Taking Memory Management to the Next Level: Unified Shared Memory in Action

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Agenda

- Let’s look at Shared Virtual Memory
- Introducing Unified Shared Memory
- Unified Shared Memory in DPC++
- Future Plans and Call To Action
Let's look at Shared Virtual Memory (SVM)!
SVM allocations and devices with local memory

**Good:**
- Direct access to System Memory

**Bad:**
- Low Bandwidth due to PCI access
SVM allocations and devices with local memory

**Good:**
- Fast access to local memory

**Bad:**
- Requires transfer to system when host wants to use memory
**clSvmAlloc and devices with local memory**

```c
void * clSVMAlloc (cl_context context,
                   cl_svm_mem_flags flags,
                   size_t size,
                   cl_uint alignment)
```

**Problem (1) – Memory placement**

- Where to place memory?
  - Host?
    - What if host never access?
  - Device?
    - What if caller wants host based allocation?
Problem (2) – Multi device memory placement

- Where to place memory?
  - First Device Used?
  - All devices?
  - System memory?
  - Automatic migration?
  - How to synchronize contents with multi local memory placements?

Driver heuristics are bad!
## OpenCL 2.0 SVM: Programmer Convenience

(NOT Performance!)

<table>
<thead>
<tr>
<th></th>
<th>Coarse Grain</th>
<th>Fine Grain</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Buffer</strong></td>
<td><code>clSVMAlloc/Free, Pointer Representation, Address Equivalence, Specify All Allocations, No Concurrent Access, Map/Unmap</code></td>
<td><code>clSVMAlloc/Free, Pointer Representation, Address Equivalence, Specify All Allocations, Concurrent Access (Fine Grain) No Map/Unmap</code></td>
</tr>
<tr>
<td><strong>System</strong></td>
<td>(N/A) Most Implementations Are Here 😊</td>
<td><code>malloc/free, Pointer Representation, Address Equivalence, Access Any Allocation, Concurrent Access (Fine Grain) No Map/Unmap</code></td>
</tr>
</tbody>
</table>
Introducing Unified Shared Memory (USM)
Introducing 3 new memory types

- System Memory
  - SHARED
  - HOST

- DEVICE
  - HOST
  - SHARED

- GPU
  - Local Memory
    - SHARED
  - DEVICE
Device Allocations: Performance

- No Host access
- No migration
- Available only in one device
- No Map/Unmap
- Best Performance possible
- Pointer representation

```c
void* clDeviceMemAllocINTEL(
    cl_context context,
    cl_device_id device,
    const cl_mem_properties_intel* properties,
    size_t size,
    cl_uint alignment,
    cl_int* errcode_ret);
```
Host Allocations: Zero Copy Sharing (no Migration)

- Accessible by the Host
- Placed in Host memory, doesn’t migrate to local memory
- Accessible by all devices in the context
- No Map/Unmap
- Useful as input / output buffers, Pinned Memory or Staging Allocation
- Possible oversubscription
- Pointer representation
- Address equivalence

```c
void* clHostMemAllocINTEL(
    cl_context context,
    const cl_mem_properties_intel* properties,
    size_t size,
    cl_uint alignment,
    cl_int* errcode_ret);
```
Host Allocation: Direct GPU access to System Memory

Diagram showing the allocation of CPU, PCI, GPU, and System Memory with direct GPU access.
Shared Allocations: Programmer Convenience

- Shared Host-Device Ownership
- No Map/Unmap
- Automatic Migration Between Host and Device
- Accessible by all devices in context, passed device show optional initial placement
- Trades control for convenience
- Pointer representation
- Address equivalence

```c
void* clSharedMemAllocINTEL(
    cl_context context,
    cl_device_id device,
    const cl_mem_properties_intel* properties,
    size_t size,
    cl_uint alignment,
    cl_int* errcode_ret);
```
Shared allocation – automatic migration to GPU
Shared allocation – automatic migration to CPU
Freeing the memory

- Blocking version introduced for convenience,
  - Waits for completion of all associated submissions
  - Useful when application do not want to track what is used where
- Non-Blocking version requires synchronization from application

```c
cl_int clMemFreeINTEL(
    cl_context context,
    void* ptr);

cl_int clMemBlockingFreeINTEL(
    cl_context context,
    void* ptr);
```
Indirect Access

