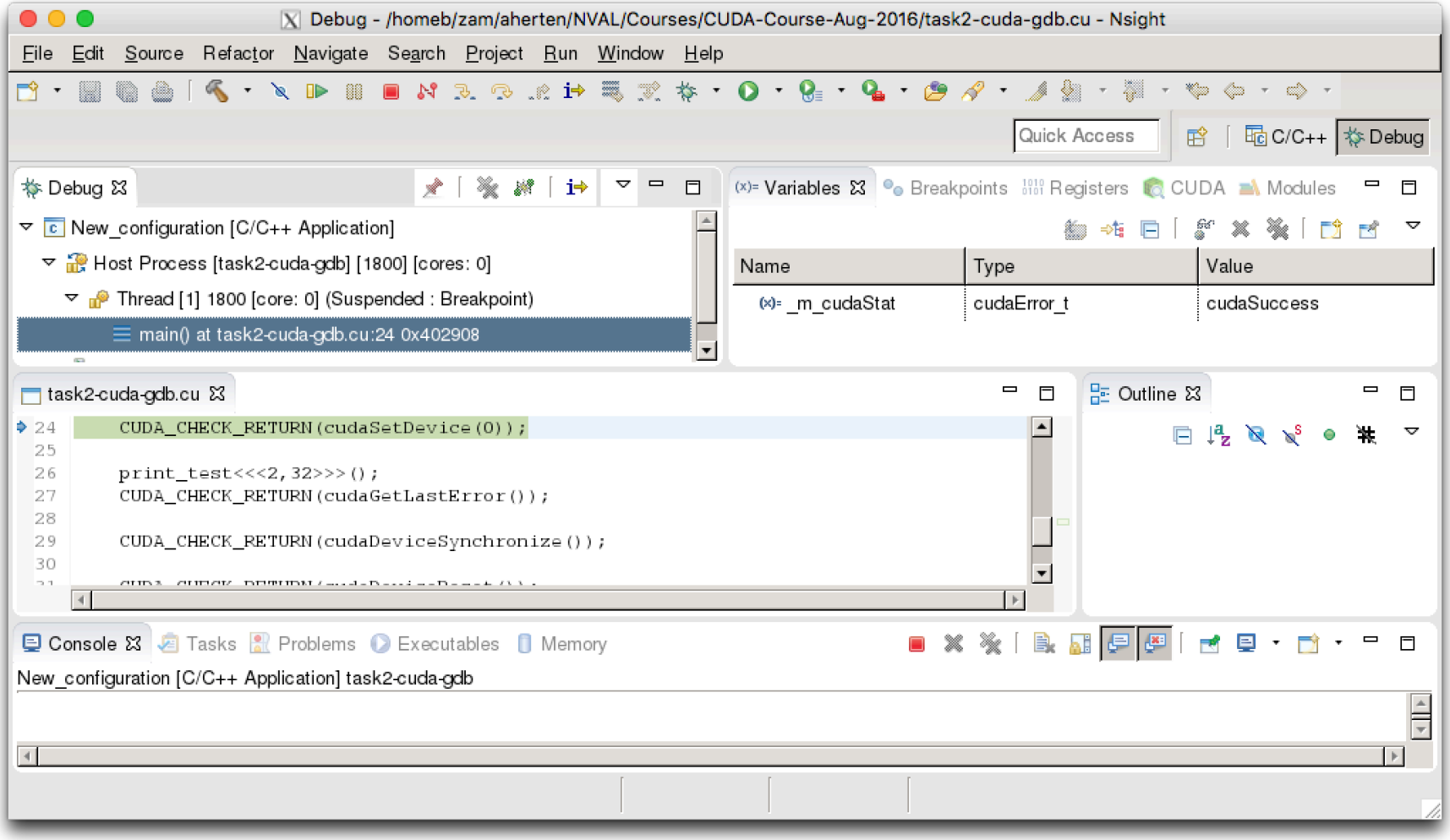
Click *Debug*



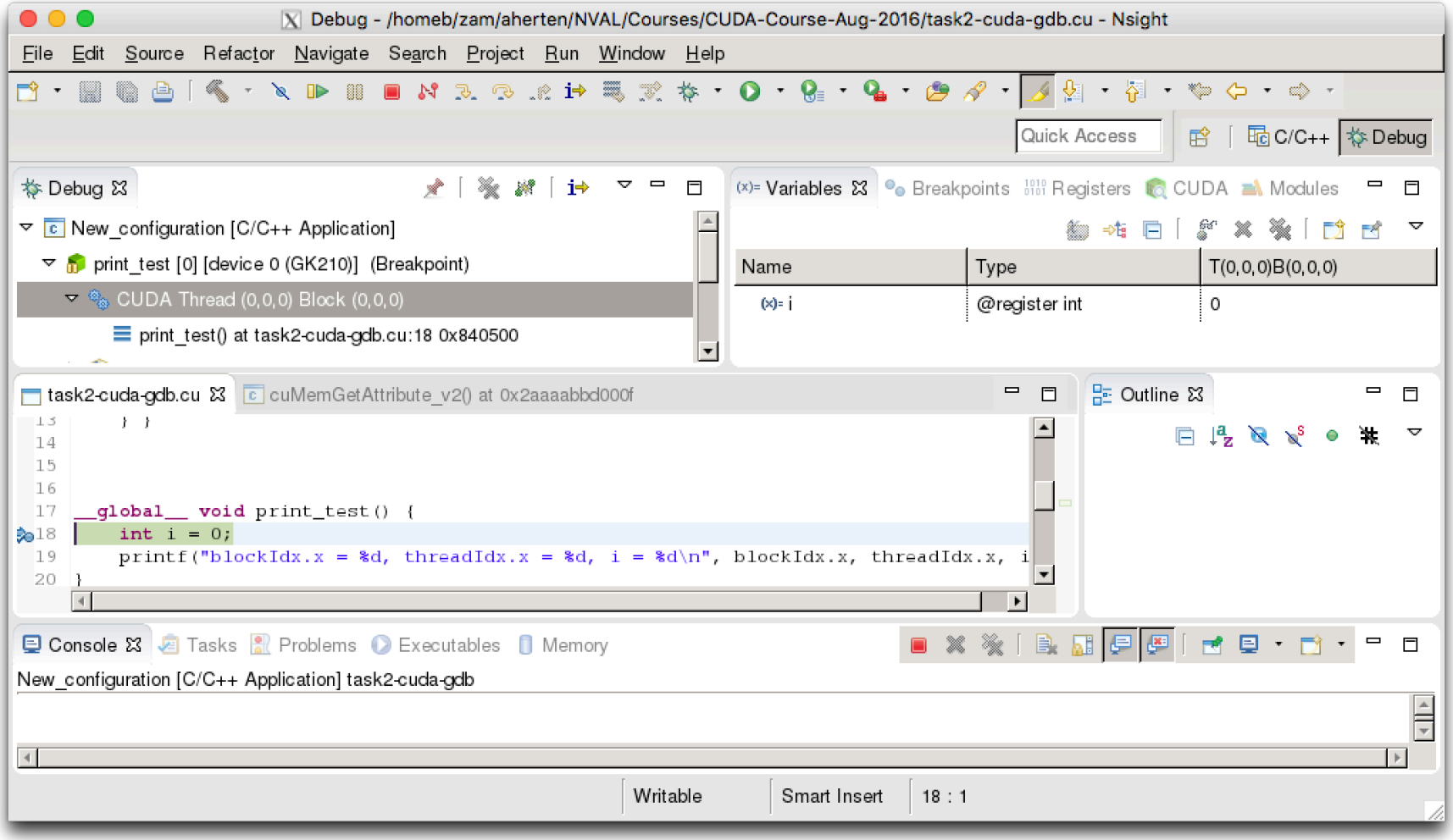
Debug CUDA Program with Nsight EE

Usage



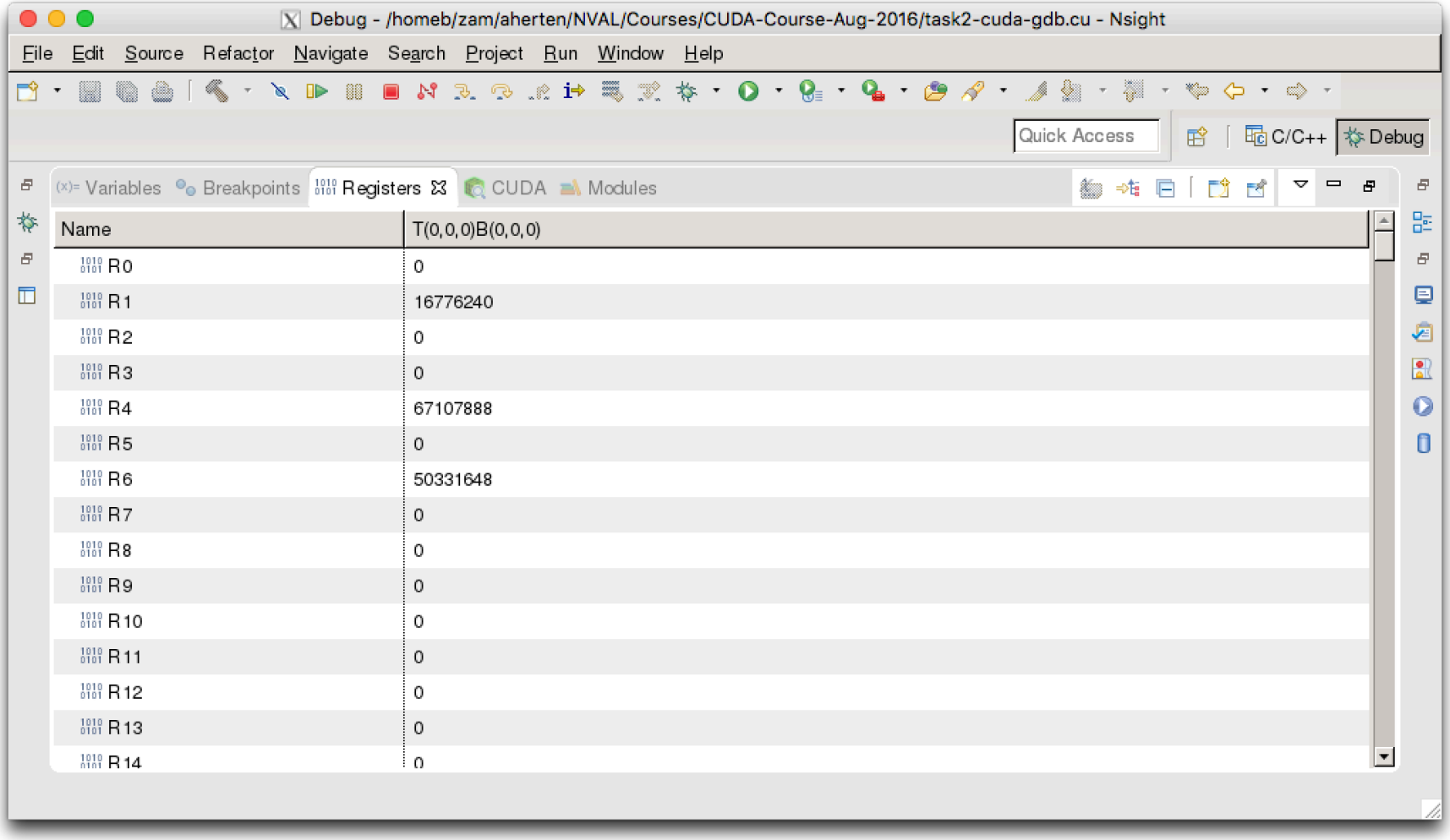
