NYU
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Graphics Processing Units (GPUs): Architecture and Programming

Lecture : OpenACC

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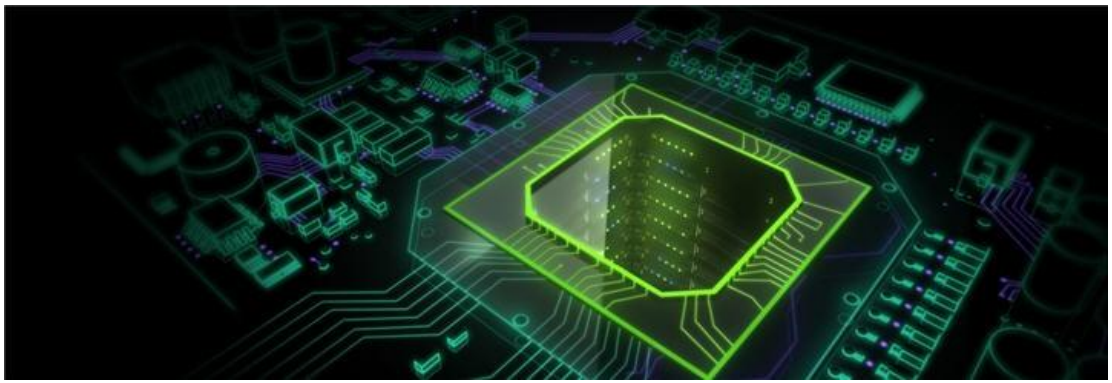
Some slides for this lecture are adopted (and slightly edited) from

- David Kirk and Wei-mei W. Hwu



What is OpenACC?

- The OpenACC Application Programming Interface provides a set of
  - compiler directives (pragmas)
  - library routines and
  - environment variables

  that can be used to write data parallel FORTRAN, C and C++ programs that run on accelerator devices.

http://www.openacc.org/

What is OpenACC?

- Initially developed by Portland Group (PGI), CRAY, NVIDIA with support from CAPS enterprise
- Announced at the Supercomputing Conference (SC11), Nov 2011.

#pragma

- In C and C++: the #pragma directive is:

the method to provide, to the compiler, information that is not specified in the standard language.

MatrixMultiplication

```
1  void computeAcc(float *P, const float *M, const float *N, int Mh, int Mw, int Nw)
2  {
3
4

5   for (int i=0; i<Mh; i++) {
6
7       for (int j=0; j<Nw; j++) {
8           float sum = 0;
9           for (int k=0; k<Mw; k++) {
10              float a = M[i*Mw+k];
11              float b = N[k*Nw+j];
12              sum += a*b;
13          }
14          P[i*Nw+j] = sum;
15      }
16   }
17 }
```

MatrixMultiplication in OpenACC

```
1  void computeAcc(float *P, const float *M, const float *N, int Mh, int Mw, int Nw)
2  {
3
4   #pragma acc parallel loop copyin(M[0:Mh*Mw]) copyin(N[0:Nw*Mw])
                copyout(P[0:Mh*Nw])
5   for (int i=0; i<Mh; i++) {
6      #pragma acc loop
7      for (int j=0; j<Nw; j++) {
8         float sum = 0;
9         for (int k=0; k<Mw; k++) {
10           float a = M[i*Mw+k];
11           float b = N[k*Nw+j];
12           sum += a*b;
13        }
14        P[i*Nw+j] = sum;
15     }
16  }
17 }
```

MatrixMultiplication in OpenACC

```
1  void computeAcc(float *P, const float *M, const float *N, int Mh, int Mw, int Nw)
2  {
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4   #pragma acc parallel loop copyin(M[0:Mh*Mw]) copyin(N[0:Nw*Mw])
                copyout(P[0:Mh*Nw])
5   for (int i=0; i<Mh; i++) {
6      #pragma acc loop
7      for (int j=0; j<Nw; j++) {
8         float sum = 0;
9         for (int k=0; k<Mw; k++) {
10           float a = M[i*Mw+k];
11           float b = N[k*Nw+j];
12           sum += a*b;
13        }
14        P[i*Nw+j] = sum;
15     }
16  }
17 }
```

The copyin clause and the copyout clause specify how the matrix data should be transferred between the host and the accelerator.

instructs the compiler to map the inner 'j' loop on the accelerator.

