An Introduction to OpenACC

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CISC 879 — Advanced Parallel Programming

Outline

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    - About OpenACC
2. The OpenACC API
    - Directives
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Methods of Accelerating Applications

- Targeting Multi-core CPUs
- Targeting Multi-node CPUs
- Targeting GPUs

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    - OpenMP
    - PThreads, QThreads, etc …

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- Targeting GPUs
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  - OpenCL

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What’s left? …**OpenACC!**

Methods of Accelerating Applications

- Targeting Multi-core CPUs
    - OpenMP
    - PThreads, QThreads, etc …
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- Targeting Multi-node CPUs
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- Targeting GPUs
    - CUDA
    - OpenCL
    - OpenACC

What's left? …**OpenACC!**

What is OpenACC?

- is an API using compiler directives that
- allows for small segments of code, called kernels, to be run on the GPU and
- requires little to no modifications to the original program
- is compatible with C/C++ and Fortran

Reason Behind Formation

OpenACC was formed to help create and foster a cross platform API that would allow any scientist or programmer to easily accelerate their application on modern many-core and multi-core processors using directives.

History of OpenACC

- Initially collaboration between CAPS Entreprise, Cray Inc., The Portland Group (PGI), and NVIDIA
- Built from OpenMP-style directives
    - `#pragma omp parallel` vs. `#pragma acc parallel`
    - Creators of OpenACC are all members of the OpenMP Working Group on accelerators
- Standardized in November 2011 at SuperComputing 2011
- Compilers available from Cray, CAPS, and PGI
- Potential API merge with OpenMP in the future?

Directives Overview

Format

`#pragma acc` *directive-name [clause [[,] clause] …]*

Possible directives are:

`parallel`	starts parallel execution on the accelerator
`kernels`	defines a region that should be converted to a kernel
`data`	defines contiguous data to be allocated on the accelerator
`host_data`	makes the address of accelerator data available on the host
`loop`	defines type of parallelism to apply to proceeding loop

Directives Overview (continued)

`cache`	defines elements or subarrays that should be fetched into cache
`declare`	defines that a variable should be allocated in accelerator memory
`update`	update all or part of host memory from device memory, or vice versa
`wait`	forces program to wait for completion of asynchronous activity

Clauses Overview

Each directive can have zero (or more) clauses associated.

Example clauses are:

`if (e)`	condition used to determine if command should be executed (data transfer, accelerator computation, etc)
`async [(n)]`	tells the current command to be executed asynchronously. Used with `wait` for synchronization.

Clauses found in either `kernels` or `parallel` directives:

`reduction (op:list)`

`private (list)`

`firstprivate (list)`

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Clauses found in either `kernels` or `parallel` directives:

`reduction (op:list)`

`private (list)` similar to OpenMP

`firstprivate (list)`

Clauses — `parallel` and `loop`

Clauses — `parallel` directive

`num_gangs(e)`	specify the number of gangs to execute in the region
`num_workers(e)`	specify number of workers to launch in each gang
`vector_length(e)`	define vector length to use

Clauses — `loop` directive

`collapse(n)`	specifies # of loops associated
`gang(e)`	distribute across gang
`worker(e)`	distribute across worker (within gang)
`vector(e)`	operate in SIMD (within gang or worker)
`seq`	execute sequentially on the accelerator
`independent`	tell the compiler loops are data-independent

Clauses — Data Operations (optional with most directives)

`copy(list)`	transfer to/from device
`copyin(list)`	transfer to device
`copyout(list)`	transfer from device
`create(list)`	allocate on device
`present(list)`	data which is already on the device
`deviceptr(list)`	used to inform which variables are device pointers (opposed to host)
`device_resident(list)`	allocate on device instead of host

Clauses — Data Operations (optional with most directives)

`pcopy(list)`	transfer to/from device
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`pcreate(list)`	allocate on device
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`device_resident(list)`	allocate on device instead of host

Checks for presence before issuing data command

Clauses — `host_data` and `update`

Clauses — use with `host_data` directive

`use_device (list)`	make the device address data available in host code

Clauses — use with `update` directive

`host (list)`	variables to copy from device to host
`device (list)`	variables to copy from host to device

Data Clauses

We mentioned data clauses such as `copy` and `create` but never went over what we do when the memory was dynamically allocated (using malloc).