Debug CUDA Program with Nsight EE

Usage



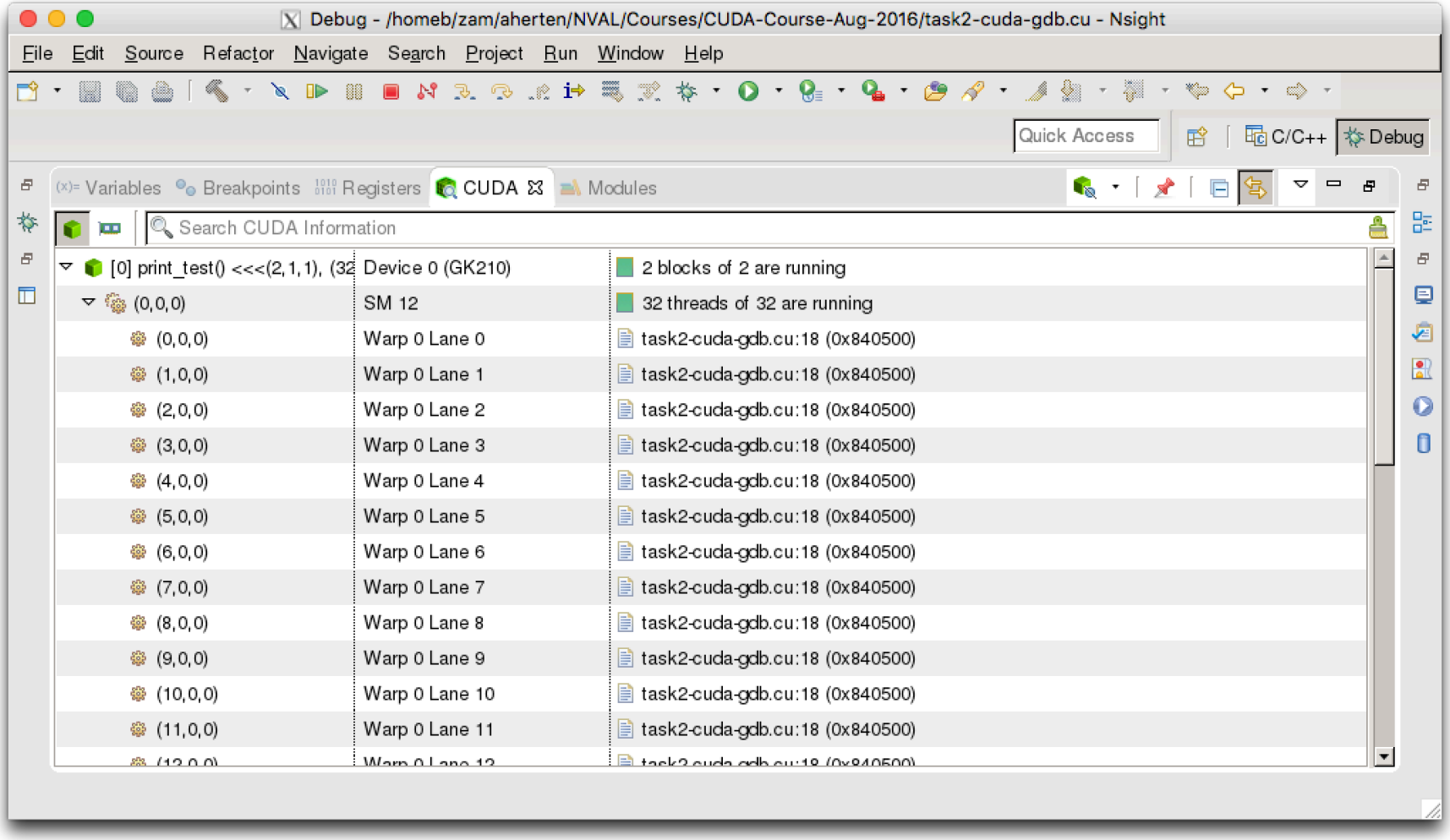
Debug CUDA Program with Nsight EE

Usage



Debug CUDA Program with Nsight EE

Usage



Task 1

Use `cuda-memcheck` to identify error

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- Location of code: `CUDATools/Exercises/Tasks/`
- Steps
  - Build:
    `make task1-cuda-memcheck`
  - Run:
    `cuda-memcheck ./task1-cuda-memcheck`
  - Fix!
    Look into `task1-cuda-memcheck.cu` and fix error; `cuda-memcheck` should run without errors!

