Introduction to OpenACC

OpenACC
More Science, Less Programming

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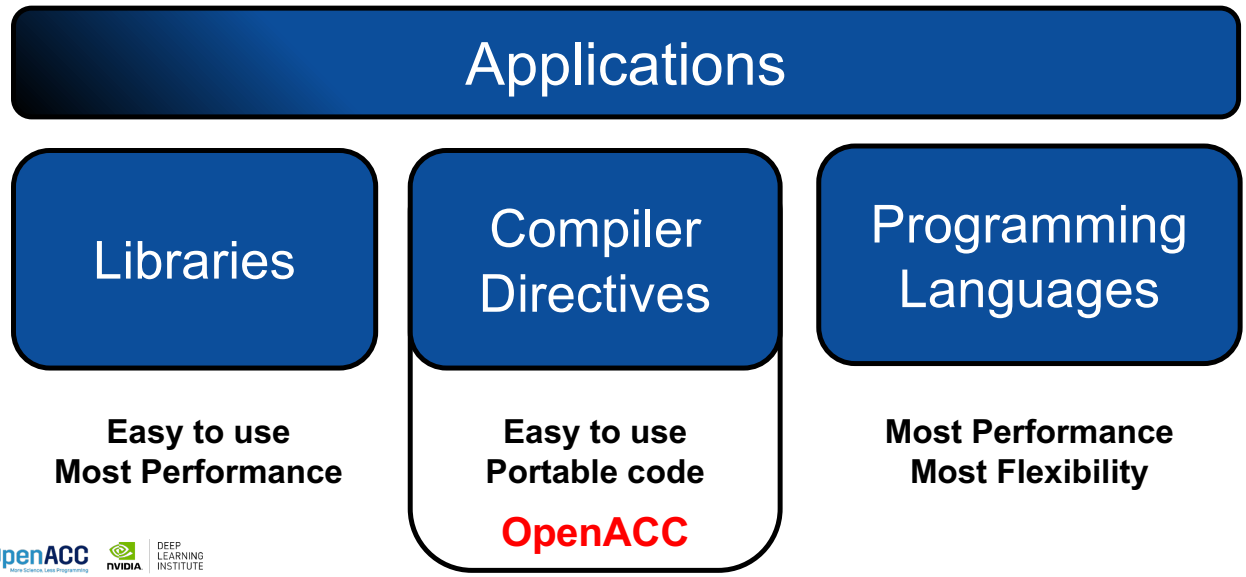
OpenACC is a directives-based programming approach to **parallel computing** designed for **performance** and **portability** on CPUs and GPUs for HPC.

Add Simple Compiler Directive

```
main()
 {
  <serial code>
  #pragma acc kernels
  {
    <parallel code>
  }
}
```

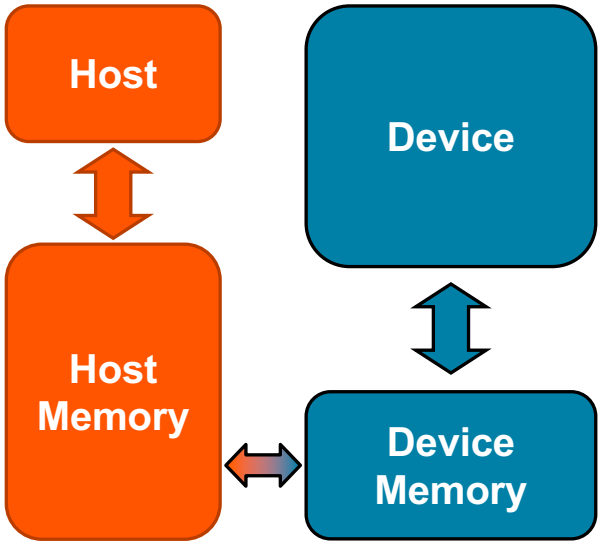
3 WAYS TO ACCELERATE APPLICATIONS



OPENACC PORTABILITY

Describing a generic parallel machine

- OpenACC is designed to be portable to many existing and future parallel platforms
- The programmer need not think about specific hardware details, but rather express the parallelism in generic terms
- An OpenACC program runs on a *host* (typically a CPU) that manages one or more parallel *devices* (GPUs, etc.). The host and device(s) are logically thought of as having separate memories.



OPENACC

Three major strengths

Incremental	Single Source	Low Learning Curve

OPENACC

Incremental

- Maintain existing sequential code
- Add annotations to expose parallelism
- After verifying correctness, annotate more of the code

Enhance Sequential Code

```
#pragma acc parallel loop
for( i = 0; i < N; i++ )
{
   < loop code >
}

#pragma acc parallel loop
for( i = 0; i < N; i++ )
{
   < loop code >
}
```

Begin with a working sequential code.

Parallelize it with OpenACC.

Rerun the code to verify correct behavior, remove/alter OpenACC code as needed.

