ECE408/CS483/CSE408 Fall 2021

Applied Parallel Programming

Lecture 23: Introduction to OpenACC

Objective

- to understand OpenACC (see openacc.org)
  - a directive-based programming model for heterogeneous platforms
  - a valuable tool to quickly adapt existing C/C++/FORTRAN applications to GPUs
- basic concepts and pragma types
- simple examples to illustrate basic concepts and functionalities

OpenACC

The OpenACC Application Programming Interface (API) provides a set of

- compiler directives (pragmas),
- library routines, and
- environment variables

that enable

- FORTRAN, C and C++ programs
- to execute on accelerator devices
- including GPUs and CPUs.

Pragmas Provide Extra Information

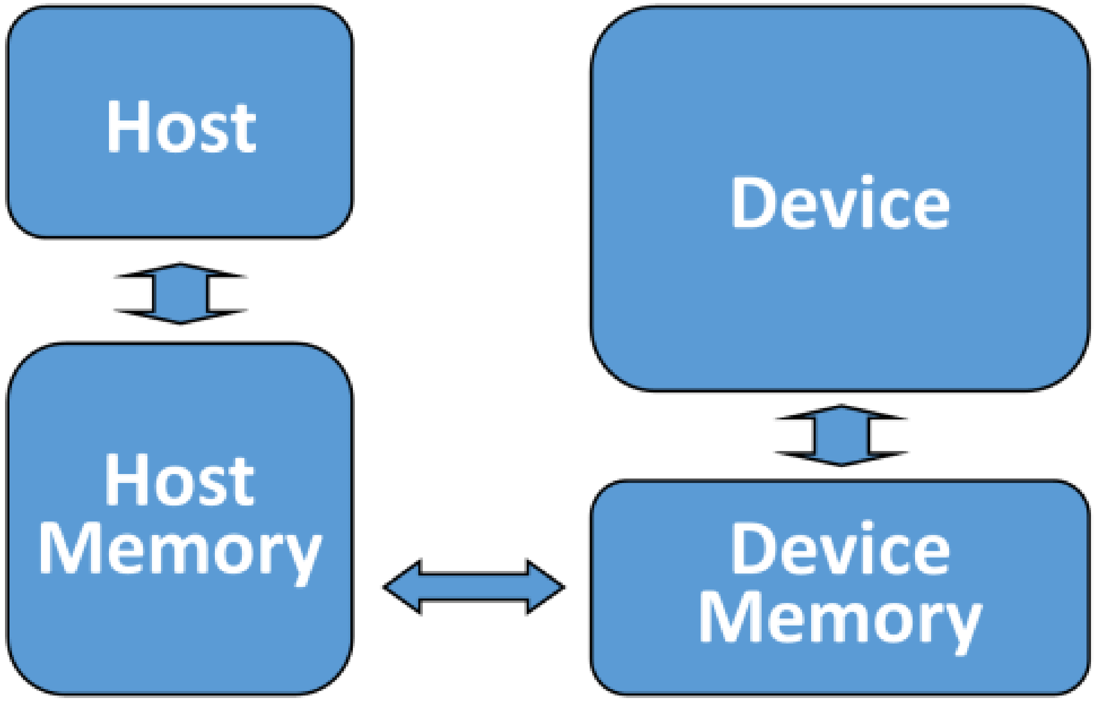
In C and C++,

- the `#pragma` directive
- provides the compiler with
- information not specified in the language.

For OpenACC, they look like this:

#pragma acc [the information goes here]

The OpenACC Abstract Machine Model



The OpenACC Directives

Manage Data Movement

Initiate Parallel Execution

Optimize Loop Mappings

```
#pragma acc data copyin(x,y) copyout(z)
{
  ...
  #pragma acc parallel
  {
  #pragma acc loop gang vector
      for (i = 0; i < n; ++i) {
          z[i] = x[i] + y[i];
          ...
      }
  }
  ...
}
```

Simple Matrix-Matrix Multiplication in OpenACC

```
void computeAcc(float *P, const float *M, const float *N, int Mh, int Mw, int Nw)  {
 #pragma acc parallel loop copyin(M[0:Mh*Mw]) copyin(N[0:Nw*Mw]) copyout(P[0:Mh*Nw])
 for (int i=0; i<Mh; i++) {
     #pragma acc loop
     for (int j=0; j<Nw; j++) {
         float sum = 0;
         for (int k=0; k<Mw; k++) {
            float a = M[i*Mw+k];
            float b = N[k*Nw+j];
              sum += a*b;
          }
          P[i*Nw+j] = sum;
     }
  }
}
```

Add Pragmas to Sequential Code

The **code** is

- **identical to** the **sequential** version
- **except for** the two **pragmas**
- at lines 2 and 4.