JURECA Getting Started

```
module load GCC/4.9.3-2.25 CUDA/7.5.18
salloc --reservation=gpu-kurs --partition=gpus --nodes=1 --time=1:30:00 --gres=mem128,gpu:4
srun cuda-memcheck ./task1-cuda-memcheck
```

Task 2

Use Nsight Eclipse Edition to debug program

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- Location of code: `CUDATools/Exercises/Tasks/`
- Steps
  - Build program:
    `make task2-cuda-gdb`
  - Start Nsight Eclipse Edition:
    `nsight`
  - Setup debug session:
    See above
  - Let thread 4 from first block print 42 (instead of 0)
    Do not change the source code! Use the variable view.

JURECA Interactivity

```
module load GCC/4.9.3-2.25 CUDA/7.5.18
salloc --reservation=gpu-kurs --partition=gpus --nodes=1 --time=1:30:00 --gres=mem128,gpu:4
srun --forward-x --pty /bin/bash -i
nsight
```

Profiling

Motivation for Measuring Performance

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- **Improvement** possible only if program is **measured**

  Don't trust your gut!

- Identify:

  Hotspots Which functions take most of the time?

  Bottlenecks What are the limiters of performance?

- Manual timing possible, but tedious and error-prone
  Feasible for small applications, impractical for complex ones

- Easy access to hardware counters (PAPI, CUPTI)

nvprof

Command-line GPU profiler

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- Profiles CUDA kernels and API calls; also CPU code!
- Basic default profiling data, much more available with:
  - `--events E1,E2`: Measure specific events
    List available events via `--query-events`
  - `--metrics M1,M2`: Measure combined metrics
    List available metrics via `--query-metrics`
- Further useful options
  - `--export-profile`: Generate profiling data for Visual Profiler
    Handy together with `--analysis-metrics` (gather data for *analysis mode* of Visual Profiler)
  - `--print-gpu-trace`: Show trace of function calls
  - `--unified-memory-profiling per-process-device`: Print unified memory profiling information
    Prevent zero-copy fallback with `CUDA_MANAGED_FORCE_DEVICE_ALLOC=1`
    Attention with Multi-GPU setups!
  - `--help`: For all the rest…

→ `http://docs.nvidia.com/cuda/profiler-users-guide/`

nvprof

Example I

Start via `nvprof` *PROGRAM*

Tasks — ssh jureca -X — ssh jureca -X

..urse-2016-Aug | jureca

```
aherten@jrl11:~/NVAL/Courses/CUDA-Course-Aug-2016$ srun nvprof ./task3-scale_vector_um
==32741== NVPROF is profiling process 32741, command: ./task3-scale_vector_um
==32741== Profiling application: ./task3-scale_vector_um
==32741== Profiling result:
Time(%)      Time     Calls       Avg       Min       Max  Name
100.00%  4.0960us         1  4.0960us  4.0960us  4.0960us  scale(float, float*, float*, int)

==32741== API calls:
Time(%)      Time     Calls       Avg       Min       Max  Name
 99.15%  215.42ms         2  107.71ms  44.070us  215.37ms  cudaMallocManaged
  0.58%  1.2695ms       166  7.6470us     100ns  298.86us  cuDeviceGetAttribute
  0.09%  204.39us         2  102.19us  20.279us  184.11us  cudaFree
  0.06%  138.65us         2  69.327us  69.133us  69.521us  cuDeviceTotalMem
  0.06%  124.73us         2  62.365us  55.657us  69.074us  cuDeviceGetName
  0.03%  74.989us         1  74.989us  74.989us  74.989us  cudaLaunch
  0.01%  17.613us         1  17.613us  17.613us  17.613us  cudaDeviceSynchronize
  0.00%  10.225us         1  10.225us  10.225us  10.225us  cudaSetDevice
  0.00%  10.041us         4  2.5100us     143ns  8.9340us  cudaSetupArgument
  0.00%  1.7620us         2     881ns     355ns  1.4070us  cuDeviceGetCount
  0.00%  1.7040us         1  1.7040us  1.7040us  1.7040us  cudaConfigureCall
  0.00%     935ns         4     233ns     116ns     469ns  cuDeviceGet
Passed!
```

nvprof

Example II

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nvprof --metrics inst_execu[…] --cpu-profiling on *PROGRAM*

