GPU Teaching Kit

Accelerated Computing

Lecture 21.1 - Related Programming Models: OpenACC

Introduction to OpenACC

Objective

- To understand the OpenACC programming model
  - basic concepts and pragma types
  - simple examples

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 including GPUs and CPUs

OpenACC Pragmas

- In C and C++, the #pragma directive is the method to provide to the compiler information that is not specified in the standard language.
  - These pragmas extend the base language

Vector Addition in OpenACC

```
void VecAdd(float * __restrict__ output, const float * input1, const float * input 2, int inputLength)
{
 #pragma acc parallel loop copyin(input1[0:inputLength],input2[0:inputLength]),
       copyout(output[0:inputLength])
    for(i = 0; i < inputLength; ++i) {
        output[i] = input1[i] + input2[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:Mw*Nw]) 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;
     }
 }
}
```

Some Observations (1)

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

The code is almost identical to the sequential version, except for the two lines with #pragma at line 3 and line 5.

Some Observations (2)

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

The #pragma at line 3 tells the compiler to generate code for the ‘i’ loop at line 4 through 15 so that the loop iterations are executed at the first level of parallelism on the accelerator.

Some Observations (3)

```
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:Mw*Nw]) 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;
     }
 }
}
```

The copyin() clause and the copyout() clause specify how the compiler should arrange for the matrix data to be transferred between the host and the accelerator.

Some Observations (4)

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

The #pragma at line 5 instructs the compiler to map the inner ‘j’ loop to the second level of parallelism on the accelerator.

Motivation

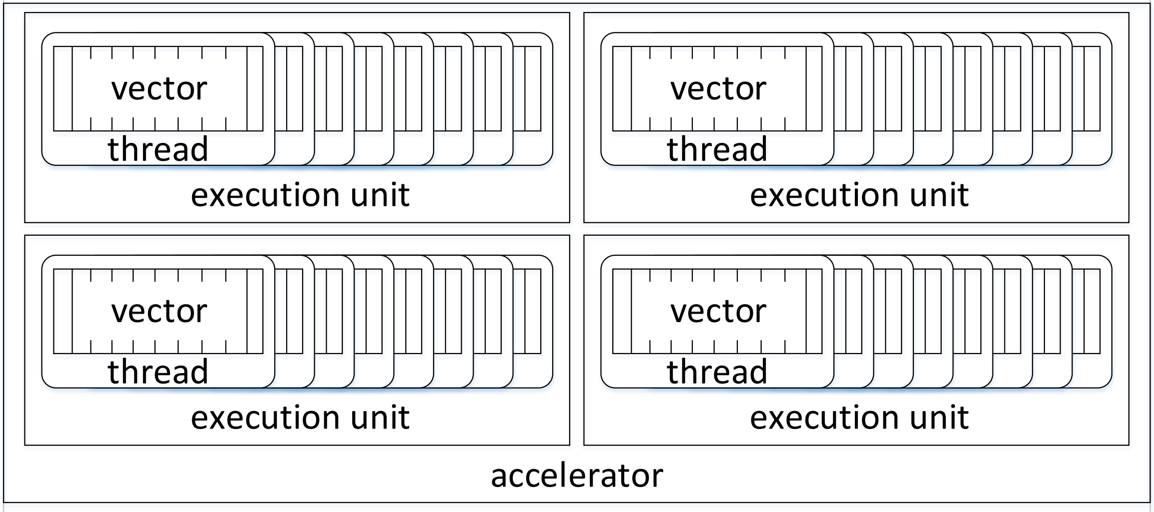
– OpenACC programmers can often start with writing a sequential version and then annotate their sequential program with OpenACC directives.
  – leave most of the details in generating a kernel, memory allocation, and data transfers to the OpenACC compiler.

