OpenMP Offloading

-- getting started through examples --

by

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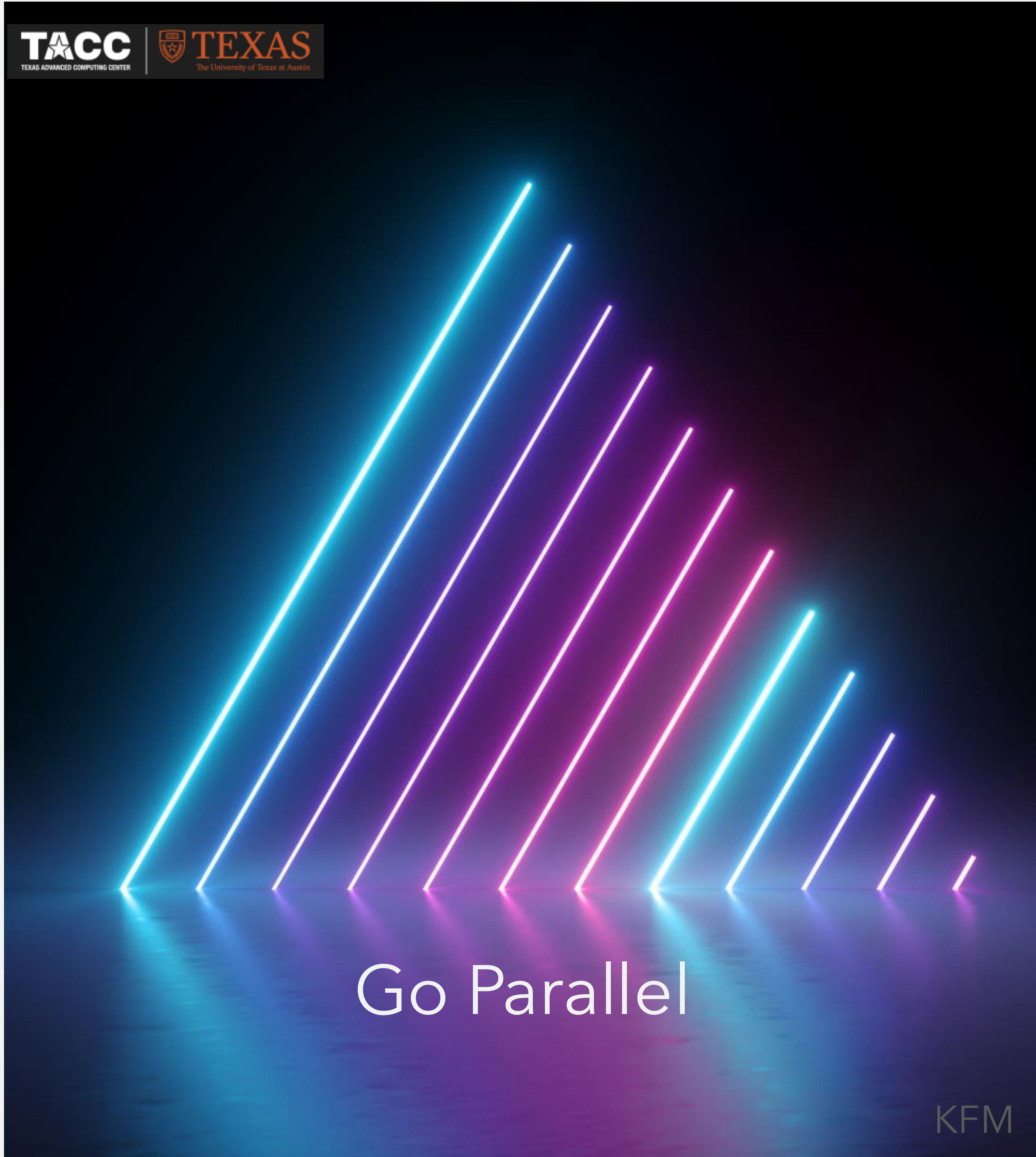
https://tinyurl.com/tacc-2025-appi



OpenMP Offloading

Required Proficiency:

- Some experience or basic knowledge of OpenMP
- Working knowledge of C/C++ or F90
- Basic GPU Architecture Understanding

References: **openmp.org**/specifications

6.0 Specification
6.0 Examples

Basic operations/concepts of code are explained in tutorial.

(Non-tutorial viewers should read grammar/syntax text after code sections first, then peruse code.)

Agenda

We will not cover Unified Shared Memory.

OpenMP

- Background and Levels of Parallelism.
- GPU Programming.
- Review Worksharing Loop.
- Quick Intro to Simple Tasking.

Useful for understanding modern OpenMP, but not necessary for basic offloading.

OpenMP Offloading

- Launch and direct device execution with target.
- Explicit/Implicit mapping ("transfer") to/from device.
- teams, distribute, and loop.
- Data Persistence: target data.
  Data Movers: target enter/exit data, target update.
- declare target (ensure function/data execution/access on device).
  Asynchronous Offloading with nowait and depend.

OpenMP -- board and membership

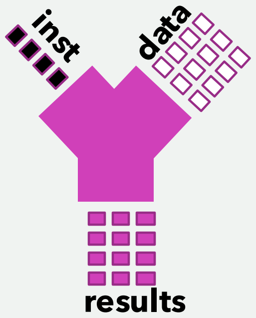
Since 1997
A non-profit organization
Governed by OpenMP Architecture Review Board (ARB)

www.openmp.org

OpenMP deals with multiple levels of Parallelism

parallel do/for, task — Across Cores

simd — Across SIMD Lanes



target — Across Devices

Modern OpenMP -- beyond Worksharing Loops

Just a few directives and clauses.

Version	Directives	Parallelism
pre-3.0	parallel for|do	worksharing loops
3.0	task	explicit tasking,
	depend	dependence scheduling
4.0	simd	SIMD
	target	device offloading
	(teams distribute,	
	loop	
	and *data-mapping)*	
:		
6.0	...	

Other important directives and clauses.

CPU affinity (5.0)
loop transforms (5.1-6.0)
free-agent threads (6.0)
taskgraphs (6.0)

Computing on GPU (with separate host and device storage)

compile prog.c # creates fat binary

./a.out # run on host, exec foo binary on gpu

h_ == host d_ == device

```
declare foo a gpu cuda kernel

main() {
declare h_x,    d_x (pointer)
...
    alloc_on_dev( sz          d_x )
    copy_to_dev(      h_x -> d_x )
    foo(d_x)
    copy_from_dev( h_x <- d_x )
    dealloc_on dev(           d_x )
...
```

Host Device

CUDA programs looks like this, where it all began.

