OpenMP

SC25 OpenMP Tech Talk Series

Accelerating with OpenMP
Latest and Upcoming Features

Kevin Sala – Postdoctoral Researcher
Lawrence Livermore National Laboratory (LLNL)

Outline

- Accelerating with OpenMP
- Static Shared Memory
- Dynamic Shared Memory
- Multidimensional Grid Programming
- Reducing Device Runtime Overhead
- Conclusions

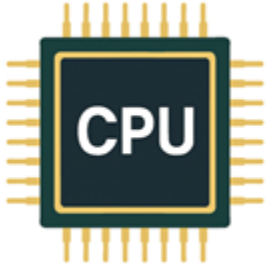
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-PRES-2013109.

Parallelizing with OpenMP

OpenMP

```
#pragma omp parallel for collapse(3)
for (int z = 0; z < N; z++)
  for (int y = 0; y < N; y++)
    for (int x = 0; x < N; x++)
      Matrix[x + y*N + z*N*N] *= Val;
```

OpenMP app



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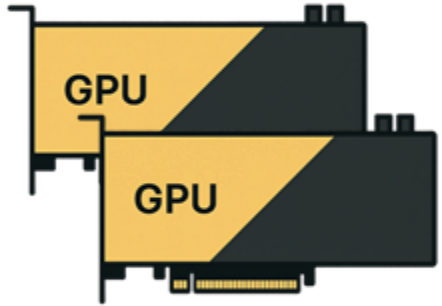
Accelerating with OpenMP?

OpenMP

```
#pragma omp parallel for collapse(3)
for (int z = 0; z < N; z++)
  for (int y = 0; y < N; y++)
    for (int x = 0; x < N; x++)
      Matrix[x + y*N + z*N*N] *= Val;
```

?

OpenMP app



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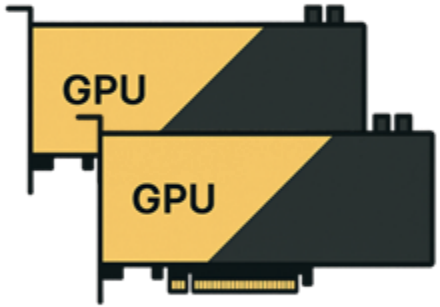
Accelerating with OpenMP

OpenMP

```
#pragma omp target parallel for collapse(3)
for (int z = 0; z < N; z++)
  for (int y = 0; y < N; y++)
    for (int x = 0; x < N; x++)
      Matrix[x + y*N + z*N*N] *= Val;
```

OpenMP app



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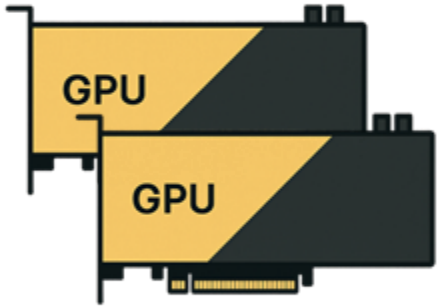
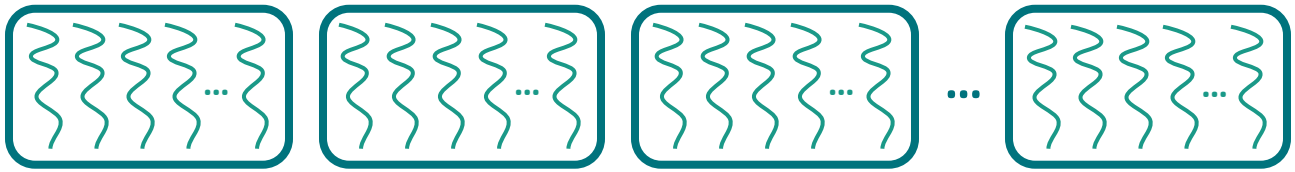
Accelerating with OpenMP

OpenMP

```
#pragma omp target teams distribute parallel for \
    map(tofrom: Matrix[0:N*N*N]) collapse(3)
for (int z = 0; z < N; z++)
  for (int y = 0; y < N; y++)
    for (int x = 0; x < N; x++)
      Matrix[x + y*N + z*N*N] *= Val;
```

