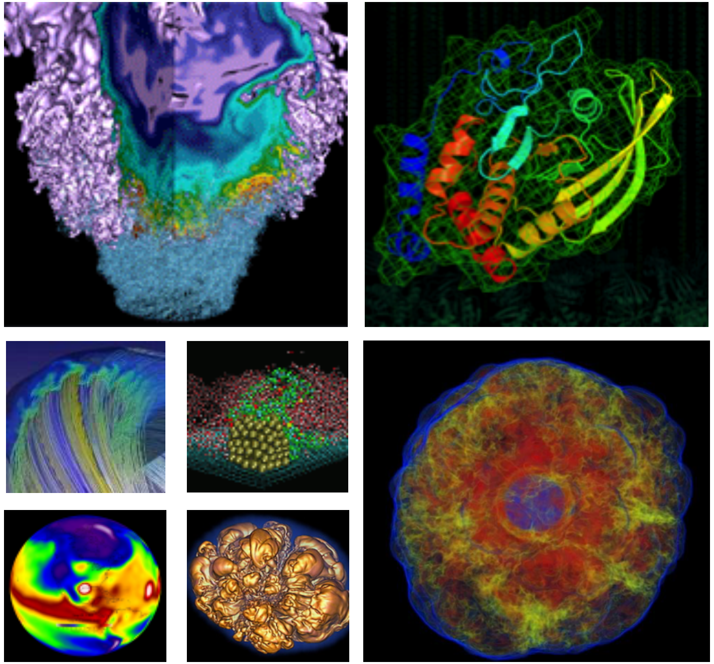
OpenACC Updates

Committee Meeting
Feb 19-21



NERSC

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OpenACC vs. OpenMP

- **Aims to build a 'leaner' set of directives**
    - targeting scalable parallelism, not general parallelism
    - e.g. no tasking, less synchronization primitives
- **Descriptive vs. Prescriptive**
    - lets compilers figure out how to move data/parallelize compute
    - less directed by the programmer
    - hence more performance portable
- **More mature for accelerators whereas OpenMP more mature for multi-cores**
    - can work together though
    - e.g. OpenACC inside OpenMP

- **At the end of the day, the method of parallelizing is the most valuable!**

OpenACC vs. OpenMP

OpenACC	OpenMP
• Focused on accelerated computing	• General purpose parallelism
• More agile	• More measured
• Performance portability	• Performance portability a challenge
• Descriptive	• Prescriptive
• Extensive interoperability	• Limited interoperability
• More mature for accelerators	• More mature for multi-core

* Michael Wolfe, Duncan Poole
https://www.nextplatform.com/2015/11/30/is-openacc-the-best-thing-to-happen-to-openmp/

Face-to-Face Meeting

We're a member now!!

- **Feedback from previous hackathons**
  - OLCF GPU Hackathons
  - OpenACC Hackathons

- **Issues from previous discussions or GitHub OpenACC/openacc-spec/Issues**
  - **Deep copy**
  - **Multiple devices**
  - **Task graphs**
  - **Optimization directives**
  - **C++ Lambdas**
  - Aliasing on data clauses, #14
  - Reductions, #148, #157
  - `requires` directive
  - Cleaning up C/C++/Fortran pointers
  - Error handler
  - Memory Allocation
  - New C/C++/Fortran language features

- **Prioritizing/Assigning open issues**

Deep Copy

- Nested dynamic data structures
- e.g. ICON, climate code from CSCS, Fortran, four levels of derived structured arrays

```
type t_nh_state

  !array of prognostic states at different timelevels
  type(t_nh_prog), allocatable :: prog(:)       !< shape: (timelevels)
  type(t_var_list), allocatable :: prog_list(:) !< shape: (timelevels)

  type(t_nh_diag)    :: diag
  type(t_var_list)   :: diag_list

  type(t_nh_ref)     :: ref
  type(t_var_list)   :: ref_list

  type(t_nh_metrics) :: metrics
  type(t_var_list)   :: metrics_list

  type(t_var_list), allocatable :: tracer_list(:) !< shape: (timelevels)

end type t_nh_state

type(t_nh_state), allocatable :: p_nh_state(:)
```