Motivation

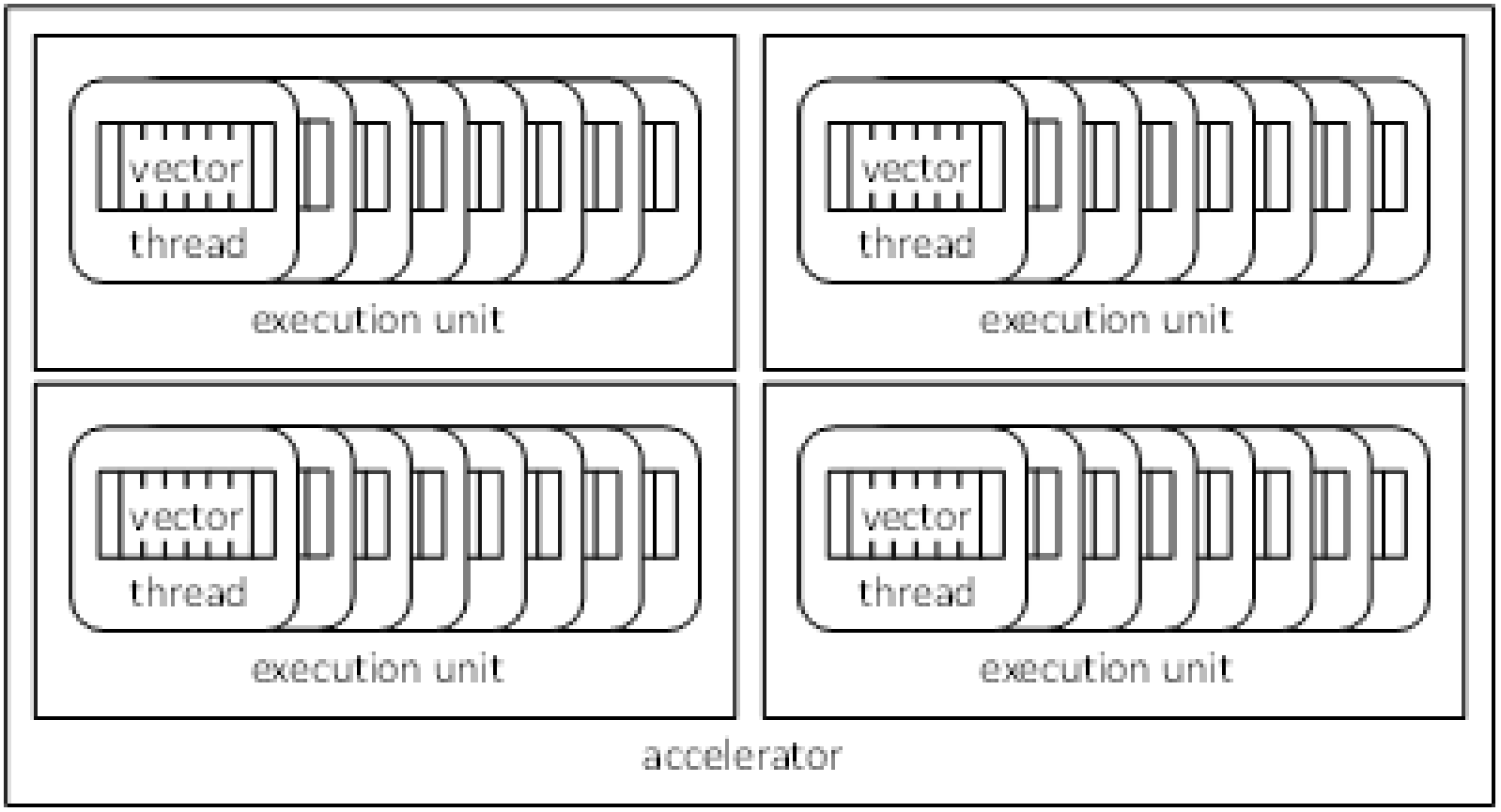
- OpenACC programmers can often start with writing a sequential version and then annotate their sequential program with OpenACC directives.
  - leave most of the details in generating a kernel and data transfers to the OpenACC compiler.

