

# OpenMP\* GPU Offload Basics



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# Objectives

- To learn the basic OpenMP\* offload constructs to deploy OpenMP application for execution on GPUs
- Prerequisites
  - Knowledge of using OpenMP with Fortran, C or C++ on CPUs

# Agenda

- oneAPI and OpenMP\* Offload
- OpenMP on CPUs Review
- Introduction to OpenMP Offload
- Constructs to Manage Device Data
- Constructs to Leverage Parallelism
- Case Study
- Summary

# oneAPI and OpenMP\* Offload



\*Other names and brands may be claimed as the property of others.

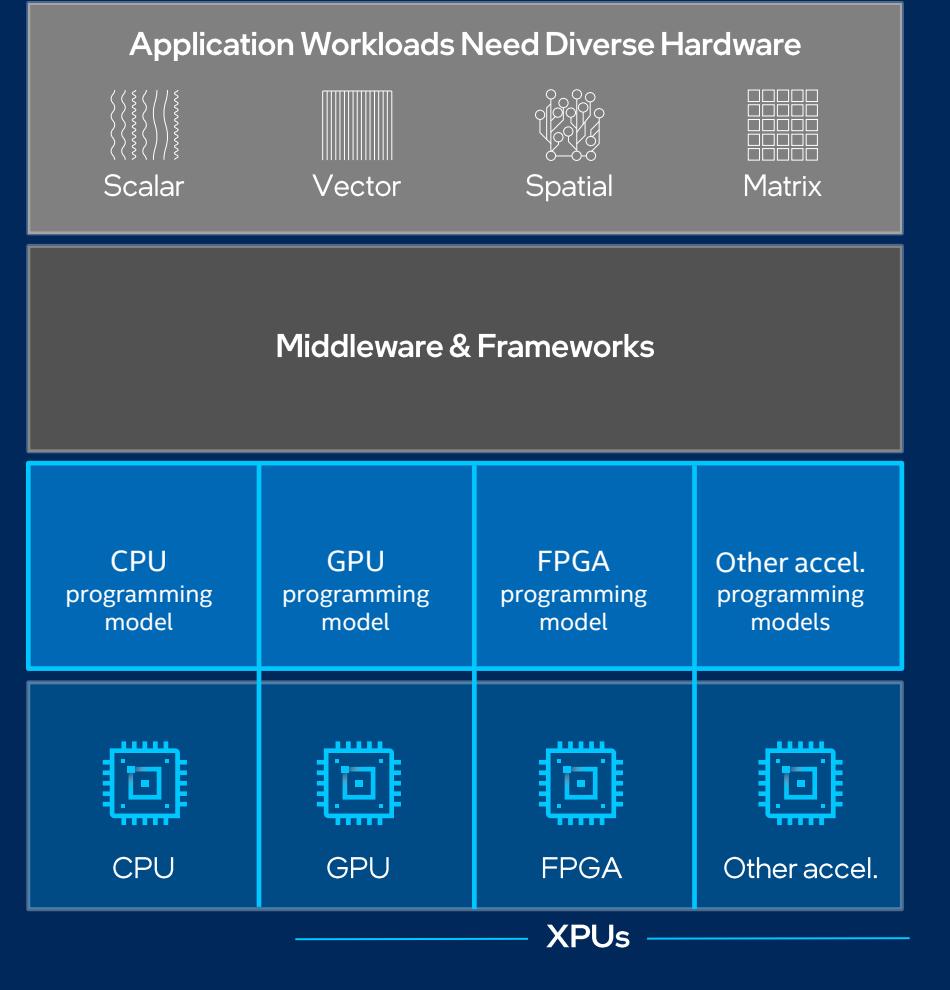
# Programming Challenges for Multiple Architectures

Growth in specialized workloads

Variety of data-centric hardware required

Separate programming models and toolchains for each architecture are required today

Software development complexity limits freedom of architectural choice



# oneAPI

## One Programming Model for Multiple Architectures and Vendors

### Freedom to Make Your Best Choice

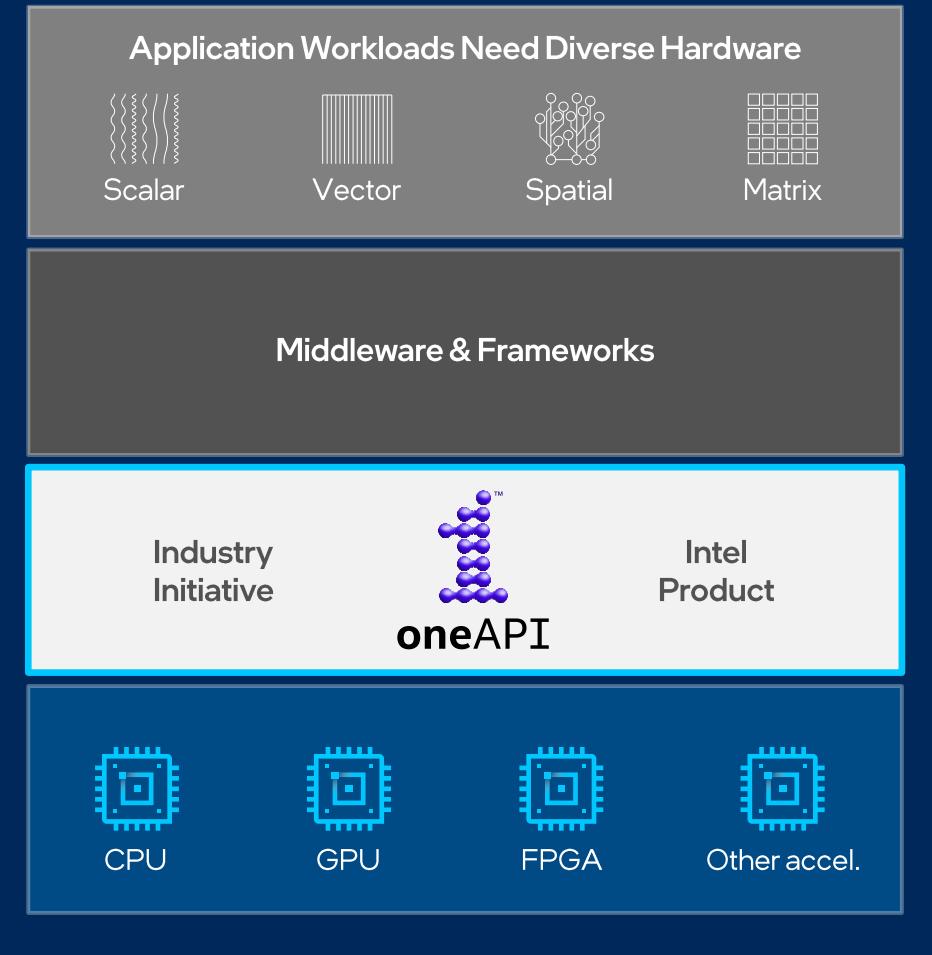
- Choose the best accelerated technology the software doesn't decide for you

### Realize all the Hardware Value

- Performance across CPU, GPUs, FPGAs, and other accelerators

### Develop & Deploy Software with Peace of Mind

- Open industry standards provide a safe, clear path to the future
- Compatible with existing languages and programming models including C++, Python, SYCL, OpenMP, Fortran, and MPI

