MODULE TWO: PROFILING

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OpenACC
More Science, Less Programming

MODULE OVERVIEW

Topics to be covered

- Compiling and profiling sequential code
- Explanation of multicore programming
- Compiling and profiling multicore code

COMPILING SEQUENTIAL CODE

NVIDIA'S HPC COMPILERS (AKA PGI)

NVIDIA Compiler Names (PGI names still work)

- nvc - The command to compile C code (formerly known as 'pgcc')
- nvc++ - The command to compile C++ code (formerly known as 'pgc++')
- nvfortran - The command to compile Fortran code (formerly known As pgfortran/pgf90/pgf95/pgf77)
- The -fast flag instructs the compiler to optimize the code to the best of its abilities

```
$ nvc –fast main.c
$ nvc++ -fast main.cpp
$ nvfortran –fast main.F90
```

```
$ pgcc –fast main.c
$ pgc++ -fast main.cpp
$ pgfortran –fast main.F90
```

NVIDIA’S HPC COMPILERS (AKA PGI)

-Minfo flag

- The Minfo flag will instruct the compiler to print feedback about the compiled code
- -Minfo=accel will give us information about what parts of the code were accelerated via OpenACC
- -Minfo=opt will give information about all code optimizations
- -Minfo=all will give all code feedback, whether positive or negative

```
$ pgcc –fast –Minfo=all main.c
$ pgc++ -fast -Minfo=all main.cpp
$ pgfortran –fast –Minfo=all main.f90
```

NVIDIA NSIGHT FAMILY

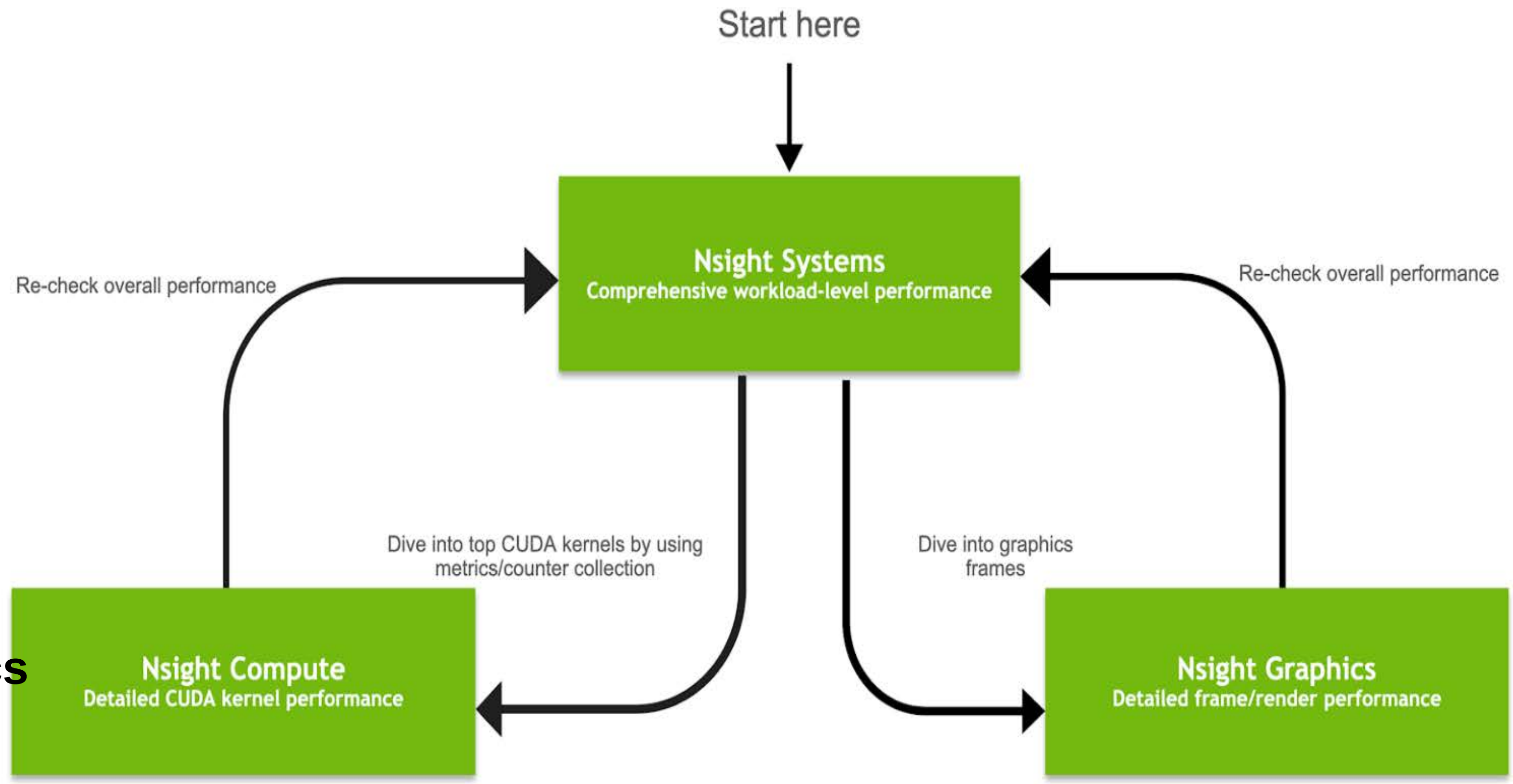
Nsight Product Family

Workflow

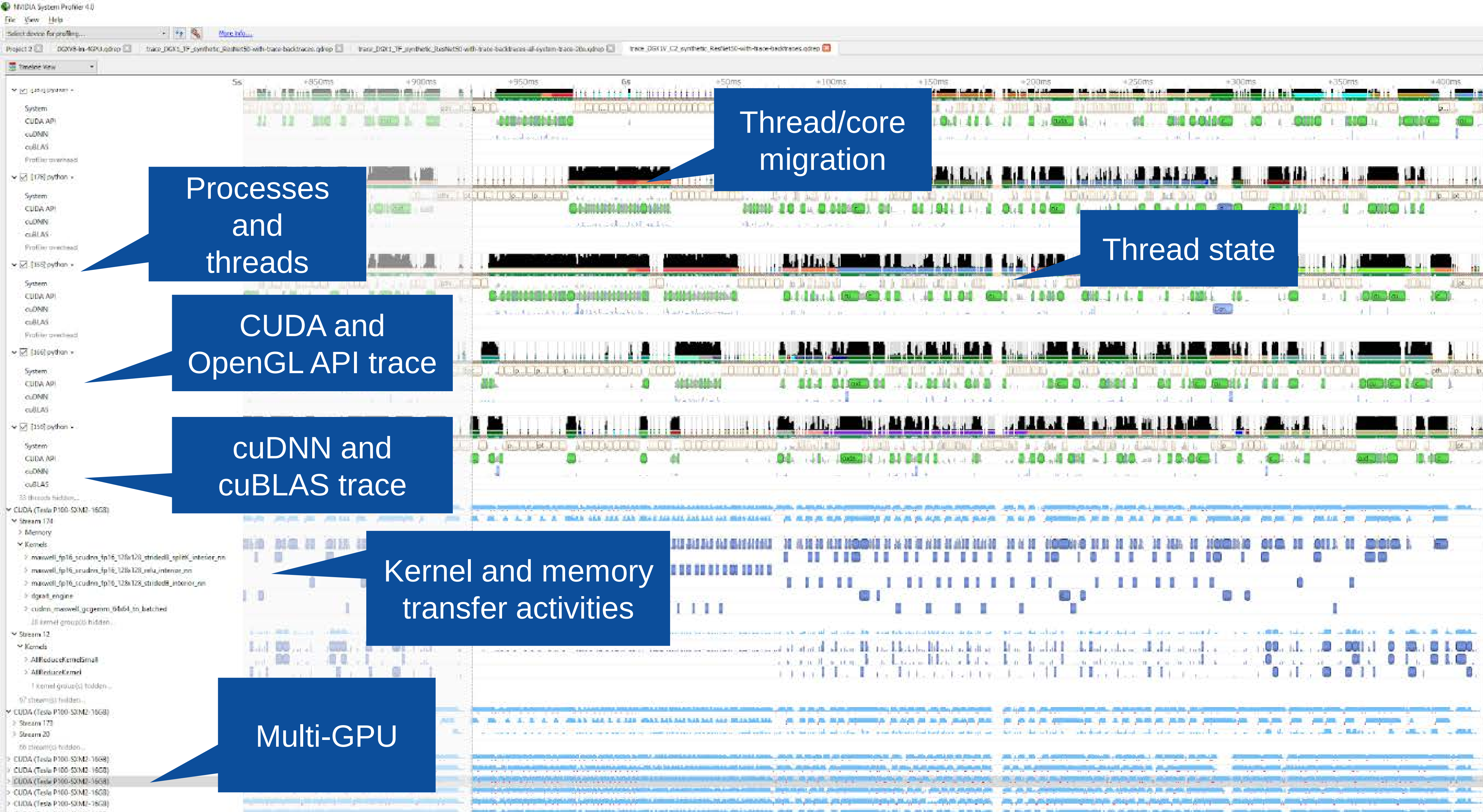
Nsight Systems - Analyze application algorithm system-wide

Nsight Compute - Debug/optimize CUDA kernel

Nsight Graphics - Debug/optimize graphics workloads



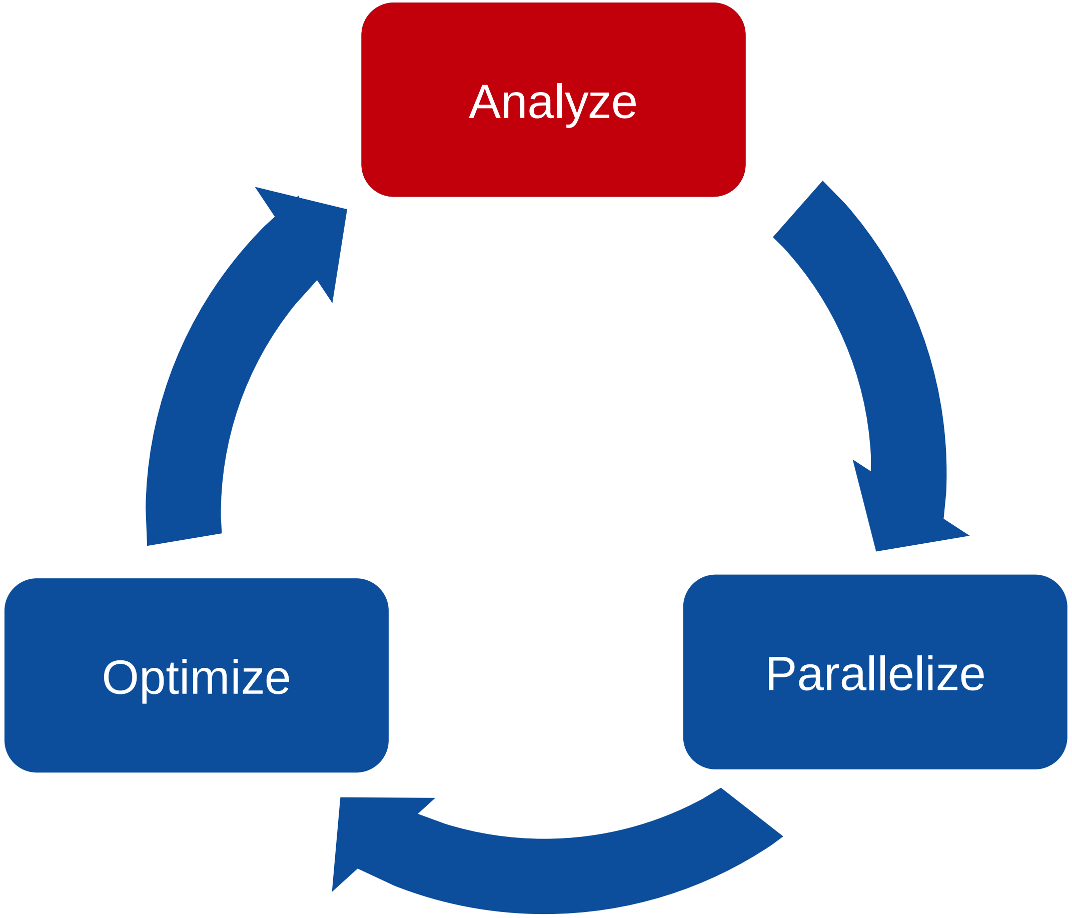
OpenACC


Thread/core migration
Processes and threads
Thread state
CUDA and OpenGL API trace
cuDNN and cuBLAS trace
Kernel and memory transfer activities
Multi-GPU

