OpenMP Target Offloading for AMD GPUs

Jan-Patrick Lehr, AMD
OpenMP® Target Offloading for AMD GPUs

AMD ROCm OpenMP Team
Relative Bandwidth Increase GPU vs CPU
Agenda

1. Overview of the ROCm™ software stack
2. OpenMP target offload
3. OpenMP® target offload example
4. OpenMP® target offload example w/ unified shared memory
5. Data environments, zero copy, and unified memory
ROCm™ integrates components for HPC and AI workloads

OpenMP®-based GPU offloading is an integral part of ROCm™ releases

OpenMP®-based GPU offloading provides standardized, portable access to GPU compute

AMD is invested in open source and open technology
ROCM™ Software Stack (Meta Packages)
OpenMP® Target Offload
OpenMP® Target Offload

- OpenMP® language-feature to use an accelerator (e.g., a GPU) for parts of your program
- Enables standardized way for offloading to an accelerator as opposed to CUDA® or HIP
- Expressed in terms of target regions
- Target regions have a data environment that is maintained/manipulated via map clauses
- Target regions execute one or multiple teams of threads on a device
- And much more …
OpenMP® Target Offload Code Example

```c
int main(int argc, char **argv) {
    int *vals = new int[1024];

    #pragma omp target teams distribute parallel for map(vals[0:1024])
    for(int i = 0; i < 1024; ++i) {
        vals[i] = 1;
    }

    for(const auto vi : vals) {
        std::cout << vi << '\n';
    }
    return 0;
}
```
OpenMP® Target Offload Code Example

```c
int main(int argc, char **argv) {
    int *vals = new int[1024];

    #pragma omp target teams distribute parallel for map(tofrom: vals[0:1024])
    for(int i = 0; i < 1024; ++i) {
        vals[i] = 1;
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    for(const auto vi : vals) {
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    for(const auto vi : vals) {
        std::cout << vi << '\n';
    }

    return 0;
}
```
Data Environments and Memory Transfer

```c++
int main(int argc, char **argv) {
    int *vals = new int[1024];

    #pragma omp target teams distribute parallel for map(vals[0:1024])
    for(int i = 0; i < 1024; ++i) {
        vals[i] = 1;
    }

    for(const auto vi : vals) {
        std::cout << vi << '
';
    }

    return 0;
}
```
OpenMP® Target Offload on Discrete GPUs (Default Mode)

int main()
{
    int *vals = new int[1024];

    #pragma omp target map(tofrom: vals[0:1024])
    {
        for(int i = 0; i < 1024; i++)
            vals[i] = i;
    }
}

For best performance, programmers minimize transfers between host and device by placing map clauses at the beginning and ending of an application.
Unified Shared Memory (USM)

**CPU CODE**

```c
double* in = (double*)malloc(Msize);
double* out = (double*)malloc(Msize);

for (int i=0; i<M; i++)
    in[i] = ...;

for (int i=0; i<M; i++)
    out[i] = ... in[i] ...;

... = out[i];
```

**W/O UNIFIED SHARED MEMORY**

```c
double* in = (double*)malloc(Msize);
double* out = (double*)malloc(Msize);

for (int i=0; i<M; i++)
    in[i] = ...;

#pragma omp target teams distribute
    parallel for 
    map(to:in[0:Msize]) 
    map(from:out[0:Msize])

for (int i=0; i<M; i++)
    out[i] = ... in[i] ...;

... = out[i];
```

**UNIFIED SHARED MEMORY**

```c
#pragma omp require unified_shared_memory

double* in = (double*)malloc(Msize);
double* out = (double*)malloc(Msize);

for (int i=0; i<M; i++)
    in[i] = ...; //writes GPU mem directly

#pragma omp target teams distribute
    parallel for

for (int i=0; i<M; i++)
    out[i] = ... in[i] ...;

... = out[i]; //reads GPU mem directly
```
OpenMP® Target Offload on Discrete GPUs (USM Mode)

```c
#pragma omp requires unified_shared_memory
int main() {
    int *vals = new int[1024];
    #pragma omp target map(tofrom: vals[0:1024])
    {
        for(int i = 0; i < 1024; i++)
            vals[i] = i;
    }
}
```

Driver handles page migrations. Migration depends on allocator being used on host.

OS allocators allocate host memory

map: just pass host pointer to kernel

Accessing a page address located on system memory provokes page migration to HBM
Zero Copy Benefits on Unified Memory Architecture

No need to explicitly transfer data to the GPU and back

Single memory shared between host and GPU

Transparencyly enabled in the runtime: No special flags needed
Data Environments and Zero Copy

```c
int main(int argc, char **argv) {
    int *vals = new int[1024];

    #pragma omp target teams distribute parallel for map(vals[0:1024])
    for(int i = 0; i < 1024; ++i) {
        vals[i] = 1;
    }

    for(const auto vi : vals) {
        std::cout << vi << ‘\n’;
    }
    return 0;
}
```
OpenMP® on APUs (MI300A): Zero-Copy Mode

```c
int main() {
    int *vals = new int[1024];
    #pragma omp target map(
        tofrom: vals[0:1024])
    {
        for(int i = 0; i < 1024; i++)
            vals[i] = i;
    }
}
```

* Interleaved allocation across the HBMs on the socket

OS allocators allocate unified memory

map: just pass pointer to kernel

No page migration necessary upon page touch (in this single socket example)
# ROCm™ Compiler Behavior (MI300A)

<table>
<thead>
<tr>
<th>Compiler Flag:</th>
<th>Programming Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>--offload-arch=gfx942</td>
<td>Default (non-unified_shared_memory)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Runtime State</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Unified-Memory-Enabled</td>
<td>Zero-copy</td>
<td>Zero-copy</td>
</tr>
<tr>
<td>Unified-Memory-Disabled</td>
<td>Copy</td>
<td>RT Error</td>
</tr>
</tbody>
</table>

* One of the options:
  - `#pragma omp requires unified_shared_memory`
  - `-fopenmp-force-usm (preview for future ROCm™ release)`
Details of AMD Zero Copy vs. OpenMP® Unified Shared Memory

- Zero Copy is a ROCm™ OpenMP® offloading-runtime feature
- Enables execution of OpenMP® programs without explicit data copies*
- Code generation is unaffected
  - OpenMP® program uses explicit map clauses
- Requires hardware/driver support and may not work across all existing devices
- Enabled via environment variable on supported devices

- Unified Shared Memory is a concept in the OpenMP® standard
- Eliminates the need for data environments via explicit map clauses
- Unified Shared Memory implies code generation that assumes host memory can be accessed
- Requires hardware/driver support and may not work across all existing devices
- Enabled via
  - #pragma omp requires unified_shared_memory
  - -fopenmp-force-usm (future ROCm™ release)

*Except for a specific case of global variables
Learn more

- Programming AMD GPUs with OpenMP®
  - Nov. 15 / 2pm @ AMD booth

- Specialized Kernels for Optimizing GPU Offload in OpenMP
  - Workshop on Accelerator Programming and Directives

[QR Code to ROCm™ Website]
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