Worksharing Loop

```c
int main(){
  float a=9.0, x[16];

  #pragma omp parallel for
  for(int i=0; i<16; i++)
    x[i]=sqrt(a*i*i);


}
```

```fortran
program main
  real :: a=9.0, x(16)

  $omp parallel do
  do i = 1,16
    x(i)=sqrt(a*i*i)
  end do

end program
```

creates *team* of threads (e.g. export OMP_NUM_THREADS=4)

implicit tasks (iteration chunks of work) executed by threads

Worksharing Loop

```c
void foo(float a, float *x, int n){

printf("id=%d\n",omp_get_thread_num());

  #pragma omp for
  for(int i=0; i<n; i++)
    x[i]=sqrt(a*i*i);
}

int main(){
  float a=9.0, x[16];
  #pragma omp parallel
  {
     foo(a,x,16);
  }
}
```

```fortran
subroutine foo(a, x, n)
  use omp_lib
  real :: a, x(*)

  print*, "id=",omp_get_thread_num()

  !$omp do
  do i = 1, n
    x(i)=sqrt(a*i*i)
  end do
end subroutine

program main
  real :: a=9.0, x(16)
  !$omp parallel
    call foo(a,x,16)
  !$omp end parallel
end program
```

parallel creates *team* of threads

for / do workshares implicit tasks among threads

OpenMP Tasking with Dependences

Makes a bundle of work (task) for asynchronous execution.

- **task** construct -- creates a task out of a code block or function to be queued for execution by any thread of team.
- **depend** clause– orders tasks
  - ❑ between tasks identified by variable
  - ❑ ordering determined by dependence type

task


```
   void init(float *x)         { for(int i=0; i<N; i++) x[i] = i;  }
   void axpy(float *x, float *y){ for(int i=0; i<N; i++) y[i] = 2*x[i] + y[i]; }
int main(){
 float x[N], y[N];


 {

   init(y);     // work (task) on y  -  write to y    (out: y)


   init(x);     // work (task) on x  -  write to x    (out: x)


   axpy(x,y);    // work (task) on x,y -  read x      (  in: x)
           //              read/write y  (inout: y)



   for(int i=0; i<N; i++){ x[i]=sqrt(y[i]); }  // special tasking for loops
 }
}
```

OpenMP "speak"

task

C/C++

```
   void init(float *x)          { for(int i=0; i<N; i++) x[i] = i;  }
   void axpy(float *x, float *y){ for(int i=0; i<N; i++) y[i] = 2*x[i] + y[i]; }
int main(){
  float x[N], y[N];

  #pragma omp parallel master  // Get team of threads; 1 thread creates tasks.
  {
    #pragma omp task          // Race here. Any team thread can execute concurrently.
    init(y);

    #pragma omp task          // Race here. Any team thread can execute concurrently.
    init(x);

    #pragma omp task          // Race here. Any team thread can execute concurrently.
    axpy(x,y);



    #pragma omp taskloop  // Race here. taskloop chunks iterations into tasks.
    for(int i=0; i<N; i++){ x[i]=sqrt(y[i]); } // Any team thread can execute chunks.
  }
}
```

task with depend clause

C/C++

```
   void init(float *x)          { for(int i=0; i<N; i++) x[i] = i;  }
   void axpy(float *x, float *y){ for(int i=0; i<N; i++) y[i] = 2*x[i] + y[i]; }
int main(){
  float x[N], y[N];

  #pragma omp parallel master
  {
    #pragma omp task depend(out: y)    // Task1 writes to y
    init(y);

    #pragma omp task depend(out: x)    // Task2 writes to x
    init(x);

    #pragma omp task depend(in: x) depend(inout: y) // Task3 reads x, reads/writes y
    axpy(x,y);                         // Task3 runs after Task1 & Task2

    #pragma omp taskwait               // Wait for all (sibling) tasks to complete.

    #pragma omp taskloop               // could use depend here and avoid taskwait
    for(int i=0; i<N; i++){ x[i]=sqrt(y[i]); } // execute iteration chunks in parallel
  }
}
```

Task 1 & 2 can run concurrently

task

```
subroutine init(x,n)
real :: x(n)
  do i=1,n; x(i) = i; enddo
end subroutine
subroutine axpy(x,y,n)
real :: x(n),y(n)
  do i=1,n; y(i)=2*x(i)+ y(i); enddo
end subroutine
```

Fortran

OpenMP "speak"

```
program main
  integer, parameter ::   N=16
  real            :: x(N), y(N)

   call init(x,N)    !! work (task) on x -   write to x   (out: x)

   call init(y,N)    !! work (task) on y -   write to y   (out: y)

   call axpy(x,y,N)  !! work (task) on x,y - read from  x (   in: x)
                  !!                 read/write y (inout: y)

   do i=1,N; x(i)=sqrt(y(i)); enddo  !! special tasking for loops

end program
```

task


```
program main
  integer, parameter ::   N=16
  real              :: x(N), y(N)

   !$omp parallel master      !! Get team of threads; 1 thread creates tasks
   !$omp task                 !! Race here. Any team thread can execute concurrently.
   call init(x,N)
   !$omp end task

   !$omp task                 !! Race here. Any team thread can execute concurrently.
   call init(y,N)
   !$omp end task

   !$omp task                 !! Race here. Any team thread can execute concurrently.
   call axpy(x,y,N)
   !$omp end task



   !$omp taskloop              !! Race here. taskloop chunks iterations into tasks.
   do i=1,N; x(i)=sqrt(y(i)); enddo     !! Any team thread can execute chunks.
  !$omp end parallel master

end program
```

task with depend clause

Fortran

```
program main
  integer, parameter ::   N=16
  real              :: x(N), y(N)

 !$omp parallel master
  !$omp task depend(out: y)           !! Task1 writes to y.
  call init(x,N)
  !$omp end task

  !$omp task depend(out: x)           !! Task2. writes to x.
  call init(y,N)
  !$omp end task

  !$omp task depend(in: x) depend(inout: y) !! Task3 reads x, reads/writes y.
  call axpy(x,y,N)                   !! Task3 runs after Task1 & Task2.
  !$omp end task

  !$omp taskwait                     !! Wait for all (sibling) tasks to complete.

  !$omp taskloop                     !! could use depend here and avoid taskwait.
  do i=1,N; x(i)=sqrt(y(i)); enddo   !! execute iteration chunks in parallel.

 !$omp end parallel master

end program
```

Task 1 & 2 can run concurrently

OPENMP OFFLOADING

Agenda

OpenMP Offloading

- Launch and direct device execution with target.
- Explicit/Implicit mapping ("transfer") to/from device.
- teams, distribute, and loop.
- Data Persistence: target data.
- Data Movers: target enter/exit data, target update.
- declare target (ensure function/data execution/access on device).
- Asynchronous Offloading with nowait and depend.

target (offloading)

- #pragma omp target

- !$omp target

C/C++

```c
int main(){
  float a=9.0, x[16];

  #pragma omp target
     foo(a,x);


  #pragma omp target
  {
   for(int i=0; i<16; i++)
     x[i]=sqrt(a*i*i);
  }

}
```

Fortran

```fortran
program main
  real :: a=9.0, x(16)

  !$omp target
   call foo(a,x)
  !$omp end target

  !$omp target
   do i = 1,16
     x(i)=sqrt(a*i*i)
   end do
  !$omp end target

end program
```

Runs on device with only 1 thread.