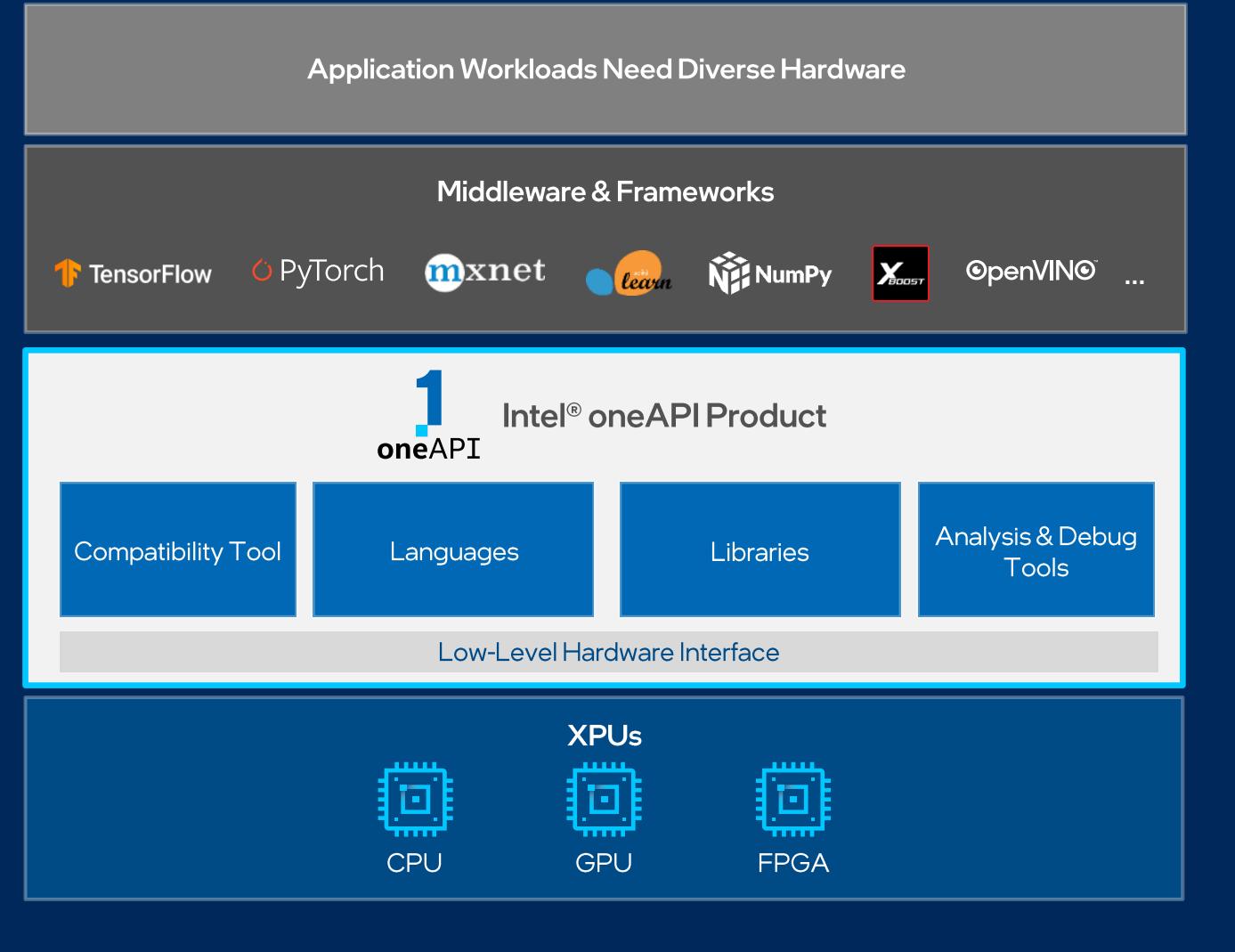


# Intel® oneAPI Product

## Built on Intel's Rich Heritage of CPU Tools Expanded to XPU

A complete set of advanced compilers, libraries, and porting, analysis and debugger tools

- Accelerates compute by exploiting cutting-edge hardware features
- Interoperable with existing programming models and code bases (C++, Fortran, Python, OpenMP, etc.), developers can be confident that existing applications work seamlessly with oneAPI
- Eases transitions to new systems and accelerators—using a single code base frees developers to invest more time on innovation



[Available Now](#)

# Intel® oneAPI Toolkits

A complete set of proven developer tools expanded from CPU to XPU



## Intel® oneAPI Base Toolkit

Native Code Developers

A core set of high-performance tools for building C++, Data Parallel C++ applications & oneAPI library-based applications



## Add-on Domain-specific Toolkits

Specialized Workloads



### Intel® oneAPI Tools for HPC

Deliver fast Fortran, OpenMP & MPI applications that scale



### Intel® oneAPI AI Analytics Toolkit

Accelerate machine learning & data science pipelines with optimized DL frameworks & high-performing Python libraries



### Intel® oneAPI Tools for IoT

Build efficient, reliable solutions that run at network's edge



### Intel® oneAPI Rendering Toolkit

Create performant, high-fidelity visualization applications

## Toolkit powered by oneAPI

Data Scientists & AI Developers



### Intel® Distribution of OpenVINO™ Toolkit

Deploy high performance inference & applications from edge to cloud

# Intel® oneAPI Tools for HPC

# Intel® oneAPI

# HPC Toolkit

## Deliver Fast Applications that Scale

### What is it?

A toolkit that adds to the Intel® oneAPI Base Toolkit for building high-performance, scalable parallel code on C++, Fortran, OpenMP & MPI from enterprise to cloud, and HPC to AI applications.

### Who needs this product?

- OEMs/ISVs
- C++, Fortran, OpenMP, MPI Developers

### Why is this important?

- Accelerate performance on Intel® Xeon® & Core™ Processors and Intel® Accelerators
- Deliver fast, scalable, reliable parallel code with less effort built on industry standards

Learn More: [intel.com/oneAPI-HPCKit](https://intel.com/oneAPI-HPCKit)

## Intel® oneAPI Base & HPC Toolkits

### Direct Programming

Intel® C++ Compiler Classic

Intel® Fortran Compiler Classic

Intel® Fortran Compiler  
(Beta)

Intel® oneAPI DPC++/C++  
Compiler

Intel® DPC++ Compatibility Tool

Intel® Distribution for Python

Intel® FPGA Add-on  
for oneAPI Base Toolkit

### API-Based Programming

Intel® MPI Library

Intel® oneAPI DPC++ Library  
oneDPL

Intel® oneAPI Math Kernel  
Library - oneMKL

Intel® oneAPI Data Analytics  
Library - oneDAL

Intel® oneAPI Threading  
Building Blocks - oneTBB

Intel® oneAPI Video Processing  
Library - oneVPL

Intel® oneAPI Collective  
Communications Library  
oneCCL

Intel® oneAPI Deep Neural  
Network Library - oneDNN

Intel® Integrated Performance  
Primitives – Intel® IPP

### Analysis & debug Tools

Intel® Inspector

Intel® Trace Analyzer  
& Collector

Intel® Cluster Checker

Intel® VTune™ Profiler

Intel® Advisor

Intel® Distribution for GDB

Intel® oneAPI HPC Toolkit +  
Intel® oneAPI Base Toolkit



# OpenMP\* on CPUs



\*Other names and brands may be claimed as the property of others.

# OpenMP\* Overview

- Cross-platform standard supporting shared-memory-multi-processing programming in C, C++ and Fortran
  - API for writing multithreaded applications
  - Set of compiler directives and library routines for parallel application programmers
  - Greatly simplifies writing multi-threaded programs in Fortran, C and C++
  - Portable across vendors and platforms
  - Supports various types of parallelism

# OpenMP\* History

- 1997: Version 1.0 for Fortran
- 1998: Version 1.0 for C/C++
- 2002-2005: Versions 2.0-2.5, Merger of Fortran and C/C++ specifications
- 2008: Version 3.0, Incorporates Task Parallelism
- 2013: Version 4.0, Support for Accelerators, SIMD support
- 2018: Version 5.0, C11/C++17/Fortran 2008 support

# OpenMP\* Threads

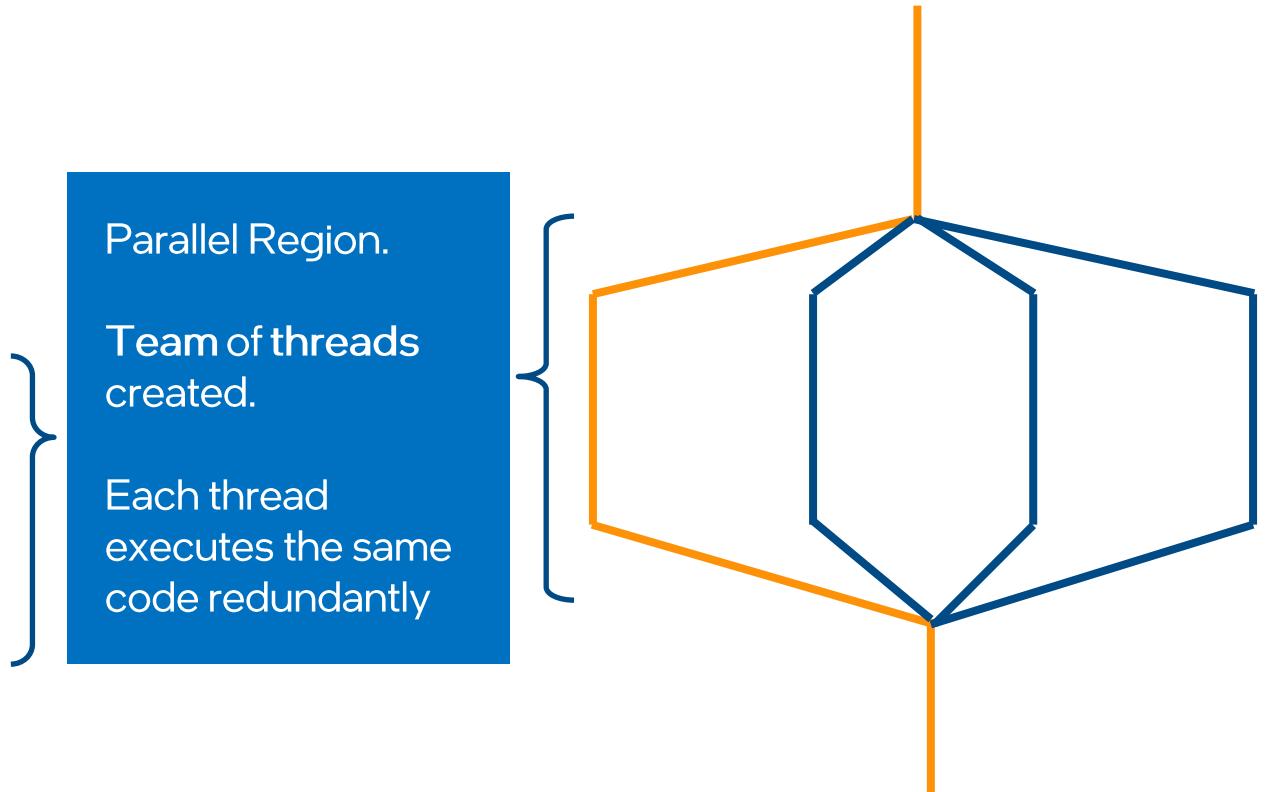
- Create threads with the **parallel** construct

