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

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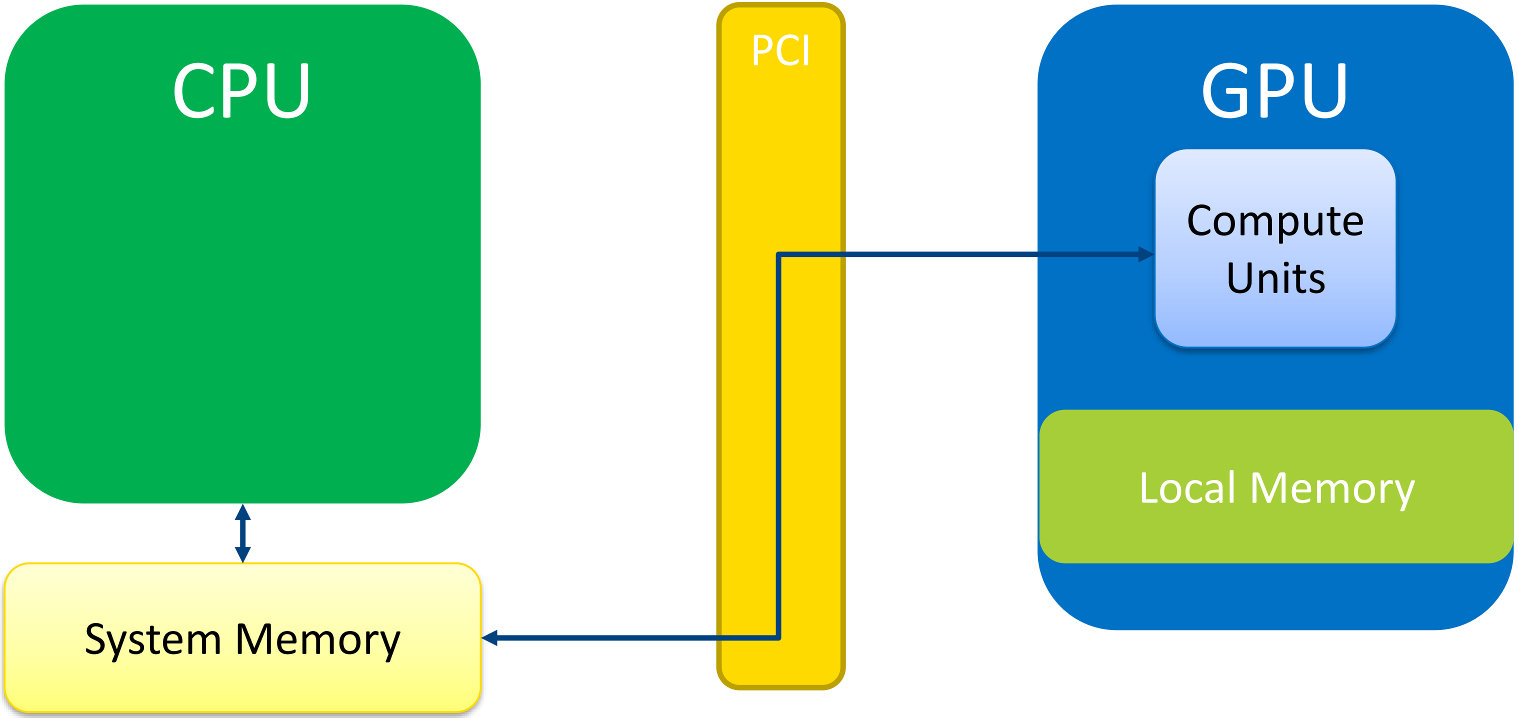
Agenda