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

Frequently Encountered Issues

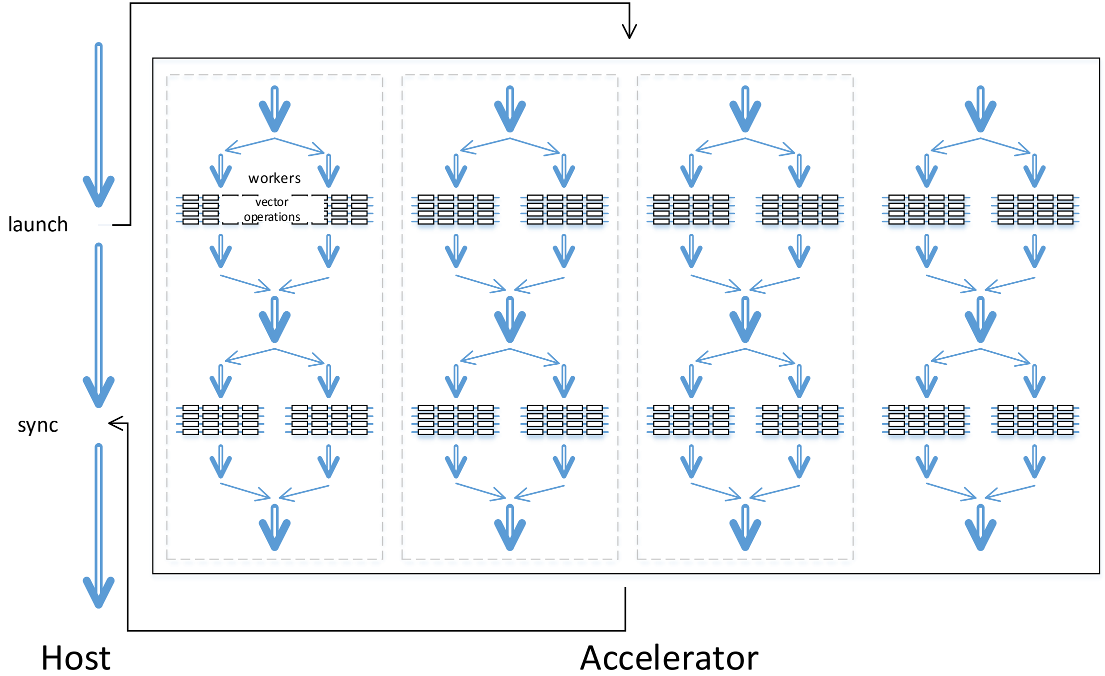
- Some OpenACC pragmas are hints to the OpenACC compiler, which may or may not be able to act accordingly
  - The performance of an OpenACC program depends heavily on the quality of the compiler.
  - It may be hard to figure out why the compiler cannot act according to your hints
  - The uncertainty is much less so for CUDA or OpenCL programs

OpenACC Device Model



Currently OpenACC does not expose synchronization across threads to the programmers.

OpenACC Execution Model



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Lecture 21.2 - Related Programming Models: OpenACC

OpenACC Subtleties

Objective

- To understand some important and sometimes subtle details in OpenACC programming
  - parallel loops
  - simple examples to illustrate basic concepts and functionalities

Parallel vs. Loop Constructs

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

(a parallel region that consists of a single loop)

More on Parallel Construct

```
#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

- A parallel construct is executed on an accelerator
- One can specify the number of gangs and number of workers in each gang
  - Equivalent to CUDA blocks and threads

What Does Each “Gang Loop” Do?

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

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

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 Substantial Example

- Statements 1, 3, 5, 6 are redundantly executed by 32 gangs

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

A More Substantial Example

- The iterations of the n and m for-loop iterations are distributed to 32 gangs
- Each gang could further distribute the iterations to its workers
  - The number of workers in each gang will be determined by the compiler/runtime

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

Avoiding Redundant Execution

- Statements 1, 3, 5, 6 will be executed only once
- Iterations of the n and m loops will be distributed to 32 workers

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

Kernel Regions

- Kernel constructs are descriptive of programmer intentions
  - The compiler has a lot of flexibility in its use of the information
- This is in contrast with Parallel, which is prescriptive of the action for the compile follow

```
#pragma acc kernels
{
  #pragma acc loop gang(1024)
  for (int i=0; i<2048; i++) {
    a[i] = b[i];
  }
  #pragma acc loop gang(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 Regions

- Code in a kernel region can be broken into multiple CUDA/OpenCL kernels
- The i, j, k loops can each become a kernel
  - The k-loop may even remain as host code
- Each kernel can have a different gang/worker configuration

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

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