Implicit data management: alloc device storage & copy data to device; dealloc & copy from at end of target region.

target clauses – for beginners

```
#pragma omp target [ clause [clause ...] ]     C/C++
       !$omp target [ clause [clause ...] ]     Fortran
```

device(dev_id)	*device #, default 0*
if(int expr)	*if false fallback to host ("! 0" in C/C++, logical in F90)*
map(map-type: var) (Explained in Next Section.)	*alloc/dealloc storage for var on device & copy data between host and device.* *on host var is called original variable/storage* *on device var is called corresponding variable/storage* *map-type keywords: to, from, or tofrom* *specify copy direction and implicitly handle storage*
nowait, depend	*makes offload async with dependences (with target task)*

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- declare target (ensure function/data execution/access on device).
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Explicit Data Mapping

C/C++

```
#define N 1048576
int main(){
  int scal, array[N], ptee[N], *ptr;

  scal = 0;
  for(int i=0; i<N; i++){ array[i] = 0; ptee[i] = 0; } // inits
  ptr=&ptee[0];

// Explicit Data Mapping (Defaults to tofrom map-type)

  #pragma omp target map(scal, array, ptr[0:N])
  {
    scal = scal + 1;
    for(int i=0; i<N; i++){ array[i] = array[i] + scal; }
    for(int i=0; i<N; i++){   ptr[i] =   ptr[i] + scal; }
  }
}
```

alloc storage
cp data **to** dev

cp data **from** dev
dealloc storage

Array Section [lb:len:stride] specifies storage pointed to by the pointer.

Efficient Explicit Data Mapping with map-types

C/C++

```
#define N 1048576
int main(){
  int scal, array[N], ptee[N], *ptr;

  scal = 1;
  for(int i=0; i<N; i++){ array[i] = 0; ptee[i] = 0; } // inits
  ptr=&ptee[0];

// Explicit Data Map(copy scal to, and array and ptee from)

#pragma omp target map(to: scal) map(from: array, ptr[0:N])
  {

    for(int i=0; i<N; i++){ array[i] = i + scal; }
    for(int i=0; i<N; i++){   ptr[i] = i + scal; }
  }
}
```

Implicit behavior – first private and data mapping

C/C++

```
#define N 1048576
int main(){
  int scal, array[N], ptee[N], *ptr;

  scal = 0;
  for(int i=0; i<N; i++){ array[i] = 0; ptee[i] = 0; } // inits
  ptr=&ptee[0];

// Implicit Behavior: Works as expected except scalars are firstprivate

  #pragma omp target:
  {
    scal = scal + 1;
    for(int i=0; i<N; i++){ array[i] = array[i] + scal; }
    for(int i=0; i<N; i++){   ptr[i] =   ptr[i] + scal; }
  }
}
```

scal **not** copied to host

Explicit Data Mapping

Fortran

```
program main
  integer, parameter :: N=1048576
  integer            :: scal, array(N)
  integer,pointer    :: ptr(:)
  integer,target     :: ptee(N)

  scal = 0
  do i=1,N;  array(i) = 0; ptee(i) = 0; enddo   !! inits
  ptr=>ptee

  !! Explicit Data Mapping (Defaults to tofrom map-type)

  !$omp target map(scal) map(array) map(ptr)
    scal = scal + 1;
    do i=1,N;  array(i) = array(i)+1; enddo
    do i=1,N;  ptr(i)   =   ptr(i)+1; enddo
  !$omp end target

end program
```

alloc storage
cp data **to** dev

cp data **from** dev
dealloc storage

Efficient Explicit Data Mapping with map-types

Fortran

```
program main
  integer, parameter :: N=1048576
  integer            :: scal, array(N)
  integer,pointer    :: ptr(:)
  integer,target     :: ptee(N)

  scal = 0
  do i=1,N;  array(i) = 0; ptee(i) = 0; enddo   !! inits
  ptr=>ptee

  // Explicit Data Map(copy scal to, and array and ptr from)

  !$ omp target map(to: scal) map(from: array, ptr)

    do i=1,N;  array(i) = array(i) + scal; enddo
    do i=1,N;  ptr(i)   =   ptr(i) + scal; enddo
  !$omp end target

end program
```

Implicit behavior – first private and data mapping

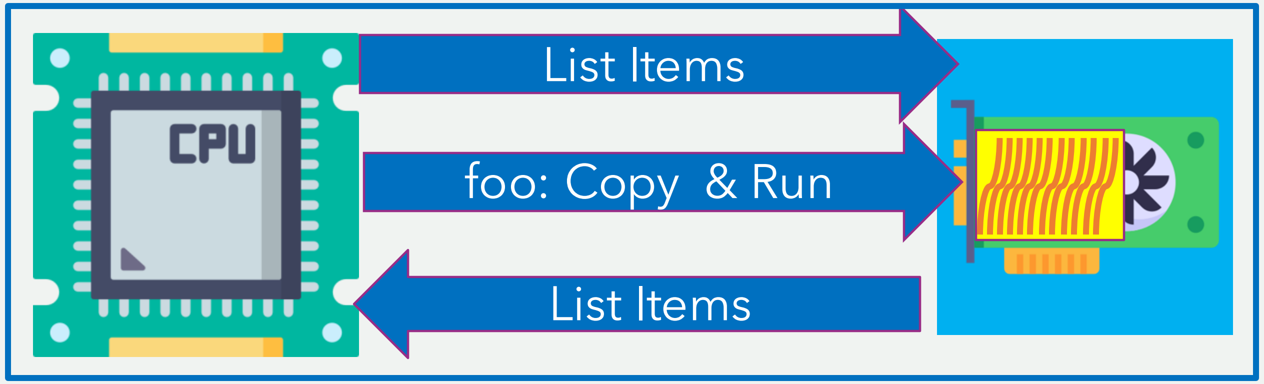
Fortran

```
program main
  integer, parameter :: N=1048576
  integer          :: scal, array(N)
  integer,pointer    :: ptr(:)
  integer,target     :: ptee(N)

  scal = 0
  do i=1,N;  array(i) = 0; ptee(i) = 0; enddo   !! inits
  ptr=>ptee

  ! Implicit Behavior: Works as expected except scalars are firstprivate

  !$omp target
    scal = scal + 1;
    do i=1,N;  array(i) = array(i)+1; enddo
    do i=1,N;  ptr(i)   =   ptr(i)+1; enddo
  !$omp end target

end program
```

scal value not copied to host

map clause

What did we just do with map?



Host
host data environment
original variables

Device
device data environment
corresponding variables

map(***action:*** ***variables***)

default ***action*** (map-type) is to and from (tofrom) device

variables in lexical extent of target region are implicitly mapped

map clause syntax

map(*modifier:* *list items*)

modifiers	
map-types	
to	allocate & cp to
from	cp from & deallocate
tofrom	cp to & from
alloc	allocate only (**storage** in 6.0)
always	
always	always perform the map-type

list items ("variables")

OMP	C/C++	F90
scalars	int a;	integer ::a
arrays	int a[8];	integer :: a[N]
pointers	int *ptr;	integer,pointer::a
objects (structures)	struct ...	data type ..
array sections	a[*start:extent,stride*] (used only in OMP directives)	

Other modifiers: delete, present, close, self, ref, mapper, iterators.

