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Exploring Dynamic Parallelism on OpenMP

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MACC: Introduction

MACC = **M**ercurium **AC**celerator **C**ompiler [1]

- **OpenMP Accelerator + OmpSs task model**
- Trying to influence the evolution of the OpenMP
- Extended OpenMP with experimental clauses
  - Three new clauses for `distribute` construct
    - Using team memory(shared) chunk by chunk without synchronization teams
    - `dist_private([CHUNK]data, …) ,dist_firstprivate([CHUNK]data, …), dist_lastprivate([CHUNK]data, …)`
- Using together Task & Target directives
  - Programmer only specifies directionality of task data, not the actual data movement
    - `#pragma omp task in(list) out(list) inout(list)`
  - Doesn't download data from GPU until `#pragma omp taskwait`
  - **Data transfer minimization** (host-2-gpu)
  - Automatically **Multi-GPU task scheduling**
  - **Ignored** target data & target update

[1] On the Roles of the Programmer, the Compiler and the Runtime System When Programming Accelerators in OpenMP. IWOMP 2014, Guray Ozen, Eduard Ayguadé, Jesús Labarta

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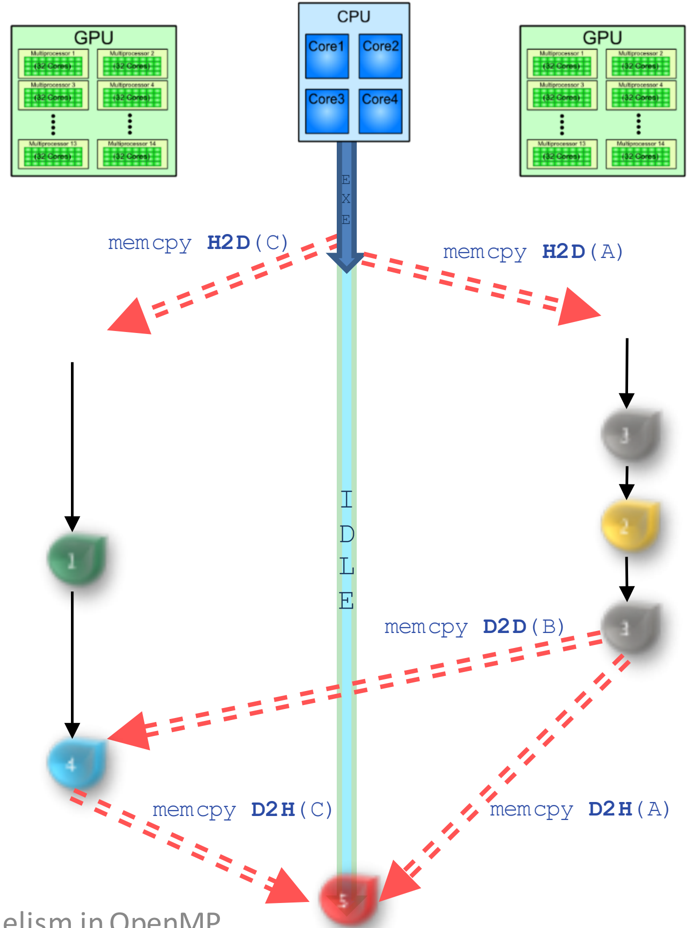
MACC: Introduction

```
int main(…) {
    double A[N], B[N], C[N] , D[N];
    while (0-> 2)
    {
      #pragma omp target device(acc)
      #pragma omp task inout(C) out(D)
      #pragma omp teams distribute parallel for
        <.. Sequential Codes to generate CUDA..>

      #pragma omp target device(acc)
      #pragma omp task in(A) out(B)
      #pragma omp teams distribute parallel for
       for(i=0 ; i< N; ++i)
        <..Sequential Codes to generate CUDA..>

      #pragma omp target device(acc)
      #pragma omp task inout(A,B)
      #pragma omp teams distribute parallel for
       for(i=0 ; i< N; ++i)
        <..Sequential Codes to generate CUDA..>
    }
    #pragma omp target device(acc)
    #pragma omp task inout(C,B) in(D)
    #pragma omp teams distribute parallel for
     for(i=0 ; i< N; ++i)
      <..Sequential Codes to generate CUDA..>

    #pragma omp target device(smp)
    #pragma omp task in(A, C)
      <..Sequential codes / Result Test..>
    #pragma omp taskwait
}
```