- Automatic specification of indirect usage per kernel
- No need to track all allocation and pass them
- Saves CPU clocks (no need to validate input)
- Each memory type has its own toggle

```c
// not shown, heavy logic to track all 10k pointers

clSetKernelExecInfo(
    kernel,
    CL_KERNEL_EXEC_INFO_SVM_PTRS,
    SvmPtrListSizeInBytes, // size of 10k pointers here
    pSvmPtrList);           // 10k pointers here

// just turn ON indirect access, no need to track anything
auto enableIndirectSharedAccess = CL_TRUE;
clSetKernelExecInfo(
    kernel,
    CL_KERNEL_EXEC_INFO_INDIRECT_SHARED_ACCESS_INTEL,
    sizeof(cl_bool),
    &enableIndirectSharedAccess);
```
Retrieving information from USM pointers

- Currently supported properties:
  - Allocation type
  - Base pointer
  - Allocation size
  - Associated device
  - Allocation flags
- Allows easy pointer integration to existing code bases

```c
cl_int clGetMemAllocInfoINTEL(
    cl_context context,
    const void* ptr,
    cl_mem_info_intel param_name,
    size_t param_value_size,
    void* param_value,
    size_t* param_value_size_ret);
```
Unified Shared Memory in DPC++
Unified Shared Memory in DPC++

USM is supported as a SYCL extension in the DPC++ compiler:

DPC++ = C++ and SYCL and **Extensions**

USM provides a pointer-based alternative to SYCL buffers:

- Simpler and more concise code for common patterns
- Easier integration into C++ code bases
- Greater control over memory ownership and accessibility
USM Code Walk-Through

// setup
ordered_queue q{ platform::get_platforms()[pi].get_devices()[di] };  

auto d = q.get_device();
auto c = q.get_context();

auto s_src = (uint32_t*)malloc_shared(gwx * sizeof(uint32_t), d, c);
auto s_dst = (uint32_t*)malloc_shared(gwx * sizeof(uint32_t), d, c);

USM allocations are made against a SYCL context
- Shared and Device USM allocations may also have an associated SYCL device

USM supports three forms of allocation
- malloc-like (this example), templated malloc, std::allocator-like
USM Code Walk-Through

// initialize memory
for( size_t i = 0; i < gwx; i++ )
    s_src[i] = (uint32_t)i;
memset(s_dst, 0, gwx * sizeof(uint32_t));

For Shared and Host USM allocations: simply access on the host!
- No need for mapping, unmapping, or accessors

For Device USM allocations: must copy to host-accessible allocations
Kernel lambda can capture and use USM pointers directly!
- No need for accessors!

New mechanisms to express dependencies between queue operations:
- `depends_on`: define explicit dependencies between queue operations
- `ordered_queue` type (this example): implicit in-order execution
Checking results and freeing allocations is straightforward

- Free function requires the same SYCL context used for allocation
// setup
ordered_queue q{ platform::get_platforms()[pi].get_devices()[di] };  
auto c = q.get_context();
auto d = q.get_device();
auto s_src = (uint32_t*)malloc_shared(gwx * sizeof(uint32_t), d, c);
auto s_dst = (uint32_t*)malloc_shared(gwx * sizeof(uint32_t), d, c);

// initialize memory
for( size_t i = 0; i < gwx; i++ )
    s_src[i] = (uint32_t)i;
memset(s_dst, 0, gwx * sizeof(uint32_t));

// execute a kernel to copy buffers
q.parallel_for(range<1>{gwx}, [=](id<1> id) {
    s_dst[id] = s_src[id];
});
q.wait();

// check results
if( memcmp(s_dst, s_src, gwx * sizeof(uint32_t)) )
    std::cerr << "Error: Found mismatches!\n";
else
    std::cout << "Success.\n";

// clean up
free(s_src, c);
free(s_dst, c);
Future Plans and Call to Action
Future Plans and Call to Action

We recommend including Unified Shared Memory in future standards:

- For both OpenCL and SYCL
- We will continue to develop USM in DPC++

Try USM!

- Your feedback is valuable before standardization!
- If you find USM useful, encourage other implementations to support USM!

Thank you!
Useful Links:

USM Specifications:

USM Implementations:
- https://github.com/intel/compute-runtime

USM Samples:
- https://github.com/intel/compute-samples
- https://github.com/bashbaug/SimpleOpenCLSamples/tree/master/samples/usm
- https://github.com/bashbaug/simple-sycl-samples/tree/master/samples/dpcpp/usm