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Parallel **Offloading** – with teams, distribute, and loop

CUDA blocks and threads --> OMP teams and threads

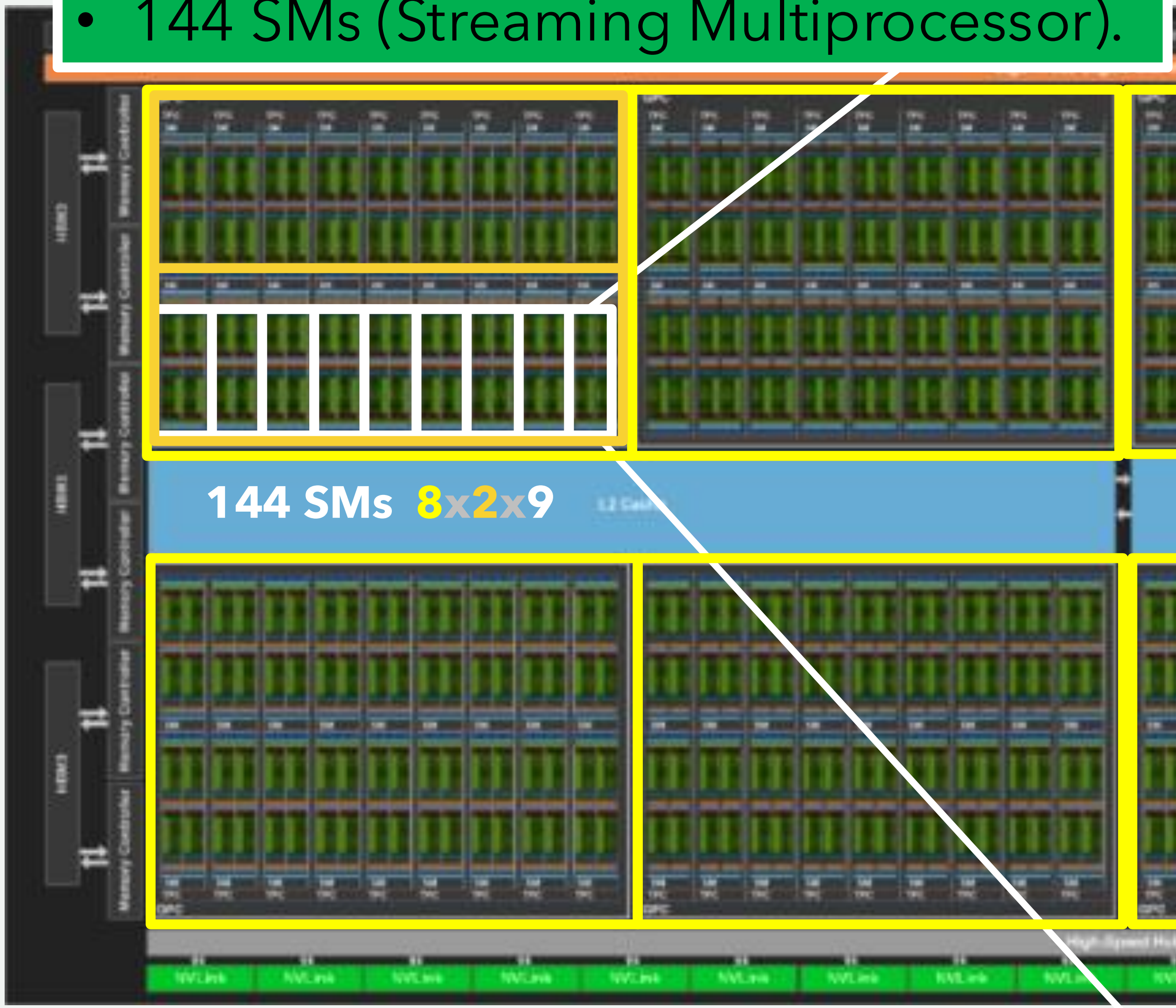
First, GPU architecture:

- ~100 SMs (Streaming Multiprocessors)
- Each SM
    - Is a set of cores (128 FP32, 64 FP64, …, 4 Tensor)
    - Memory is *shared* within set, but not with other SMs
    - Instruction streams (independent instructions) are scheduled on 32 threads (a warp) to execute simultaneously.

Hopper Architecture

- Scheduler manages warps on 32 threads

- 144 SMs (Streaming Multiprocessor).



developer.nvidia.com/blog/nvidia-hopper-architecture-in-depth

teams and parallel with target

Creates teams for the SMs
and threads within an SM

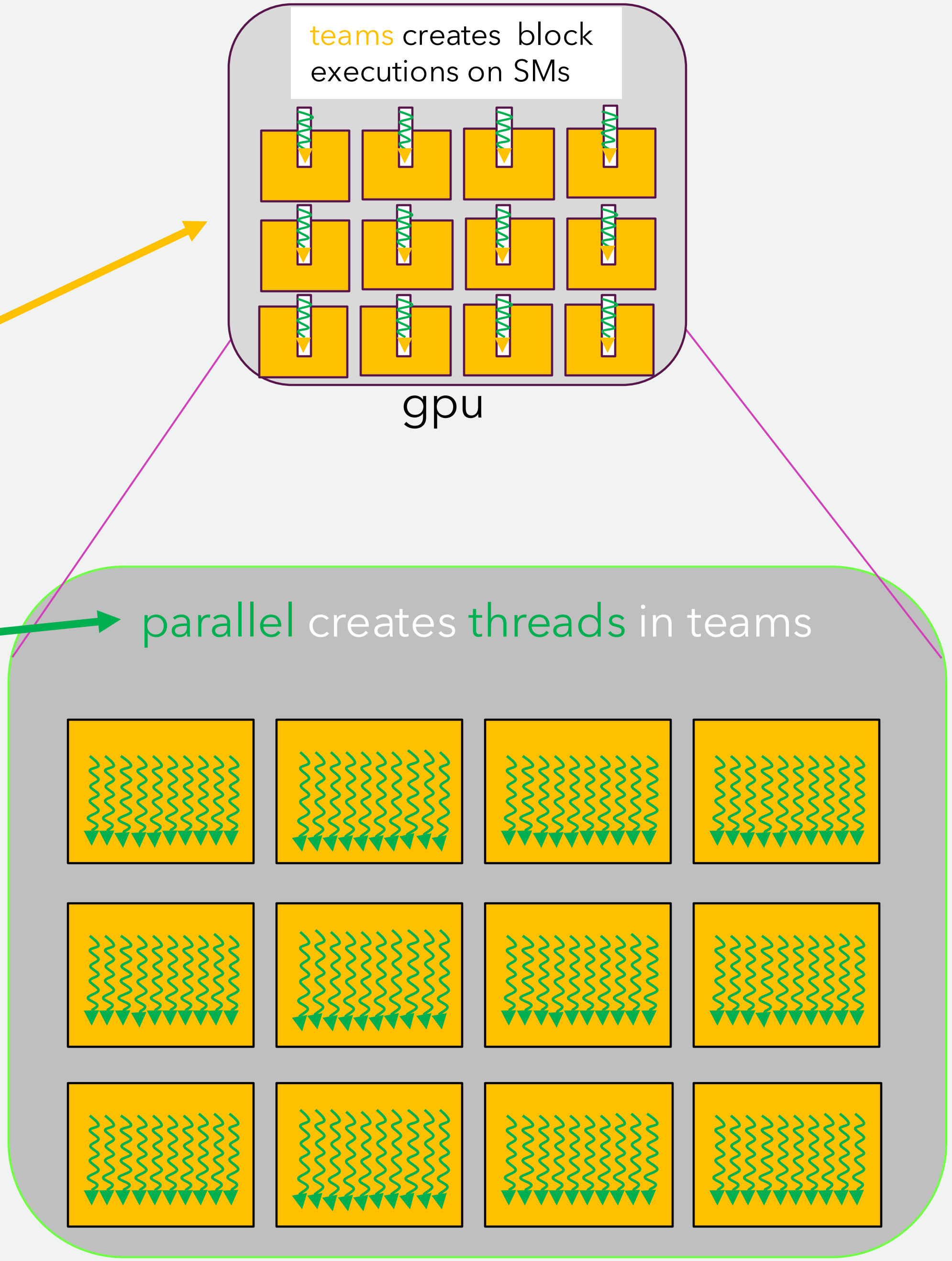
- **teams**: creates teams for execution on SMs
- **parallel**: creates threads within the team
- Default # of threads is implementation defined.

```
#pragma omp target teams
#pragma omp parallel
{
  // code block
}
```