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

Frequently Encountered Issues

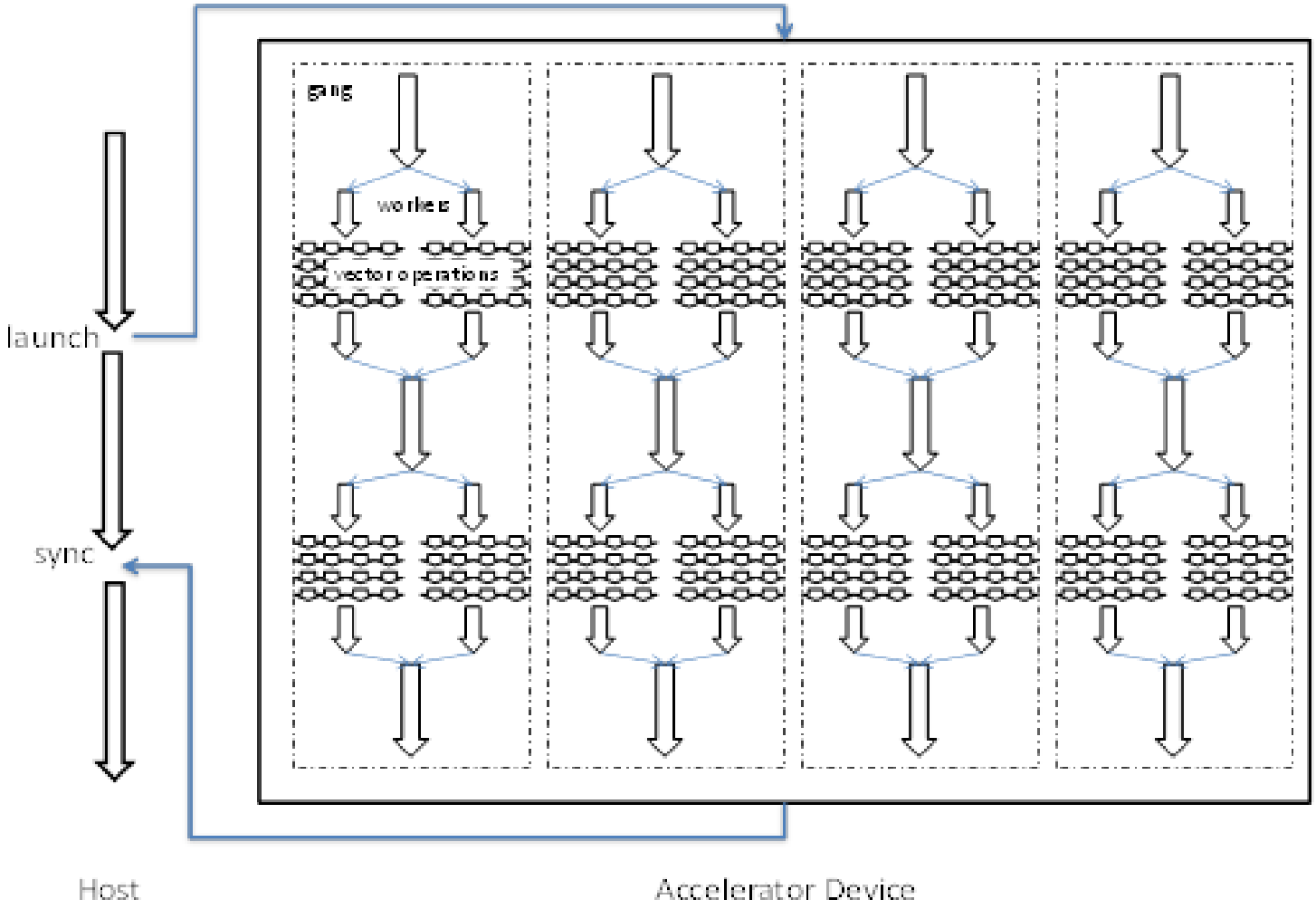
- Some OpenACC pragmas are hints to the OpenACC compiler, which may or may not be able to act accordingly
  - The performance of an OpenACC depends heavily on the quality of the compiler.
  - Much less so in CUDA or OpenCL
- Some OpenACC programs may behave differently or even incorrectly if pragmas are ignored