What should we do?

We can specify the size of the data!

A is our array of size *n* but we need to provide a hint to OpenACC

Solution:

```
#pragma acc kernels copyin(A[0:n])
```

Note

This will also work for 2-dimensional arrays i.e. `A[0:m*n])`

Combining Clauses

Observation

Similar to OpenMP, we can combine directives

- `#pragma acc parallel loop [clause [[,] clause]...]`
- `#pragma acc kernels loop [clause [[,] clause]...]`

Notice

A loop must directly follow, similar to `parallel for` in OpenMP

Runtime Routines

Runtime calls allow the programmer to obtain information about the host and accelerators during runtime, instead of compile time.

List of library routines:

`int acc_get_num_devices (acc_device_t);`

gets number of devices of passed type

`int acc_set_device_type (acc_device_t);`

sets device type to use

`acc_device_t acc_get_device_type ();`

gets current device type

`void acc_set_device_num (int, acc_device_t);`

sets device based on index and type

`void acc_get_device_num (acc_device_t);`

gets current device number

Runtime Routines — Synchronization

`int acc_async_test (int);`	tests to see if a specified async. tasks are completed
`int acc_async_test_all ();`	tests to see if all async. tasks are completed
`void acc_async_wait (int);`	waits until specified async. task is completed
`void acc_async_wait_all ();`	waits until all async. tasks are completed

Runtime Routines — Setup and Teardown

`void acc_init (acc_device_t);`	initialize OpenACC runtime for passed device type
`void acc_shutdown (acc_device_t);`	shut down connection to passed device type
`int acc_on_device (acc_device_t);`	tells the program whether it’s executing on passed device type
`void* acc_malloc (size_t);`	allocates memory on the device
`void acc_free (void*);`	frees memory on the device

Compiling OpenACC

There are a few different compilers available for OpenACC.

We will be using HMPP Workbench 3.2.1 by CAPS Entreprise

In addition to OpenACC, HMPP Workbench also supports another directive-based accelerator language, HMPP (and consequently OpenHMPP).

Compiling using Built-in (supplied) Makefiles

- Obtain HMPP Workbench 3.2.1 (see website for details)
- Extract the tarball
- Extract the OpenACC Labs tarball
- Navigate to the `OpenACC_Labs/CUDA/C/` directory
- Copy an existing lab
- Edit the code
- Invoke “make”

Compiling using the command line

Sample Invocation

```
hmpp --openacc-target=CUDA --codelet-required
gcc -O2 -o mvmult mvmult.c
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- hmpp compiler
- specify OpenACC codelet target (CUDA or OPENCL)

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- hmpp compiler
- specify OpenACC codelet target (CUDA or OPENCL)
- force proper codelet creation for compilation

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Compiling using the command line

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- hmpp compiler
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Sample Invocation

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- hmpp compiler
- specify OpenACC codelet target (CUDA or OPENCL)
- force proper codelet creation for compilation
- compiler to use for host code
- flags for host compiler
- specify output file

Compiling using the command line

Sample Invocation

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```

- hmpp compiler
- specify OpenACC codelet target (CUDA or OPENCL)
- force proper codelet creation for compilation
- compiler to use for host code
- flags for host compiler
- specify output file
- source file(s)

Problem Overview

Problem

Given two vectors, *A* and *B*, each of size *n*, we wish to compute the per-component addition and store the result into *C*.

Pseudocode