— Thread  
— Master Thread

```
#include <omp.h>

void saxpy()
{
    float a, x[ARRAY_SZ], y[ARRAY_SZ];
#pragma omp parallel
{
    int id=omp_get_thread_num();
    int nthrs=omp_get_num_threads();
    for (int i=id; i < ARRAY_SZ; i+=nthrs) {
        y[i] = a * x[i] + y[i];
    }
}
```

Parallel Region.  
Team of threads created.  
Each thread executes the same code redundantly



# Loops

- Use For/Do Loop Directive to Workshare

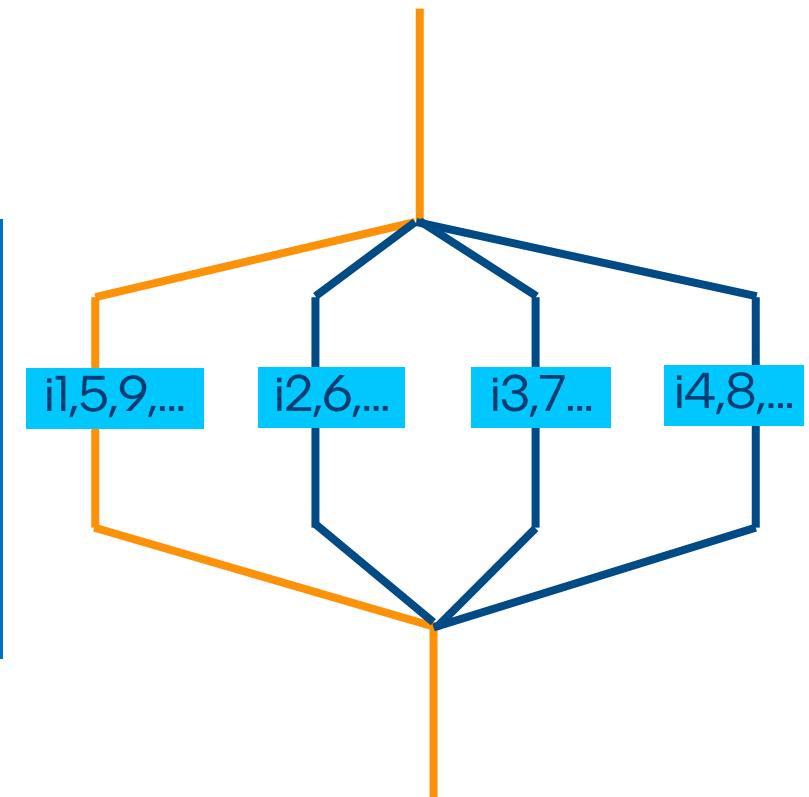
```
#include <comp.h>

void saxpy()
{
    float a, x[ARRAY_SZ], y[ARRAY_SZ];
#pragma omp parallel
{
#pragma omp for
    for (int i=0; i < ARRAY_SZ; i++) {
        y[i] = a * x[i] + y[i];
    }
}
```



Workshare:  
Distributes the execution of loop iterations across the threads

— Thread  
— Master Thread



# Basic Examples

## C/C++

```
#include <omp.h>
...
#pragma omp parallel for reduction (+:sum)
{
    for (int i=0; i<ARRAY_SZ; i++) {
        sum += x[i];
    }
}
...
```

## Fortran

```
program main
    use omp_lib
    ...
    !$omp parallel do reduction (+:total)
    do i=0,ARRAY_SZ
        total = total + x(i)
    end do
    !$omp end parallel do
    ...
end program main
```

# Other Notable OpenMP\* Constructs

- Sections/Section
  - Distribute blocks of code (sections) among existing threads
- Task
  - Create independent units of work (including code, data, and internal control variables) for execution on a thread
- SIMD
  - Specifies iterations of a given loop can be executed concurrently with SIMD instructions
    - i.e. compiler can ignore vector dependencies

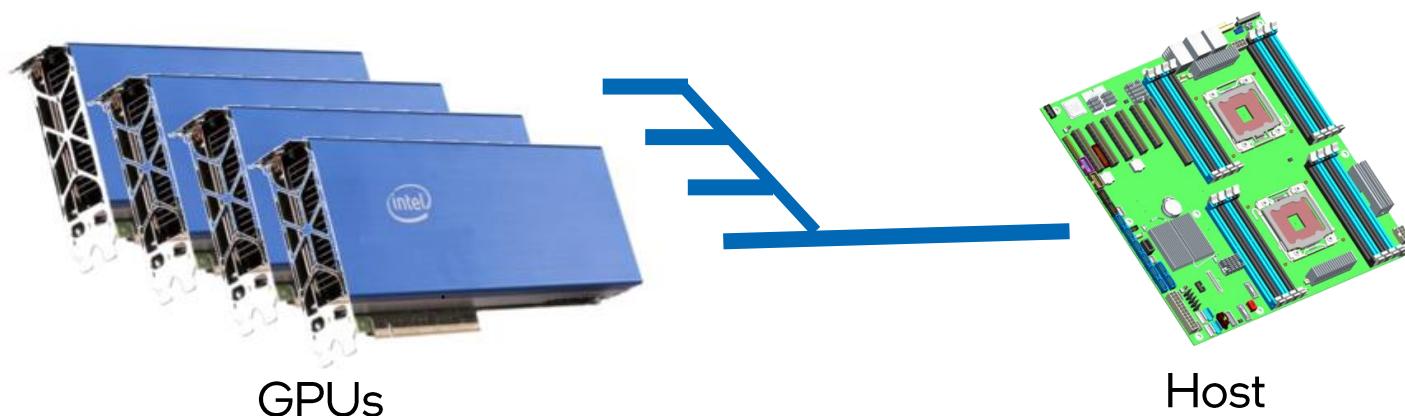
# Introduction: OpenMP\* Offload



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# OpenMP\* Device Model

- OpenMP 4.0+ supports accelerators/coprocessors (devices)
  - Not GPU-specific
- Device model:
  - One host
  - Multiple accelerators/coprocessors of the same kind



# OpenMP\* Offload Compiler Support

- OpenMP Offload Supported in the Intel® oneAPI HPC Toolkit
  - Need to enable OpenMP\* 4.5 support (-fopenmp) and OpenMP\* 4.5 offloading support (-fopenmp-targets=spir64)
  - Intel® oneAPI C++ Compiler

```
icx -fopenmp -fopenmp-targets=spir64 <source>.c
```

```
icpx -fopenmp -fopenmp-targets=spir64 <source>.cpp
```

- Intel® Fortran Compiler

```
ifx -fopenmp -fopenmp-targets=spir64 <source>.f90
```

# OpenMP\* 4.0 for Devices - Constructs

- target construct transfer control **and** data from the host to the device

- Syntax (C/C++)

```
#pragma omp target [clause[,] clause],...]  
structured-block
```

- Syntax (Fortran)

```
!$omp target [clause[,] clause],...]  
structured-block  
!$omp end target
```

- Clauses

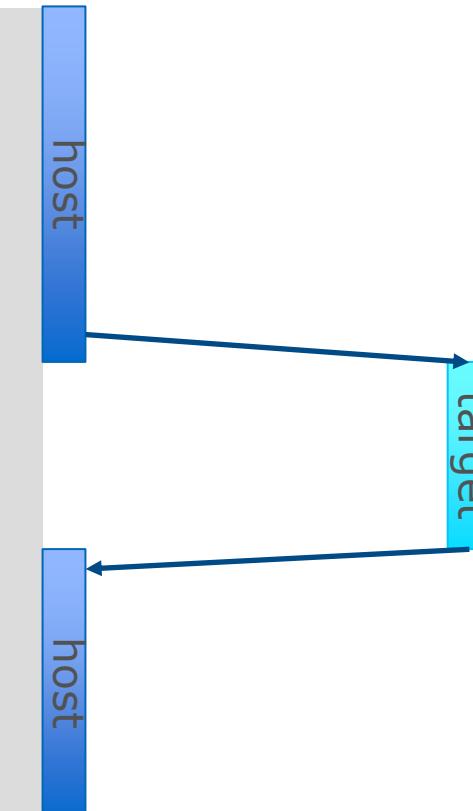
```
device(scalar-integer-expression)  
map([{alloc | to | from | tofrom}:] list)  
if(scalar-expr)
```