OpenMP app





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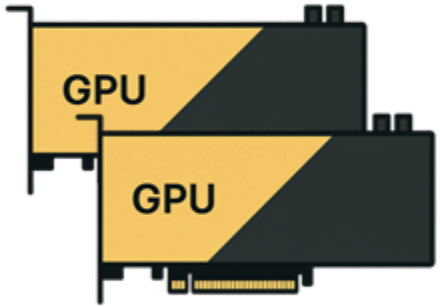
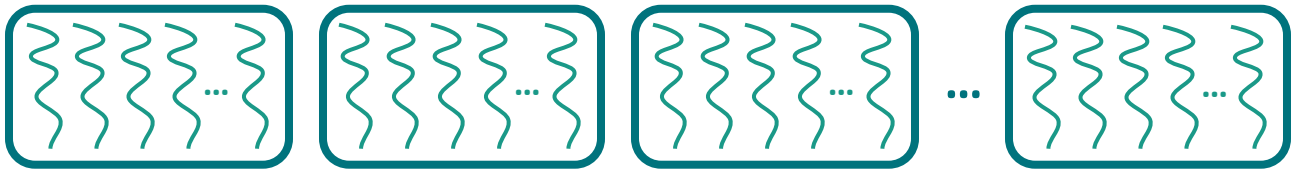
Accelerating with OpenMP

OpenMP

```
#pragma omp target teams distribute parallel for \
    num_teams(N*N*N/256) thread_limit(256)       \
    map(tofrom: Matrix[0:N*N*N]) collapse(3)
for (int z = 0; z < N; z++)
  for (int y = 0; y < N; y++)
    for (int x = 0; x < N; x++)
      Matrix[x + y*N + z*N*N] *= Val;
```

OpenMP app





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Accelerating with Native APIs

CUDA app

HIP app

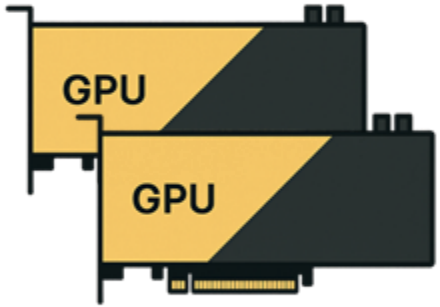
```
__global__ kernel(double *matrix, size_t N, size_t S) {
  __shared__ double tmp1[512];
  __shared__ double tmp2[];

  int x = blockIdx.x * blockDim.x + threadIdx.x;
  int y = blockIdx.y * blockDim.y + threadIdx.y;
  int z = blockIdx.z * blockDim.z + threadIdx.z;

  init(tmp1, 512);
  init(tmp2, S);
  __syncthreads();

  if (x < N && y < N && z < N)
    matrix[x + y * N + z * N * N] = ... + tmp1[...] + tmp2[...];
}

dim3 nblocks(N/256,N/256,N/256);
dim3 nthreads(256,256,256);
kernel<<<nblocks,nthreads,S*sizeof(double)>>>(matrix, N, S);
```

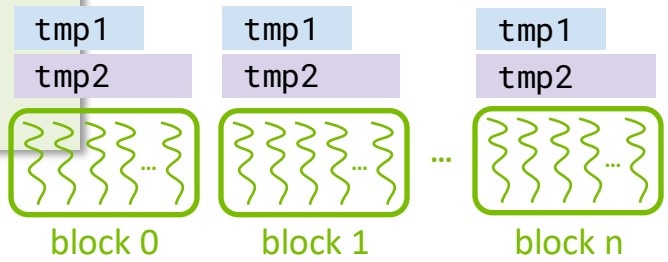
Shared memory

Single program, multiple data (SPMD)

3-D grids and blocks

Dynamic shared memory





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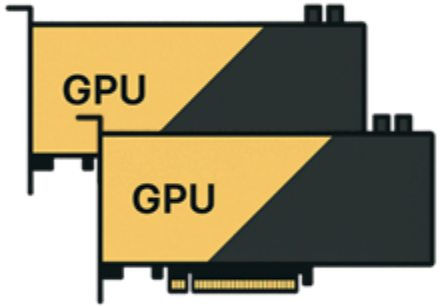
Accelerating with OpenMP

- OpenMP should expose such features to
  - Close the **performance gap** with native APIs
  - Become a **stronger alternative** to native APIs
  - Reduce application **porting effort**

OpenMP

?