PROFILING SEQUENTIAL CODE

OPENACC DEVELOPMENT CYCLE

- **Analyze** your code to determine most likely places needing parallelization or optimization.
- **Parallelize** your code by starting with the most time consuming parts, check for correctness and then analyze it again.
- **Optimize** your code to improve observed speed-up from parallelization.



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PROFILING SEQUENTIAL CODE

Step 1: Run Your Code

Record the time it takes for your sequential program to run.

Note the final results to verify correctness later.

Always run a problem that is representative of your real jobs.

Terminal Window

```
$ pgcc -fast jacobi.c laplace2d.c
$ ./a.out
    0, 0.250000
  100, 0.002397
  200, 0.001204
  300, 0.000804
  400, 0.000603
  500, 0.000483
  600, 0.000403
  700, 0.000345
  800, 0.000302
  900, 0.000269
  total: 39.432648 s
```

PROFILING SEQUENTIAL CODE

Step 2: Profile Your Code

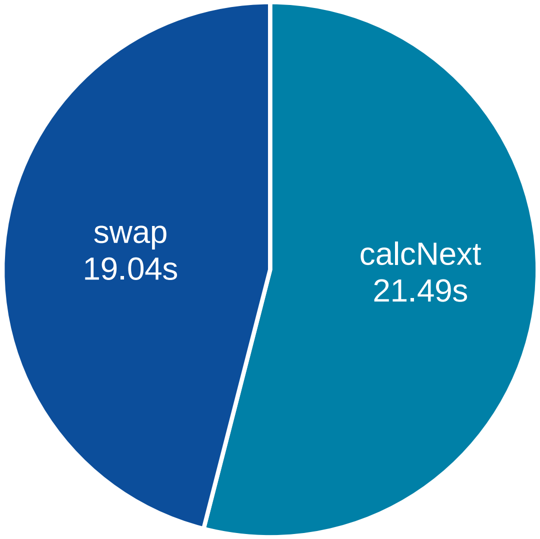
Obtain detailed information about how the code ran.

This can include information such as:
- Total runtime
- Runtime of individual routines
- Hardware counters

Identify the portions of code that took the longest to run. We want to focus on these “hotspots” when parallelizing.

Lab Code: Laplace Heat Transfer

Total Runtime: 39.43 seconds



PROFILING WITH NSIGHT SYSTEM AND NVTX

PROFILING SEQUENTIAL CODE

Using Command Line Interface (CLI)

NVIDIA Nsight Systems CLI provides

- Simple interface to collect data
- Can be copied to any system and analysed later
- Profiles both serial and parallel code
- For more info enter `nsys --help` on the terminal

To profile a serial application with NVIDIA Nsight Systems, we use NVIDIA Tools Extension (NVTX) API functions in addition to collecting backtraces while sampling.

PROFILING SEQUENTIAL CODE

NVIDIA Tools Extension API (NVTX) library

What is it?

- A C-based Application Programming Interface (API) for annotating events
- Can be easily integrated to the application
- Can be used with NVIDIA Nsight Systems

Why?

- Allows manual instrumentation of the application
- Allows additional information for profiling (e.g: tracing of CPU events and time ranges)

How?

- Import the header only C library `nvToolsExt.h`
- Wrap the code region or a specific function with `nvtxRangePush()` and `nvtxRangPop()`

```c
#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#include <omp.h>
#include "laplace2d.h"
#include <nvtx3/nvToolsExt.h>

int main(int argc, char** argv)
{
    const int n = 4096;
    const int m = 4096;
    const int iter_max = 1000;

    const double tol = 1.0e-6;
    double error = 1.0;

    double *restrict A    = (double*)malloc(sizeof(double)*n*m);
    double *restrict Anew = (double*)malloc(sizeof(double)*n*m);

    nvtxRangePushA("init");
    initialize(A, Anew, m, n);
    nvtxRangePop();

    printf("Jacobi relaxation Calculation: %d x %d mesh\n", n, m);

    double st = omp_get_wtime();
    int iter = 0;

    nvtxRangePushA("while");
    while ( error > tol && iter < iter_max )
    {
        nvtxRangePushA("calc");
        error = calcNext(A, Anew, m, n);
        nvtxRangePop();

        nvtxRangePushA("swap");
        swap(A, Anew, m, n);
        nvtxRangePop();

        if(iter % 100 == 0) printf("%5d, %0.6f\n", iter, error);

        iter++;
    }
    nvtxRangePop();

    double runtime = omp_get_wtime() - st;

    printf(" total: %f s\n", runtime);

    deallocate(A, Anew);

    return 0;
}
```

jacobi.c
(starting and ending of ranges are **highlighted** with the **same** color)

`-t`	Selects the APIs to be traced (nvtx in this example)
`--status`	if true, generates summary of statistics after the collection
`-b`	Selects the backtrace method to use while sampling. The option dwarf uses DWARF's CFI (Call Frame Information).
`--force-overwrite`	if true, overwrites the existing results
`-o`	sets the output (qdrep) filename

```
mozhgank@prm-dgx-32:~/Code/openacc-training-materials/labs/module4/English/C/solutions/parallel$ nsys profile -t nvtx --stats=true -b dwarf --force-overwrite true -o laplace-seq ./laplace-seq
Collecting data...
Jacobi relaxation Calculation: 4096 x 4096 mesh
    0, 0.250000
  100, 0.002397
  200, 0.001204
  300, 0.000804
  400, 0.000603
  500, 0.000483
  600, 0.000403
  700, 0.000345
  800, 0.000302
  900, 0.000269
 total: 55.754501 s
Processing events...
Capturing symbol files...
Saving intermediate "/home/mozhgank/Code/openacc-training-materials/labs/module4/English/C/solutions/parallel/laplace-seq.qdstrm" file to disk...

Importing [==============================================================100%]
Saved report file to "/home/mozhgank/Code/openacc-training-materials/labs/module4/English/C/solutions/parallel/laplace-seq.qdrep"
Exporting 70802 events: [=============================================100%]

Exported successfully to
/home/mozhgank/Code/openacc-training-materials/labs/module4/English/C/solutions/parallel/laplace-seq.sqlite

Generating NVTX Push-Pop Range Statistics...
NVTX Push-Pop Range Statistics (nanoseconds)

Time(%)      Total Time   Instances         Average         Minimum         Maximum  Range
-------  --------------  ----------  --------------  --------------  --------------  --------
   49.9     55754497966           1   55754497966.0     55754497966     55754497966  while
   26.5     29577817696        1000      29577817.7        29092956        65008545  calc
   23.4     26163892482        1000      26163892.5        25761418        60129514  swap
    0.1       137489808           1     137489808.0       137489808       137489808  init
```

NVTX range statistics

"calc" region (calcNext function) takes 26.6% "swap" region (swap function) takes 23.4% of total execution time

Open laplace-seq.qdrep with Nsight System GUI to view the timeline

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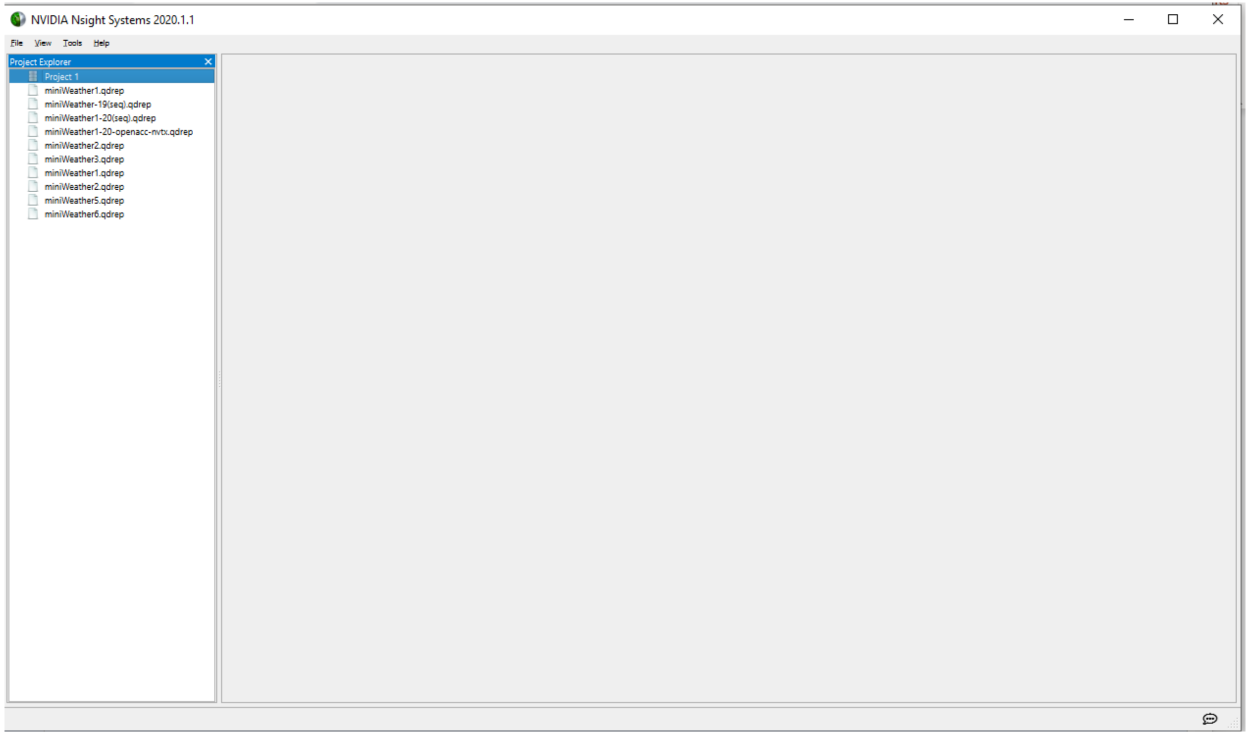
PROFILING SEQUENTIAL CODE

Using Nsight Systems

Open the generated report files (*.qdrep) from command line in the Nsight Systems profiler.