OPENACC

Incremental

- Maintain existing sequential code
- Add annotations to expose parallelism
- After verifying correctness, annotate more of the code

Single Source

Low Learning Curve

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OPENACC

Supported Platforms

POWER

Sunway

x86 CPU

x86 Xeon Phi

NVIDIA GPU

PEZY-SC

Single Source

- Rebuild the same code on multiple architectures
- Compiler determines how to parallelize for the desired machine
- Sequential code is maintained

The compiler can **ignore** your OpenACC code additions, so the same code can be used for **parallel** or **sequential** execution.

```
int main(){

...

#pragma acc parallel loop
for(int i = 0; i < N; i++)
< loop code >

}
```

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OPENACC

Incremental

- Maintain existing sequential code
- Add annotations to expose parallelism
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Single Source

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Low Learning Curve

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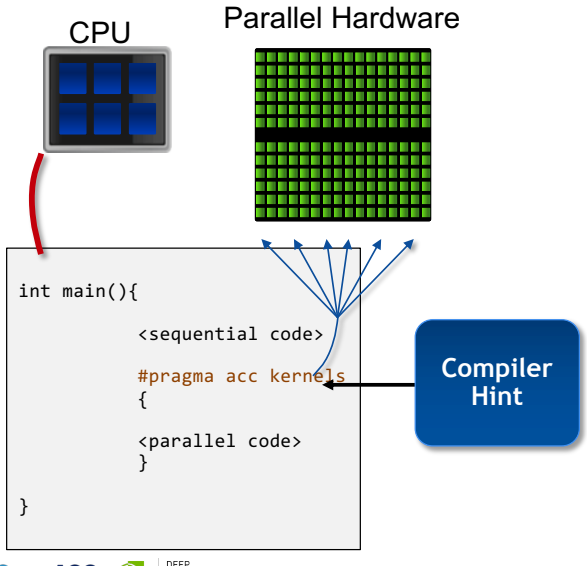
OPENACC



The programmer will give hints to the compiler about which parts of the code to parallelize.

The compiler will then generate parallelism for the target parallel hardware.

Low Learning Curve

- OpenACC is meant to be easy to use, and easy to learn
- Programmer remains in familiar C, C++, or Fortran
- No reason to learn low-level details of the hardware.

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OPENACC

Incremental	Single Source	Low Learning Curve
▪ Maintain existing sequential code ▪ Add annotations to expose parallelism ▪ After verifying correctness, annotate more of the code	▪ Rebuild the same code on multiple architectures ▪ Compiler determines how to parallelize for the desired machine ▪ Sequential code is maintained	▪ OpenACC is meant to be easy to use, and easy to learn ▪ Programmer remains in familiar C, C++, or Fortran ▪ No reason to learn low-level details of the hardware.

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EXPRESSING PARALLELISM WITH OPENACC

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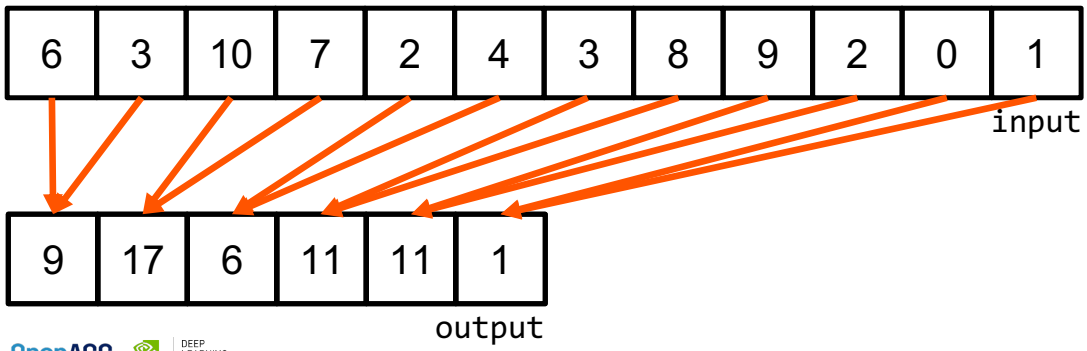
CODING WITH OPENACC

Array pairing example

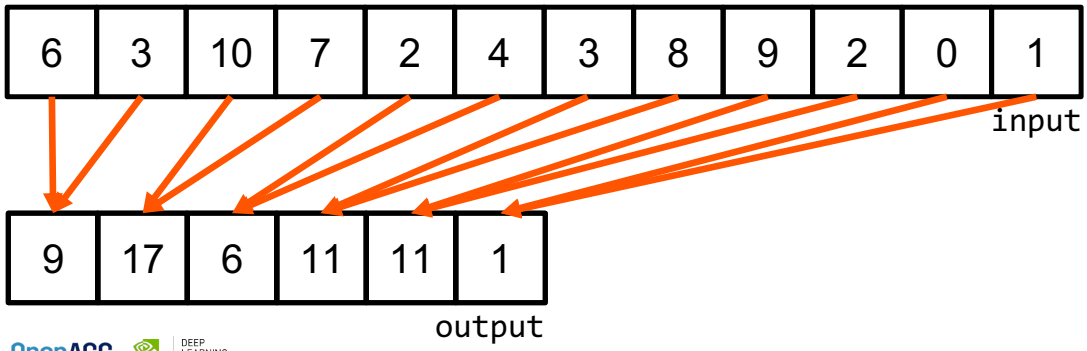
```
void pairing(int *input, int *output, int N){

        for(int i = 0; i < N; i++)
                output[i] = input[i*2] + input[i*2+1];
}
```