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Dynamic Parallelism (DP)

What's DP

- Autonomously launching kernel without CPU-host intervention
- CUDA thread(parent) launches kernel(child)

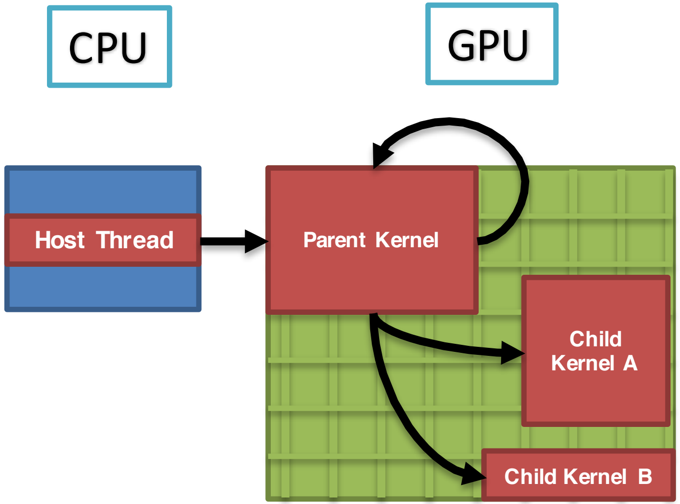
- **What can we do with DP ?**
  - Improved programmability
  - Dynamic load balancing
  - Increase occupancy
  - Ability to implement recursive algorithms

- **Issues with DP**
  - Device kernel launch might incur overhead
  - Shared is not visible between kernels
  - Global memory is visible between kernels
    - Weak consistent
    - With synchronization, can be strong

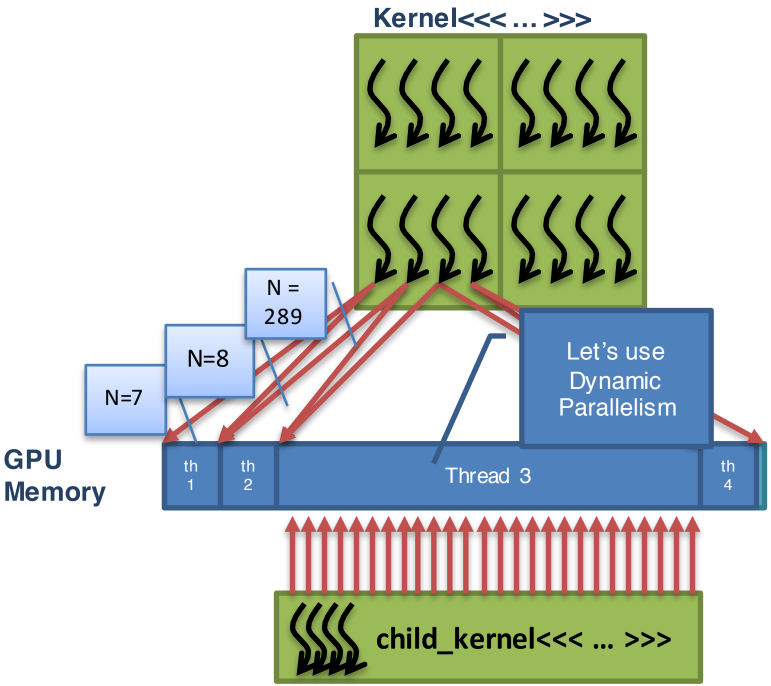
Syntax of Dynamic Parallelism (DP)

```
void main()
{
    parent_kernel<<<…>>>();
}
void __global__ parent_kernel()
{
    child_kernel_A<<<…>>>();
    child_kernel_B<<<…>>>();
    parent_kernel <<<…>>>();
}

void __global__ child_kernel_A()
{
    <.. Codes ..>
}
void __global__ child_kernel_B()
{
    <.. Codes ..>
}
```