# Execution Model

- The `target` construct transfers the control flow to the target device
  - Transfer of control is sequential and synchronous
  - The transfer clauses control direction of data flow
  - Array notation is used to describe array length

# Target Region Example: saxpy

```
void saxpy() {  
    float a, x[ARRAY_SZ], y[ARRAY_SZ];  
    double t = 0.0;  
    double tb, te;  
    tb = omp_get_wtime();  
#pragma omp target  
    for (int i = 0; i < ARRAY_SZ; i++) {  
        y[i] = a * x[i] + y[i];  
    }  
    te = omp_get_wtime();  
    t = te - tb;  
    printf("Time of kernel: %lf\n", t);  
}
```



```
icx -fopenmp -fopenmp-targets=spir64 -o saxpy saxpy.c
```

# Device Clause

- Specify which device to offload to in a multi-device environment

```
#pragma omp target device(i)
```

- Device number an integer
  - Assignment is implementation-specific
  - Usually start at 0 and sequentially increments
- Works with **target**, **target data**, **target enter/exit data**, **target update** directives

# Calling Functions Inside Target Area

- **declare target** construct compiles a version of the function/subroutine for the target device
- Function compiled for both host execution and target execution by default

```
#pragma omp declare target
int devicefunc(){
...
}
#pragma omp end declare target

#pragma omp target
{
    result = devicefunc();
}
```

```
subroutine devicefunc()
!$omp declare target device_type(device)
...
end subroutine

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

Optional device\_type specifies host and/or device execution  
if device is specified, it needs to be always available

# Managing Device Data



# Offload Data

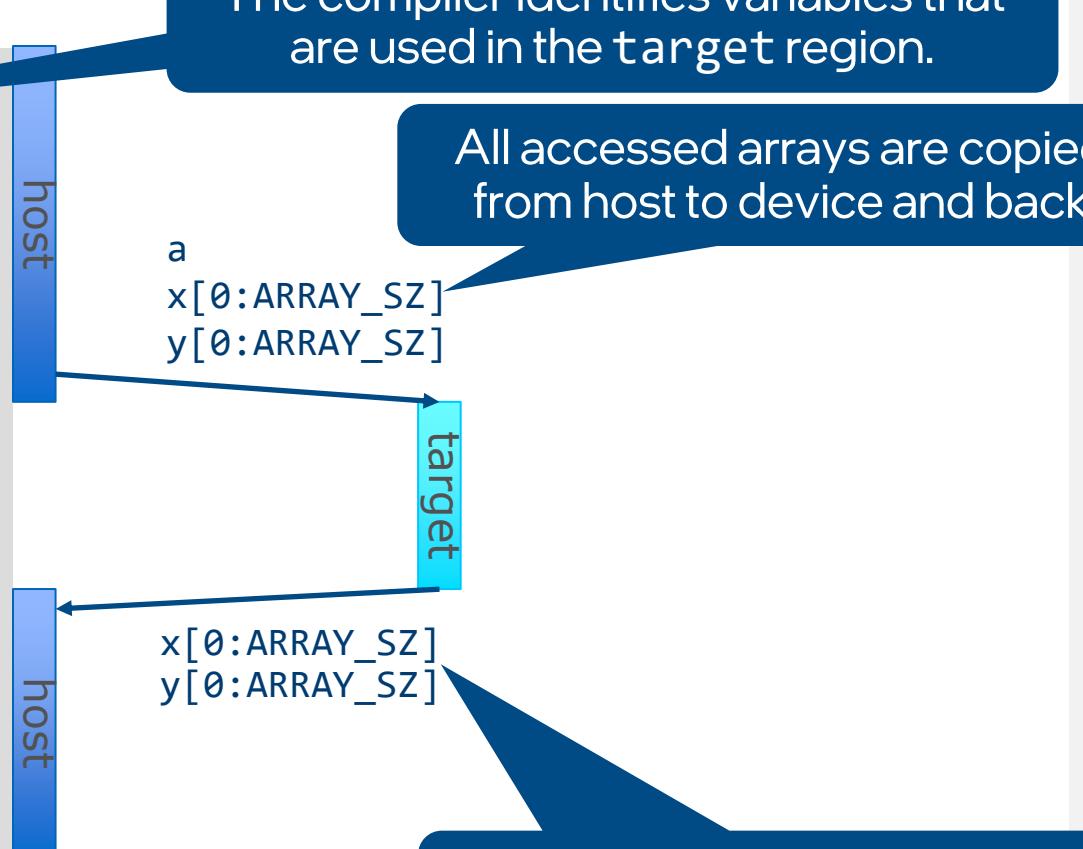
- Host and devices have separate memory spaces
  - Data needs to be mapped to the target device in order to be accessed inside the target region
  - Default for variables accessed inside the target region:
    - Scalars: treated as `firstprivate`
    - Static arrays: copied to and from the device on entry and exit
- Data environment is lexically scoped
  - Data environment is destroyed at closing curly brace
  - Allocated buffers/data are automatically released

# Example: saxpy

```
void saxpy() {  
    float a, x[ARRAY_SZ], y[ARRAY_SZ];  
    double t = 0.0;  
    double tb, te;  
    tb = omp_get_wtime();  
#pragma omp target  
    for (int i = 0; i < ARRAY_SZ; i++) {  
        y[i] = a * x[i] + y[i];  
    }  
    te = omp_get_wtime();  
    t = te - tb;  
    printf("Time of kernel: %lf\n", t);  
}
```

The compiler identifies variables that are used in the target region.

All accessed arrays are copied from host to device and back



Copying x back is not necessary: it was not changed.

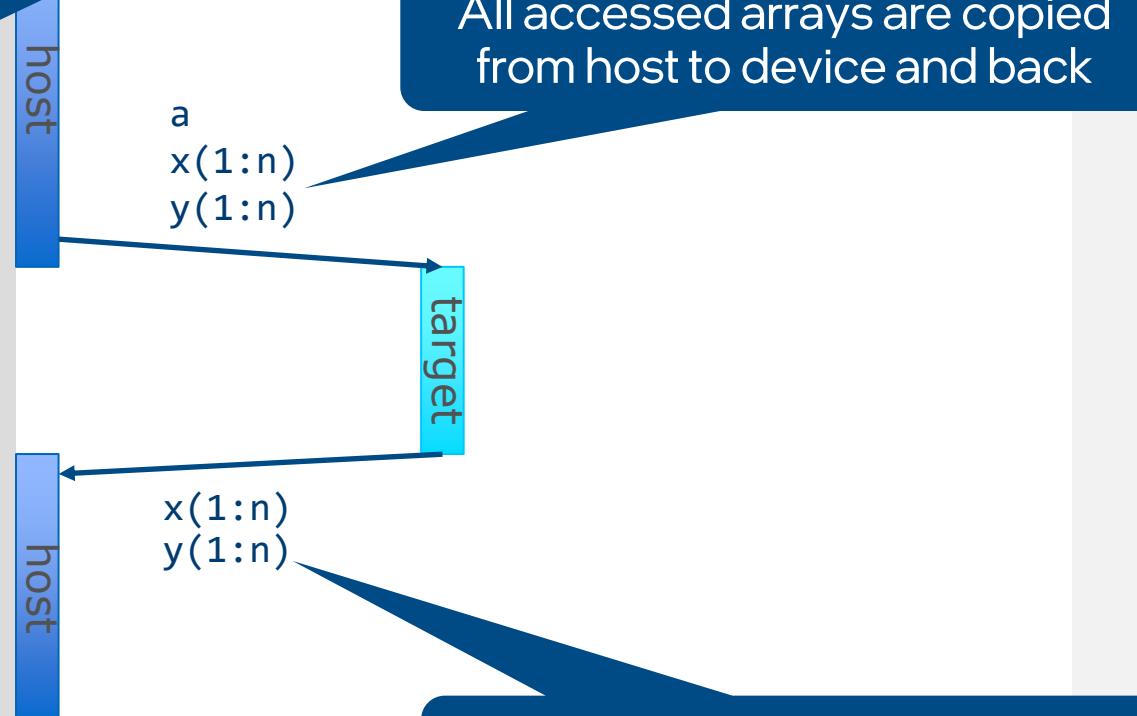
```
icx -fopenmp -fopenmp-targets=spir64 -o saxpy saxpy.c
```

# Example: saxpy

The compiler identifies variables that are used in the target region.