CODING WITH OPENACC

Array pairing example - parallel

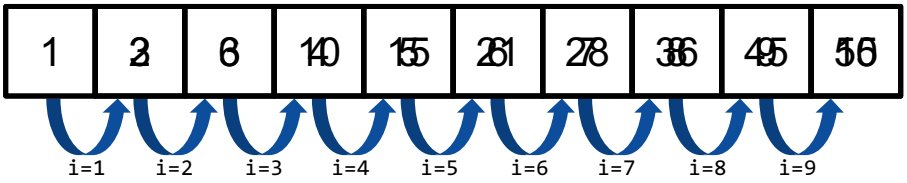
```
void pairing(int *input, int *output, int N){
        #pragma acc parallel loop
        for(int i = 0; i < N; i++)
                output[i] = input[i*2] + input[i*2+1];
}
```



DATA DEPENDENCIES

Not all loops are parallel

```
void pairing(int *a, int N){

        for(int i = 1; i < N; i++)
                a[i] = a[i] + a[i-1];
}
```

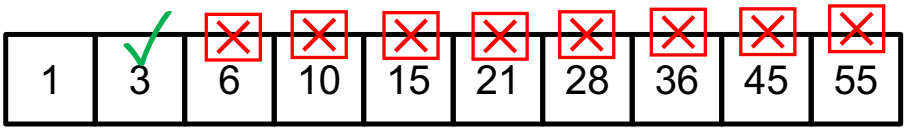


DATA DEPENDENCIES

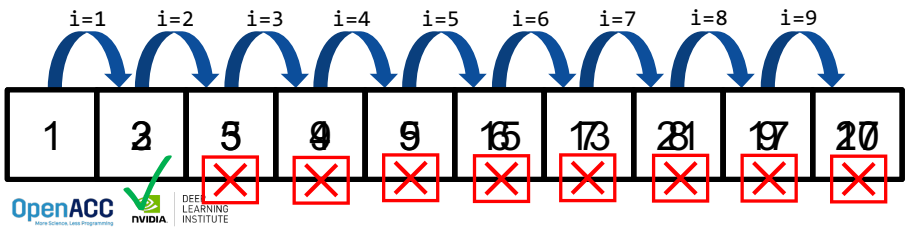
Not all loops are parallel

```
void pairing(int *a, int N){
        #pragma acc parallel loop
        for(int i = 1; i < N; i++)
                a[i] = a[i] + a[i-1];
}
```

If we attempted to parallelize this loop we would get wrong answers due to a *forward dependency.*



Sequential



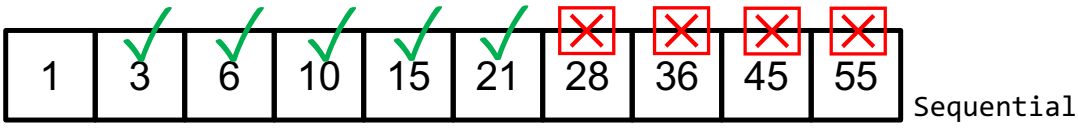
Parallel

DATA DEPENDENCIES

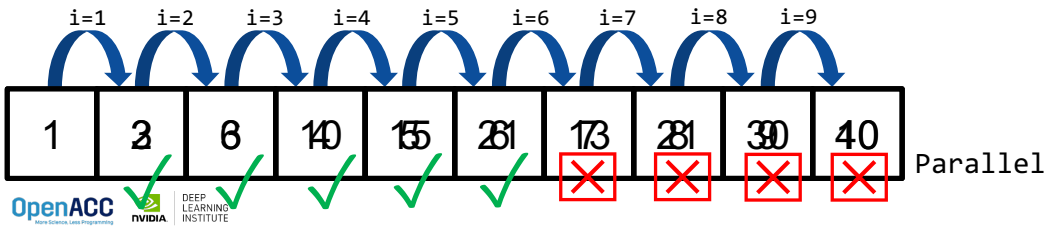
Not all loops are parallel

```
void pairing(int *a, int N){
        #pragma acc parallel loop
        for(int i = 1; i < N; i++)
                a[i] = a[i] + a[i-1];
}
```

Even changing how the iterations are parallelized will not make this loop safe to parallelize.



Sequential



Parallel

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Profiling

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COMPILING SEQUENTIAL CODE

PGI COMPILER BASICS

pgcc, pgc++ and pgfortran

- The command to compile C code is ‘pgcc’
- The command to compile C++ code is ‘pgc++’
- The -fast flag instructs the compiler to optimize the code to the best of its abilities

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

PGI COMPILER BASICS

-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
```


GCC COMPILER BASICS

gcc, gc++ and gfortran

- The command to compile C code is ‘gcc’
- The command to compile C++ code is ‘g++’
- The command to compile Fortran code is ‘gfortran’
- The -O2 flag sets the optimization level to 2 (a safe starting point)

```
$       gcc -O2 main.c
$       g++ -O2 main.cpp
```

GCC COMPILER BASICS

Compiler feedback

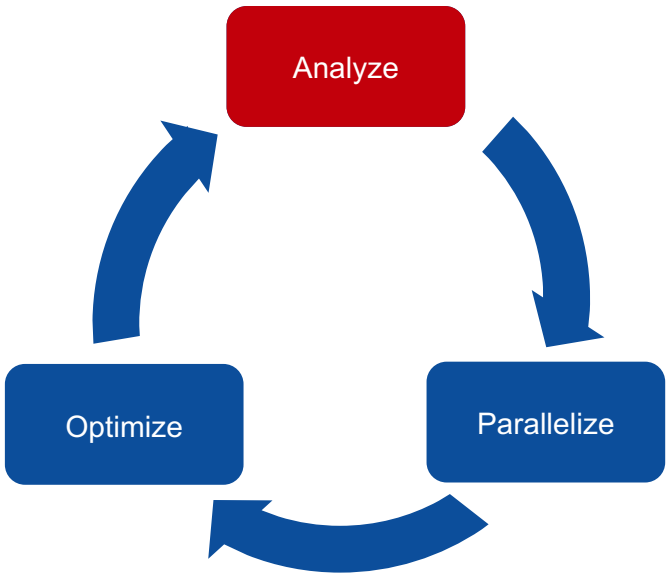
- The -fopt-info flag will print limited compiler feedback
- The -flto-report flag will also print link-time optimizations, but should be used sparingly due to volume of information