Motivation




```
__global__ kernel(double* A, double* X, int* iter, int N, double alpha)
{
    int i = threadIdx.x + blockDim.x * gridDim.x;
    <.. Code ..>
    N = iter[i] - iter[i+1];

    for(j = iter[i]; j < iter[i+1]; j++)
      X[j] += A[j] * alpha;

    if(N > 256)
      child_kernel<<<1,N>>>(A, X, alpha);
    else
    <.. Code ..>
      for (j = iter[i]; j < iter[i+1]; j++)
        X[j] += A[j] * alpha;
}
    <.. Code ..>
}
```

Workload dependency

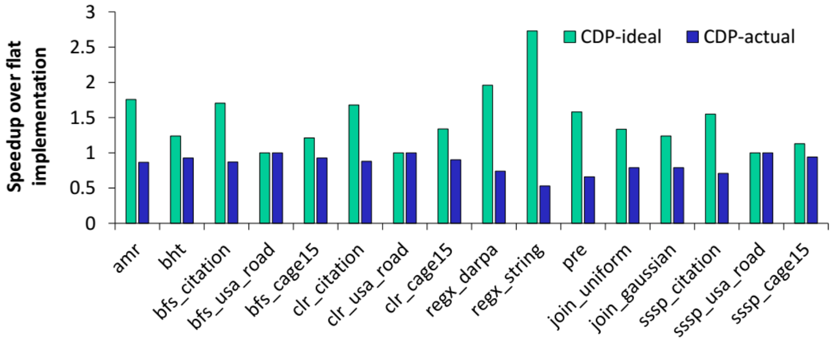
Also not coalesced

```
__global__ child_kernel(double* A, double* X, int* iter, int N, double alpha)
{
    int j = threadIdx.x + blockDim.x * gridDim.x;

    X[j] += A[j] * alpha;
}
```

UNMotivation

- DP can increase performance
- Kernel launching overhead could negate performance benefit



Overall Performance: Speedup over flat implementations

- CDP-ideal: excluding launch overhead, average 1.47x speedup
- CDP-actual: including launch overhead, average 1.21x slowdown

*IISWC'14, Characterization and Analysis of Dynamic Parallelism in Unstructured GPU Applications, Jin Wang, Sudhakar Yalamanchili

Dynamic Parallelism in Pragmatic Programming Models

- **OpenMP 4.x**
  - There are no directives which express dynamic parallelism
  - Using `teams/distribute` construct is prohibited

- **OpenACC 2.0**
  - Standard supports
  - As we know, only ENZO compiler involves its implementation

Proposal of Dynamic Parallelism for OpenMP

- We defined a semantic to **nested teams** constructs
  - To express explicitly DP
  - The teams construct already has definition clauses for number of teams/threads

- Inner device constructs (`distribute`, `parallel for` etc.) bind to **closest teams**
  - Allows inner teams' code scope to be specified parallelism level

- We propose **if** clause to conditionally activate nested teams construct
  - DP might incur overhead, conditional usage can prevent

Proposal of Dynamic Parallelism for OpenMP

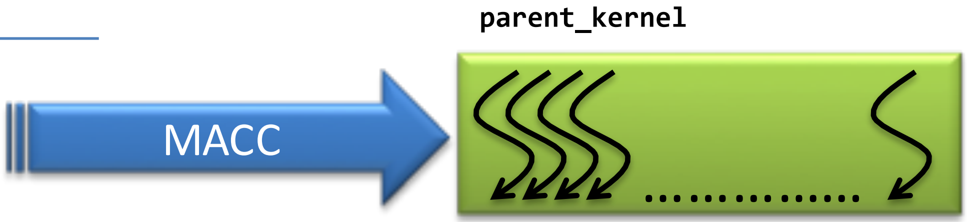
- The **if** clause can avoid redundant DP invocations
  - Disables pragma directive. Compiler creates if-then-else in the parent kernel
  - In this case, inner code block is executed sequentially