`diag` and `metrics` both have 80 allocatable/pointer array members

Deep Copy

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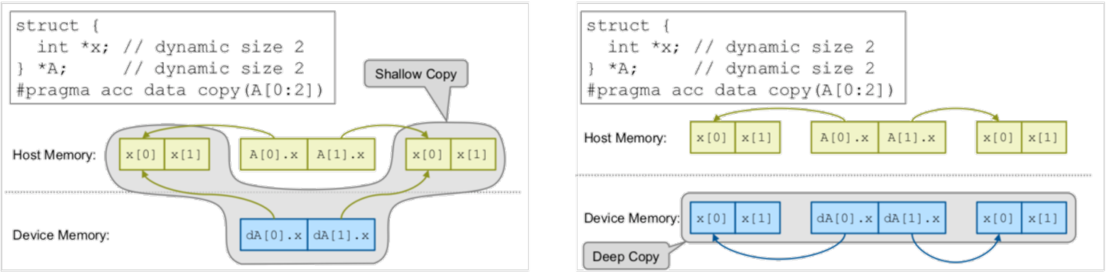
A motivating example:

```
struct deep_type {
     int n;
     float* a;
     float* b;
     float* c;
};
deep_type X;

// Performs shallow copy of X
#pragma acc data copy(X)
```



(a) Shallow copy

(b) Deep copy

Deep Copy

Manual deep copy:

- attach/detach pointers, multi-level pointers

```
struct deep_type {
      int n;
      float* a;
      float* b;
      float* c;
};
deep_type X;

// Performs copy of X, X.a, X.b, X.c and attach a, b, c to parent pointer X (top-down copy)
#pragma acc data copy(X)
#pragma acc data copy(X.a[0:n],X.b[0:n],X.c[0:n])
```

Deep Copy

True deep copy:

- **`shape`** allows defining the size of global deep-copy behavior
- **`policy`** enables defining selective direction behavior of deep-copy

```
struct deep_type {
     int n;
     float* a;
     float* b;
     float* c;

     // This default shape includes deep copy of members a, b, and c, and
     // it ensures member n is always initialized
     #pragma acc shape init_needed(n) include(a[0:n],b[0:n],c[0:n])
};
deep_type X;
// Performs deep copy of X
#pragma acc data copy(X)
```

Deep Copy

True deep copy: shape syntax

```
struct deep_type {
     int n;
     float* a;
     float* b;
     float* c;

     // This default shape includes deep copy of members a, b, and c, and
     // it ensures member n is always initialized
     #pragma acc shape init_needed(n) include(a[0:n],b[0:n],c[0:n])
};
deep_type* Y;
int size;

// Performs a deep copy of Y; note that member n can be different for each element of Y
#pragma acc data copy(Y[0:size])
```

Deep Copy

True deep copy: two layers

```
template <Type T>
class vector {
     T* base;
     T* end;
     #pragma acc shape include base[0:size()], end[@base])
};

class Data {
     vector <float> d1;
     vector <float> d2;
};
Data d;

// This directive performs full deep-copy, since shape is default(include) and each member
has a default shape
#pragma data copy(d)
```

Deep Copy

True deep copy: `policy` syntax

```
struct deep_type {
     int n;
     float* a;
     float* b;
     float* c;

     #pragma acc shape init_needed(n) include(a[0:n],b[0:n],c[0:n])
     // Policy to copyin members b and c and copyout member a (which might be used
     for a computation like a = b + c)
     #pragma acc policy(calc_a) default(copyin) copyout(a)
};
deep_type X;

// Performs selective directional deep copy of X
#pragma acc data invoke<calc_a>(X)
```

Deep Copy

- Syntax is still in discussion

- Details are at
  - https://www.openacc.org/sites/default/files/inline-files/TR-14-1.pdf
  - https://www.openacc.org/sites/default/files/inline-files/TR-16-1.pdf

- May make it to OpenACC 3.0, releasing in Nov 2019.