all executing the same code block

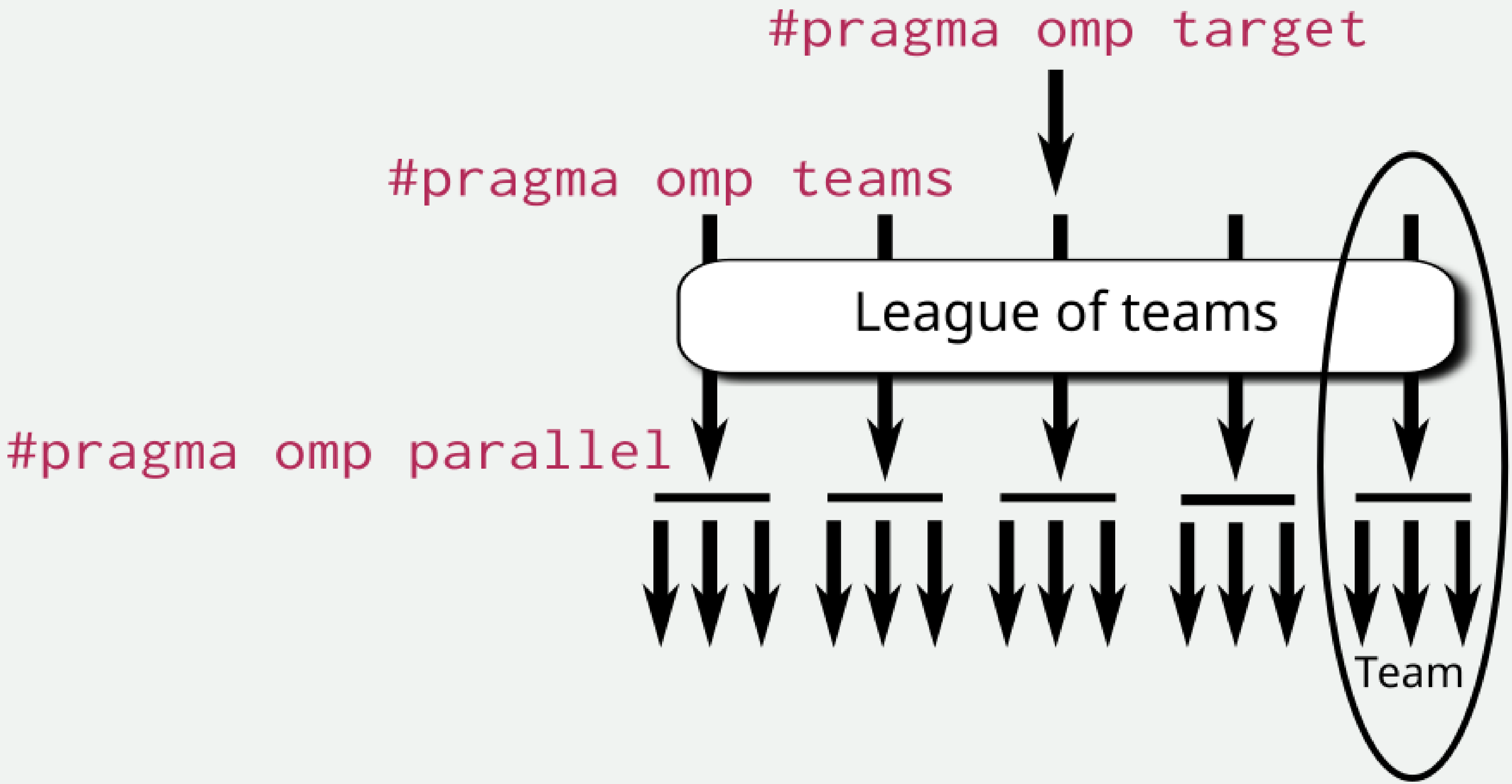
or

```
#pragma omp target teams parallel
{
  // code block
}
```



Without num_threads(), number of threads is implementation defined.

League of multi-threaded teams



work-distribution directives:

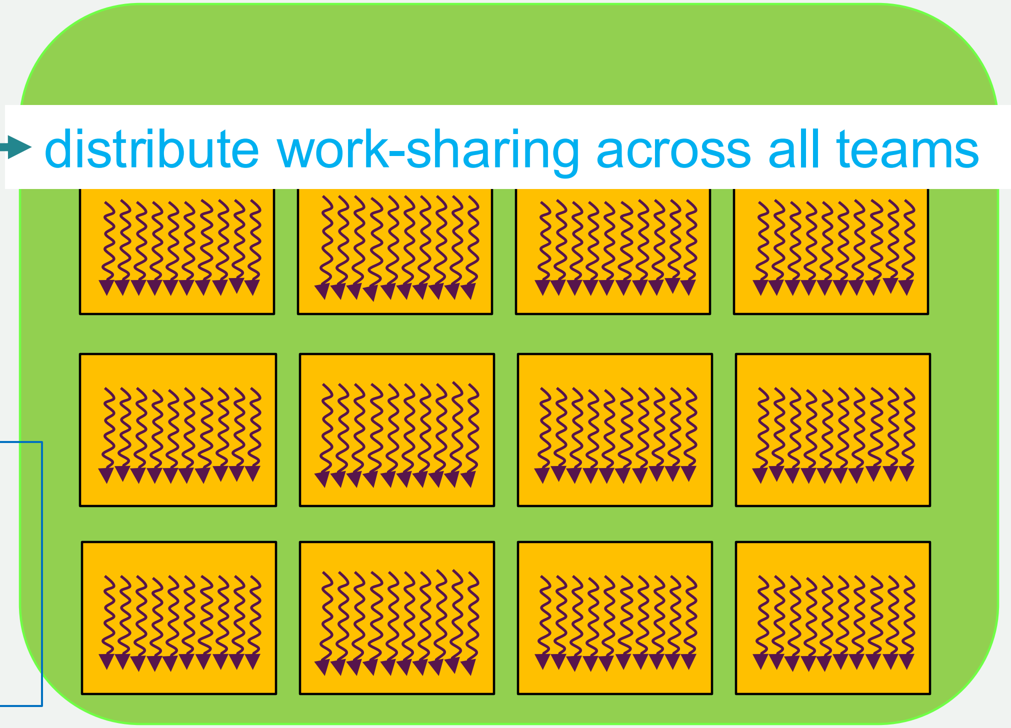
partitioning loop iterations across teams and parallel constructs