Tasks — ssh jureca -X — ssh jureca -X

..urse-2016-Aug | jureca

```
aherten@jrl11:~/NVAL/Courses/CUDA-Course-Aug-2016$ srun nvprof --metrics inst_executed,inst_issued,issued_ipc,flop_count_sp,flop_cou
nt_dp --cpu-profiling on ./task3-scale_vector_um
==787== NVPROF is profiling process 787, command: ./task3-scale_vector_um
==787== Some kernel(s) will be replayed on device 0 in order to collect all events/metrics.
==787== Profiling application: ./task3-scale_vector_um
==787== Profiling result:
==787== Metric result:
Invocations                               Metric Name                        Metric Description         Min         Max         Avg
Device "Tesla K80 (0)"
       Kernel: scale(float, float*, float*, int)
         1                            inst_executed                     Instructions Executed        1088        1088        1088
         1                              inst_issued                       Instructions Issued        1576        1576        1576
         1                               issued_ipc                                Issued IPC    0.094433    0.094433    0.094433
         1                            flop_count_sp  Floating Point Operations(Single Precisi        2048        2048        2048
         1                            flop_count_dp  Floating Point Operations(Double Precisi           0           0           0
Passed!

======== CPU profiling result (bottom up):
38.89% cudbgGetAPIVersion
| 38.89% start_thread
|   38.89% clone
30.56% cuDevicePrimaryCtxRetain
| 30.56% cudart::contextStateManager::initPrimaryContext(cudart::device*)
```

Visual Profiler

The insight provider

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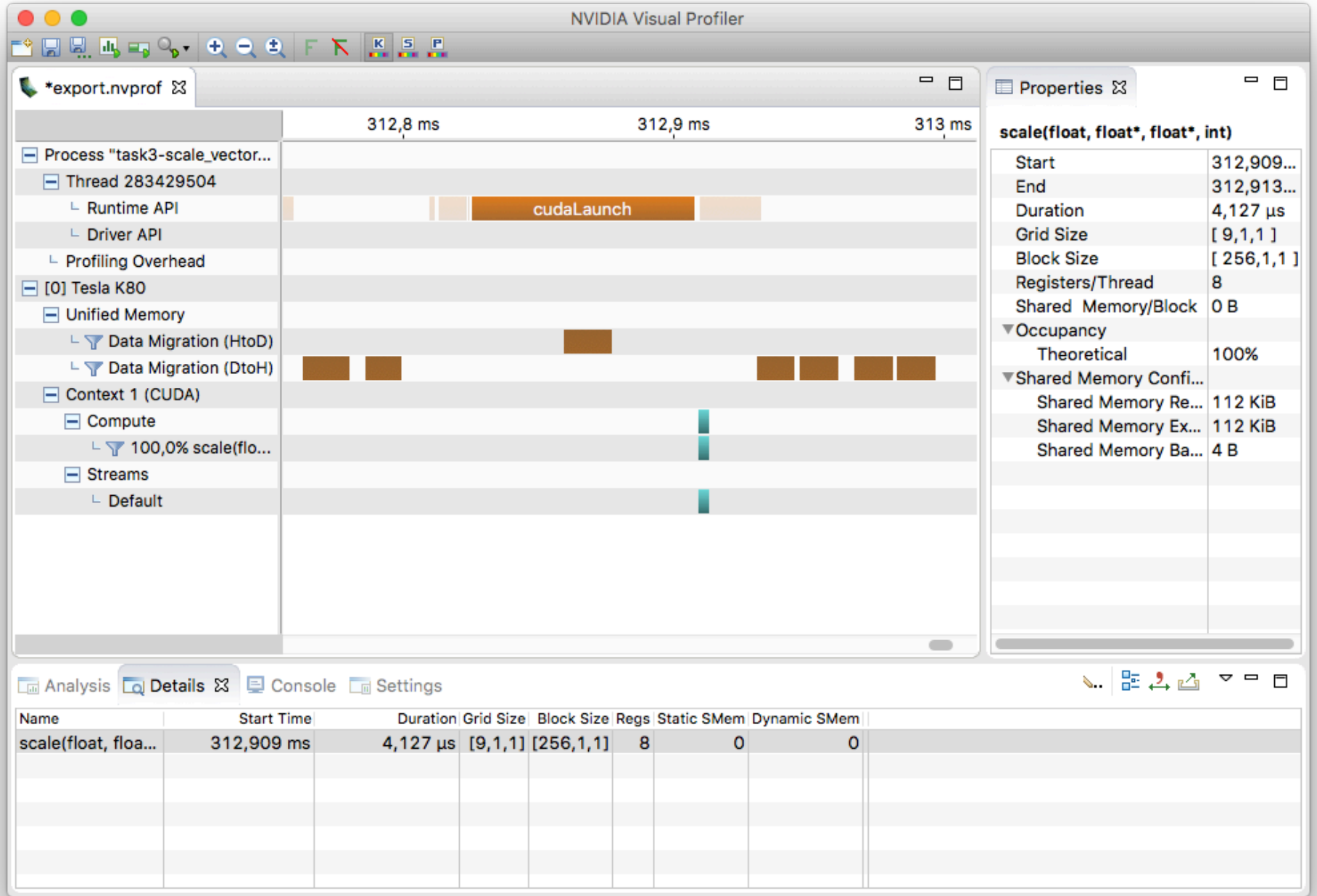
- Timeline view of all things GPU (API calls, kernels, memory)
- View launch and run configurations
- Guided and unguided analysis, with (among others):
  - Performance limiters
  - Kernel and execution properties
  - Memory access patterns
- NVIDIA Tools Extension NVTX (for annotation)