```
$       gcc -O2 -fopt-info main.c
$       g++ -O2 -fopt-info main.cpp
```


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.



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

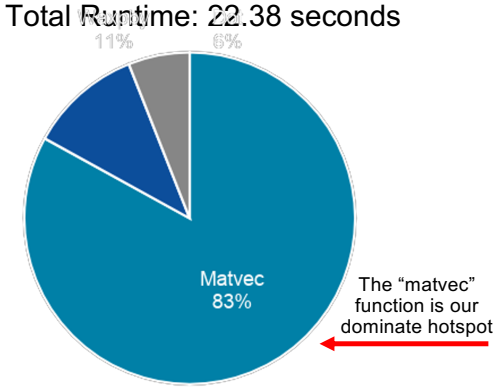
Obtain detailed information about how the code ran.

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.

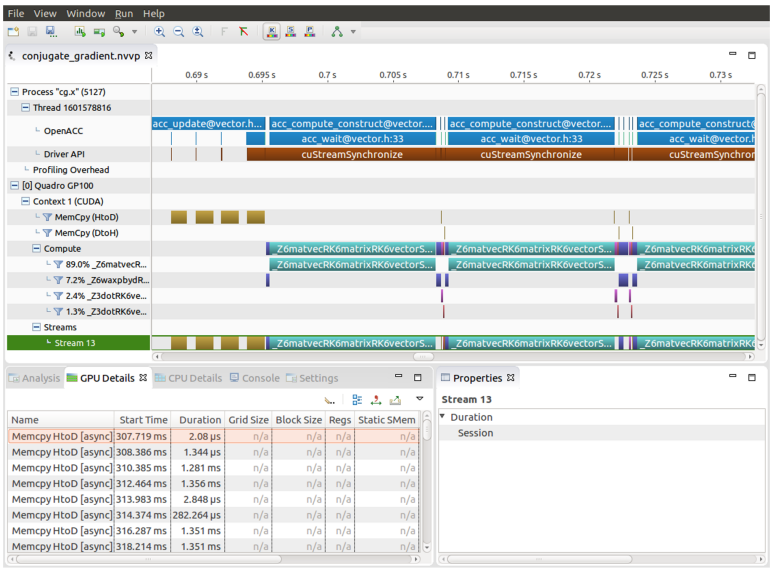
Sample Code: Conjugate Gradient



PROFILING SEQUENTIAL CODE

Introduction to PGProf

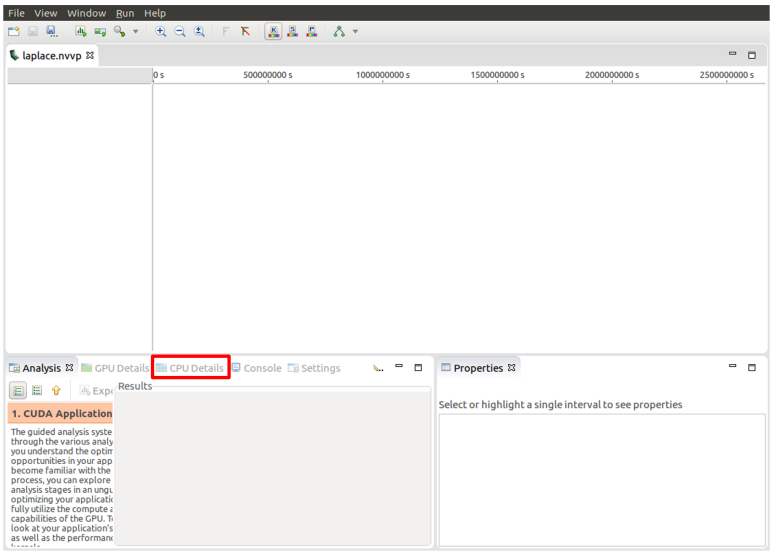
- Gives visual feedback of how the code ran
- Gives numbers and statistics, such as program runtime
- Also gives runtime information for individual functions/loops within the code
- Includes many extra features for profiling parallel code



PROFILING SEQUENTIAL CODE

First sight when using PGPROF

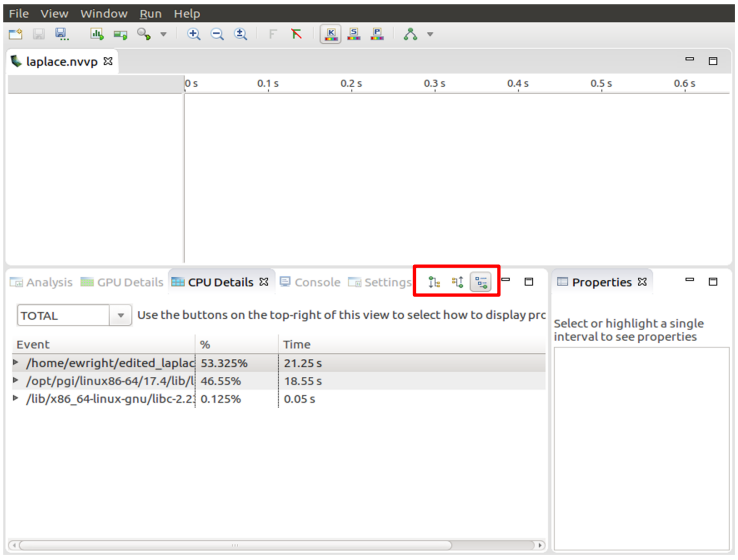
- Profiling a simple, sequential code
- Our sequential program will on run on the CPU
- To view information about how our code ran, we should select the “CPU Details” tab



PROFILING SEQUENTIAL CODE

CPU Details

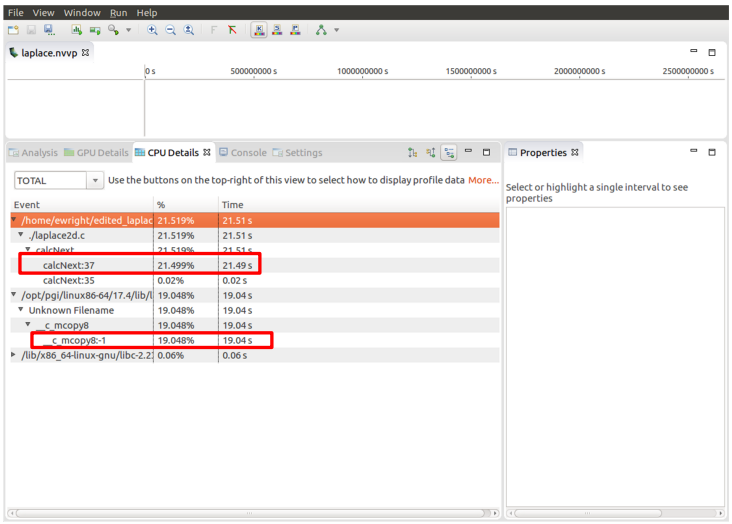
- Within the “CPU Details” tab, we can see the various parts of our code, and how long they took to run
- We can reorganize this info using the three options in the top-right portion of the tab