OpenMP app



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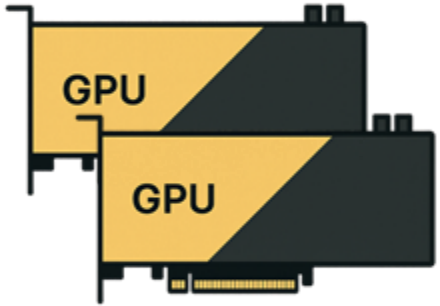
Accelerating with OpenMP

- OpenMP should expose such features to
  - Close the **performance gap** with native APIs
  - Become a **stronger alternative** to native APIs
  - Reduce application **porting effort**

OpenMP

Let's review them!

OpenMP app



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Grouppprivate Directive

- Specify variables with static storage duration as grouppprivate
  - Each *contention group* gets its own **copy**
  - File-scope, namespace-scope or static block-scope variables

- Implementation can use **static shared memory** on the GPU

Contention group: All implicit tasks and their descendent tasks that are generated in an implicit parallel region, *R*, and in all nested regions for which *R* is the innermost enclosing implicit parallel region.

C++

```
void func(int *sum, int tid) {
  static int tmp[1000];
  #pragma omp grouppprivate(tmp)

  #pragma omp for
  for (int i = 0; i < 1000; i++)
    tmp[i] = tid + i;

  #pragma omp for reduction(+: sum)
  for (int i = 0; i < 1000; i++)
    sum += tmp[i];
}

int main() {
  int sums[10];

  #pragma omp target teams num_teams(10) thread_limit(256)
  #pragma omp parallel
  func(&sums[omp_get_team_num()], omp_get_thread_num());
}
```

Available OpenMP 6.0

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Grouppprivate Directive

- Similar to CUDA / HIP

C++

```
__global__ void func(int *sum, size_t N) {
  __shared__ int tmp[1000];
  ...
}

func<<<10,256>>>(sum, N);
```

C++

```
void func(int *sum, int tid) {
  static int tmp[1000];
  #pragma omp grouppprivate(tmp)

  #pragma omp for
  for (int i = 0; i < 1000; i++)
    tmp[i] = tid + i;

  #pragma omp for reduction(+: sum)
  for (int i = 0; i < 1000; i++)
    sum += tmp[i];
}

int main() {
  int sums[10];

  #pragma omp target teams num_teams(10) thread_limit(256)
  #pragma omp parallel
  func(&sums[omp_get_team_num()], omp_get_thread_num());
}
```

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Dynamic Grouppprivate Clause

- **Not allowed** with variable length array (VLA)
  - Static variables can't be VLA

C++

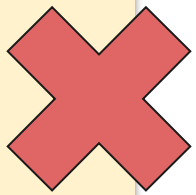
```
void func(int *sum, int tid, int N) {
  static int tmp[N];
  #pragma omp groupprivate(tmp)

  #pragma omp for
  for (int i = 0; i < N; i++)
    tmp[i] = tid + i;

  #pragma omp for reduction(+: sum)
  for (int i = 0; i < N; i++)
    sum += tmp[i];
}

int main(int argc, char **argv) {
  int N = atoi(argv[1]);
  int sums[10];

  #pragma omp target teams num_teams(10) thread_limit(256)
  #pragma omp parallel
  func(&sums[omp_get_team_num()], omp_get_thread_num(), N);
}
```



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Dynamic Groupprivate Clause

- Request a groupprivate buffer with size determined at runtime
  - Each *contention group* gets its own **copy**
  - Available on target and teams
- Implementation can use **dynamic shared memory** on the GPU

Contention group: All implicit tasks and their descendent tasks that are generated in an implicit parallel region, *R*, and in all nested regions for which *R* is the innermost enclosing implicit parallel region.

C++

```
void func(int *sum, int tid, int N) {
  int *tmp = omp_get_dyn_groupprivate_ptr();

  #pragma omp for
  for (int i = 0; i < N; i++)
    tmp[i] = tid + i;

  #pragma omp for reduction(+: sum)
  for (int i = 0; i < N; i++)
    sum += tmp[i];
}

int main(int argc, char **argv) {
  int N = atoi(argv[1]);
  int sums[10];

  #pragma omp target teams dyn_groupprivate(N*sizeof(int)) \
              num_teams(10) thread_limit(256)
  #pragma omp parallel
  func(&sums[omp_get_team_num()], omp_get_thread_num(), N);
}
```

Approved OpenMP 6.1

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Dynamic Groupprivate Clause

- Similar to CUDA / HIP

C++

```
__global__ void func(int *sum, size_t N) {
  __shared__ int tmp[];
  ...
}

func<<<10,256,N*sizeof(double)>>>(sum, N);
```