OpenACC uses the compiler directive mechanism to extend the base language.

Simple Matrix-Matrix Multiplication in OpenACC

```
1  void computeAcc(float *P, const float *M, const float *N, int Mh, int Mw, int Nw) {
2   #pragma acc parallel loop copyin(M[0:Mh*Mw]) copyin(N[0:Nw*Mw]) copyout(P[0:Mh*Nw])
3   for (int i=0; i<Mh; i++) {
4       #pragma acc loop
5       for (int j=0; j<Nw; j++) {
6           float sum = 0;
7           for (int k=0; k<Mw; k++) {
8               float a = M[i*Mw+k];
9               float b = N[k*Nw+j];
10              sum += a*b;
11          }
12          P[i*Nw+j] = sum;
13      }
14  }
15 }
```

tells compiler
- to execute 'i' loop
- (lines 3 through 14)
- in parallel on accelerator.

copyin/copyout specify
- how matrix data
- should be transferred
  between memories.

Simple Matrix-Matrix Multiplication in OpenACC

```
1  void computeAcc(float *P, const float *M, const float *N, int Mh, int Mw, int Nw) {
2   #pragma acc parallel loop copyin(M[0:Mh*Mw]) copyin(N[0:Nw*Mw]) copyout(P[0:Mh*Nw])
3   for (int i=0; i<Mh; i++) {
4       #pragma acc loop
5       for (int j=0; j<Nw; j++) {
6           float sum = 0;
7           for (int k=0; k<Mw; k++) {
8              float a = M[i*Mw+k];
9              float b = N[k*Nw+j];
10               sum += a*b;
11           }
12           P[i*Nw+j] = sum;
13      }
14   }
15 }
```

tells compiler
- to map ‘j’ loop
- (lines 5 through 13)
- to second level
- of parallelism on accelerator.

Motivating Goal: One Version of Code

OpenACC programmers

- can often start with a sequential version,
- then annotate their program with directives.,
- leaving most kernel details and data transfers
- to the OpenACC compiler.

OpenACC code can be compiled by non-OpenACC compilers by ignoring the pragmas.

Reality is More Complicated

Reality check:

- can be **difficult to write code**
- that works **correctly and well**
- **with and without pragmas**.

Some OpenACC programs

- behave differently or even incorrectly
- if pragmas are ignored.