- We will expand this information, and see more details about our code



PROFILING SEQUENTIAL CODE

CPU Details

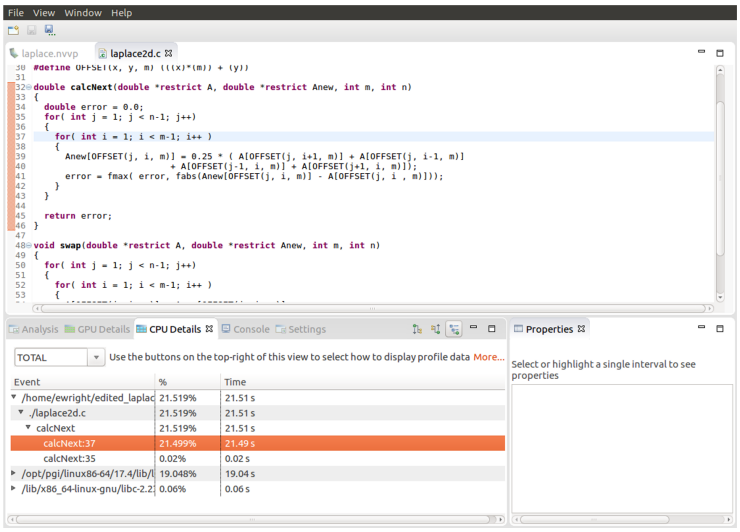
- We can see that there are two places that our code is spending most of its time
- 21.49 seconds in the “calcNext” function
- 19.04 seconds in a memcpy function
- The c_mcopy8 that we see is actually a compiler optimization that is being applied to our “swap” function



PROFILING SEQUENTIAL CODE

PGPROF

- We are also able to select the different elements in the CPU Details by double-clicking to open the associated source code
- Here we have selected the “calcNext:37” element, which opened up our code to show the exact line (line 37) that is associated with that element



PROFILING SEQUENTIAL CODE

Step 2: Profile Your Code

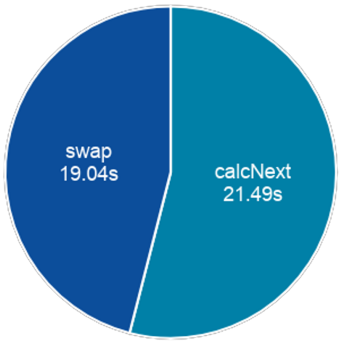
Obtain detailed information about how the code ran.

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 SEQUENTIAL CODE

Step 3: Identify Parallelism

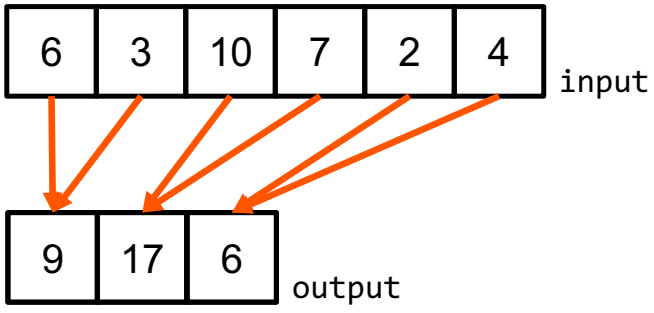
Observe the loops contained within the identified hotspots

Are these loops parallelizable?
Can the loop iterations execute independently of each other?
Are the loops multi-dimensional, and does that make them very large?

Loops that are good to parallelize tend to have a lot of iterations to map to parallel hardware.