C++

```
void func(int *sum, int tid, int N) {
  int *tmp = omp_get_dyn_groupprivate_ptr();

  #pragma omp for
  nt i = 0; i < N; i++)
  i] = tid + i;

  a omp for reduction(+: sum)
  nt i = 0; i < N; i++)
  += tmp[i];
}

int main(int argc, char **argv) {
  int N = atoi(argv[1]);
  int sums[10];

  #pragma omp target teams dyn_groupprivate(N*sizeof(int)) \
              num_teams(10) thread_limit(256)
  #pragma omp parallel
  func(&sums[omp_get_team_num()], omp_get_thread_num(), N);
}
```

Approved
OpenMP 6.1

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Dynamic Groupprivate Clause

- The fallback modifier determines what to do when **no enough** groupprivate memory to satisfy the request
  - **Abort** the execution
  - Return **null** when requesting pointer
  - Use memory from a **default memspace** (e.g., global) for each contention group

default_mem if not specified

```
#pragma omp target dyn_groupprivate(fallback(abort): N)
{
}
```

```
#pragma omp target dyn_groupprivate(fallback(null): N)
{
}
```

```
#pragma omp target dyn_groupprivate(fallback(default_mem): N)
{
}
```

```
#pragma omp target dyn_groupprivate(N)
{
}
```

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Dynamic Groupprivate Clause

- Routine to get pointer to the groupprivate buffer

only cgroup supported for now

C++

```
#pragma omp target teams dyn_groupprivate(N)
#pragma omp parallel
{
  double *tmp = omp_get_dyn_groupprivate_ptr();
  tmp[...] = ...;
}
```

C / C++

```
void *omp_get_dyn_groupprivate_ptr(
    size_t offset = 0, int *is_fallback = NULL,
    omp_access_t access_group = omp_access_cgroup);
```

Fortran

```
type (c_ptr) function omp_get_dyn_groupprivate_ptr(&
    offset, is_fallback, access_group)
  use, intrinsic :: iso_c_binding, only : c_ptr, c_size_t
  integer (kind=c_size_t), value, optional :: offset
  logical, intent(out), optional :: is_fallback
  integer (kind=omp_access_kind), value, optional :: access_group
```

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Dynamic Groupprivate Clause

- Routine to get size of the groupprivate buffer

C++

```
#pragma omp target teams dyn_groupprivate(N)
#pragma omp parallel
{
  size_t size = omp_get_dyn_groupprivate_size();
  if (size != 0)
    ...
}
```

C / C++

```
size_t omp_get_dyn_groupprivate_size(
    omp_access_t access_group = omp_access_cgroup);
```

Fortran

```
integer (kind=c_size_t) function omp_get_dyn_groupprivate_size(&
    access_group)
  use, intrinsic :: iso_c_binding, only : c_size_t
  integer (kind=omp_access_kind), value, optional :: access_group
```

Approved OpenMP 6.1

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Multidimensional Grid Programming

- Many accelerated applications follow multidimensional grid programming

CUDA / HIP

```
__global__ kernel(double *matrix, size_t N) {
  int x = blockIdx.x * blockDim.x + threadIdx.x;
  int y = blockIdx.y * blockDim.y + threadIdx.y;
  int z = blockIdx.z * blockDim.z + threadIdx.z;

  if (x < N && y < N && z < N)
    matrix[x + y * N + z * N * N] = ...;
}

dim3 nblocks(N/256,N/256,N/256);
dim3 nthreads(256,256,256);
kernel<<<nblocks,nthreads>>>(matrix, N);
```

Single Program,
Multiple Data (SPMD)

3-D grids and blocks

Under Discussion

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Multidimensional Grid Programming

- Many accelerated applications follow multidimensional grid programming

CUDA / HIP

```
__global__ kernel(double *matrix, size_t N) {
  int x = blockIdx.x * blockDim.x + threadIdx.x;
  int y = blockIdx.y * blockDim.y + threadIdx.y;
  int z = blockIdx.z * blockDim.z + threadIdx.z;

  if (x < N && y < N && z < N)
    matrix[x + y * N + z * N * N] = ...;
}

dim3 nblocks(N/256,N/256,N/256);
dim3 nthreads(256,256,256);
kernel<<<nblocks,nthreads>>>(matrix, N);
```