```
int i;
for (i = 0; i < N; ++i) {
 C [i] = A [i] + B [i];
}
```

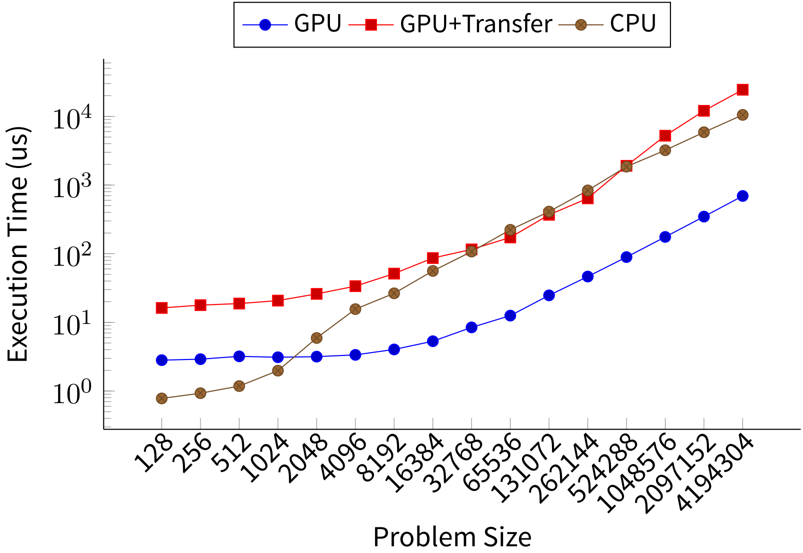
C Implementation

```c
const int N = 1000;
float A [N];
float B [N];
float C [N];
int i;

// Initialization Loop
for (i = 0; i < N; ++i) {
  A [i] = i;
  B [i] = 2* i - 1;
}

// Computation Loop

for (i = 0; i < N; ++i) {
  C [i] = A [i] + B [i];
}
```

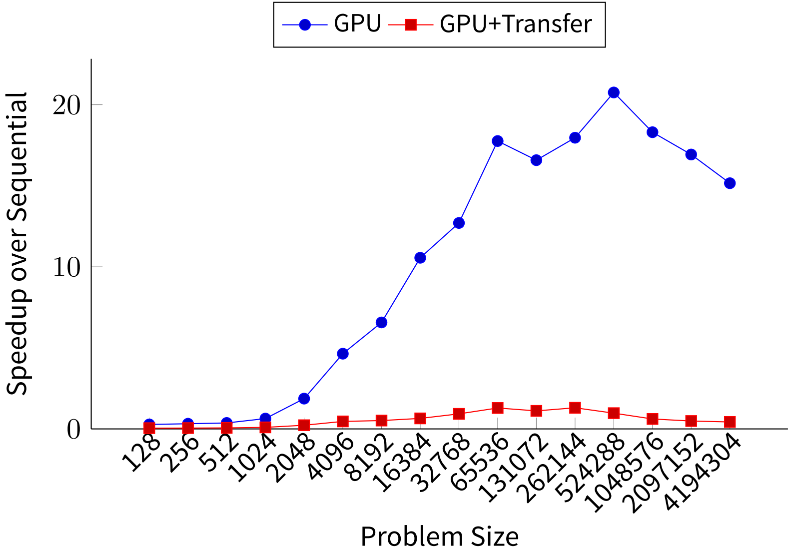
OpenACC Implementation

```c
const int N = 1000;
float A [N];
float B [N];
float C [N];
int i;

// Initialization Loop
for (i = 0; i < N; ++i) {
  A [i] = i;
  B [i] = 2* i - 1;
}

// Computation Loop
#pragma acc kernels loop independent copyin(A,B), copyout(C)
for (i = 0; i < N; ++i) {
  C [i] = A [i] + B [i];
}
```

Execution time of Vector-Vector Addition



Speedup of Vector-Vector Addition



Problem Overview

Problem

Given two matricies, *A* and *B*, with *A* having dimensions *m* x *p* and *B* having dimensions *p* x *n*, we wish to compute the row-column inner product into *C*, a matrix with dimensions *m* x *n*.

Pseudocode

```
int i, j, k;
for (i = 0; i < M; ++i)
    for (j = 0; j < N; ++j) {
        C [i][j] = 0;
        for (k = 0; k < P; ++k)
            C [i][j] += A [i][k] * B [k][j];
    }
```

C Implementation (Initialization)

```
#define INDEX(M,N,i,j) (i + j * M)

int main() {

  float* A; float* B; float* C;
  int i, j, k;