File > Open



PROFILING SEQUENTIAL CODE

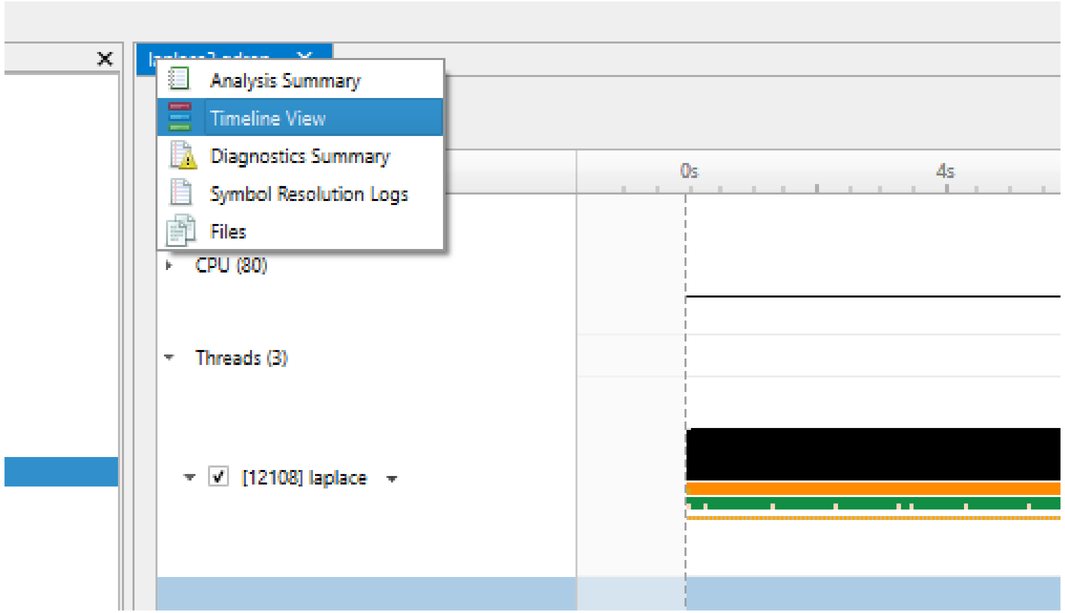
Using Nsight Systems

Navigate through the "view selector".

"Analysis summary" shows a summary of the profiling session. To review the project configuration used to generate this report, see next slide.

"Timeline View" contains the timeline at the top, and a bottom pane that contains the events view and the function table.

Read more: https://docs.nvidia.com/nsight-systems



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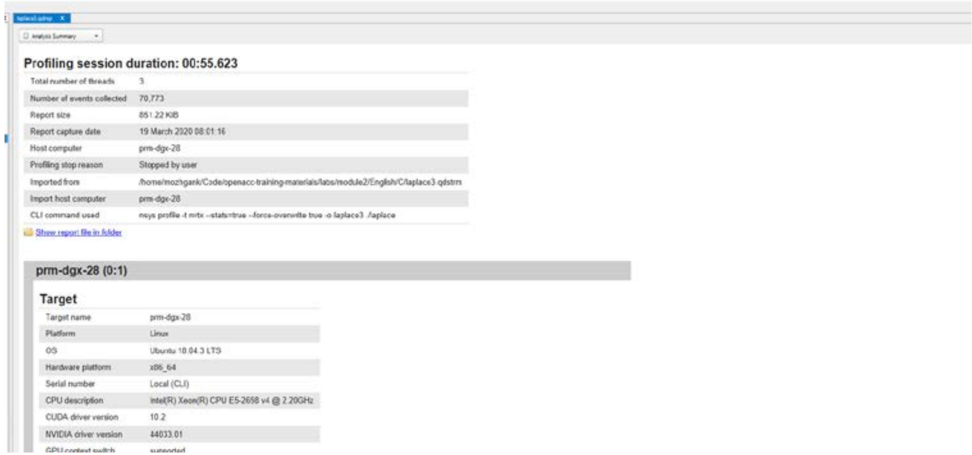
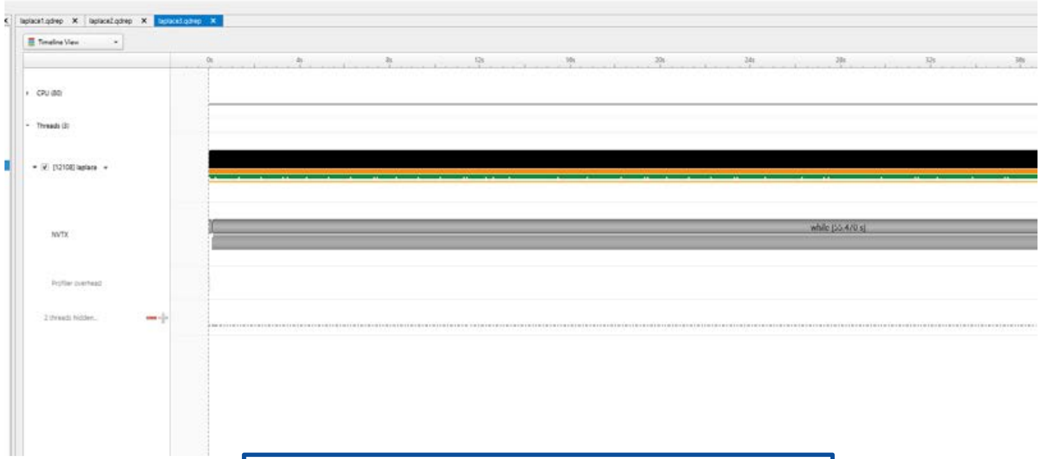
PROFILING SEQUENTIAL CODE

Using Nsight Systems



Analysis Summary



Timeline view
(charts and the hierarchy on the top pane)

Timeline view
(event view and function table on the bottom pane)

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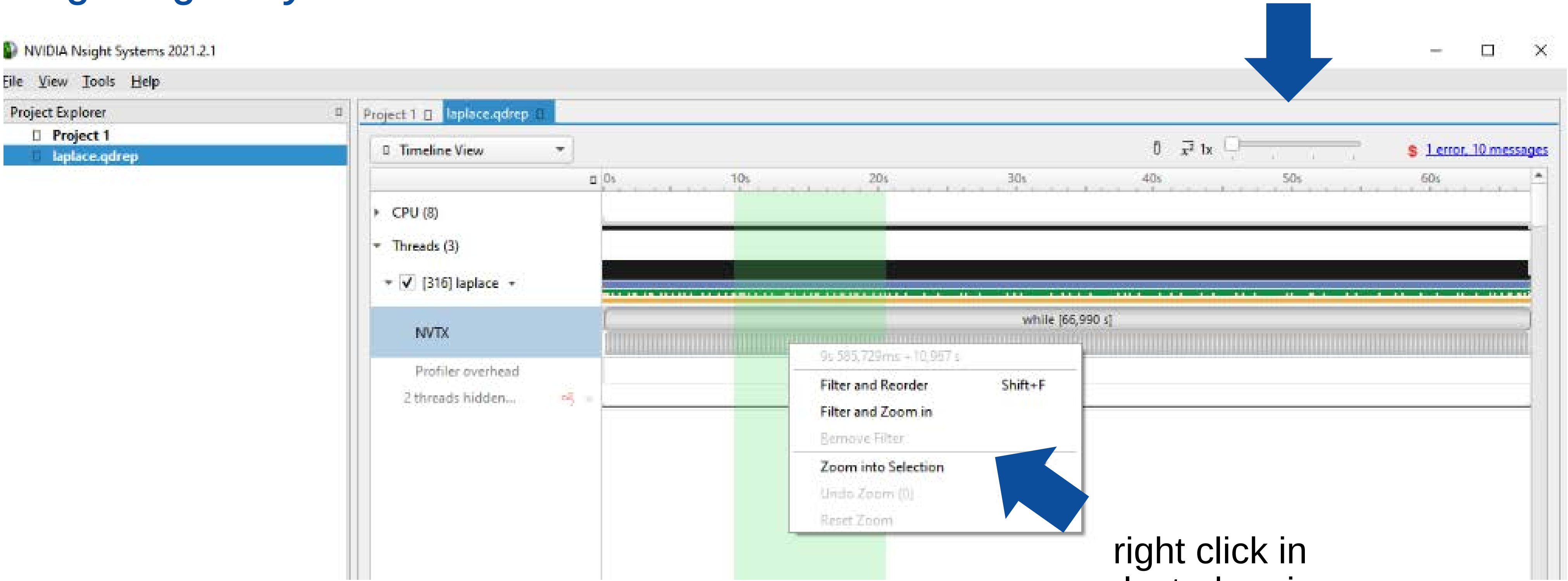
PROFILING SEQUENTIAL CODE

Using Nsight Systems

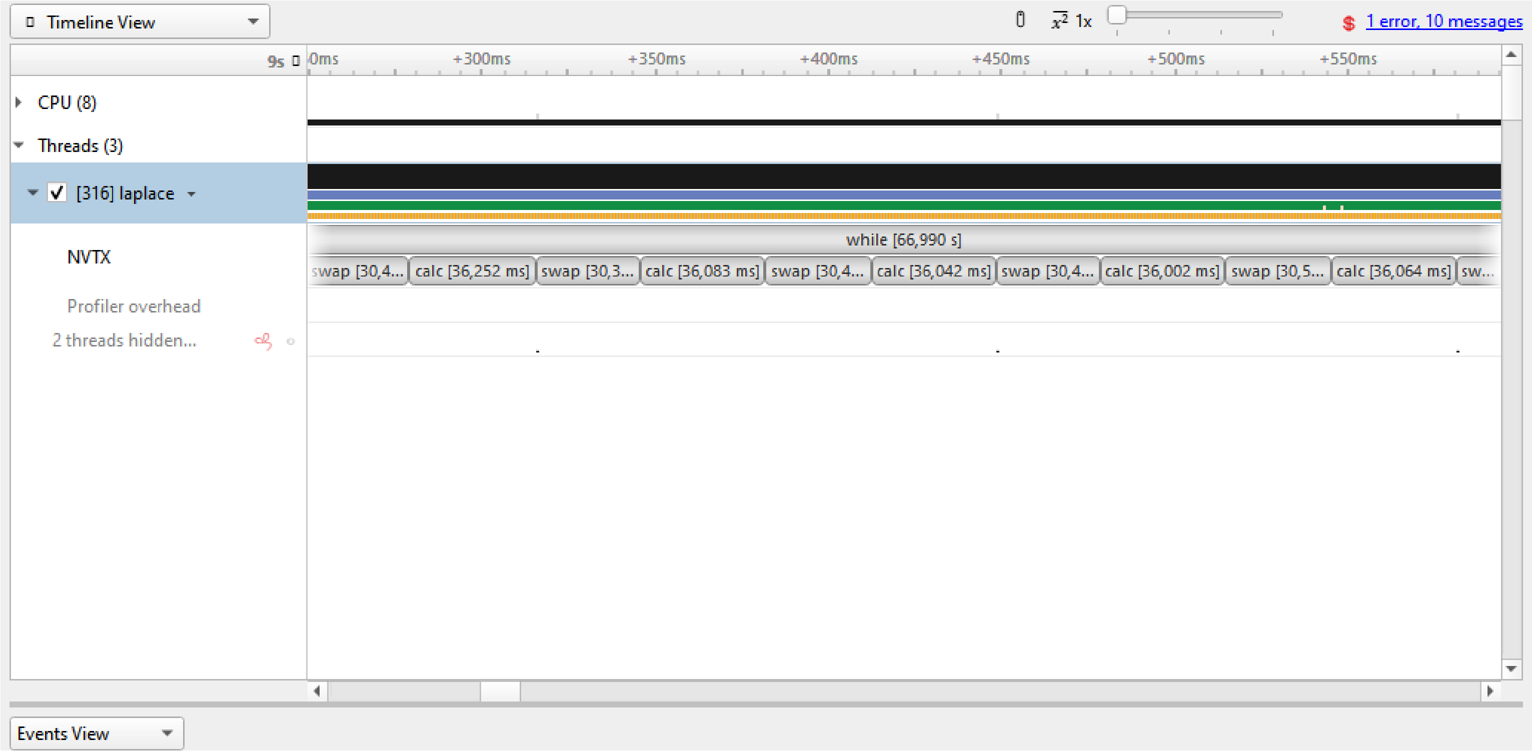
Enlarge view!



right click in selected region and Zoom into selection!