```
subroutine saxpy(a, x, y, n)
  use iso_fortran_env
  integer :: n, i
  real(kind=real32) :: a
  real(kind=real32), dimension(n) :: x
  real(kind=real32), dimension(n) :: y

  !$omp target
  do i=1,n
    y(i) = a * x(i) + y(i)
  end do
  !$omp end target
end subroutine
```



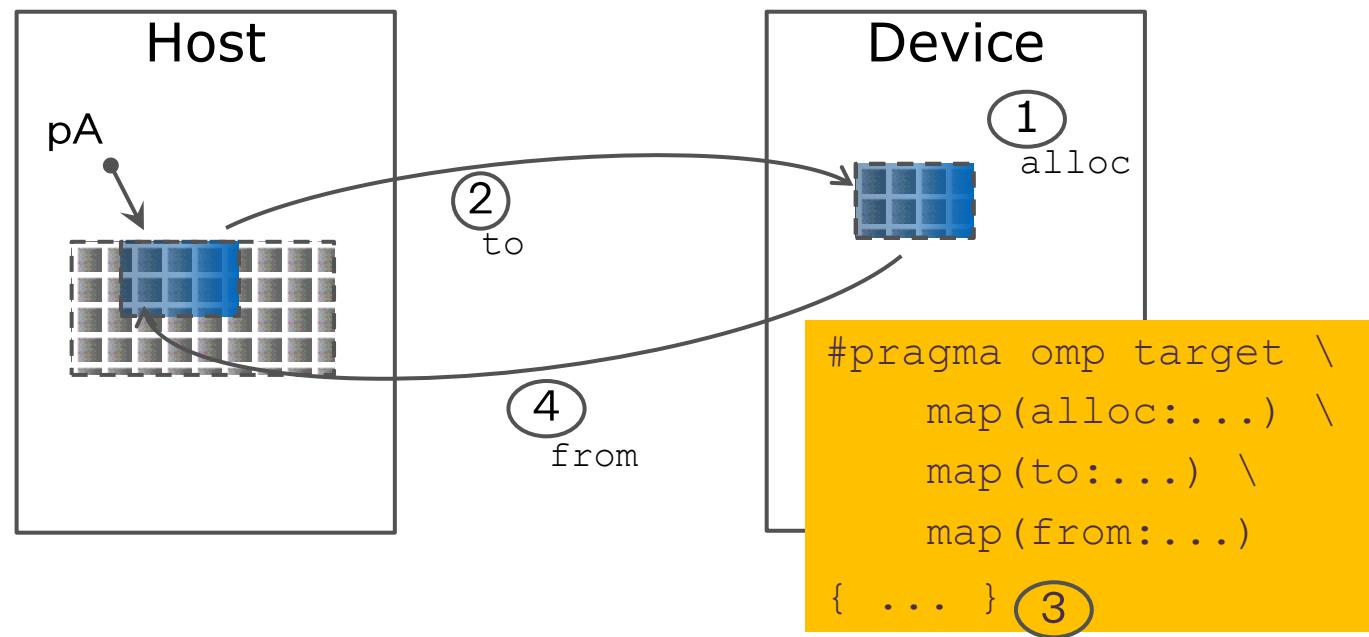
```
ifx -fopenmp -fopenmp-targets=spir64 -o saxpy saxpy.f90
```

# Map Clause

- Use **map** clause to manually determine how an original variable in a data environment is mapped to a corresponding variable in a device data environment
  - `omp target map (map-type: List)`
  - Available map-type
    - alloc : allocate storage for variable on target device (values not copied)
    - to : alloc and assign value of original variable on target region entry
    - from : alloc and assign value to original variable on target region exit
    - tofrom: default, both to and from

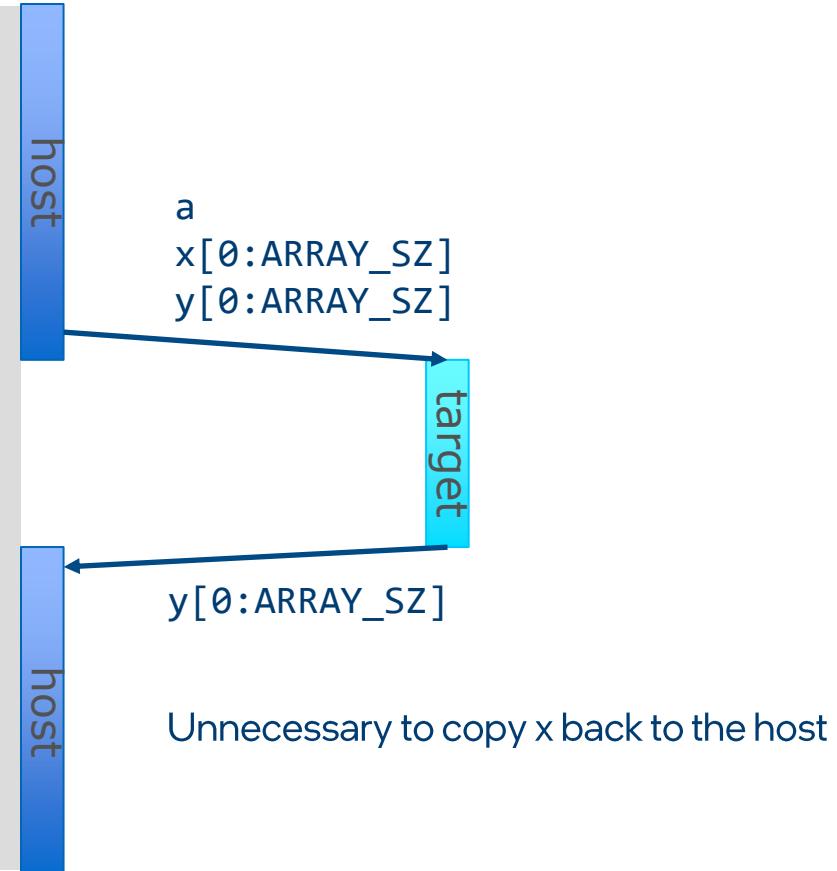
# Map Clause

- Use **map** clause to manually determine how an original variable in a data environment is mapped to a corresponding variable in a device data environment



# Example: saxpy

```
void saxpy() {  
    double a, x[ARRAY_SZ], y[ARRAY_SZ];  
    double t = 0.0;  
    double tb, te;  
    tb = omp_get_wtime();  
#pragma omp target map(to:x) \  
            map(tofrom:y)  
    for (int i = 0; i < ARRAY_SZ; i++) {  
        y[i] = a * x[i] + y[i];  
    }  
    te = omp_get_wtime();  
    t = te - tb;  
    printf("Time of kernel: %lf\n", t);  
}
```



```
icx -fopenmp -fopenmp-targets=spir64 -o saxpy saxpy.c
```

# Mapping Dynamically Allocated Data

- When pointers are dynamically allocated, number of elements to be mapped must be explicitly specified

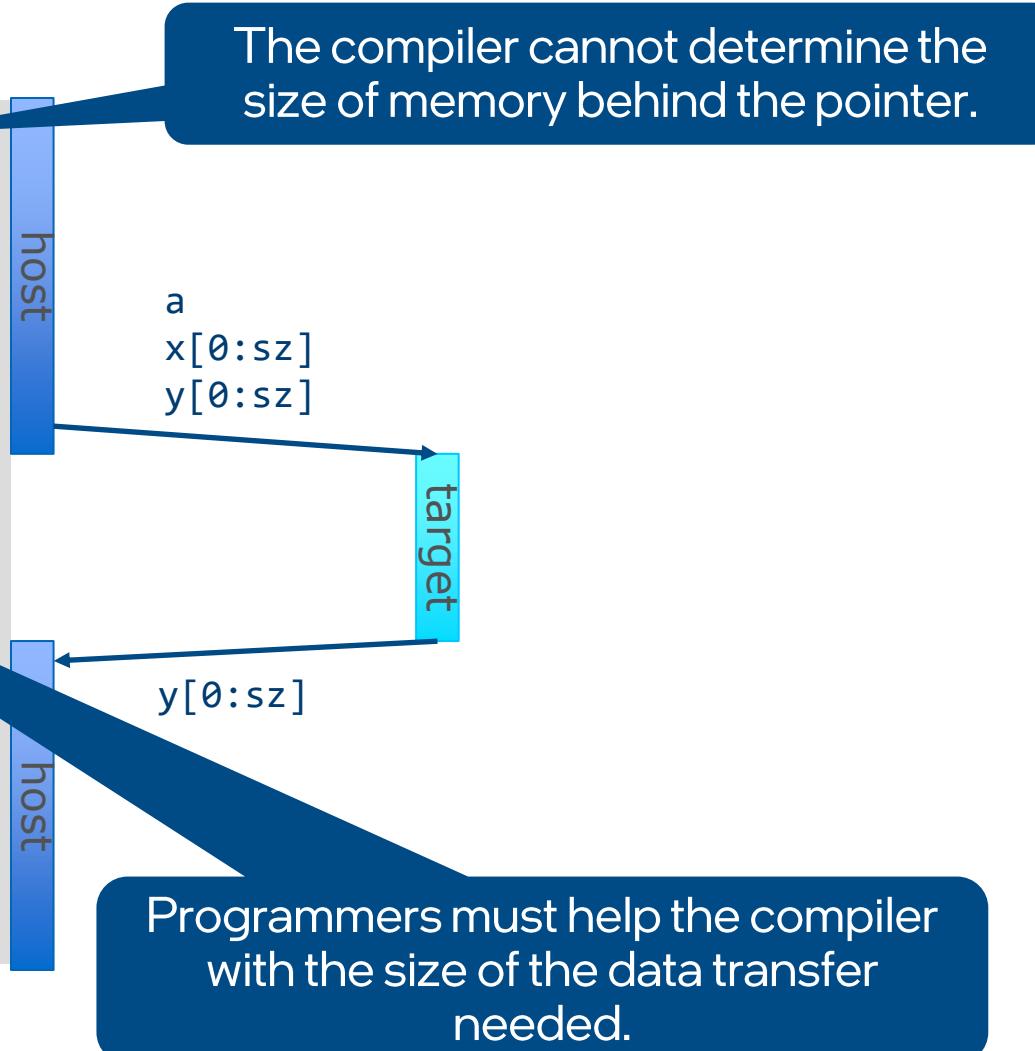
```
#pragma omp target map(to:array[start:length])
```