→ `https://developer.nvidia.com/nvidia-visual-profiler`


NVIDIA Visual Profiler
*export.nvprof
312,8 ms
312,9 ms
313 ms
Process "task3-scale_vector...
Thread 283429504
Runtime API
Driver API
Profiling Overhead
[0] Tesla K80
Unified Memory
Data Migration (HtoD)
Data Migration (DtoH)
Context 1 (CUDA)
Compute
100,0% scale(flo...
Streams
Default
cudaLaunch
Properties
scale(float, float*, float*, int)
Start 312,909...
End 312,913...
Duration 4,127 µs
Grid Size [9,1,1]
Block Size [256,1,1]
Registers/Thread 8
Shared Memory/Block 0 B
Occupancy
Theoretical 100%
Shared Memory Confi...
Shared Memory Re... 112 KiB
Shared Memory Ex... 112 KiB
Shared Memory Ba... 4 B
Analysis
Details
Console
Settings
Name Start Time Duration Grid Size Block Size Regs Static SMem Dynamic SMem
scale(float, floa... 312,909 ms 4,127 µs [9,1,1] [256,1,1] 8 0 0

Task 3

Analyze and profile `scale_vector_um`

Do any (all?) of the following:

A. Use `nvprof` to gather profile, Visual Profiler for viewing
   - Use `nvprof` to write `scale_vector_um`'s timeline to file
   - Import to Visual Profiler
   - Use `nvprof` to add metric information to timeline
   - Import, run guided analysis in Visual Profiler

B. Use Visual Profiler for everything
   - Start an interactive session on JURECA
   - Launch Visual Profiler (`nvvp`)
   - Start, profile, and run guided analysis in Visual Profiler

JURECA Reminder

```
module load GCC/4.9.3-2.25 CUDA/7.5.18
salloc --reservation=gpu-kurs --partition=gpus --nodes=1 --time=1:30:00 --gres=mem128,gpu:2


  srun nvprof ./scale_vector_um                    srun --forward-x --pty /bin/bash -i
                                                   nvvp
```

Summary

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- NVIDIA has handy tools to gain insight into application
- Debugging:
  - `cuda-memcheck`
  - `cuda-gdb`
  - Nsight Eclipse Edition
- Profiling:
  - nvprof
  - Visual Profiler
- All come with the CUDA Toolkit

Thank you!

Slides based on Jiri Kraus' *CUDA Tools* presentation