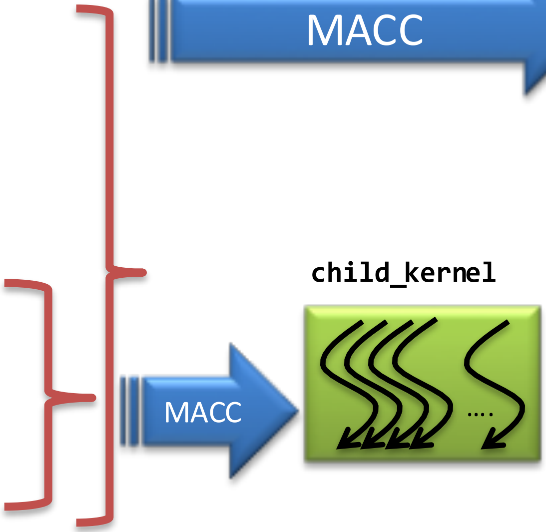
```
#define THRESHOLD 256

#pragma omp target map(…)
#pragma omp teams distribute parallel for
for (i = 0; i < N; ++i)
{
  <..Computation Code..>

  int M =  <..Compute M value..>

  #pragma omp teams distribute parallel for
                   nowait if( M>THRESHOLD )
  for (j = 0; j < M; ++j)
     for (k = 0; k < N; ++k)
     {
         <..Computation Code..>
     }
}
```






```
__global__ parent_kernel(…){
  <.Parallelized Computation Code.>

  int M =  <..Compute M value..>

  if ( M > THRESHOLD )
     child_kernel<<<…>>>(…);
  else
    for (j = 0; j < M; ++j)
     for (k = 0; k < N; ++k)
      <..Computation Code..>
}
```

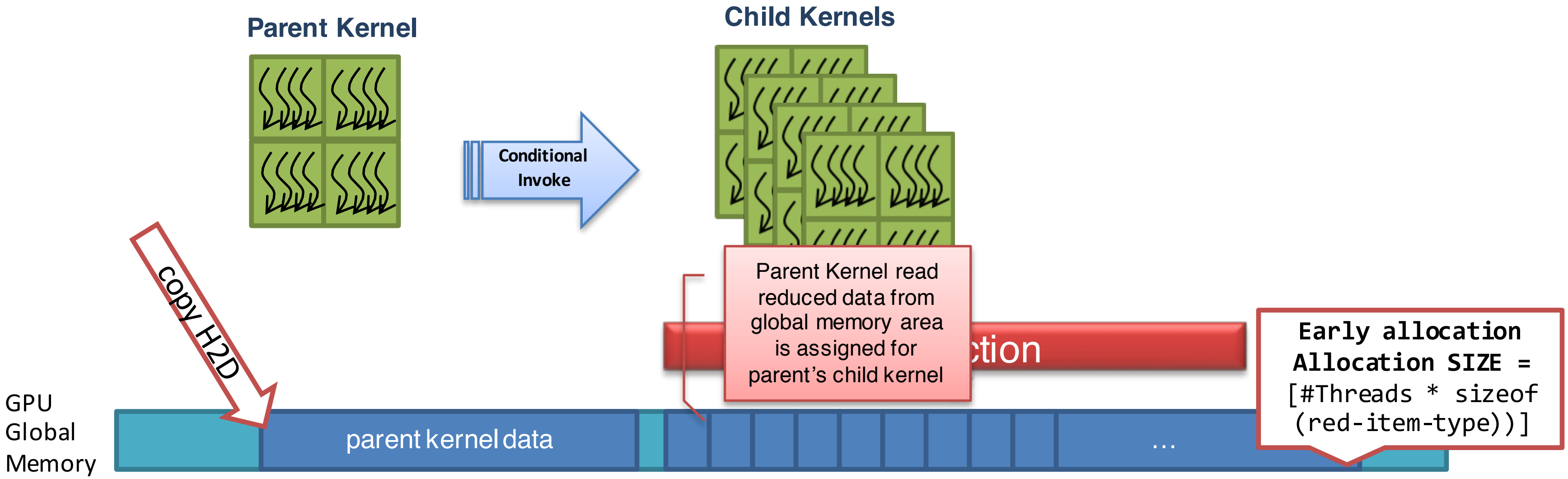
Proposal of Dynamic Parallelism for OpenMP

- **Issue** child-2-parent kernels can communicate only via global memory
  - When it's necessary, spare space from global memory is needed
  - However doing allocation in the runtime incurs overheads

- **Solution:**
  - We've implemented early memory allocation mechanism
  - Global memory for communication is allocated by host in advance
  - It's also used when `reduction` is used with inner `teams`
  - It allocates memory for every single parent thread even if not used