Pitfall: Strong Dependence on Compiler

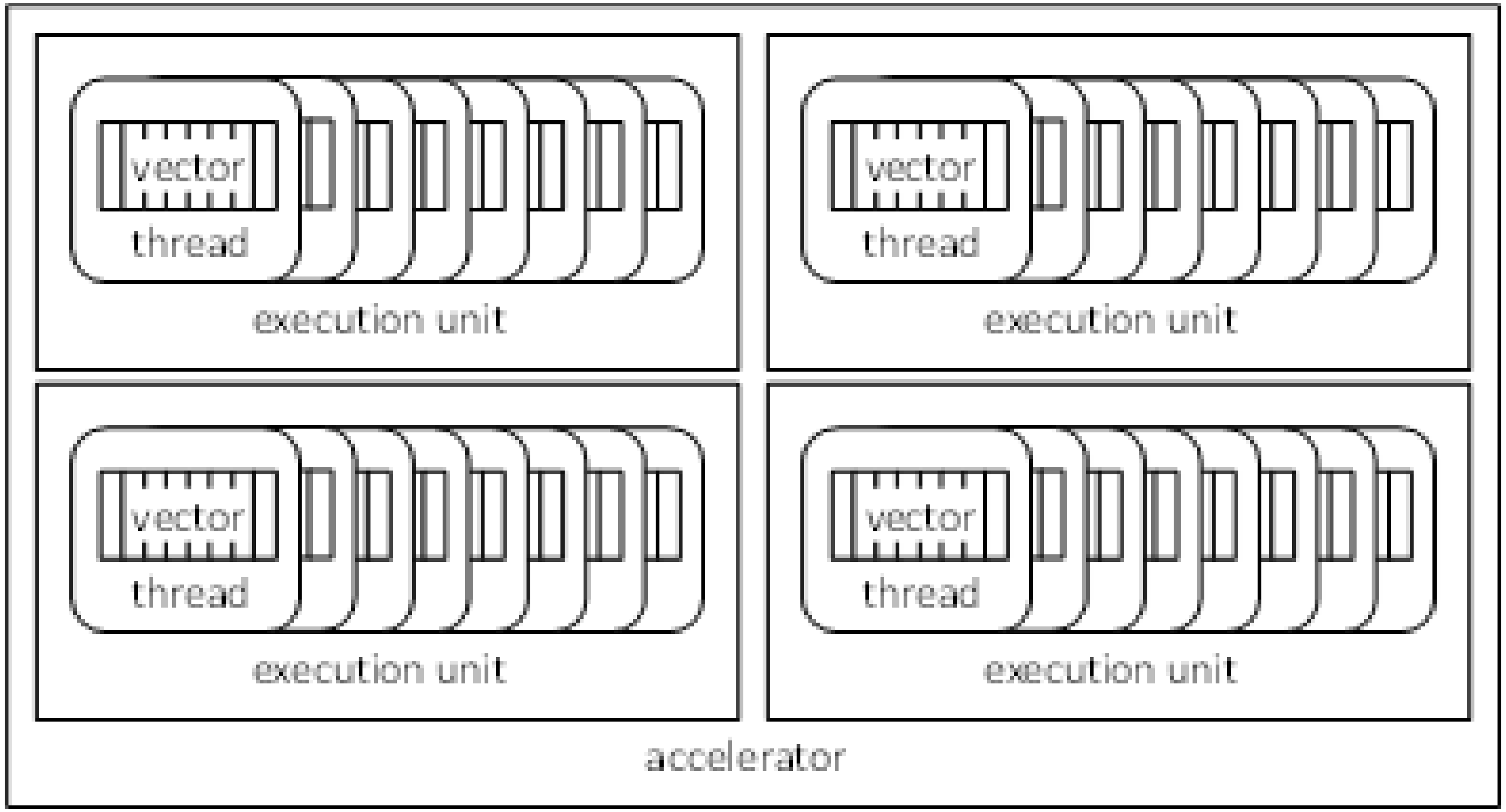
Some OpenACC pragmas

- are hints to the OpenACC compiler,
- which may or may not be able to act accordingly

Performance depends heavily

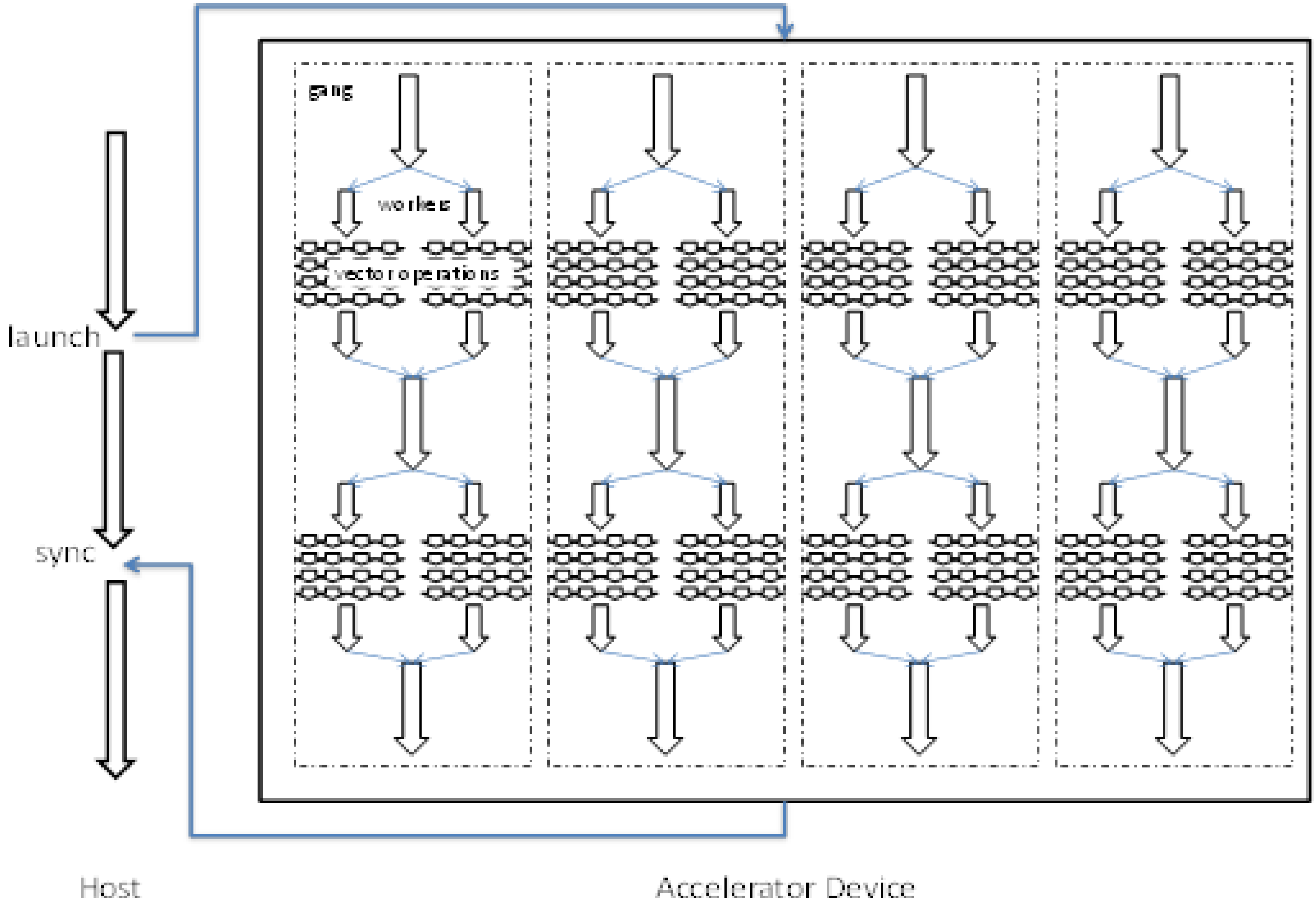
- **on** the **quality of** the **compiler**
- (more so than with CUDA or OpenCL).