OpenACC Device Model

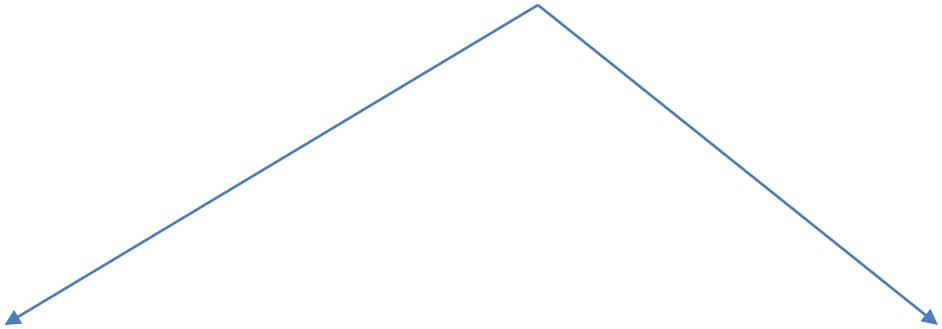


Currently OpenACC does not allow synchronization across threads.

OpenACC Execution Model



OpenACC has two main constructs



Parallel Construct

Kernels Construct

Parallel Construct

```
#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 workers in each gang

```
#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

Gangs Loop

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

One worker within each gang
will execute the parallel region.
So, the 2048 iterations
will be executed redundantly
and sequentially by 1024 gang leaders.

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

The 2048 loop iterations will be
distributed among the 1024 gangs.
Each gang leader will execute 2 iterations.

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()

```
#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 gang leaders (32)
- The n for-loop iterations are distributed to 32 gangs, each gang will distribute its share to a number of workers.

What if statements: 1, 2, 5, 6, 9, and 10 must be executed only once for the correctness of the program?

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

Multiple level of Parallelism

```
{
        for(int i =0; i < 2048; i++){
            for( j = 0; j < 512; j++){
                for( k = 0; k < 1024; k++) {
                    foo(i, j, k);
            }
        }
    }
}
```

Multiple level of Parallelism

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

Kernel Constructs

```
#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
- Kernel region may be broken into a series of kernels, each of which executed on the accelerator.

```
void foo(int * x, int * y, int n, int m){
  int a[2048], b[2048];

  #pragma acc kernels copy(x[0:2048], y[0:2048], a, b)
  {
     //no data dependence
     #pragma acc loop
     for( int i =0; i < 2047; i++){
                    a[i] = b[i+1] + 1;
     }

    //data dependence
    #pragma acc loop
     for( int j =0; j < 2047; j++){
                    a[j] = a[j+1] + 1;
     }

    // Data dependence if x[] is not aliased with y[]
    #pragma acc loop
     for( int k =0; k < 2047; k++){
                    x[i] = y[i+1] + 1;
     }

    //no data dependence if n >= m
    #pragma acc loop
     for( int l =0; l < m; l++){
                    x[l] = x[l+n] + 1;
     }


  }
}
```

```
void foo(int * x, int * y, int n, int m){
  int a[2048], b[2048];

  #pragma acc kernels copy(x[0:2048], y[0:2048], a, b)
  {
     //no data dependence
     #pragma acc loop
     for( int i =0; i < 2047; i++){
                a[i] = b[i+1] + 1;
     }

    //data dependence
    #pragma acc loop
     for( int j =0; j < 2047; j++){
                a[j] = a[j+1] + 1;
     }

    // Data dependence if x[] is not aliased with y[]
    #pragma acc loop
     for( int k =0; k < 2047; k++){
                x[i] = y[i+1] + 1;
     }

    //no data dependence if n >= m
    #pragma acc loop
     for( int l =0; l < m; l++){
                x[l] = x[l+n] + 1;
     }


  }
}
```