PROFILING SEQUENTIAL CODE

Using Nsight Systems

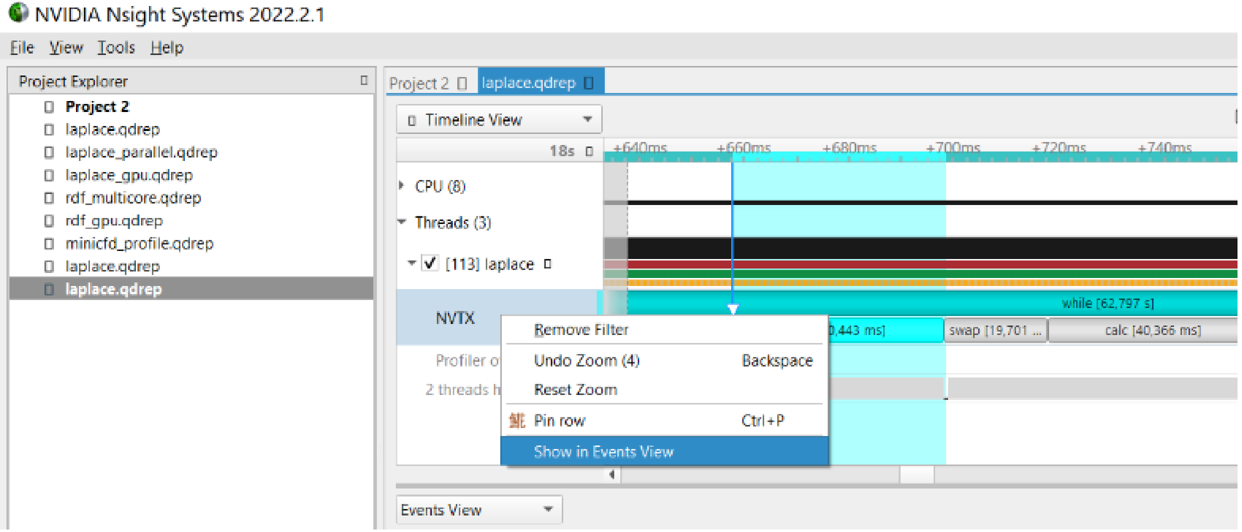


PROFILING SEQUENTIAL CODE

Viewing captured NVTX events and time ranges via Nsight Systems GUI

From the Timeline view, right click on the “NVTX” from the top pane and choose “Show in Events View”.

From the bottom pane, you can now see name of the events captured with the duration.



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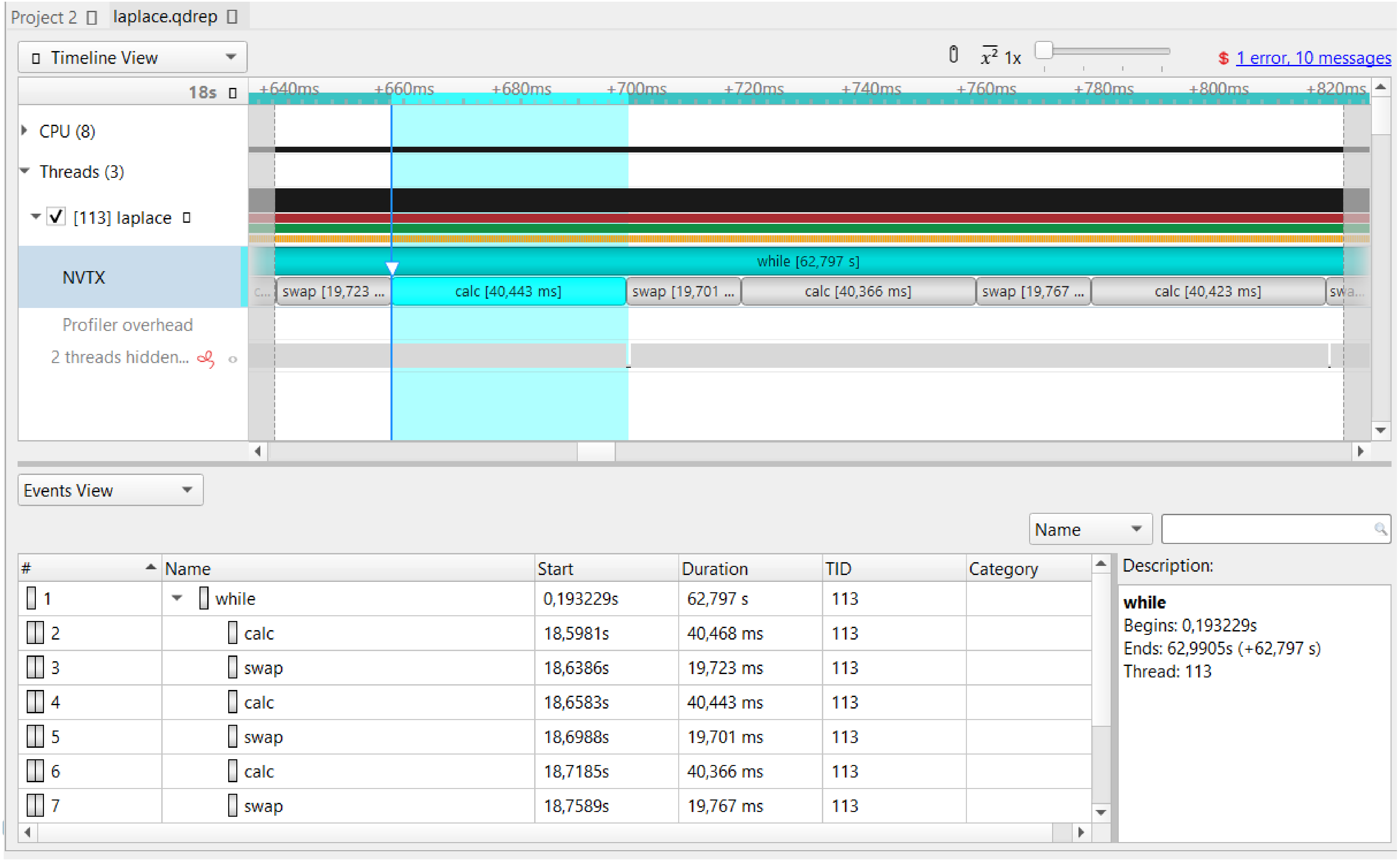

Project 2
laplace.qdrep
Timeline View
1x
1 error, 10 messages
18s
+640ms
+660ms
+680ms
+700ms
+720ms
+740ms
+760ms
+780ms
+800ms
+820ms
CPU (8)
Threads (3)
[113] laplace
NVTX
while [62,797 s]
swap [19,723 ...
calc [40,443 ms]
swap [19,701 ...
calc [40,366 ms]
swap [19,767 ...
calc [40,423 ms]
Profiler overhead
2 threads hidden...
Events View
Name
Name Start Duration TID Category
1 while 0,193229s 62,797 s 113
2 calc 18,5981s 40,468 ms 113
3 swap 18,6386s 19,723 ms 113
4 calc 18,6583s 40,443 ms 113
5 swap 18,6988s 19,701 ms 113
6 calc 18,7185s 40,366 ms 113
7 swap 18,7589s 19,767 ms 113
Description:
while
Begins: 0,193229s
Ends: 62,9905s (+62,797 s)
Thread: 113

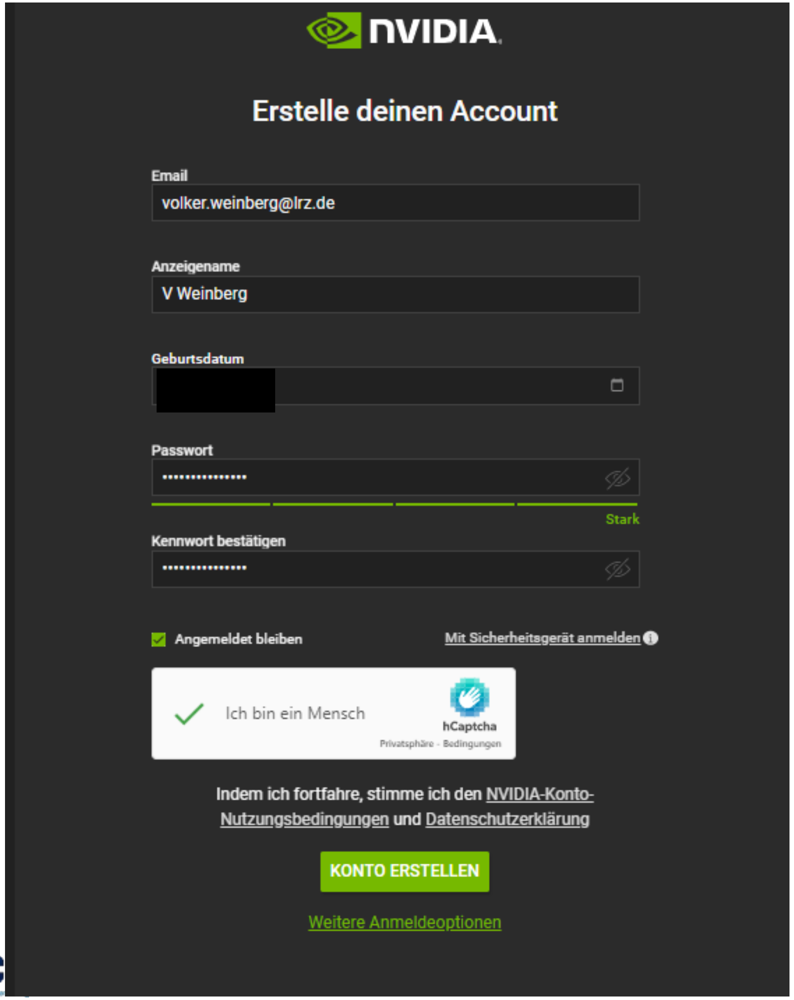
PLEASE START LAB NOW!