```
!$omp target map(to:array(start:end))
```

- Partial array may be specified
- Note: syntax in C/C++ (uses *length*) is different from Fortran (uses *end*)

# Example: saxpy

```
void saxpy(float a, float* x, float* y,  
          int sz) {  
    double t = 0.0;  
    double tb, te;  
    tb = omp_get_wtime();  
#pragma omp target map(to:x[0:sz]) \  
               map(tofrom:y[0:sz])  
    for (int i = 0; i < sz; i++) {  
        y[i] = a * x[i] + y[i];  
    }  
    te = omp_get_wtime();  
    t = te - tb;  
    printf("Time of kernel: %lf\n", t);  
}
```



```
icx -fopenmp -fopenmp-targets=spir64 -o saxpy saxpy.c
```

# Minimize Data Copy Across Target Regions

- Use **target data**, **target enter data**, and **target exit data** to form target data region and optimize sharing of data between host and device
  - Maps variables, code execution not offloaded
  - Variables remain on device for duration of the target data region
  - **target update** construct can copy values between host and device

# target data Construct Syntax

- Create scoped data environment and transfer **data** from the host to the device and back

- Syntax (C/C++)

```
#pragma omp target data [clause[,] clause,...]  
structured-block
```

- Syntax (Fortran)

```
!$omp target data [clause[,] clause,...]  
structured-block  
!$omp end target data
```

- Clauses

```
device(scalar-integer-expression)  
map([{alloc | to | from | tofrom | release | delete}:] list)  
if(scalar-expr)
```

# Target Data Example

- Use target data construct to create target data environment

```
#pragma omp target data map(tofrom: x)
{
    #pragma omp target map(to: y)
    {
        ...//1st target region, device operations on x and y
    }
    host_update(y);
    #pragma omp target map(to: y)
    {
        ...//2nd target region, device operations on x and y
    }
}
```

Device data environment created,  
array x is mapped

y must be mapped at each target region since  
it's updated by the host here

# target update Construct Syntax

- Issue data transfers to or from existing data device environment
- Syntax (C/C++)

```
#pragma omp target update [clause[[, ] clause],...]
```

Syntax (Fortran)

```
!$omp target update [clause[[, ] clause],...]
```

Clauses

*device(scalar-integer-expression)*  
*to(list)*  
*from(list)*  
*if(scalar-expr)*

# Target Enter/Exit Data and Update Example

- Use **target enter/exit data** to map to/from target data environment
- Use **target update** to maintain consistency between host and device

```
#pragma omp target enter data map(to: y) map(alloc: x)  
#pragma omp target  
{  
    ...//1st target region, device operations on x and y  
}
```

Unstructured mapping, data environment can span multiple functions

```
#pragma omp target update from(y)  
host_update(y);  
#pragma omp target update to(y)
```

y must be updated from and to the device since it's updated by the host here

```
#pragma omp target  
{  
    ...//2nd target region, device operations on x and y  
}  
#pragma omp target exit data map(from:x)
```

# Map Global Variable to Device

- Use **declare target** construct for to map variables to the device for the duration of the program

```
#pragma omp declare target
int a[N]
#pragma omp end declare target
...
init(a);
#pragma omp target update to(a)
...
#pragma omp target teams\
distribute parallel for
for (int i=0; i<N; i++){
    result[i] = process(a[i]);
}
```

```
module my_arrays
!$omp declare target (a)
integer :: a(N)
end module
...
use my_arrays
integer :: i
call init(a);
!$omp target update to(a)
...
!$omp target teams distribute &
!$omp&      parallel do
do i=1,N
    result(i) =
process(a(i));
end do
```

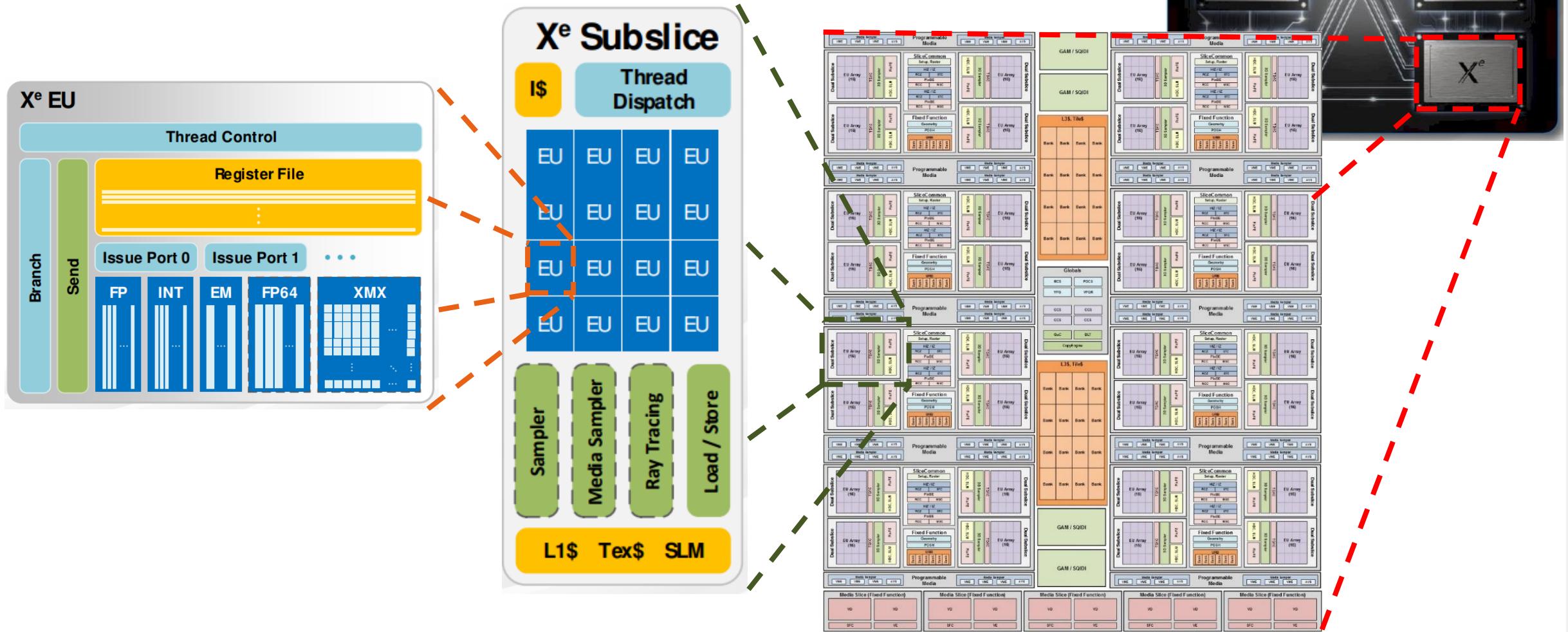
# Parallelism



# Creating Parallelism on the Target Device

- The **target construct** transfers the control flow to the target device
  - Transfer of control is sequential and synchronous
- OpenMP\* separates offload and parallelism
  - Programmers need to explicitly create parallel regions on the target device
  - In theory, this can be combined with any OpenMP construct
  - In practice, there is only a useful subset of OpenMP for a target device  
(more later)

# GPU Architecture



# OpenMP\* GPU Offload and OpenMP Constructs

- OpenMP GPU offload support all “normal” OpenMP constructs
  - E.g. parallel, for/do, barrier, sections, tasks, etc.
  - Not every construct will be useful
- Full threading model outside of a single GPU subslice **not** supported
  - No synchronization among subslices
  - No coherence and memory fence between among subslice L1 caches

# Example: saxpy

- On the device, the **parallel** construct creates a team of threads to be executed on **one** subslice or stream multiprocessor