OpenMP 6.0

```
#pragma omp target teams distribute parallel for \
    num_teams(N*N*N/256) thread_limit(256) collapse(3)
for (int z = 0; z < N; ++z)
  for (int y = 0; y < N; ++y)
    for (int x = 0; x < N; ++x)
      matrix[x + y * N + z * N * N] = ...;
}
```

Under Discussion

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Multidimensional Grid Programming

- Allow **multidimensional** OpenMP teams and leagues

CUDA / HIP

```
__global__ kernel(double *matrix, size_t N) {
  int x = blockIdx.x * blockDim.x + threadIdx.x;
  int y = blockIdx.y * blockDim.y + threadIdx.y;
  int z = blockIdx.z * blockDim.z + threadIdx.z;

  if (x < N && y < N && z < N)
    matrix[x + y * N + z * N * N] = ...;
}

dim3 nblocks(N/256,N/256,N/256);
dim3 nthreads(256,256,256);
kernel<<<nblocks,nthreads>>>(matrix, N);
```

Future OpenMP

```
#pragma omp target teams num_teams(dims(3): N/256,N/256,N/256) \
    thread_limit(dims(3): 256,256,256)
#pragma omp parallel
{
  int x = omp_get_team_num_dim(1) * omp_get_num_teams_dim(1)
      + omp_get_thread_num_dim(1);
  int y = omp_get_team_num_dim(2) * omp_get_num_teams_dim(2)
      + omp_get_thread_num_dim(2);
  int z = omp_get_team_num_dim(3) * omp_get_num_teams_dim(3)
      + omp_get_thread_num_dim(3);

  matrix[x + y * N + z * N * N] = ...;
}
```

Under Discussion

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Multidimensional Grid Programming

Future OpenMP Grid Programming

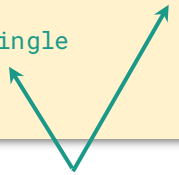
```
#pragma omp target teams num_teams(dims(3): N/256,N/256,N/256) \
    thread_limit(dims(3): 256,256,256)
#pragma omp parallel
{
  int x = omp_get_team_num_dim(1) * omp_get_num_teams_dim(1)
      + omp_get_thread_num_dim(1);
  int y = omp_get_team_num_dim(2) * omp_get_num_teams_dim(2)
      + omp_get_thread_num_dim(2);
  int z = omp_get_team_num_dim(3) * omp_get_num_teams_dim(3)
      + omp_get_thread_num_dim(3);

  matrix[x + y * N + z * N * N] = ...;
}
```

Compatibility with **unidimensional** world

```
#pragma omp target teams num_teams(dims(3): N/256,N/256,N/256) \
    thread_limit(dims(3): 256,256,256)
#pragma omp parallel
{
  int team = omp_get_team_num();
  int thread = omp_get_thread_num();
  int nthreads = omp_get_num_threads();

  #pragma omp single
  { ... }
}
```



Automatic **flattening** of identifiers/sizes in constructs/routines that are not designed for the multidimensional space (or not supported yet)

Under Discussion

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Reducing Device Runtime Overhead

- The OpenMP **device runtime** can be a source of **overhead** in target regions
  - State of internal control variables (ICV)
  - Other runtime state not related to ICV

- Where does the overhead come from?
  - **Extra kernel code** due to the runtime code
  - Necessary **runtime state**, even if it may not be actually used
  - May **prevent optimizations** of the user kernel code

- Native APIs have **minimal** to none device runtime overhead

Under Discussion

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Reducing Device Runtime Overhead

- OpenMP is considering **opt-in** methods to **minimize** device overhead
  - Disallow constructs/routines that use ICV (too restrictive)
  - Allow ICV within target regions as immutable
  - Allow ICV within target regions as **immutable**, and the **compiler** can decide/compute their values

- For instance, a new clause in the target construct

Under Discussion

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Outline

- Accelerating with OpenMP
- Static Shared Memory
- Dynamic Shared Memory
- Multidimensional Grid Programming
- Reducing Device Runtime Overhead
- **Conclusions**

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Conclusions

- **Available** and **upcoming** features for accelerating code
  - groupprivate directive in OpenMP 6.0
  - dyn_groupprivate clause approved for OpenMP 6.1
  - Multidimensional teams and leagues under discussion
  - Reducing target runtime overhead under discussion

- Why?
  - **Closing** the **performance gap** with native models
  - **Porting** accelerated applications becomes **simpler**
  - Using **low-level features** but still on a widely-supported standard

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