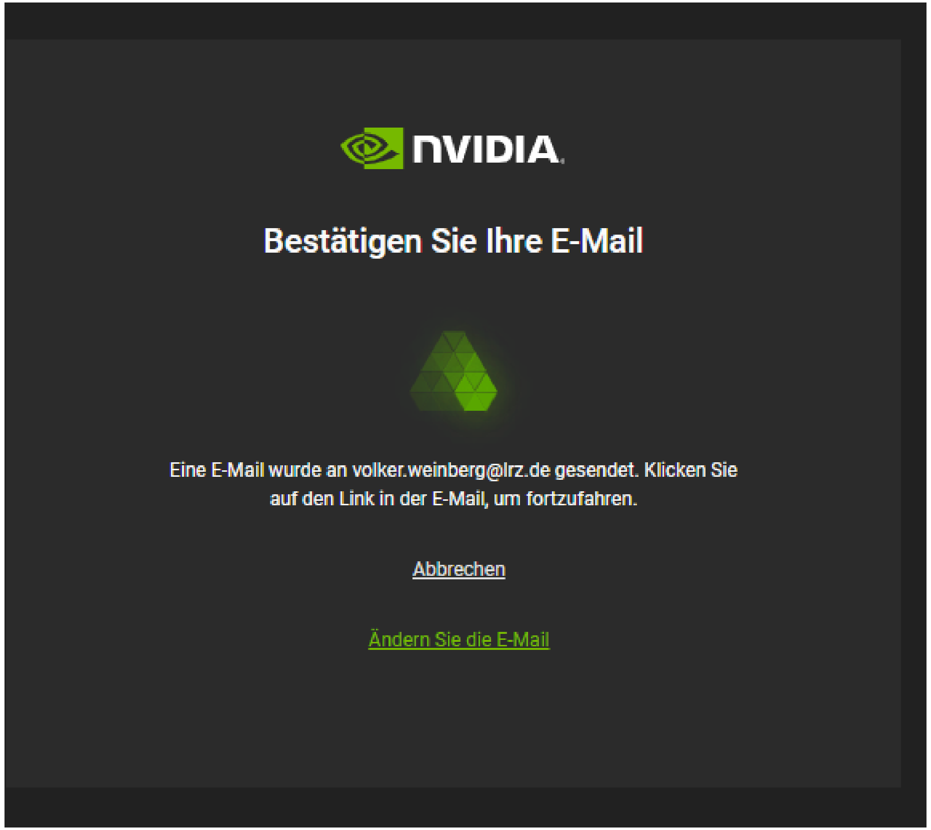
TRAINING SETUP

- To get started, follow these steps:
- Create an NVIDIA Developer account at http://courses.nvidia.com/join Select "Log in with my NVIDIA Account" and then "'Create Account“
- Visit http://courses.nvidia.com/dli-event and enter the event code