OpenACC Device Model



Currently OpenACC does not allow user-specified synchronization across threads.

OpenACC Execution Model (Terminology: Gangs and Works)



Parallel vs. Loop Constructs

```
#pragma acc parallel loop copyin(M[0:Mh*Mw]) copyin(N[0:Nw*Mw]) copyout(P[0:Mh*Nw])
for (int i=0; i<Mh; i++) {
…
}
```

is equivalent to:

```
#pragma acc parallel copyin(M[0:Mh*Mw]) copyin(N[0:Nw*Mw]) copyout(P[0:Mh*Nw])
{
    #pragma acc loop
    for (int i=0; i<Mh; i++) {
        …
    }
}
```

(a parallel region that consists of just a loop)

Parallel Construct

- A parallel construct is executed on an accelerator
- One can specify the number of gangs and number of works in each gang
- Programmer's directive

```
#pragma acc parallel copyout(a) num_gangs(1024) num_workers(32)
{
        a = 23;
}
```

1024*32 workers will be created. a=23 will be executed redundantly by all 1024 gang leads

What does each “Gang Loop” do?

```
#pragma acc parallel num_gangs(1024)
{
    for (int i=0; i<2048; i++) {
        …
    }
}
```

The for-loop will be redundantly executed by 1024 gangs

```
#pragma acc parallel num_gangs(1024)
{
#pragma acc loop gang
    for (int i=0; i<2048; i++) {
        …
    }
}
```

The 2048 iterations of the for-loop will be divided among 1024 gangs for execution

Worker Loop

```
#pragma acc parallel num_gangs(1024) num_workers(32)
{
    #pragma acc loop gang
    for (int i=0; i<2048; i++) {
        #pragma acc loop worker
        for (int j=0; j<512; j++) {
            foo(i,j);
        }
    }
}
```

1024*32=32K workers will be created, each executing 1M/32K = 32 instance of foo()

A More Complex Example

```
#pragma acc parallel num_gangs(32)
{
    Statement 1; Statement 2;
    #pragma acc loop gang
    for (int i=0; i<n; i++) {
        Statement 3; Statement 4;
    }
    Statement 5;  Statement 6;
    #pragma acc loop gang
    for (int i=0; i<m; i++) {
        Statement 7;  Statement 8;
    }
    Statement 9;
    if (condition)
       Statement 10;
}
```

- Statements 1 and 2 are redundantly executed by 32 gangs
- The n for-loop iterations are distributed to 32 gangs

Kernel Regions

```
#pragma acc kernels
{
    #pragma acc loop num_gangs(1024)
    for (int i=0; i<2048; i++) {
        a[i] = b[i];
    }
    #pragma acc loop num_gangs(512)
    for (int j=0; j<2048; j++) {
        c[j] = a[j]*2;
    }
    for (int k=0; k<2048; k++) {
        d[k] = c[k];
    }
}
```

- Kernel constructs are descriptive of programmer intentions (suggestions)

Reduction

```
#pragma acc parallel loop
 reduction(+:sum)
  for(int i=0;i<n;i++) {
    sum +=
      xcoefs[i]*ycoefs[i];
  }
```

- Because each iteration of the loop adds to the variable sum, we must declare a reduction.
- A parallel reduction may return a slightly different result than a sequential addition due to floating point limitations.

C/C++ vs. FORTRAN

```
// C or C++
#pragma acc <directive> <clauses>
{ … }

! Fortran
!$acc <directive> <clauses>
…
!$acc end <directive>
```

ANY MORE QUESTIONS? READ CHAPTER 15

Also see https://developer.nvidia.com/intro-to-openacc-course-2016