- **distribute** construct specifies iterations of an associated loop are to be distributed across the teams.
- **for** construct is for worksharing across the threads.

```
#pragma omp target teams distribute
#pragma omp parallel for
for (...){
  // code block
}
```

or

```
#pragma omp target teams distribute parallel for
for (...){
  // code block
}
```



Distribute worksharing with target **teams, distribute parallel for**, and (“new”) **loop**

```
#define N (1 << 27)
int main()
{
  float a=2.0, y[N], x[N];
  for( int i=0; i<N; i++){x[i]=(float)i/N; y[i]=(float)i/N;}



    #pragma omp target teams distribute parallel for
    for (int i=0; i<N; i++) {y[i]=a*x[i]+y[i];}

    #pragma omp target teams loop
    for (int i=0; i<N; i++) {y[i]=a*x[i]+y[i];}

}
```

More control with clauses.

More control by Implementation.

Number of teams and threads are Implementation defined.

Distribute worksharing with **target teams, distribute parallel for**, and ("new") **loop**

```
program main
  integer, parameter :: N=1024*1024*128
  real  ::  a=2.0, y(N), x(N), rN=N
  do i=1,N; y(i)=i/rN; x(i)=i/rN; end do


    !$omp target teams distribute parallel do
      do i=1,N; y(i)=a*x(i)+y(i); end do


    !$omp target teams loop
      do i=1,N; y(i)=a*x(i)+y(i); end do


end program
```

More control with clauses.

More control by Implementation.

Number of teams and threads are Implementation defined.

loop

Allows compiler to control work distribution and worksharing with loop construct.

- CONS: limited user control (clauses)
- PROS: simple syntax, compiler handles the parallelism

```
#pragma omp target teams
#pragma omp loop
for (...){
  // code block
}
```

or

```
#pragma omp target teams loop
for (...){
  // code block
}
```

```
!$omp target teams
!$omp loop
do i=...
  !! code block
end do
```

or

```
!$omp target teams loop
do i=1...
  !! code block
end do
```

* General: can be use in lieu of parallel for|do on host.

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- declare target (ensure function/data execution/access on device).
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target data – Creating a Data-Persistence Region

C/C++

```
int main () {
  int A[2]={10,11};

  #pragma omp target data map(tofrom: A) // map applies to the region {}
  {                                   // Here: A is allocated & copied to device

     #pragma omp target    //   implicit map
                    No          (ref count to keep track)
     {
       A[0]++; A[1]++;
     }

     #pragma omp target    //   implicit map
                    No          (ref count to keep track)
     {
       A[0]++; A[1]++;
     }
                   // <= Here: On Host A=10,11; On device A=12,13.

  }                // <= Here: A is copied from device & deallocated, and
}                  //       Host and Device have same values, A=12,13
```

target data – Creating a Data-Persistence Region

FORTRAN

```
program main
  integer :: A(2)=(/10,11/)

 !$omp target data map(tofrom: A) !! map applies to region (here to end target data)
                                   !! Here: A is allocated & copied to device


          !$omp target            !! (ref counter keeping track)
            A(1)=A(1)+1; A(2)=A(2)+1
          !$omp end target


          !$omp target            !! (ref counter keeping track)
            A(1)=A(1)+1; A(2)=A(2)+1
          !$omp end target

                  !! <= Here: On Host A=10,11; On device A=12,13.

 !$omp end target data   !!<= Here: A is copied from device & deallocated, and
                  !!      Host and Device have same values, A=12,13
end program
```

target data Syntax

- map applies to target data region
  employs reference counter

target data map(*modifiers*: *vars*)

map modifiers

map-type:
    to, from, tofrom, alloc
other modifiers: ...

clauses

device -- device number(s)
if -- on host | device
nowait -- async (6.0)
depend -- task ordering (6.0)
... -- many others (6.0)

target enter/exit data -- simple example

```cpp
#include <iostream>
using namespace std;

int main(){
  int A[2]={10,11};

  #pragma omp target enter data map(to: A)

  A[0]=200; A[1]=200;

  #pragma omp target  //ref count->no copy
  {A[0]++; A[1]++;}


  #pragma omp target exit data map(from: A)

  cout << A[0]<< "  " << A[1] <<endl; //11,12
}
```

C++

```fortran
program main


  integer :: A(2)=(/10,11/)

  !$omp target enter data map(to: A)

  A(1)=200; A(2)=200;

  !$omp target    !!ref count->no copy
    A(1)=A(1)+1; A(2)=A(2)+1
  !$omp end target


  !$omp target exit data map(from: A)

  print*, A(1), A(2)  !! 11, 12
end program
```

target update -- simple example

C++

```cpp
#include <iostream>
using namespace std;

int main(){
 int A[2]={10,11};

 #pragma omp target data map(A)
 {
  {A[0]=200; A[1]=200;}
  #pragma omp target update to(A)

  #pragma omp target  //ref count->no copy
  {A[0]++; A[1]++;}


 }

 cout << A[0]<< "  " << A[1] <<endl; //11,12

}
```

FORTRAN

```fortran
program main


 integer :: A(2)=(/10,11/)

 !$omp target data map(A)

 A(1)=200; A(2)=200;
 !$omp target update to(A)

 !$omp target    !!ref count->no copy
  A(1)=A(1)+1; A(2)=A(2)+1
 !$omp end target

 !$omp end target data

 print*, A(1), A(2)  !! 11, 12

end program
```

Directives for directional data movement: syntax

- map data motion restricted to one direction
- employs reference counter

(async with nowait clause)

target_enter_data map(type: vars) types: to, alloc

target_exit_data map(*type*: *vars*) types: from (release, delete)

- Similar to target_enter/exit_data, but
- updates without reference counter.

target update to(*vars*)
target update from(*vars*)

to and from
are the data motion clauses

Compiling code with OpenMP offloading statements

NVHPC <nvc, nvc++, nvfortran>

```
<compiler> -fopenmp -O3 -mp=gpu
```

LLVM <clang, clang++, flang>

```
<compiler> -fopenmp -O3 -fopenmp-targets=nvptx64
```

GNU <gcc, g++, gfortran>

```
<compiler> -fopenmp -O3 -foffload=nvptx-none
```

LAB I – basic offload

- Create interactive session on gpu compute node.
- Compile and run "hello from gpu" code.
- Compile and run target code block/function for single thread.
- Optimize code for efficient data transfer.
- Compare parallel axpy execution on host and device
- Instrument offloading code to run asynchronously.

```
ssh vista.tacc.utexas.edu
tar –xvf ~train00/openmp_offload_2025.tar
cd openmp_offload
```

- Login to Vista
- Untar files and cd to lab directory
- **Read top directory Instructions** file, cd into code directories and **follow instructions in README.md** file.