```
void saxpy(float a, float* x, float* y,  
          int sz) {  
#pragma omp target map(to:x[0:sz]) \  
               map(tofrom(y[0:sz])  
#pragma omp parallel for simd  
    for (int i = 0; i < sz; i++) {  
        y[i] = a * x[i] + y[i];  
    }  
}
```

host  
target

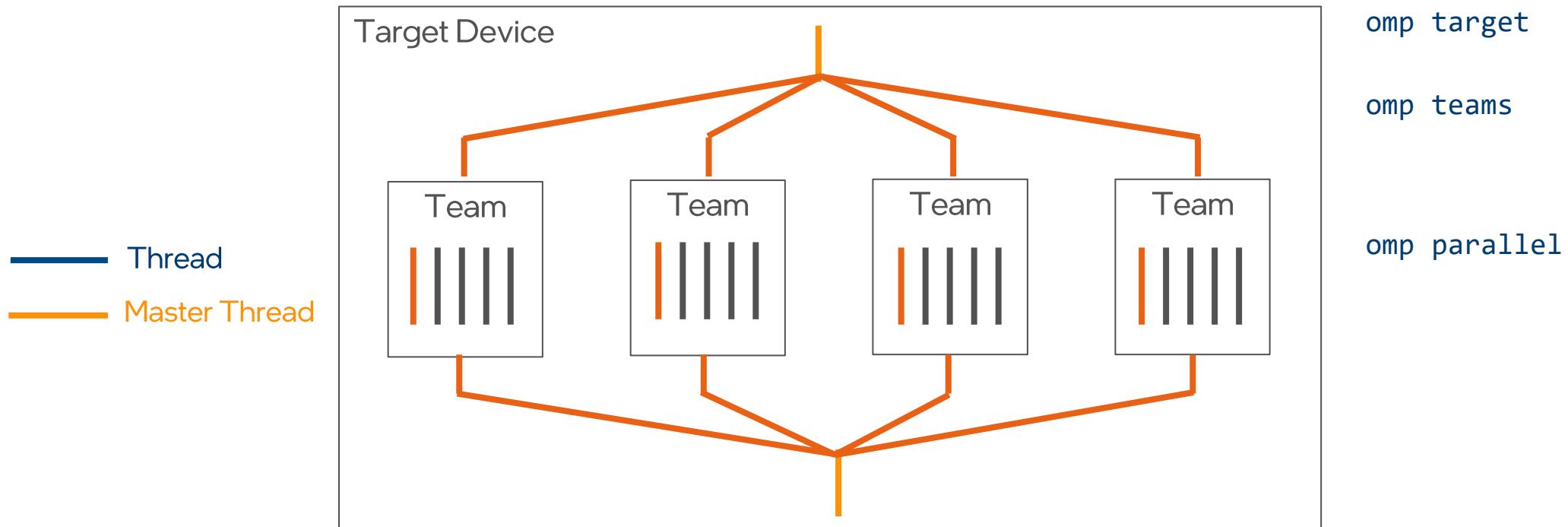
GPUs are multi-level devices:  
SIMD, threads, thread blocks

Create a team of threads to execute the loop  
in parallel and SIMDify.  
Only one GPU subslice utilized, GPU  
significantly underutilized

```
icx -fopenmp -fopenmp-targets=spir64 -o saxpy saxpy.c
```

# Teams Construct

- Creates multiple master threads, effectively creates a set of thread teams (league)
- Synchronization does not apply across teams.



# Teams Construct

- Support multi-level parallel devices

- Syntax (C/C++):

```
#pragma omp teams [clause[,] clause],...]  
structured-block
```

- Syntax (Fortran):

```
!$omp teams [clause[,] clause],...]  
structured-block
```

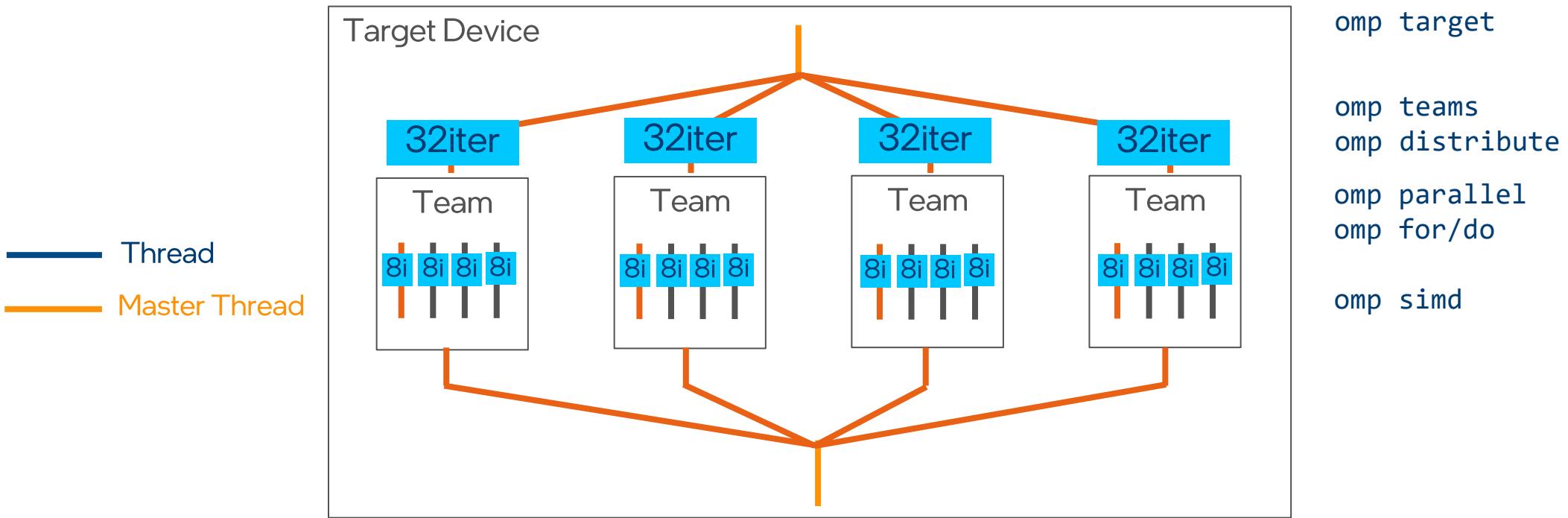
- Clauses

```
num_teams(integer-expression), thread_limit(integer-expression)  
default(shared | firstprivate | private none)  
private(list), firstprivate(list), shared(List), reduction(operator:list)
```

# Distribute Construct

- **distribute** construct distributes iterations of a loop across the different teams
  - Worksharing within a league
  - Nested inside a **teams** region
  - Can specify distribution schedule
  - Similar to for/do construct for parallel regions
  - Syntax
    - `#pragma omp distribute [clause[,] clause]...`
    - `!$omp distribute [clause[,] clause]...`

# Distribute Diagram



# Multi-level Parallel saxpy

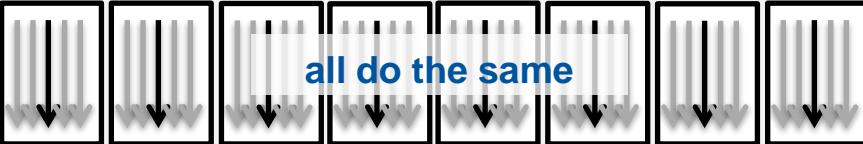
```
void saxpy(float a, float* x, float* y, int sz) {
    #pragma omp target map(to:x[0:sz]) map(tofrom(y[0:sz])
    {

        for (ib = 0; ib < sz; ib += num_blocks) {

            for (int i = ib; i < ib + num_blocks; i++) {

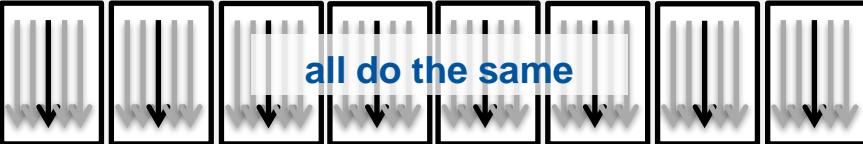
                y[i] = a * x[i] + y[i];
            }
        }
    }
}
```

# Multi-level Parallel saxpy

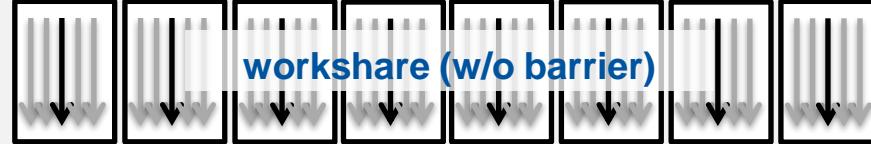
```
void saxpy(float a, float* x, float* y, int sz) {
    #pragma omp target map(to:x[0:sz]) map(tofrom(y[0:sz])
    {
        #pragma omp teams num_teams(num_blocks)
        {
            
            for (ib = 0; ib < sz; ib += num_blocks) {

                for (int i = ib; i < ib + num_blocks; i++) {
                    y[i] = a * x[i] + y[i];
                }
            }
        }
    }
}
```

# Multi-level Parallel saxpy