Multiple Devices

- Currently, the OpenACC execution model is one device at a time
- To support multiple devices, we need to think about expanding the execution model
  - today, OMP/MPI outer, then single device programming within OMP/MPI thread/rank
- One growth area is multiple-device fat workstations/nodes
  - want to be able to control multiple GPUs all within OpenACC

- Two bits of low-hanging fruit when there's only one host thread/rank
  - copying directly between different devices
  - synchronization across device queues

Multiple Devices

- Copying directly between different devices
  - how to specify source and/or target device
  - do we want to support broadcast to multiple devices
  - do we want to support host as a device

```
acc update device(a[0:n]) dstdev(1) srcdev(0)
acc update device(a[0:n]) device_num(0,1) // destination, src
acc update device(a[0:n]) device_num(from:0,to:1)
acc update device(a[0:n]) device_num(1) // no 'from' implies self
acc update device(a[0:n]) device_num(from:1) // no 'to' implies current device
acc update device(a[0:n]) device_num(0,:) // colon implies current device
acc update device(from:a[0:n],to:b[0:n]) device_num(from:0,to:1)
acc update (from:a[0:n],to:b[0:n]) device_num(from:0,toself)
acc memcpy (from:a[0:n],to:b[0:n]) device_num(from:0,toself)
acc set (from:a[0:n],to:b[0:n]) device_num(from:0,toself)
acc update (from:a[0:n],to:b[0:n]) device_num(from:0,to:1)
```

Multiple Devices

- Synchronization across device queues
  - the host waits for each device individually
  - do we want to allow waiting on more than one device

```
acc wait(1,2) device_num(0,1)
acc wait(0:1,1:2)
acc wait(0:1) async(1:2) // device_num:queuenum
acc wait(dev=0:1,dev=1:2) async(dev=2:2)
acc wait([device_num:1,queue:1], device_num:1,queue:2]) async([device_num:2,queue:2])
acc wait([d:1,q:1], d:1,q:2]) async([d:2,q:2])
```

Multiple Devices

- All of this is probably not a functionality issue but more of a syntax issue

- In the future,
  - support ‘any’ integer levels of parallelism
  - how to map parallelism to the fixed levels of parallelism on the device

Task Graphs

- Stephen Jones, Asynchronous Task Graphs in CUDA
- CUDA operations are submitted in streams, FIFO queues with dependences between operations
- Executional dependences and data dependences
- Easy to translate CUDA streams with dependences into a task DAG

- Graph nodes are kernels, data movement, CPU callbacks, subgraphs
- Define the CUDA graph, and launch (and relaunch) the graph very cheaply [instantiate + execute]
  - graph sequence and configurations must be invariant

- A simple example with a sequence of short OpenACC parallel loops launched many times
  - 10 iterations
  - CUDA graph took .014us, and the regular version took .410us -- 30x improvement !

Optimization Directives

- An `unroll` directive for loops?
- An IWOMP paper proposed a plethora of loop transformations for OpenMP
  - unroll
  - tile
  - interchange
  - cache-tiling / strip-mining
  - unroll-and-jam
  - fusion
  - distribute / fission
  - vectorization / simd
  - interleave
  - software pipelining
  - loop invariant code motoin
  - if conversion
  - collapsing

C++ Lambdas

- Compiler generates an anonymous struct with an operator() containing the lambda body, and a struct member for each captured item, either by value or by reference (address)

- Problems
  - unnamed struct does not get copied to the device as there is no named symbol for it
  - operator() function has no 'acc routine' information
  - how to attach pointer members
- Solutions
  - for named lambdas, let user specify 'acc routine' above the lambda declaration
  - for unnamed lambdas, let compiler inject 'acc routine seq'?
  - deep copy lambda members
    - copyin(lambda_struct), copyin(reference members), no_create/attach(pointer_members)

Reference

- All notes are available here
  - https://github.com/OpenACC/openacc-spec/wiki/Notes