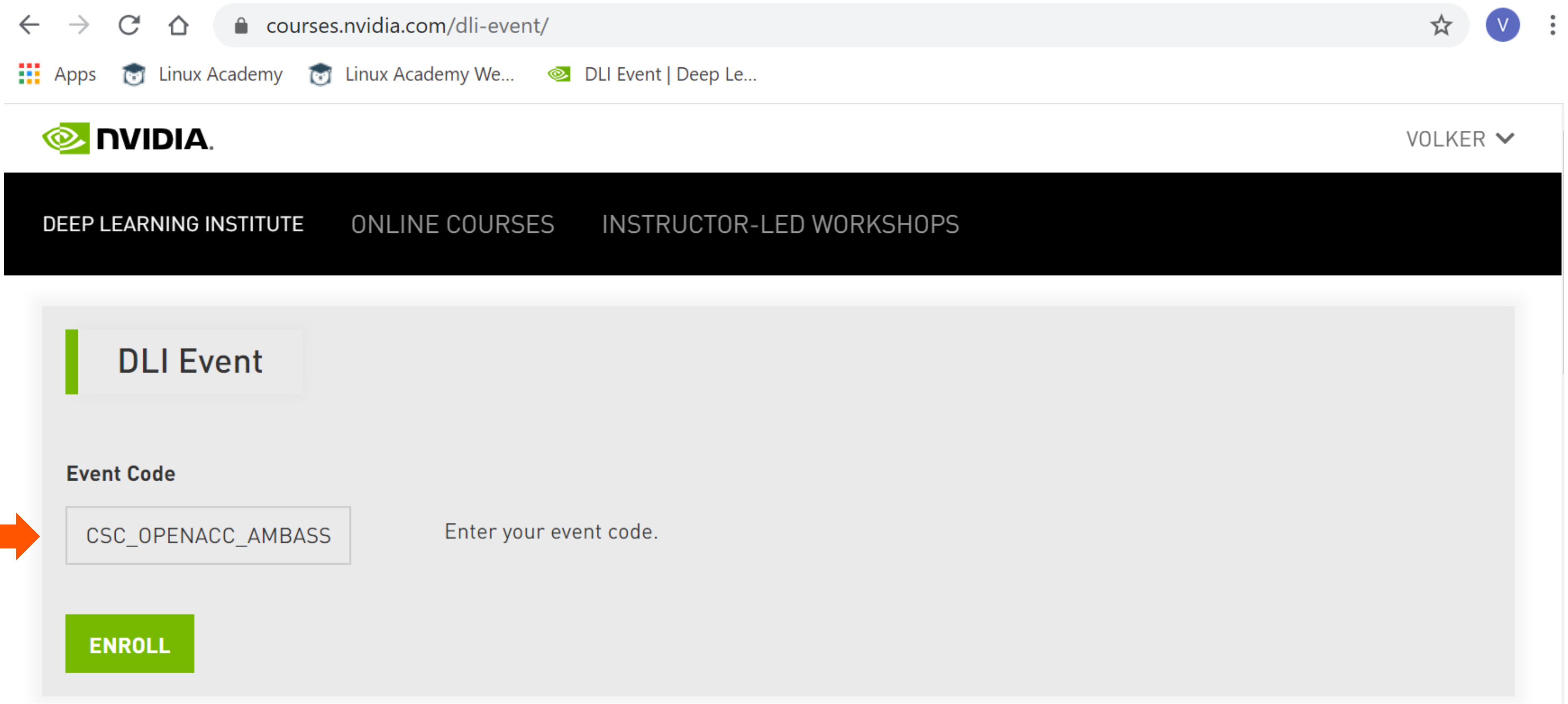
LRZ_OPENACC_AMBASSADOR_MY22

TRAINING SETUP

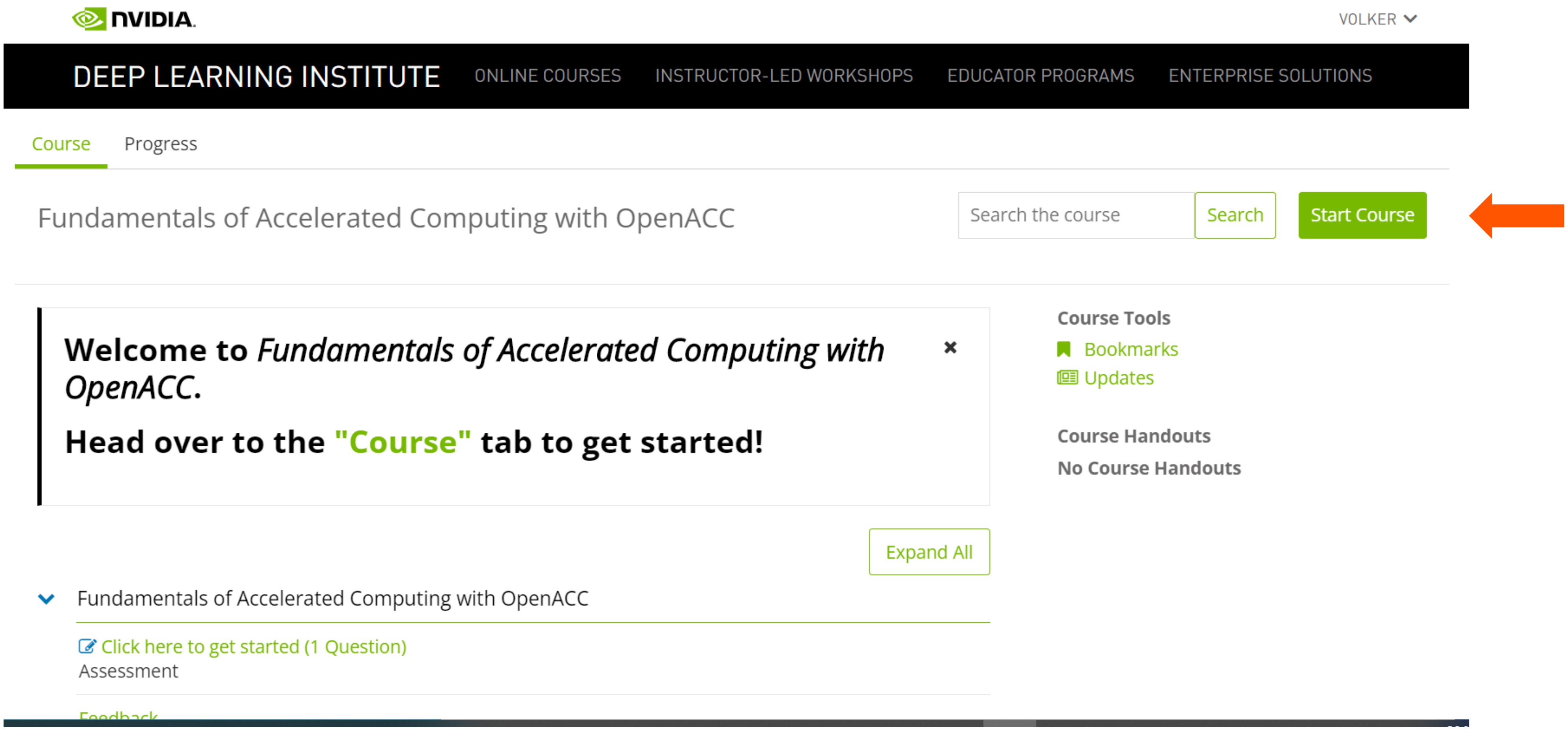




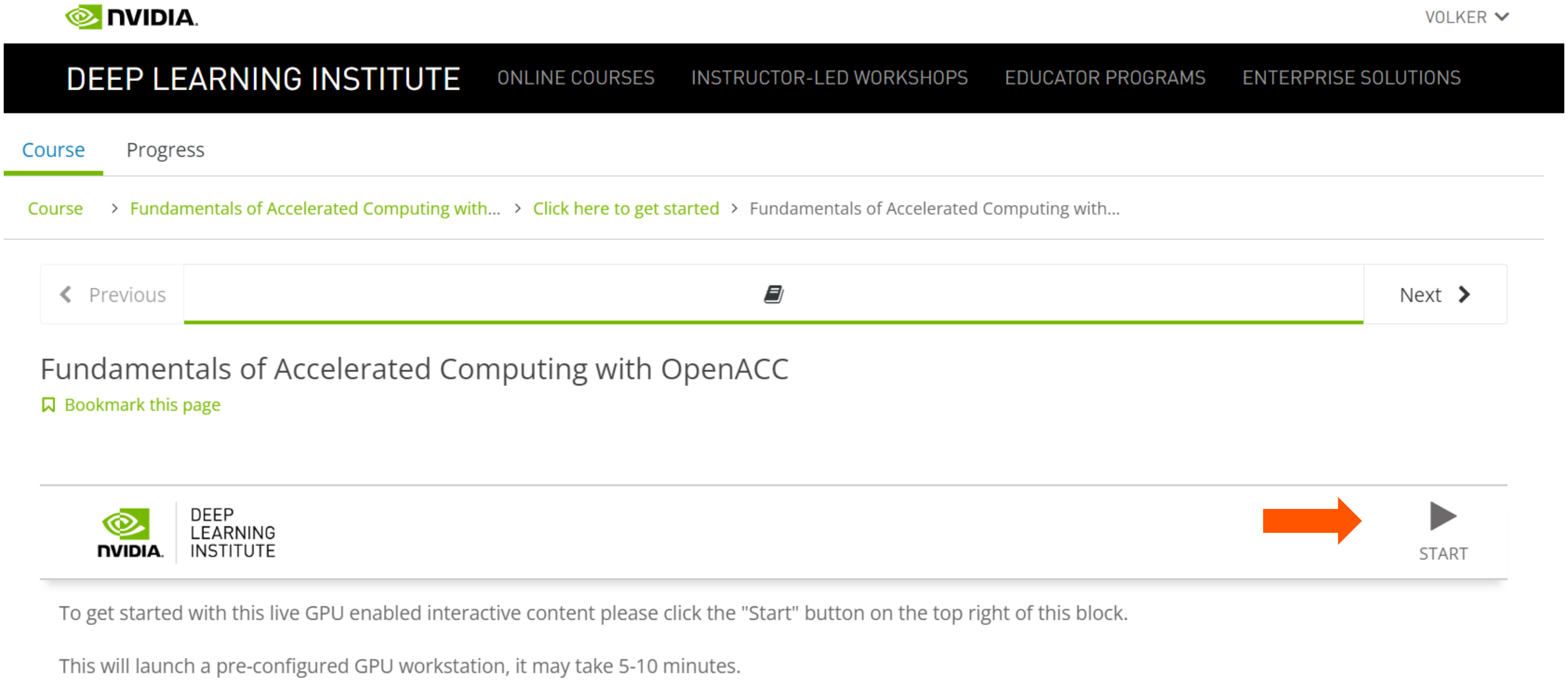
TRAINING SETUP



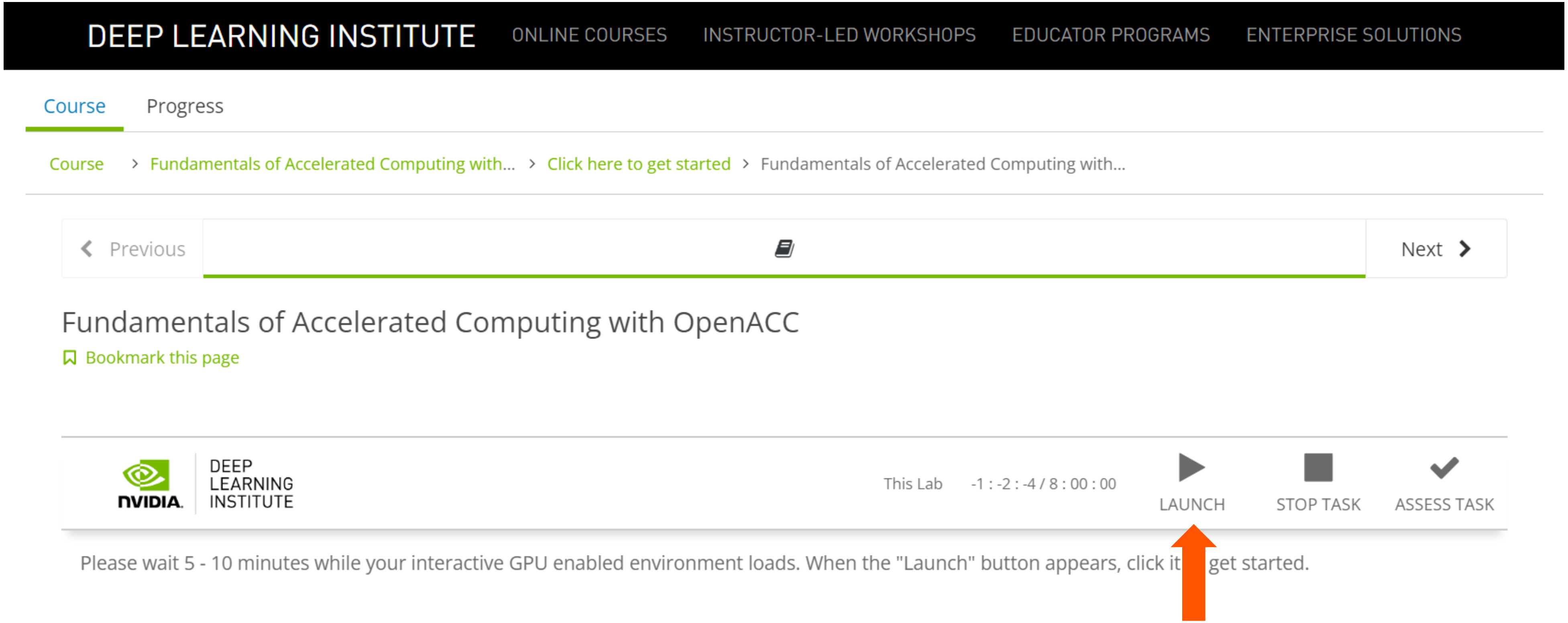
TRAINING SETUP



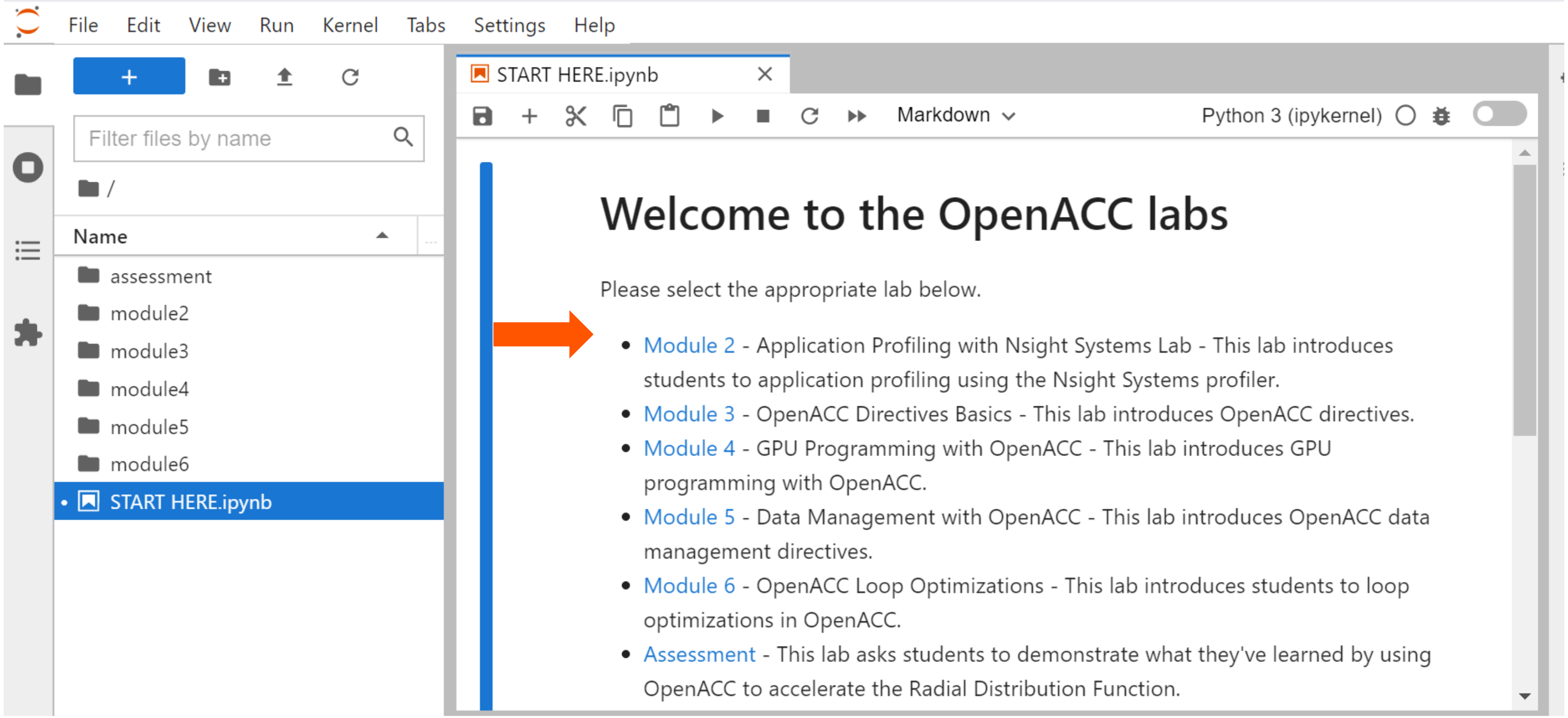
TRAINING SETUP



TRAINING SETUP



TRAINING SETUP



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TRAINING SETUP

- To be able to visualise Nsight System profiler output during the course, please install Nsight System latest version on your local system before the course. The software can be downloaded from https://developer.nvidia.com/nsight-systems.

PROFILING MULTICORE CODE

PROFILING MULTICORE CODE

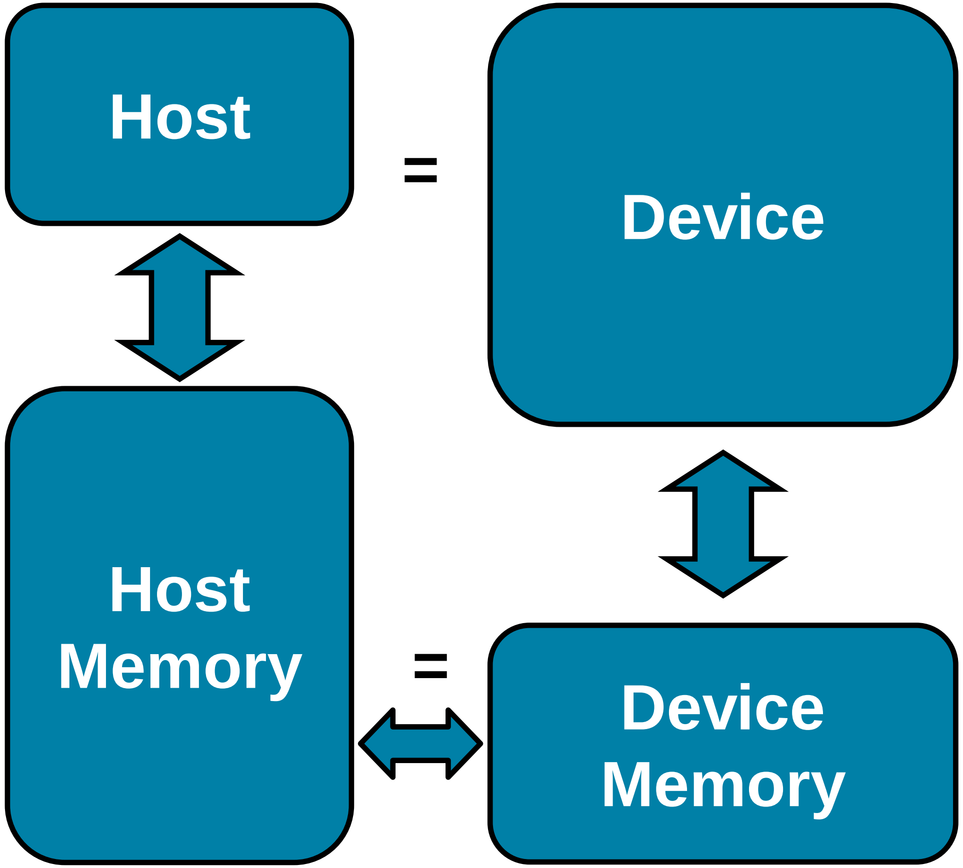
What is multicore?