Proposal of Dynamic Parallelism for OpenMP

How reduction works for inner teams



Proposal of Dynamic Parallelism for OpenMP

- Preliminary support for **recursion**
  - Max nesting depth is 24 for devices compute capability 3.5
  - Three functions are generated

```
#pragma omp declare target
 void foo ( ) {
   /* code 1 */

   #pragma omp target teams distribute parallel for
   for ( int i = 0 ; i < count ; ++i )
      foo ( ) ;

   /* code 2 */
}
#pragma omp end declare target
```

MACC

```
void foo ( ){
  /* code 1 */
  gpu_foo<<< . . . >>> (... , 0) ;
  /* code 2 */
}

__global__ gpu_foo (... , int depth ) {
  . . .
  if ( depth > MAXDEPTH)
     dev_in_foo ( ) ;
  else {
     /* code 1 */
     gpu_foo<<< . . . >>> ( . . . , depth + 1 ) ;
     /* code 2 */
  }
}

__device__ dev_in_foo( ) {
   /* code 1 */
   for ( int i = 0 ; i < count ; ++i )
      dev_in_foo( ) ;

   /* code 2 */
}
```

Evaluation

- **GOALS**
  - Apply DP onto workload-based applications to gain insight how it effects
  - Observe performance when DP is limited by using if clause

- **Hardware :** NVidia K40c (2888 CUDA cores, 12GB memory)
- **Software**
  - OpenACC | PGI compiler 15.7
  - OpenMP 4.0 | MACC compiler
  - CUDA | NVCC 7.0
  - Backend Host | GCC 4.9

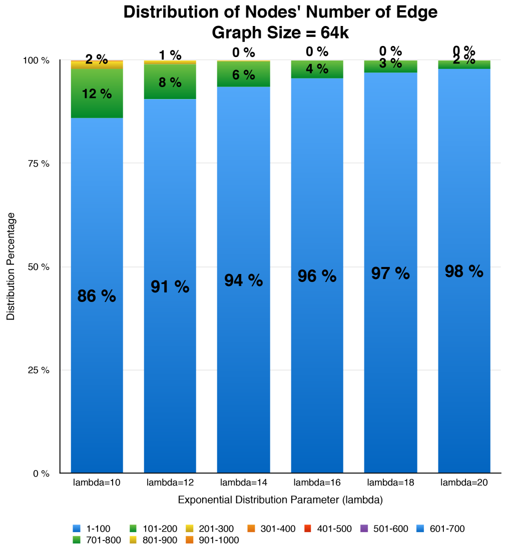
Sparse Matrix Vector Multiplication (CSR)

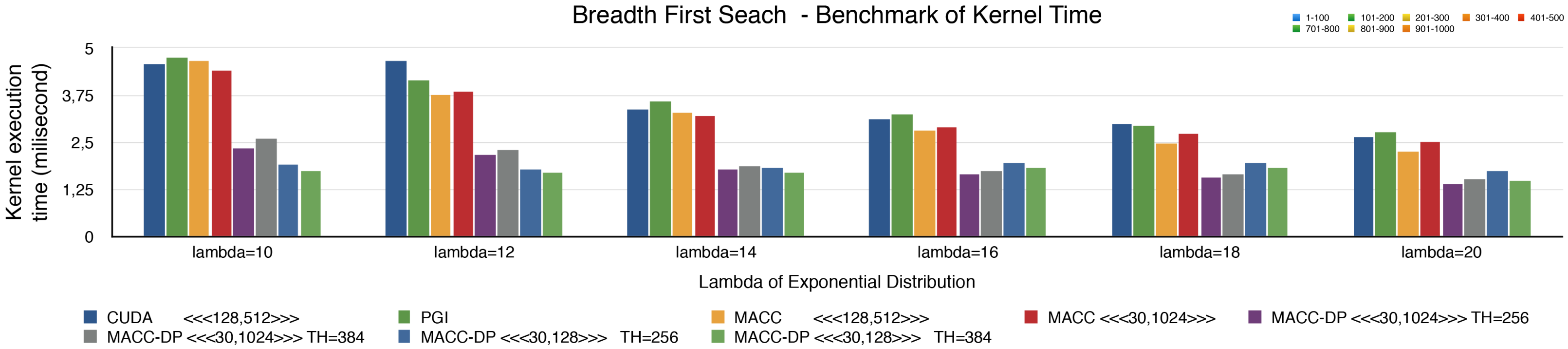
- 7 matrixes are used from University of Florida sparse matrix collection
- Matrixes are compressed CSR format
- They are mostly filled by zero
- Some rows have excessive item