```
void pairing(int *input, int *output, int N){

for(int i = 0; i < N; i++)
    output[i] = input[i*2] + input[i*2+1];
}
```



PROFILING MULTICORE CODE

PROFILING MULTICORE CODE

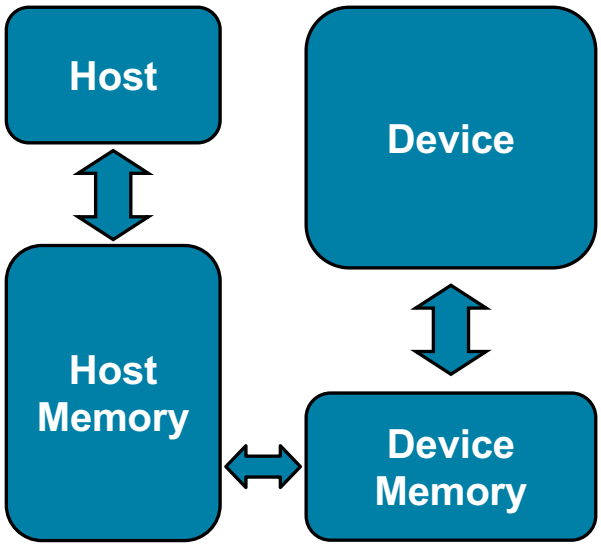
What is multicore?

- *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

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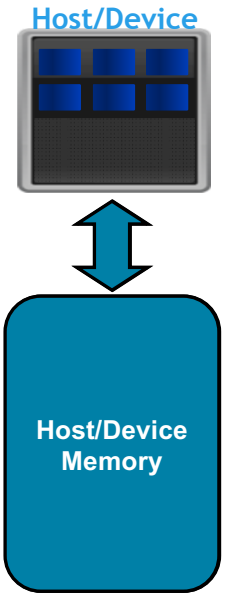

PROFILING MULTICORE CODE

Comping 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
```

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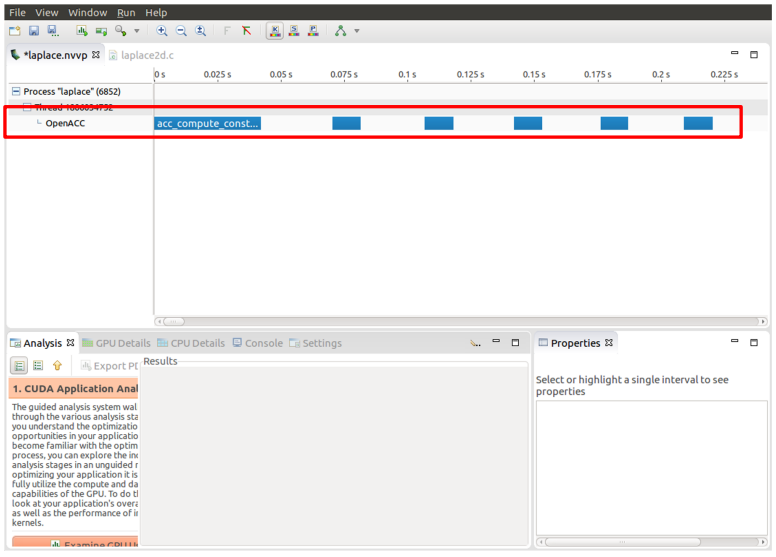
PROFILING MULTICORE CODE

PGPROF

- The first difference we see in this multicore profile is that there is now a "timeline"
- This timeline will show when our parallel hardware is being used, and how it is being used
- Each of the blue bars represent a portion of our program that was run on the multicore CPU



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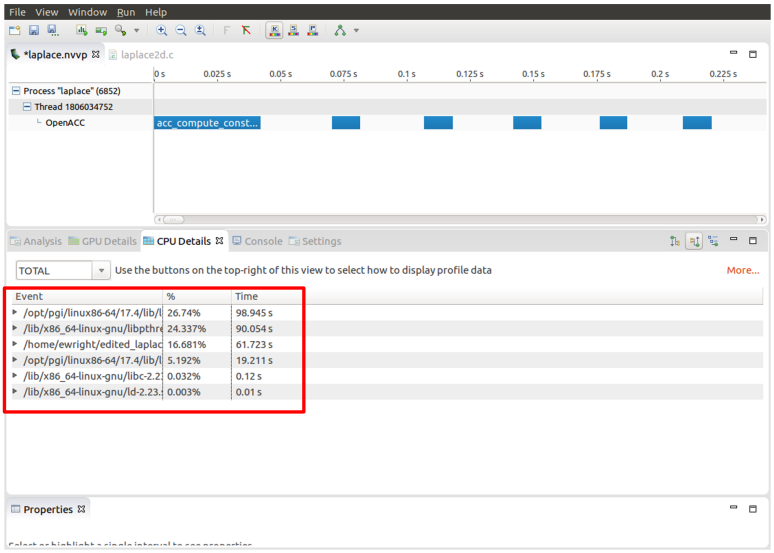
PROFILING MULTICORE CODE