```
void saxpy(float a, float* x, float* y, int sz) {
    #pragma omp target map(to:x[0:sz]) map(tofrom(y[0:sz]))
    {
        #pragma omp teams num_teams(num_blocks)
        {
            

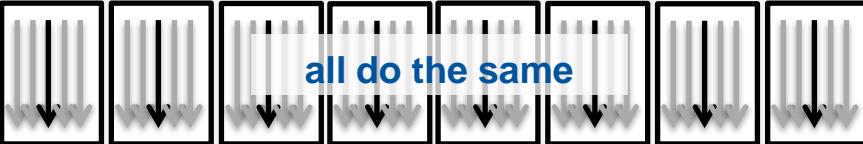
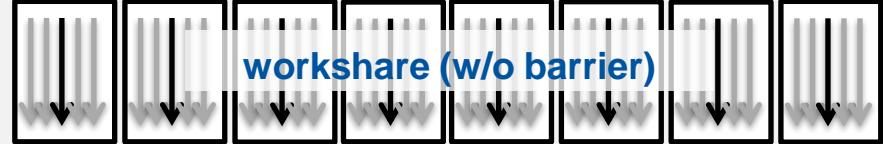
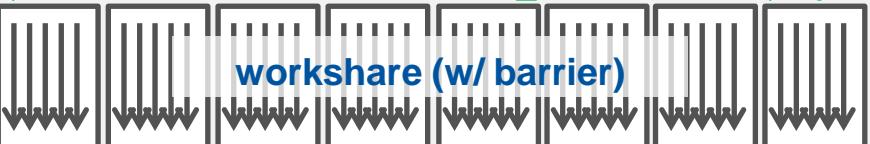
all do the same


            #pragma omp distribute
            for (ib = 0; ib < sz; ib += num_blocks) {
                

workshare (w/o barrier)


                for (int i = ib; i < ib + num_blocks; i++) {
                    y[i] = a * x[i] + y[i];
                }
            }
        }
    }
}
```

# Multi-level Parallel saxpy

```
void saxpy(float a, float* x, float* y, int sz) {
    #pragma omp target map(to:x[0:sz]) map(tofrom(y[0:sz]))
    {
        #pragma omp teams num_teams(num_blocks)
        {
            
            all do the same
            #pragma omp distribute
            for (ib = 0; ib < sz; ib += num_blocks) {
                
                workshare (w/o barrier)
                #pragma omp parallel for simd
                for (int i = ib; i < ib + num_blocks; i++) {
                    
                    workshare (w/ barrier)
                    y[i] = a * x[i] + y[i];
                }
            }
        }
    }
}
```

# Multi-level Parallel saxpy

- For convenience, OpenMP\* defines composite construct to implement the required code transformation

```
void saxpy(float a, float* x, float* y, int sz) {  
    #pragma omp target teams distribute parallel for simd \  
        num_teams(num_blocks) map(to:x[0:sz]) map(tofrom(y[0:sz]))  
    for (int i = 0; i < sz; i++) {  
        y[i] = a * x[i] + y[i];  
    }  
}
```

```
subroutine saxpy(a, x, y, n)  
    ! Declarations omitted  
    !$omp target teams distribute parallel do simd &  
    !$omp&           num_teams(num_blocks) map(to:x) map(tofrom(y))  
    do i=1,n  
        y(i) = a * x(i) + y(i)  
    end do  
    !$omp end target teams distribute parallel do simd  
end subroutine
```

# Complete Saxpy Example

```
void example() {
    float tmp[N], data_in[N], float data_out[N];
#pragma omp target data map(alloc:tmp[:N]) \
                map(to:a[:N],b[:N]) \
                map(tofrom:c[:N]) {
        zeros(tmp, N);
        compute_kernel_1(tmp, a); // uses target
        saxpy(2.0f, tmp, b);
        compute_kernel_2(tmp, b); // uses target
        saxpy(2.0f, c, tmp);
    }
}
```

```
void zeros(float* a, int n) {
#pragma omp target teams distribute parallel for
    for (int i = 0; i < n; i++)
        a[i] = 0.0f;
}
```

```
void saxpy(float a, float* y, float* x, int n) {
#pragma omp target teams distribute parallel for
    for (int i = 0; i < n; i++)
        y[i] = a * x[i] + y[i];
}
```

# Case Study: NWChem TCE CCSD(T)



# NWChem

- Computational chemistry software package
  - Quantum chemistry
  - Molecular dynamics
- Designed for large-scale supercomputers
- Developed at the EMSL at PNNL
  - EMSL: Environmental Molecular Sciences Laboratory
  - PNNL: Pacific Northern National Lab
- URL: <http://www.nwchem-sw.org>

# Finding Offload Candidates

- Requirements for offload candidates
  - Compute-intensive code regions (kernels)
  - Highly parallel
  - Compute scaling stronger than data transfer,  
e.g., compute  $O(n^3)$  vs. data size  $O(n^2)$
- Intel® Advisor: Offload Advisor can be used to identify candidates

# Example Kernel (1 of 27 in total)

```
subroutine offl_t_d1_1(h3d,h2d,h1d,p6d,p5d,p4d,  
1           h7d,triplesx,t2sub,v2sub)  
c   Declarations omitted.  
double precision triplesx(h3d*h2d,h1d,p6d,p5d,p4d)  
double precision t2sub(h7d,p4d,p5d,h1d)  
double precision v2sub(h3d*h2d,p6d,h7d)  
!$omp target  
!$omp teams distribute parallel do private(p4,p5,p6,h2,h3,h1,h7)  
do p4=1,p4d  
do p5=1,p5d  
do p6=1,p6d  
do h1=1,h1d  
do h7=1,h7d  
do h2h3=1,h3d*h2d  
    triplesx(h2h3,h1,p6,p5,p4)=triplesx(h2h3,h1,p6,p5,p4)  
1 - t2sub(h7,p4,p5,h1)*v2sub(h2h3,p6,h7)  
end do  
end do  
end do  
end do  
end do  
end do  
!$omp end teams distribute parallel do  
!$omp end target  
end subroutine
```

1.5GB data transferred (host to device)

1.5GB data transferred (device to host)

- All kernels expose the same structure
- 7 perfectly nested loops
- Some kernels contain inner product loop (then, 6 perfectly nested loops)
- Trip count per loop is equal to “tile size” (20-30 in production)
- Naïve data allocation (tile size 24)
  - Per-array transfer for each **target** construct
  - triplesx: 1458 MB
  - t2sub, v2sub: 2.5 MB

# Invoking the Kernels / Data Management

- Simplified pseudo-code

```
!$omp target enter data alloc(triplesx(1:tr_size))
c      for all tiles
do ...
    call zero_triplesx(triplesx)
    do ...
        call comm_and_sort(t2sub, v2sub)
!$omp target data map(to:t2sub(t2_size)) map(to:v2sub(v2_size))
        if (...)
            call sd_t_d1_1(h3d,h2d,h1d,p6d,...,p4d,h7,triplesx,t2sub,v2sub)
        end if
c          same for sd_t_d1_2 until sd_t_d1_9
!$omp target end data
        end do
        do ...
            Similar structure for sd_t_d2_1 until sd_t_d2_9, incl. target data
        end do
        call sum_energy(energy, triplesx)
    end do
!$omp target exit data release(triplesx(1:size))
```

Allocate 1.5GB data once,  
stays on device.

Update 4MB of data for  
(potentially) multiple kernels.

- Reduced data transfers:

- triplesx:

- allocated once
  - always kept on the target

- t2sub, v2sub:

- allocated after comm.
  - kept for (multiple) kernel invocations

# Conclusion



# Summary

- OpenMP\* offload supported by the Intel® C++ Compiler and Intel® Fortran Compiler as part of the Intel® oneAPI HPC Toolkit
- Use the **target** directive to offload
- Use the **map** clause with **target**, **target data**, **target enter/exit data** directives to improve data transfer efficiency
- Use the **teams/distribute** directives fully utilize multiple GPU subslices
- Use the **parallel/for/do** directive to use the threads within a GPU subslice
- Use the **simd** directive for optimal SIMD execution on GPU execution units

# Other Topics of Interest

- Using the Intel® Advisor : Offload Advisor to identify areas of code that are advantageous to offload
  - Provides performance speedup projection on accelerators
- Using the Intel® Advisor: Roofline Analysis to visualize hardware-imposed performance ceilings for the CPU and GPU.
  - Provides insights on bottlenecks and optimization steps

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