Agenda

- Map Review and Storage

common ways to change the device data (environment)

Evaluate on your own.

C/C++

```
int scal = 1;
 #pragma omp target data map(tofrom: scal)   //  scal is mapped for region
 {
    scal=10;
    #pragma omp target map(always,tofrom: scal) // make device/host consistent (10)
    { scal++;                                   // mapped scal =  11
    }                                       // cp back scal = 11

    scal++;
    #pragma omp target // default: scal is FIRSTPRIVATE, uses Host scal=12
    { scal++;         // 13
    }              // 12 scal Not Copied back

    scal=100;
    #pragma omp target update to(scal)   // consistent scal(100 on host & device)
    scal=500;
    #pragma omp target map(scal)        // map ignored
    {   scal++;                        // 101 Increased 100 to 101 on Device
    }                              // 500, Not Copied back
 }                                 // 101 Copied back, same on Host and Device
```

common ways to change the device data (environment)

Evaluate on your own.

FORTRAN

```
integer :: scal = 1
!$omp target data map(tofrom: scal)      !!  scal is mapped for region

   scal=10
   !$omp target map(always,tofrom: scal) !! make device/host consistent (10)
     scal=scal+1                         !! mapped scal =  11
   !$omp end target

   scal=scal+1
   !$omp target      !! default: scal is FIRSTPRIVATE, uses Host scal=12
     scal=scal+1     !! 13
   !$omp end target   !! 12 scal Not Copied back

   scal=100
   !$omp target update to(scal)   !! consistent scal(100 on host & device)

   scal=500
   !$omp target map(scal)        !! map ignored
     scal=scal+1                 !! 101 Increased 100 to 101 on Device
   !$omp end target              !! 500, Not Copied back

!$omp end target data            !! 101 Copied back, same on Host and Dev
```

device-only storage -- like cuda, uses device pointer

C/C++

```
int main(){
  double Val, *d_B, *d_C;    // (d_ = device pointers)

  int dev_id  = omp_get_default_device();         // device id number
  d_B=(double *)omp_target_alloc(N*N*sizeof(double),dev_id);
  d_C=(double *)omp_target_alloc(N*N*sizeof(double),dev_id);

  #pragma omp target map(from: Val) is_device_ptr(dev_B,dev_C) device(dev_id)
  {                                 //specify dev pointers & their device

    for(int i=0; i<N; ++i)   // B,C storage used (no data transfer)
    for(int j=0; j<N; ++j)
      {d_B[i*N+j]=i*j; d_C[i*N+j]=i*j+1;}
    ...
    Val=3.14;
  }

  omp_target_free(dev_B, dev_id);
  omp_target_free(dev_C, dev_id);
}
```

alloc maptype for temporary space

C/C++

```
float x[N], y[N];
...
#pragma omp target ... map(alloc: x) map(tofrom: y)
{
   for(int i=0;i<n;i++) x[i]=sin(i%4)*cos(i%6);

   for(int i=0;i<n;i++) y[i]=a*x[i]+y[i];
}
```

Agenda

OpenMP Offloading

- Launch and direct device execution with target.
- Explicit/Implicit mapping ("transfer") to/from device.
- teams, distribute, and loop.
- Data Persistence: target data.
  Data Movers: target enter/exit data, target update.
- declare target (ensure function/data execution/access on device).
- Asynchronous Offloading with nowait and depend.

declare target – declare functions as device procedures

- Procedures in the same "compile" unit are automatically compiled for devices.
- "Externally" compiled procedures must be declared for target devices.

C/C++

```
void fun();

int main(){
  #pragma omp target
  fun();
}
```

C/C++

```
#include <omp.h>            // Difference Compile Unit
#include <stdio.h>

void fun(){
  printf("%d\n", omp_is_initial_device()); // 0 on GPU, 1 on HOST
}
#pragma omp declare target (fun)          // Compile for GPU, too.
```

declare target -- Multiple ways to do it (global vars, too)

C/C++

```
#pragma omp begin declare target

   static float a_global=2.0f;
   void   foo(){printf("external compiled unit\n");}

#pragma omp   end declare target
```

This is for declaring everything within a region

C/C++

```
static float a_global=2.0f;
void   foo(){printf("external compiled unit\n");}

#pragma omp declare target  (a_global, foo)
```

This is for declaring specific vars and funcs.

C/C++

```
static float a_global=2.0f;
void   foo(){printf("external compiled unit\n");}

#pragma omp declare target to(a_global, foo)
```

Same as above, using clause (***to*** is default).

declare target – declare functions as device procedures

- Procedures in the same “compile” unit are automatically compiled for devices.
- “Externally” compiled procedures must be declared for target devices.

F

```
program main
  use functions
  !$omp target
    call fun()
  !$omp end target
end program
```

F

```
module functions         !! Different ”Compile” unit.
  use omp_lib
 contains
  subroutine fun()
    !$omp declare target (fun)      !! Compile for GPU, too.
    print*, omp_is_initial_device() !! F on GPU, T on HOST
  end subroutine
end module
```

declare target -- Fortran

```
module functions
contains
  subroutine fun()
    !$omp declare target to(fun)
    print*, "externally compiled"
  end subroutine
end module
```

F90

```
program main
  !$omp target
    call fun()
  !end target
end program
```

```
module functions
  integer,parameter  :: N=8
  real               :: v(N)
 contains
   subroutine fun(one)
   integer, intent(in) :: one
     !$omp declare target enter(fun,v)
     print*, "externally compiled"
     v(1:N)=one
  end subroutine
end module
```

F90

Include immediately after specifications.

List function and global variables in to/enter clause.

```
program main
  use functions
  integer :: one=1
  !$omp target
    call fun(one)
  !$omp end target
  !$omp target update from(v)
  print*,v
end program
```

declare target syntax

```
#pragma omp begin declare target
  //procedures & static variables here
#pragma omp end   declare target
```

C/C++ only
6.? Fortran

```
#pragma omp declare target (ext_list)
```

ext_list: list of procedures(pcr) and/or static variables(var)

Use !$omp for F90

```
#pragma omp declare target clauses
```

Use !$omp for F90

clauses:

	to/enter(ext_list)	avail. entire prog
	link(var_list)	avail. when mapped
	device(expr)	device specific (id)
	indirect(prc_list)	for func. pointers

to(<v5.2) enter(>=v5.2)

Asynchronous Offloading

C/C++

```
ndev=omp_get_num_devices(); // Number of devices, ids=0,...,ndev-1
n = N/ndev;

 #pragma omp parallel num_threads(ndev)
 #pragma master
 {
   for(int id=0; id<ndev; id++)
   {                              //simple,unblanced partitioning
      ib = id*n; ie = ib+n;
      if(id==ndev-1){ ie=N; n=N-ib;}                //final iter.
      #pragma omp target teams distribute parallel for \
              nowait device(id) map(y[ib:n],x[ib:n])   //ib=offset,n=sz
       for(int i=ib; i< ie; i++) y[i] = a * x[i] + y[i];
   }
 }                  // parallel barrier waits for tasks to complete
```

Could do this without *parallel master*, but use a *taskwait* at end to synchronize.