- Kyle Friedline (Udel)'s links for compiler comparisons
  - OpenACC stuff:
  - https://crpl.cis.udel.edu/blog/2018/07/15/openaccvv/
  - https://www.researchgate.net/publication/318445660_OpenACC_25_Validation_Testsuite_Targeting_Multiple_Architectures
  - OpenMP stuff:
  - https://crpl.cis.udel.edu/ompvvsollve/results/
  - https://crpl.cis.udel.edu/ompvvsollve/Publications/_index.files/paper.P2S2_2018-EvaluatingSupportForOpenMPOffloadingFeatures.pdf

Thank You

Goal/Vision

- Compared to OpenMP, OpenACC aims to build a ‘leaner’ set of directives
  - targeting scalable parallelism not general parallelism
  - no tasking, less synchronization primitives
- Descriptive vs. Prescriptive, and Performance Portability
  - lets compilers figure out how to move data/parallelize compute
  - less directed by the programmer
- More mature for accelerators whereas OpenMP more for multi-cores
  - can work together though, e.g. OpenACC inside OpenMP
- The method of parallelizing is the most valuable!

Structure of the Meeting

- **Feedback from previous hackathons**
  - OLCF GPU Hackathons
  - OpenACC Hackathons
- **Issues from previous discussions or GitHub OpenACC/openacc-spec/Issues**
  - Multiple devices
  - Aliasing on data clauses, #14
  - Task graphs
  - Reductions, #148, #157
  - C++ Lambdas
  - `requires` directive
  - Deep copy
  - Optimization directives
  - Cleaning up C/C++/Fortran pointers
  - Error handler
  - Memory Allocation
- **Prioritizing open issues**

```
template<typename D>
class foo{
        D* field;
        size_t n;
        foo(int nsize) {
            new field(nsize);
            n = nsize;
        }
        movetodevice() {
            #pragma acc enter data copyin(this)
            #pragma acc enter data copyin(field[0:n])
        }
        movefromdevice() {
            #pragma acc exit data copyout(field[0:n])
            #pragma acc exit data copyout(this)
        }
};
```

```
template<typename D>
class foo{
    D* field;
    size_t n;
    #pragma acc shape(field[0:n])
    foo(int nsize) {
        new field(nsize);
        n = nsize;
    }
    movetodevice() {
        #pragma acc enter data copyin(this)
    }
    movefromdevice() {
        #pragma acc exit data copyout(this)
    }
};
...
foo<double> *x;
foo<class yy> *y;
...
x->movetodevice();
y->movetodevice();  // if class yy has dynamic members,
                    // will not be able to move those m
                    // without true deep copy directive
```

```
struct deep_type {
     int n;
     float* a;
     float* b;
     float* c;

     // This default shape includes deep copy of members a, b, and c, and
     // it ensures member n is always initialized; C pointers must be
     // shaped to get deep copy, since the default shape is a bitcopy of
     // the pointer value
     #pragma acc shape init_needed(n) include(a[0:n],b[0:n],c[0:n])
};

deep_type X;

// Performs deep copy of X
#pragma acc data copy(X)
```

Deep Copy

A motivating example:

```
template<typename D>
class foo{
        D* field;
        size_t n;
        foo(int nsize) {
            new field(nsize);
            n = nsize;
        }

        movetodevice() {
            #pragma acc enter data copyin(this)

        }
        movefromdevice() {
            #pragma acc exit data copyout(field[0:n])

        }
};
```

```
foo<double> *x;

...
x->movetodevice();
```

If class yy has dynamic members, this will not be able to move those members without true deep copy directives.

Deep Copy

A motivating example:

```
template<typename D>
class foo{
        D* field;
        size_t n;
        foo(int nsize) {
            new field(nsize);
            n = nsize;
        }

        movetodevice() {
            #pragma acc enter data copyin(this)

        }
        movefromdevice() {

            #pragma acc exit data copyout(this)
        }
};
```

```
foo<double> *x;
foo<class yy> *y;
...
x->movetodevice();
y->movetodevice();
```

If class yy has dynamic members, this will not be able to move those members without true deep copy directives.