OpenACC compiler has no problem parallelizing this loop.

```
void foo(int * x, int * y, int n, int m){
 int a[2048], b[2048];

 #pragma acc kernels copy(x[0:2048], y[0:2048], a, b)
 {
    //no data dependence
    #pragma acc loop
    for( int i =0; i < 2047; i++){
                a[i] = b[i+1] + 1;
    }

    //data dependence
    #pragma acc loop
    for( int j =0; j < 2047; j++){
                a[j] = a[j+1] + 1;
    }

    // Data dependence if x[] is not aliased with y[]
    #pragma acc loop
    for( int k =0; k < 2047; k++){
                x[i] = y[i+1] + 1;
    }

    //no data dependence if n >= m
    #pragma acc loop
    for( int l =0; l < m; l++){
                x[l] = x[l+n] + 1;
    }


 }
}
```

OpenACC compiler has no problem deciding that this loop is not parallelizable.

```
void foo(int * x, int * y, int n, int m){
 int a[2048], b[2048];

 #pragma acc kernels copy(x[0:2048], y[0:2048], a, b)
 {
    //no data dependence
    #pragma acc loop
    for( int i =0; i < 2047; i++){
                a[i] = b[i+1] + 1;
    }

   //data dependence
   #pragma acc loop
    for( int j =0; j < 2047; j++){
                a[j] = a[j+1] + 1;
    }

   // Data dependence if x[] is not aliased with y[]
   #pragma acc loop
    for( int k =0; k < 2047; k++){
                x[i] = y[i+1] + 1;
    }

   //no data dependence if n >= m
   #pragma acc loop
    for( int l =0; l < m; l++){
                x[l] = x[l+n] + 1;
    }


 }
}
```

The compiler will take the conservative approach and not parallelize this loop.
If you are sure that x[] and y[] are not aliased then use:

foo(int * restricted x, int * restricted y, ….)

```
void foo(int * x, int * y, int n, int m){
 int a[2048], b[2048];

 #pragma acc kernels copy(x[0:2048], y[0:2048], a, b)
 {
    //no data dependence
    #pragma acc loop
    for( int i =0; i < 2047; i++){
                a[i] = b[i+1] + 1;
    }

   //data dependence
   #pragma acc loop
    for( int j =0; j < 2047; j++){
                a[j] = a[j+1] + 1;
    }

   // Data dependence if x[] is not aliased with y[]
   #pragma acc loop
    for( int k =0; k < 2047; k++){
                x[i] = y[i+1] + 1;
    }

   //no data dependence if n >= m
   #pragma acc loop
    for( int l =0; l < m; l++){
                x[l] = x[l+n] + 1;
    }


 }
}
```

The compiler will take the conservative approach and not parallelize this loop.

If you are sure that it can be parallelized, then use:

#pragma acc loop independent

Conclusions

- OpenACC is easy to learn and gets you to a fast start to use an accelerators.
- Directives on top of C, C++, and Fortran
- Compared with CUDA, OpenACC gives you less control of how the final code on the accelerator will be.
- OpenACC can be used fairly fine with CUDA and its libraries.