- *Multicore* refers to using a CPU with multiple computational cores as our parallel device
- These cores can run independently of each other, but have shared access to memory
- Loop iterations can be spread across CPU threads and can utilize SIMD/vector instructions (SSE, AVX, etc.)
- Parallelizing on a multicore CPU is a good starting place, since data management is unnecessary

PROFILING MULTICORE CODE

Using a multicore CPU with OpenACC

- OpenACC's generic model involves a combination of a host and a device
- Host generally means a CPU, and the device is some parallel hardware
- When running with a multicore CPU as our device, typically this means that our host/device will be the same
- This also means that their memories will be the same



PROFILING MULTICORE CODE

Compiling code for a specific parallel hardware

- The '-ta' flag will allow us to compile our code for a specific, target parallel hardware
- 'ta' stands for "Target Accelerator," an accelerator being another way to refer to a parallel hardware
- Our OpenACC code can be compiled for many different kinds of parallel hardware without having to change the code

```
$ pgcc -fast -Minfo=accel -ta=multicore laplace2d.c
  calcNext:
        35, Generating Multicore code
            36, #pragma acc loop gang
```

PROFILING MULTICORE CODE

Compiling code for a specific parallel hardware

- `nsys profile -t nvtx --stats=true --force-overwrite true -o laplace_parallel ./laplace_parallel`

```
NVTX Push-Pop Range Statistics:

 Time(%)  Total Time (ns)  Instances     Average       Minimum      Maximum    Range
 -------  ---------------  ---------  -------------  -----------  -----------  -----
    49.9      24908340742          1  24908340742.0  24908340742  24908340742  while
    26.4      13167317033       1000     13167317.0      9986457     52044034  calc
    23.4      11711313301       1000     11711313.3      8693117     62627309  swap
     0.4        175394843          1    175394843.0    175394843    175394843  init

Report file moved to "/home/openacc/labs/module2/English/C/laplace_parallel.qdrep"
Report file moved to "/home/openacc/labs/module2/English/C/laplace_parallel.sqlite"
```

PROFILING OPENACC CODE

PARALLEL VS SEQUENTIAL

Compiler feedback

Have a close look at the PGI compiler feedback for both sequential and parallel implementation of the application.

It provides information about how your program was optimized or why a particular optimization was not made.

Note: Adding `–Minfo` flag or `-Minfo=accel` or `-Minfo=all` when compiling, will enable compiler feedback messages, giving details about the parallel code generated.

```
jacobi.c:
main:
     59, Loop not vectorized/parallelized: potential early exits
laplace2d.c:
"laplace2d.c", line 24: warning: function "memset" declared implicitly
       memset(A, 0, n * m * sizeof(double));
       ^

initialize:
     27, Generated vector simd code for the loop
calcNext:
     40, Generated vector simd code for the loop containing reductions
swap:
     56, Memory copy idiom, loop replaced by call to __c_mcopy8
```

Sequential

```
jacobi.c:
main:
     59, Loop not vectorized/parallelized: potential early exits
laplace2d.c:
"laplace2d.c", line 24: warning: function "memset" declared implicitly
       memset(A, 0, n * m * sizeof(double));
       ^

initialize:
     27, Generated vector simd code for the loop
calcNext:
     35, Generating Tesla code
         37, #pragma acc loop gang /* blockIdx.x */
             Generating implicit reduction(max:error)
         40, #pragma acc loop vector(128) /* threadIdx.x */
     35, Generating implicit copyin(A[:]) [if not already present]
         Generating implicit copy(error) [if not already present]
         Generating implicit copyout(Anew[:]) [if not already present]
     40, Loop is parallelizable
swap:
     51, Generating Tesla code
         53, #pragma acc loop gang /* blockIdx.x */
         56, #pragma acc loop vector(128) /* threadIdx.x */
     51, Generating implicit copyout(A[:]) [if not already present]
         Generating implicit copyin(Anew[:]) [if not already present]
     56, Loop is parallelizable
```

Parallel

```c
#include <math.h>
#include <stdlib.h>

#define OFFSET(x, y, m) (((x)*(m)) + (y))

void initialize(double *restrict A, double *restrict Anew, int m, int n)
{
    memset(A, 0, n * m * sizeof(double));
    memset(Anew, 0, n * m * sizeof(double));

    for(int i = 0; i < m; i++){
        A[i] = 1.0;
        Anew[i] = 1.0;
    }
}

double calcNext(double *restrict A, double *restrict Anew, int m, int n)
{
    double error = 0.0;
    #pragma acc parallel loop reduction(max:err)

    for( int j = 1; j < n-1; j++)
    {
        #pragma acc loop
        for( int i = 1; i < m-1; i++ )
        {
            Anew[OFFSET(j, i, m)] = 0.25 * ( A[OFFSET(j, i+1, m)] + A[OFFSET(j, i-1, m)]
                                          + A[OFFSET(j-1, i, m)] + A[OFFSET(j+1, i, m)]);
            error = max( error, fabs(Anew[OFFSET(j, i, m)] - A[OFFSET(j, i , m)]));
        }
    }
    return error;
}

void swap(double *restrict A, double *restrict Anew, int m, int n)
{
    #pragma acc parallel loop
    for( int j = 1; j < n-1; j++)
    {
        #pragma acc loop
        for( int i = 1; i < m-1; i++ )
        {
            A[OFFSET(j, i, m)] = Anew[OFFSET(j, i, m)];
        }
    }
}

void deallocate(double *restrict A, double *restrict Anew)
{
    free(A);
    free(Anew);
}
```

laplace2d.c
(Parallelised using OpenACC parallel directives (pragmas highlighted)

```
Importing [==================================================================100%]
Saved report file to "/home/mozhgank/Code/openacc-training-materials/labs/module4/English/C/solutions/parallel/laplace-par.qdrep"
Exporting 59427 events: [================================================100%]

Exported successfully to
/home/mozhgank/Code/openacc-training-materials/labs/module4/English/C/solutions/parallel/laplace-par.sqlite

Generating CUDA API Statistics...
CUDA API Statistics (nanoseconds)

Time(%)      Total Time       Calls         Average         Minimum         Maximum  Name
-------  --------------  ----------  --------------  --------------  --------------  ------------------------------
   93.1      1107821913        4000        276955.5            2205        63176580  cuStreamSynchronize
    2.2        25667004           1      25667004.0        25667004        25667004  cuMemHostAlloc
    1.8        21314088           1      21314088.0        21314088        21314088  cuMemAllocManaged
    1.6        18919205        3000          6306.4            4141           38827  cuLaunchKernel
    0.6         6575301        1000          6575.3            5719           37100  cuMemcpyDtoHAsync_v2
    0.4         4672638        1000          4672.6            3898           23307  cuMemsetD32Async
    0.2         1957950        1000          1958.0            1656            9112  cuEventRecord
    0.2         1835300        1000          1835.3            1685           15602  cuEventSynchronize
    0.1         1013630           1       1013630.0         1013630         1013630  cuMemAllocHost_v2
    0.0          498778           3        166259.3            7731          462241  cuMemAlloc_v2
    0.0          251874           1        251874.0          251874          251874  cuModuleLoadDataEx
    0.0            9531           1          9531.0            9531            9531  cuStreamCreate
    0.0            3936           2          1968.0            1136            2800  cuEventCreate


Generating CUDA Kernel Statistics...
CUDA Kernel Statistics (nanoseconds)

Time(%)      Total Time   Instances         Average         Minimum         Maximum  Name
-------  --------------  ----------  --------------  --------------  --------------  ------------------------------
   58.9       643260973        1000        643261.0          563448        63174901  calcNext_35_gpu
   40.4       441862005        1000        441862.0          434490          452729  swap_51_gpu
    0.7         7350076        1000          7350.1            6880            7936  calcNext_35_gpu__red


Generating CUDA Memory Operation Statistics...
CUDA Memory Operation Statistics (nanoseconds)

Time(%)      Total Time  Operations         Average         Minimum         Maximum  Name
-------  --------------  ----------  --------------  --------------  --------------  ------------------------------
   94.0        47346144        8191          5780.3            2688           71456  [CUDA Unified Memory memcpy HtoD]
    3.1         1567908        1000          1567.9            1535            2816  [CUDA memcpy DtoH]
    2.9         1447303        1000          1447.3            1407            2080  [CUDA memset]

CUDA Memory Operation Statistics (KiB)

              Total      Operations              Average            Minimum              Maximum  Name
-------------------  --------------  -------------------  -----------------  -------------------  ------------------------------
              7.813            1000                0.008              0.008                0.008  [CUDA memcpy DtoH]
              7.813            1000                0.008              0.008                0.008  [CUDA memset]
         260072.000            8191               31.751              4.000              732.000  [CUDA Unified Memory memcpy HtoD]


Generating NVTX Push-Pop Range Statistics...
NVTX Push-Pop Range Statistics (nanoseconds)

Time(%)      Total Time   Instances         Average         Minimum         Maximum  Range
-------  --------------  ----------  --------------  --------------  --------------  --------
   47.6      1199130726           1    1199130726.0      1199130726      1199130726  while
   29.2       734660957        1000        734661.0          627348        89307285  calc
   18.3       461447578        1000        461447.6          454563          490929  swap
    4.9       122270944           1     122270944.0       122270944       122270944  init
```

CUDA API statistics

CUDA Kernel statistics

CUDA Memory Operation statistics

NVTX range statistics

“calc” region (calcNext function) takes 29.2%
“swap” region (swap function) takes 18.3% of total execution time

Open laplace-par.qdrep with Nsight System GUI to view the timeline

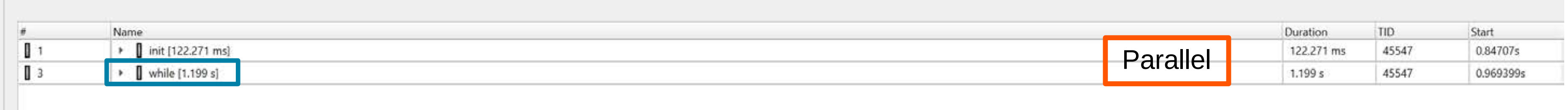
PARALLEL VS SEQUENTIAL SPEEDUP

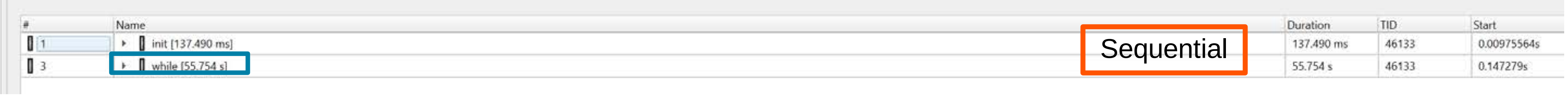
Viewing captured NVTX events

Have a close look at the captured NVTX events for both serial and parallel implementations.