Deep Copy

Manual deep copy:

```
template<typename D>
class foo{
        D* field;
        size_t n;
        foo(int nsize) {
            new field(nsize);
            n = nsize;
        }

        movetodevice() {
            #pragma acc enter data copyin(this)
            #pragma acc enter data copyin(field[0:n])
        }
        movefromdevice() {
            #pragma acc exit data copyout(field[0:n])
            #pragma acc exit data copyout(this)
        }
};
```

```
foo<double> *x;
foo<class yy> *y;
...
x->movetodevice();
y->movetodevice();
```

This will move the dynamic members of `yy`, but requires manual work. Can get very tedious for large codes.

Deep Copy

True deep copy:

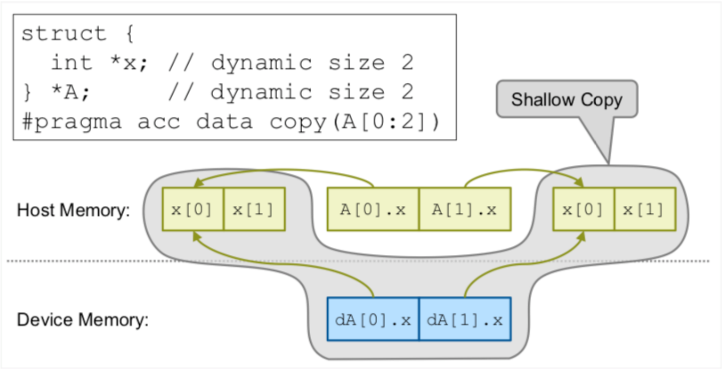
```
template<typename D>
class foo{
        D* field;
        size_t n;
        foo(int nsize) {
            new field(nsize);
            n = nsize;
        }
        #pragma acc shape init_needed(n) include(field[0:n])
        movetodevice() {
            #pragma acc enter data copyin(this)

        }
        movefromdevice() {
            #pragma acc exit data copyout(field[0:n])

        }
};
```

```
foo<double> *x;
foo<class yy> *y;
...
x->movetodevice();
y->movetodevice();
```

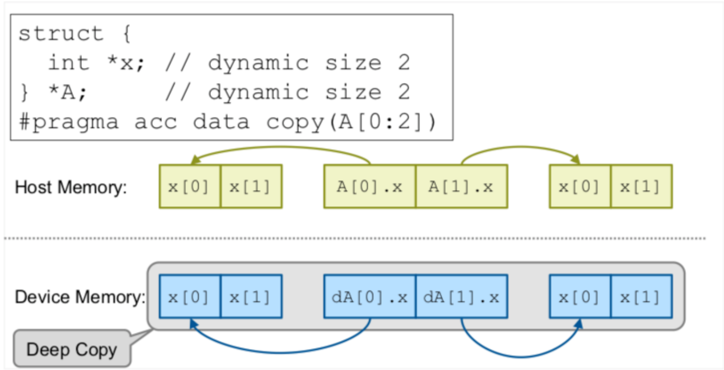
This will move the dynamic members of `yy`, with much manual work.

Deep Copy

- Copy semantics



(a) Shallow copy



(b) Deep copy

- The simple shape syntax allows defining global deep-copy behavior for all objects of a particular type, but it is limited to full and selective-member deep-copy. The policy syntax enables defining global selective direction behavior for all objects of a particular type

- Sync between threadblocks/threads
- Update dev_num
- Wait

- Aliasing in copyin/out

- Task graphs
- Small kernels - launch time 2-3 micro sec
- Code size not changing but device count is increasing
- 0.04s vs 0.4s

- Reductions — two reduction clauses

- Lambda
- Deep copy mechanism

- Deep copy
- ICON code climate fortran 4 levels of derived structured arrays
- CSCS
- Nov 2019, 3.0 Specs

- -Mx,203,n to control threadblock size for PGI compiler
- Memory allocation
- Kyle's links; Pittsburgh tutorials
- Issue 106 vector private variable

Reductions

Fix spec text regarding reductions

```
#pragma acc parallel reduction(+:s)
{
#pragma acc loop gang reduction(+:s)
for(...){
s += 1;
} // reduces gang-private copy of s to something here
} // reduces gang-private copy of s to shared s here
```