Matrix	Size	NNZ	IIT > 256	IIT > 128
rajat30	643994	6175377	121	277
ASIC 680k	682862	3871773	2	76
rajat29	643994	4866270	22	27
transient	178866	961790	13	31
c-big	345241	2341011	2	160
Raj-1	263743	1302464	65	93
trans5	116835	766396	8	32

Breadth First Search

- BFS is ported from Rodinia Benchmark Suite
- Six graphs are used. Their nodes' number of edge are generated by exponential distribution.
- Some nodes of graph have massive amount of edges
  - DP is activated for these nodes

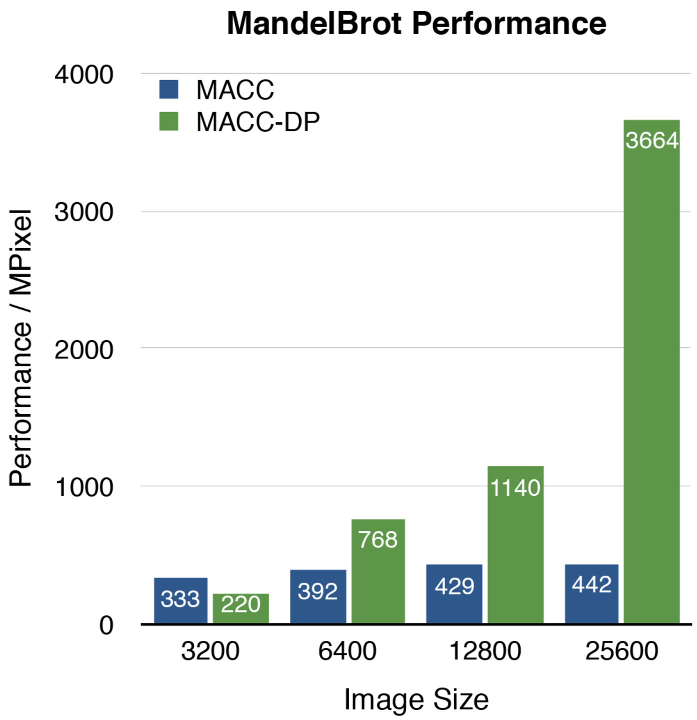




Mandelbrot

Two algorithms are used

- **Escape algorithm**
  - Each pixel is handled by CUDA thread
- **Mariani-Silver algorithm**
  - Block by block
  - Involves recursion



Conclusion & Future work

- Dynamic parallelism is able to gain performance, but it incurs some overheads
- **In this paper we showed:**
  1. We don’t need activate DP in every single case
  2. Essentially it is good for irregular cases
  3. When it is used conditionally (only irregular case), it could increase performance
- **In directive based Programming Models:**
  1. Expressing explicitly DP is useful since user might know their application behavior
  2. Conditional usage is possible

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To download MACC OpenMP 4.0+OmpSs compiler