Time spent in “while” loop has significantly decreased.

Achieved speedup: ~47





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PROFILING PARALLEL CODE

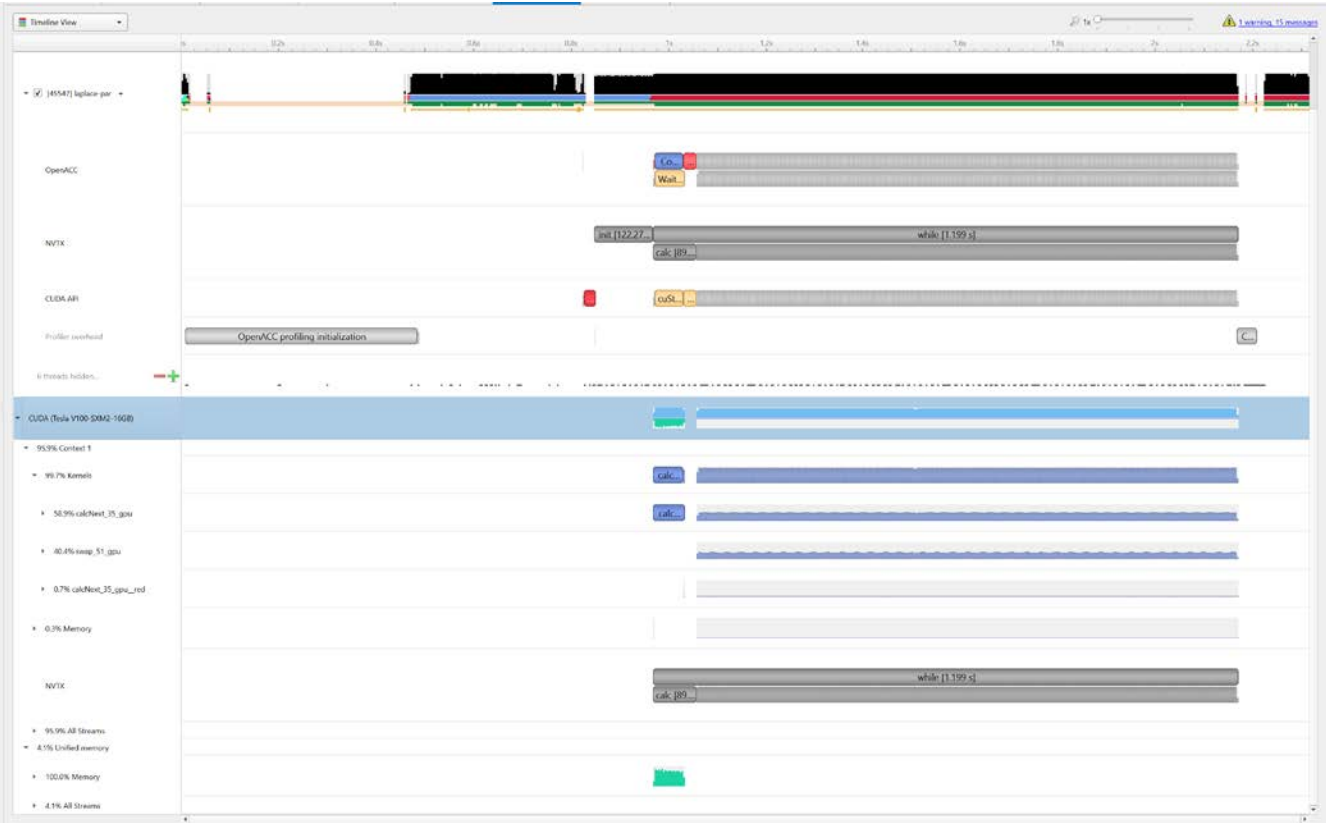
Viewing timeline via Nsight Systems

Contents of the tree-like hierarchy on the left depend on the project settings used to collect this report.

If a certain feature has not been enabled, corresponding rows will not be shown on the timeline.

In this example, we chose to trace NVTX and OpenACC while sampling.

Note: Kernel launches are represented by blue and memory transfers are displayed in green.



LAB CODE

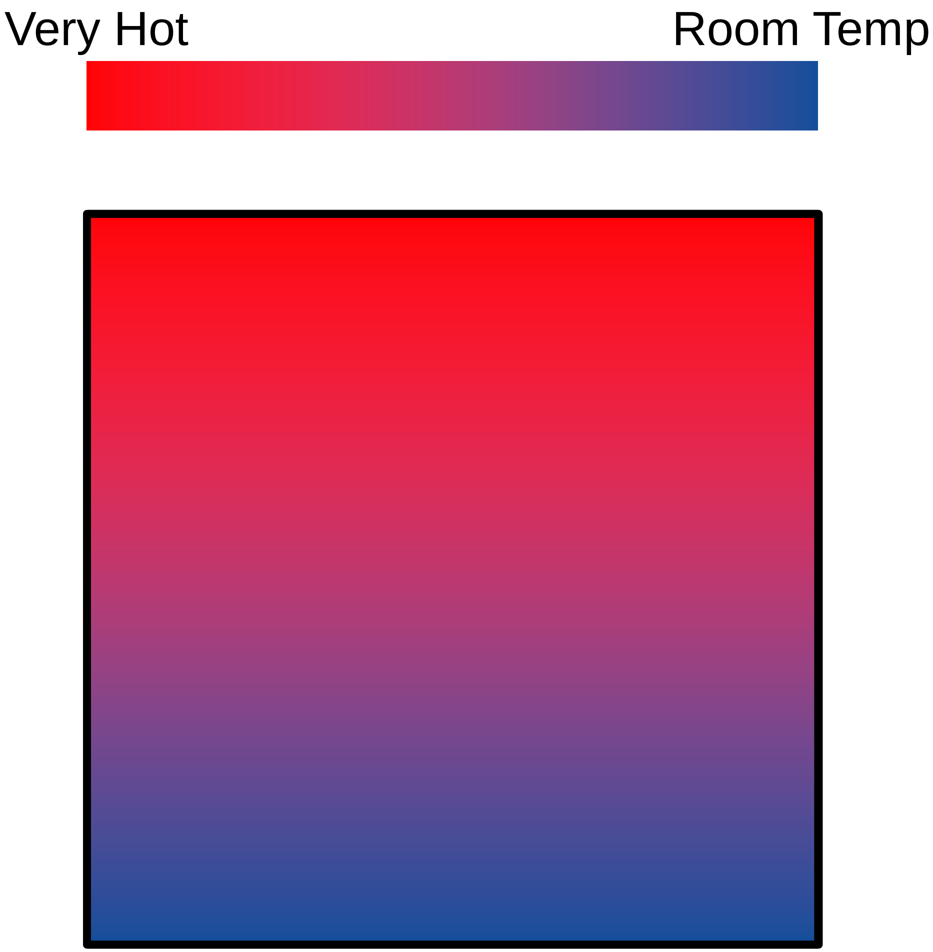
LAPLACE HEAT TRANSFER

Introduction to lab code - visual

We will observe a simple simulation of heat distributing across a metal plate.

We will apply a consistent heat to the top of the plate.

Then, we will simulate the heat distributing across the plate.



LAPLACE HEAT TRANSFER

Introduction to lab code - technical

The lab simulates a very basic 2-dimensional heat transfer problem. We have two 2-dimensional arrays, **A** and **Anew**.

The arrays represent a 2-dimensional, metal plate. Each element in the array is a **double** value that represents temperature.

We will simulate the distribution of heat until a **minimum change value** is achieved, or until we exceed a **maximum number of iterations.**

`A`

0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0

`Anew`

0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0

LAPLACE HEAT TRANSFER

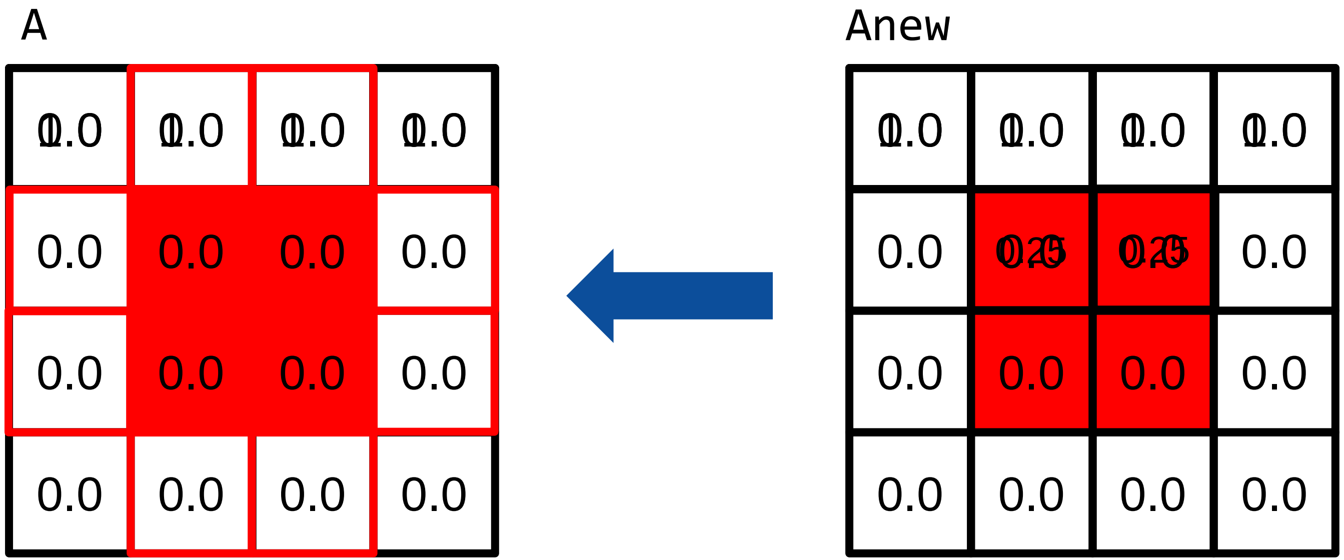
Introduction to lab code - technical

We initialize the top row to be a temperature of 1.0

The **calcNext** function will iterate through all of the inner elements of array A, and update the corresponding elements in Anew

We will take the average of the neighboring cells, and record it in **Anew.**

The **swap** function will copy the contents of Anew to A



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LAPLACE HEAT TRANSFER

Introduction to lab code

A

1.0	1.0	1.0	1.0
0.0	0.25	0.25	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0

Anew

1.0	1.0	1.0	1.0
0.0	0.25	0.25	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0

The **swap** function will copy the contents of Anew to A

KEY CONCEPTS

In this module we discussed…

- Compiling sequential and parallel code
- CPU profiling for sequential and parallel execution
- Specifics of our Laplace Heat Transfer lab code

LAB GOALS

In this lab you will do the following…

- Build and run the example code using the NVIDIA’s HPC compiler
- Use Nsight Systems to understand where the program spends its time

THANK YOU

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