CPU Details

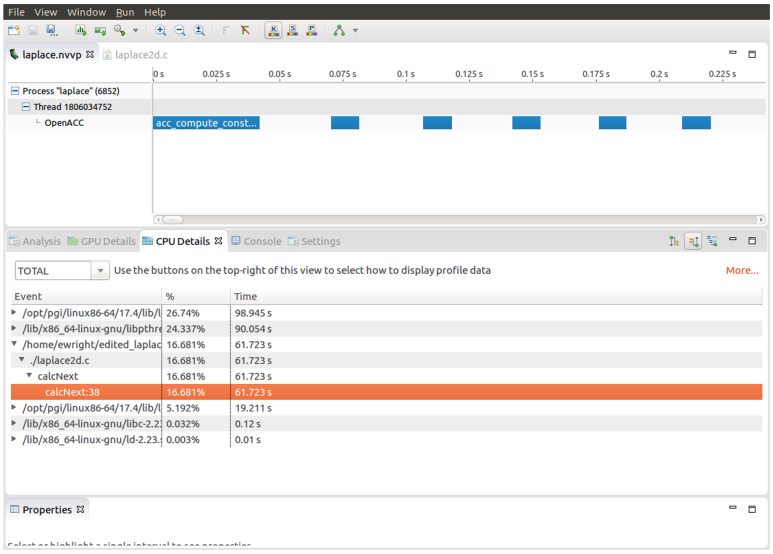
- Looking at our CPU Details, we can see that there is a lot more happening compared to our sequential program
- For the most part, these extra details revolve around the need for the CPU cores to communicate with each other



PROFILING MULTICORE CODE

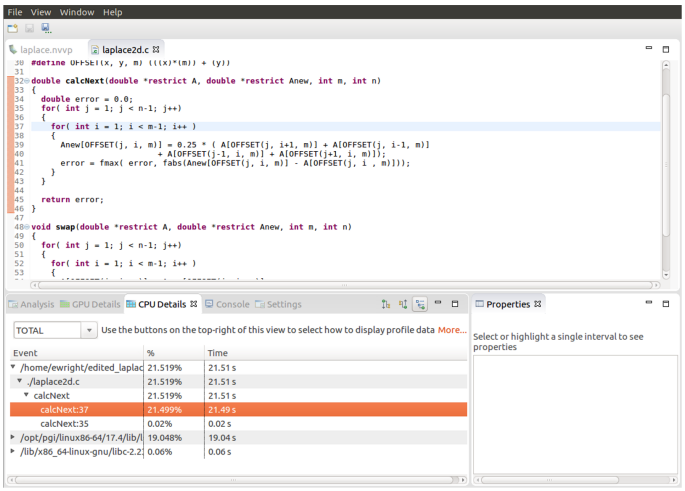
PGPROF

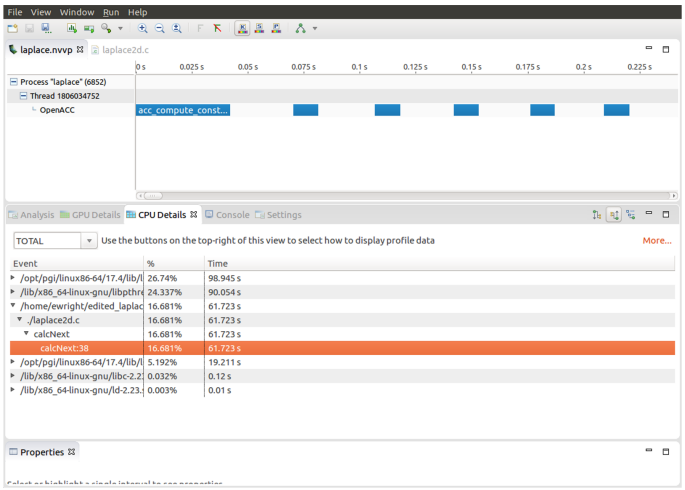
- Just like earlier, we see our “calcNext” function
- We also see that PGPROF is reporting this function to take 61.72 seconds to run
- Looking at the program now, it looks like it performs much worse than the sequential version



PROFILING MULTICORE CODE

PGPROF





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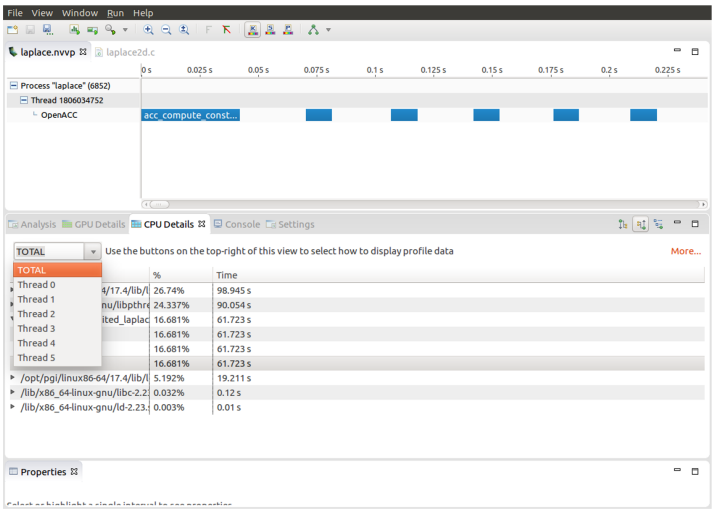
PROFILING MULTICORE CODE