PLEASE ASK

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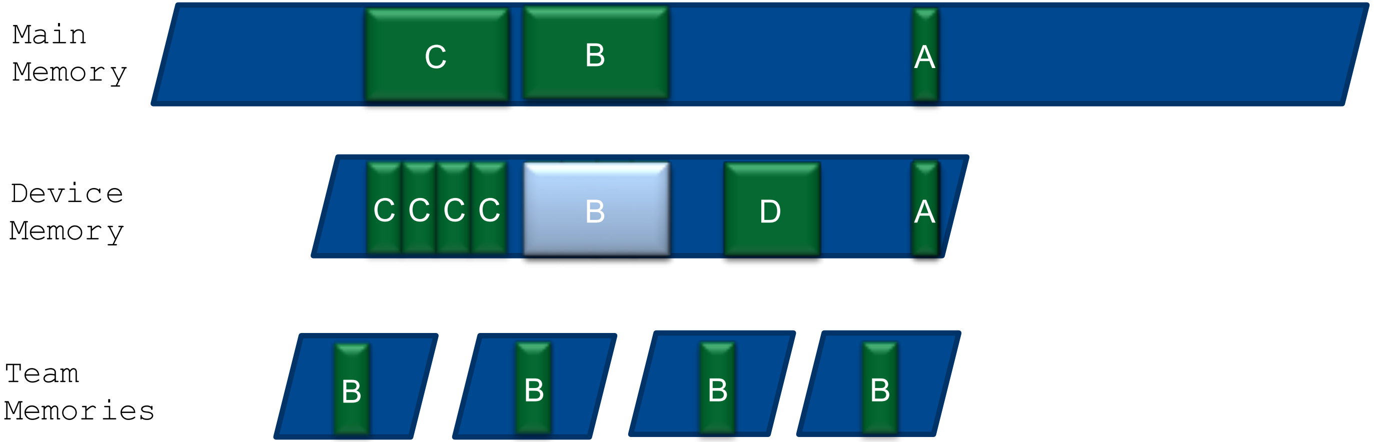
- Data sharing clauses with `teams` | `private` | `first_private`
- Offers experimental 3 new clauses for `distribute` directive
  - `dist_private([CHUNK]data1, [CHUNK]data2 …)`
  - `dist_firstprivate([CHUNK]data1, [CHUNK]data2 …)`
  - `dist_lastprivate([CHUNK]data1, [CHUNK]data2 …)`

Data movement to **Device Memory**

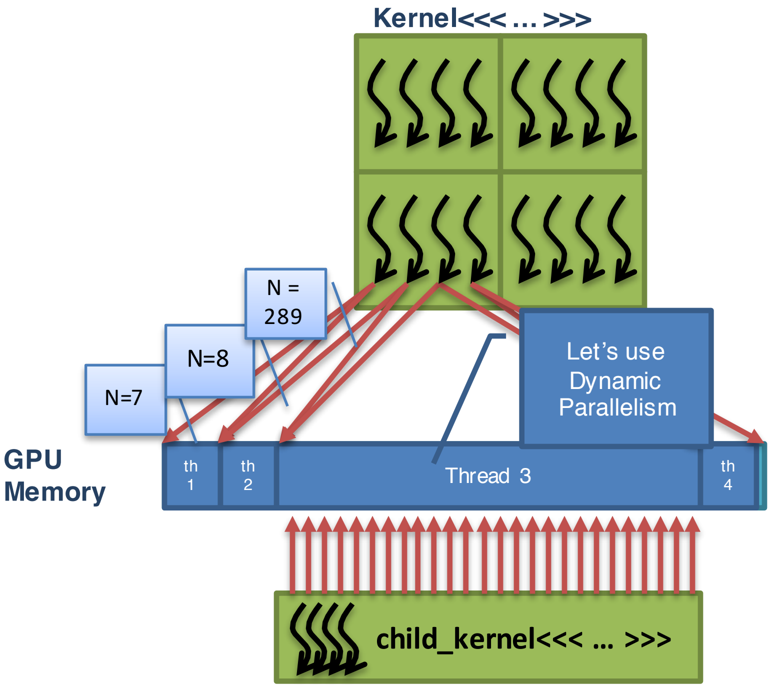
```
#pragma omp target device(acc) copy_deps
#pragma omp task in(A[0:SMALL],C[0:HUGE]) inout(B[0:HUGE]) out(0:D[BIG])
#pragma omp teams first_private(A)
#pragma omp distribute parallel for dist_first_private([CHUNK]C) dist_first_last_private([CHUNK]B)
for(...)
   <<..Computation..>>
```

Using **TeamMem** with **Small DATA**

Using **TeamMem** with **Big DATA**



Motivation




```
__global__ kernel(double* A, double* X, int* iter, int N, double alpha)
{
   int i = threadIdx.x + blockDim.x * gridDim.x;
   <.. Code ..>
   N = iter[i] - iter[i+1];

   for (j = iter[i]; j < iter[i+1]; j++)
     X[j] += A[j] * alpha;

   <.. Code ..>
}
```

Workload dependency

Also not coalesced

- What has changed when DP is activated ?
  - Granularity is increased
  - Memory behavior could be changed
  - Control-flow behavior could be changed