Asynchronous Offloading

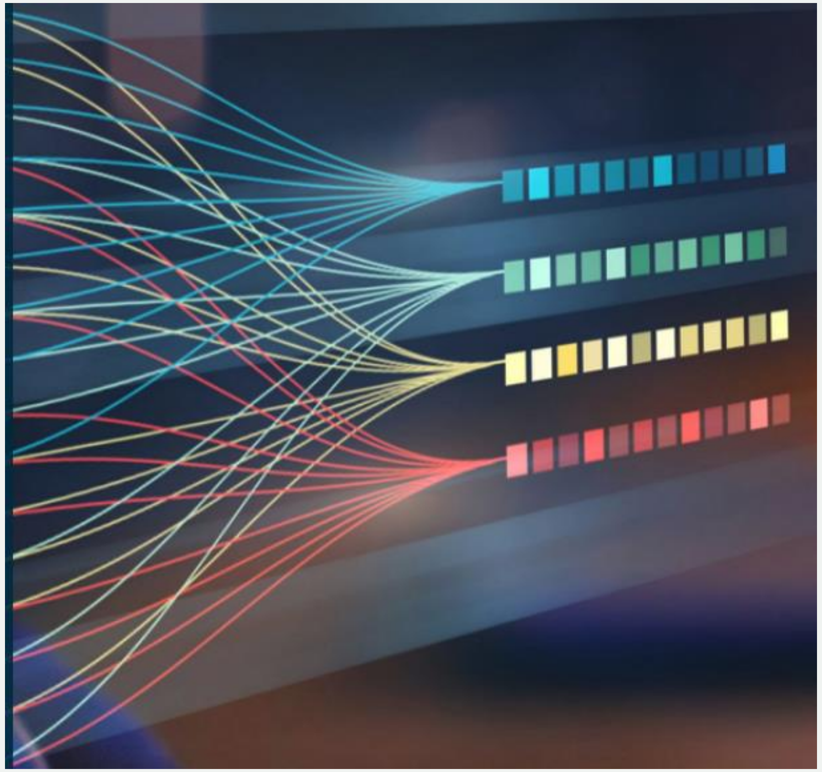
```
ndev=omp_get_num_devices()       !! Number of devices, ids=0,...,ndev-1
n = NT/ndev

 !$omp parallel num_threads(ndev)
 !$omp master
   do id=0,ndev-1
                                 !!partitioning: simple,unblanced
     ib = 1 + id*n; ie = ib + n-1
     if(id == ndev-1) then; ie=NT;  endif    !!final iter.

     !$omp  target teams distribute parallel for &
     !$omp&       nowait device(id) map(y(ib:ie),x(ib:ie))
       do i=ib,ie;  y(i) = a * x(i) + y(i);  enddo
   enddo
 !$omp end master
 !$omp end parallel     !! parallel barrier waits for tasks to complete
```

F

begin
end
Fortran
Array
Syntax

Could do this without parallel master, but use a taskwait at end to synchronize.

Extras



Map: Reference count

- On entry to device environment:
  - If a corresponding list item is not present in the device data environment, then:
    - A new list item corresponding to original list item (on host) is created in the device data environment;
    - The corresponding list item has a reference count that is initialized to zero; and
    - The value of the corresponding list item is undefined;
  - If ref count is not incremented due to map clause, it is incremented by 1

Atomic Operation

- On exit from device environment:
  - if map-type is **delete** ref count is set to 0
  - if map-type is not **delete** the ref count is decremented by 1 (min 0)
  - If the reference count is zero then the corresponding list item is removed from the device data environment.

Atomic Operation

Thanks to Henry Jin (JPL) and Swaroop (Oak Ridge) and (CSC/EuroHPC JU) for slide and content collaboration.

Direct Device Allocation: omp_target_alloc() + is_device_ptr

C/C++

```
#include <omp.h>
int main(){
int a=2, N=1<<4; // 16
 int dev_no = omp_get_default_device();

 int *y  =(int*)         malloc(N*sizeof(N) );
 int *x_d=(int*)omp_target_alloc(N*sizeof(N), dev_no);

  for(int i=0;i<N;i++){ y[i]=1; }

  #pragma omp target is_device_ptr(x_d)
  for(int i=0;i<N;i++) x_d[i]=1;          //INIT

  #pragma omp target is_device_ptr(x_d) \
                    map(tofrom: y[0:N])
  for(int i=0;i<N;i++) y[i]=a*x_d[i]+y[i]; //AXPY

  omp_target_free(x_d, dev_no);
}
```

omp_target_alloc syntax

Syntax: void* omp_target_alloc(size_t size, int device_num);

returns the device address of
a storage location of size bytes

device_num : less than the result of
omp_get_num_devices() or the result of a call to
omp_get_initial_device().

```
int init_dev =omp_get_initial_device();
int     ndevs=omp_get_num_devices();
cout<<"init_dev#= "<<init_dev <<" # non-host_devs"<< ndevs<<endl;

OUTPUT: init_dev#= 3 # non-host_devs3
```

Direct memory copy with omp_target_memcpy

C/C++

```
void get_dev_cos(double *mem, int s){
  int h, t, i;
  double * mem_dev_cpy;
  h = omp_get_initial_device();
  t = omp_get_default_device();

  mem_dev_cpy = (double *)omp_target_alloc( sizeof(double) * s, t);

                     /* dst  src */
  omp_target_memcpy(mem_dev_cpy, mem, sizeof(double)*s,
                        0,    0,
                        t,   h);

  #pragma omp target is_device_ptr(mem_dev_cpy) device(t)
  #pragma omp teams distribute parallel for
    for(i=0;i<s;i++){ mem_dev_cpy[i] = cos((double)i); } /* init data */

                /* dst  src */
   omp_target_memcpy(mem, mem_dev_cpy, sizeof(double)*s,
                  0,           0,
                  h,           t);
   omp_target_free(mem_dev_cpy, t);
}
```

Verifying OpenMP Offloading

- When the (generic) OpenMP flag is on (e.g. usually –fopenmp) and a compiler doesn't understand the target compiler flag it **defaults to fallback execution of the region on the host**.

How to check if target is offloading to GPU.

C/C++

```c
#include <stdio.h>
#include   <omp.h>
int main(){
  #pragma omp target
  {printf("%d\n", omp_is_initial_device());} // 0 run on GPU, 1 run on HOST
}
```

Fortran

```fortran
program main
  use omp_lib
  !$omp target
    print*, omp_is_initial_device()          !! F run on GPU, T run on HOST
  !$omp end target
end program
```

Verifying OpenMP Offloading

Useful offloading test.

```c
#include <stdio.h>
#include   <omp.h>
int main(){
  #pragma omp target
  {printf(”ranOnGPU=%c T=true\n", (omp_is_initial_device()==0) ? 'T':'F');}
}
```

C/C++

```fortran
program main
  use omp_lib
  !$omp target
    print*, ”ranOnGPU= ", .not. omp_is_initial_device(), " T=TRUE, F=FALSE"
  !$omp end target
end program
```

Fortran