View of all computational threads

- The program is actually performing better than the sequential version
- We are only looking at the “TOTAL” view, which means that PGPROF is combining information from all of our CPU cores



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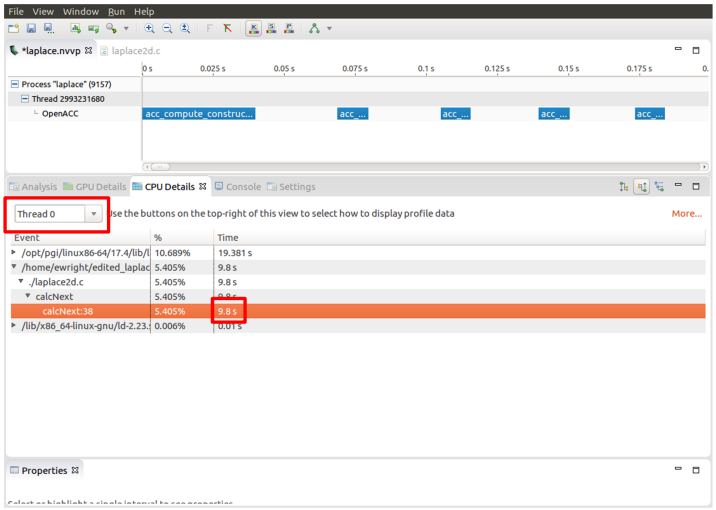
PROFILING MULTICORE CODE

Observing a single thread

- Now we have selected to view a specific thread (for us, a thread would be a single CPU core)
- We can see that this single thread only spent 9.8 seconds running calcNext
- Each thread will take a similar amount of time and execute simultaneously, resulting in a faster run



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Lab

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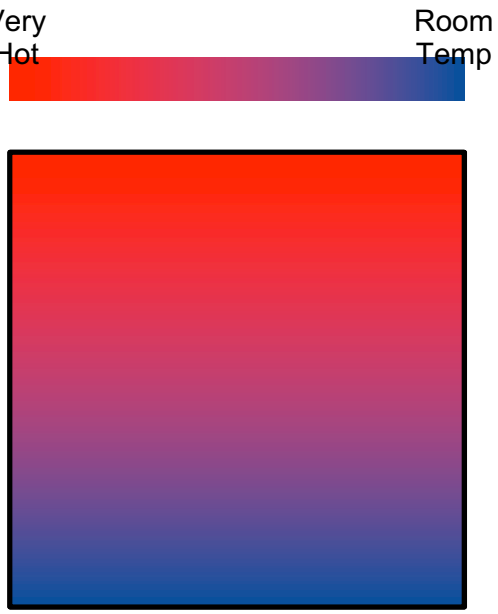
LAPLACE HEAT TRANSFER

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

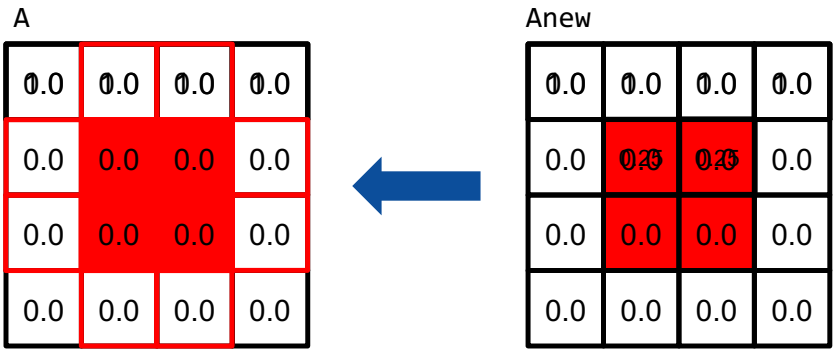
Introduction to lab code - technical

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

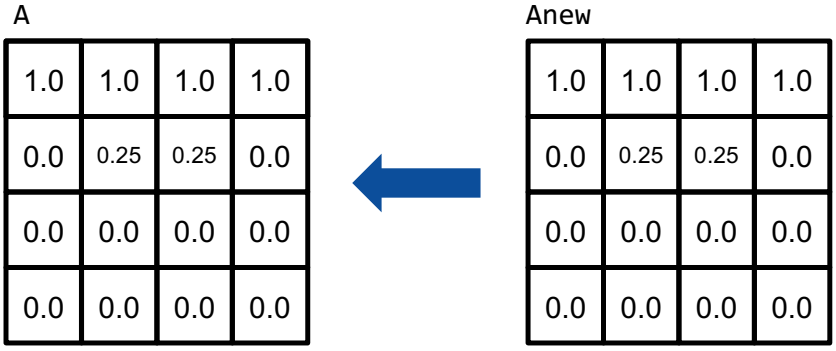
We will take the average of the neighboring cells, and record it in **Anew.**

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



LAPLACE HEAT TRANSFER

Introduction to lab code



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 PGI compiler
- Use PGProf to understand where the program spends its time

THANK YOU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