  A = (float*) malloc (M * P * sizeof (float));
  B = (float*) malloc (P * N * sizeof (float));
  C = (float*) malloc (M * N * sizeof (float));

  for (i = 0; i < P; ++i) {
    for (j = 0; j < M; ++j)
      A [INDEX(M,P,i,j)] = (float) rand () / RAND_MAX;
    for (k = 0; k < N; ++k)
      B [INDEX(P,N,k,i)] = (float) rand () / RAND_MAX;
  }
```

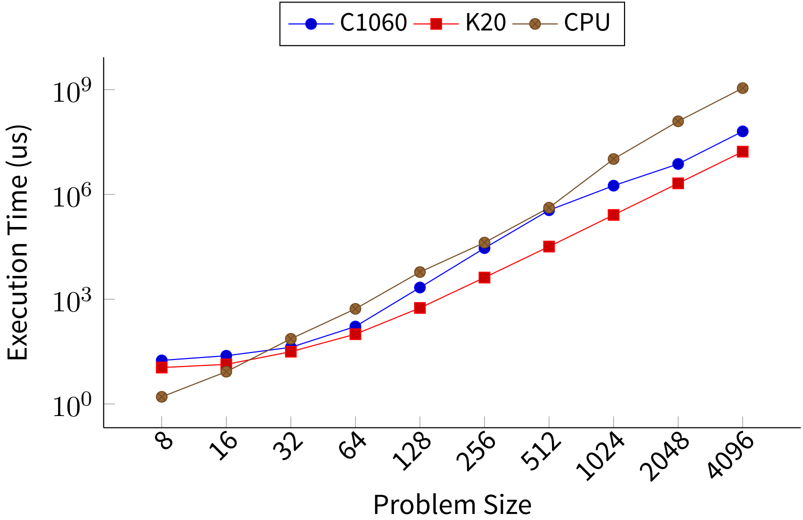
C Implementation (Computation)

```c
  for (i = 0; i < M; ++i) {
    for (j = 0; j < N; ++j) {
      float sum = 0.0f;
      for (k = 0; k < P; ++k) {
        sum += A [INDEX(M,P,i,k)] * B [INDEX(P,N,k,j)];
      }
      C [INDEX(M,N,i,j)] = sum;
    }
  }
```

OpenACC Implementation (Computation)

```
 int m, n, p;
 m = M; n = N; p = P;
 // computation
#pragma acc kernels copyin(A[0:m*p],B[0:p*n]), copyout(C[0:m*n
 {
#pragma acc loop independent
  for (i = 0; i < M; ++i) {
#pragma acc loop independent
   for (j = 0; j < N; ++j) {
    float sum = 0.0f;
    for (k = 0; k < P; ++k) {
     sum += A [INDEX(M,P,i,k)] * B [INDEX(P,N,k,j)];
    }
    C [INDEX(M,N,i,j)] = sum;
   }
  }
 }

```

Execution time of Matrix-Matrix Multiplication



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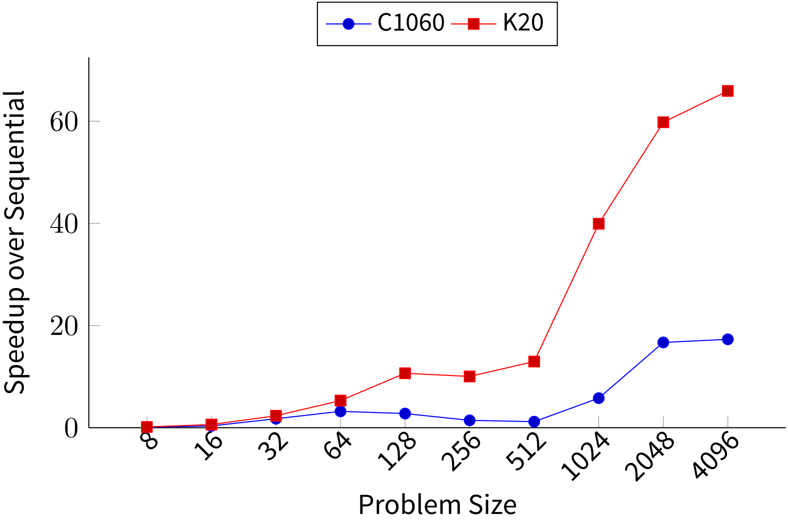

Summary

- OpenACC makes targeting accelerators much easier
- Designed for use by scientists to make GPGPU much easier
- Syntax similar to OpenMP
- Compiling with HMPP Workbench 3.2.1 can target CUDA or OpenCL

OpenACC Reference API

`http://www.openacc.org/sites/default/files/OpenACC.1.0_0.pdf`