- 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



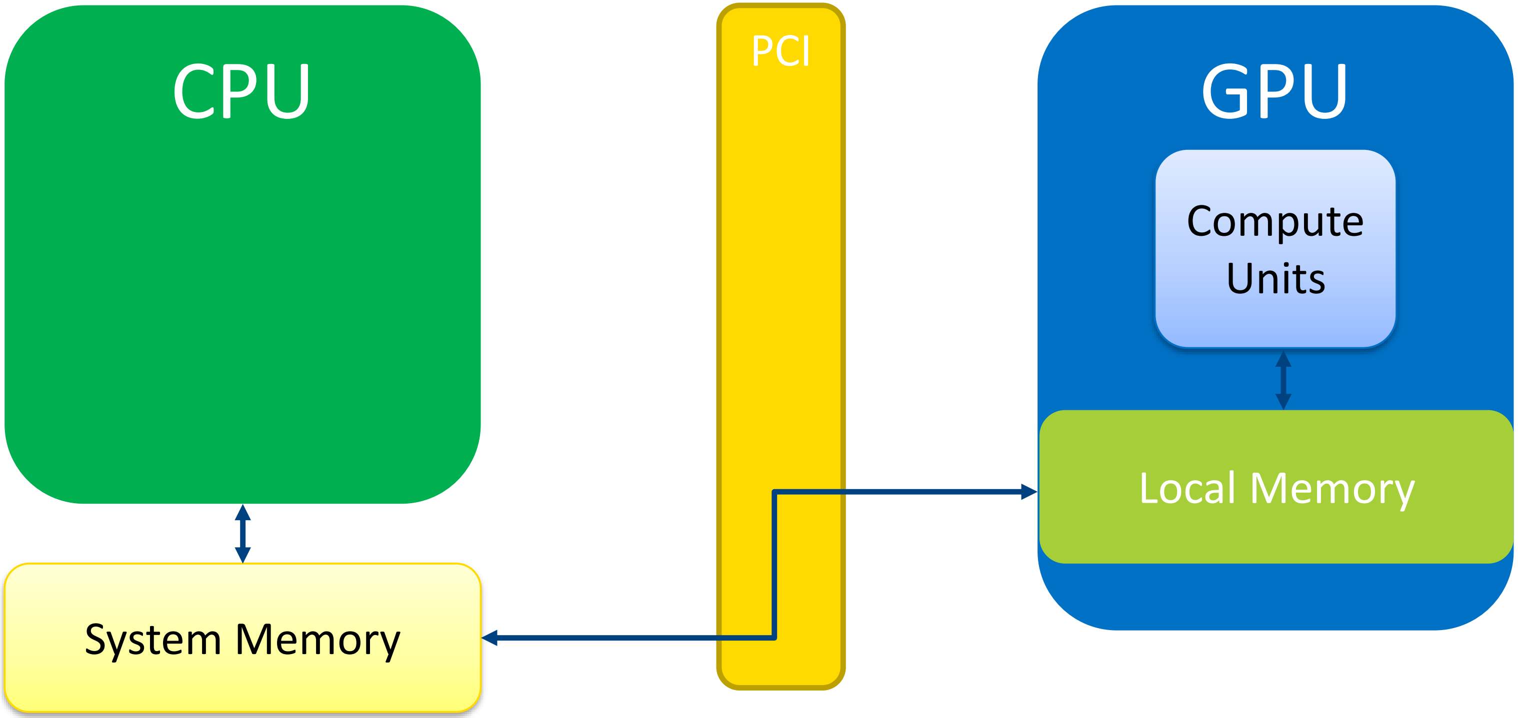
Good:

- Direct access to System Memory

Bad:

- Low Bandwidth due to PCI access

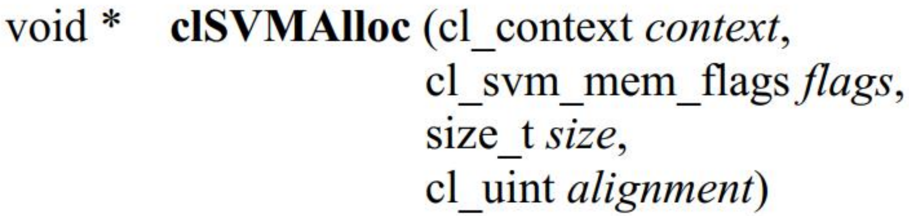
SVM allocations and devices with local memory



Good:
- Fast access to local memory

Bad:
- Requires transfer to system when host wants to use memory

clSvmAlloc and devices with local memory

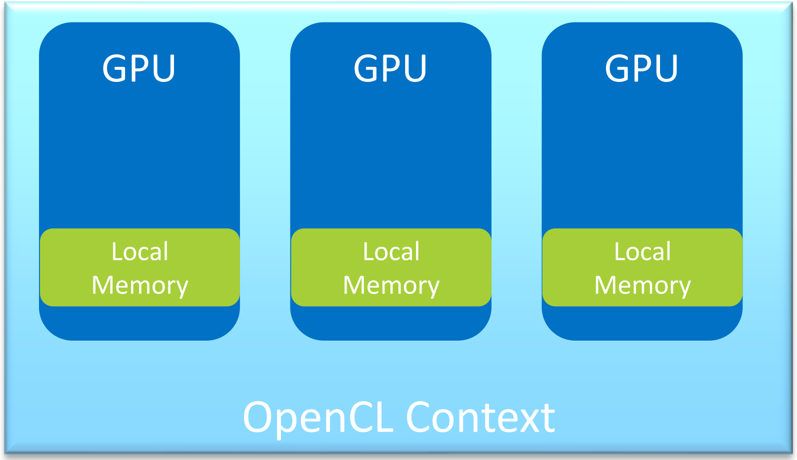


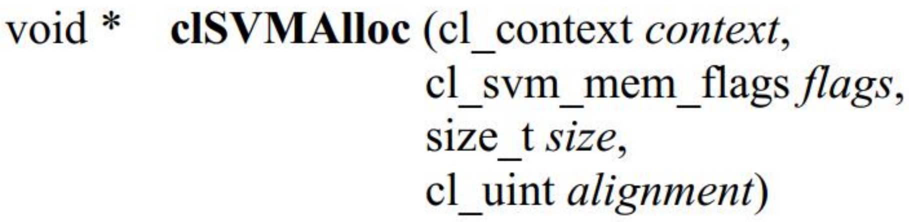
```
void *    clSVMAlloc (cl_context context,
                      cl_svm_mem_flags flags,
                      size_t size,
                      cl_uint alignment)
```

Problem (1) – Memory placement

- Where to place memory ?
  - Host ?
    - What if host never access?
  - Device ?
    - What if caller wants host based allocation?

SVM and multiple devices





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

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!

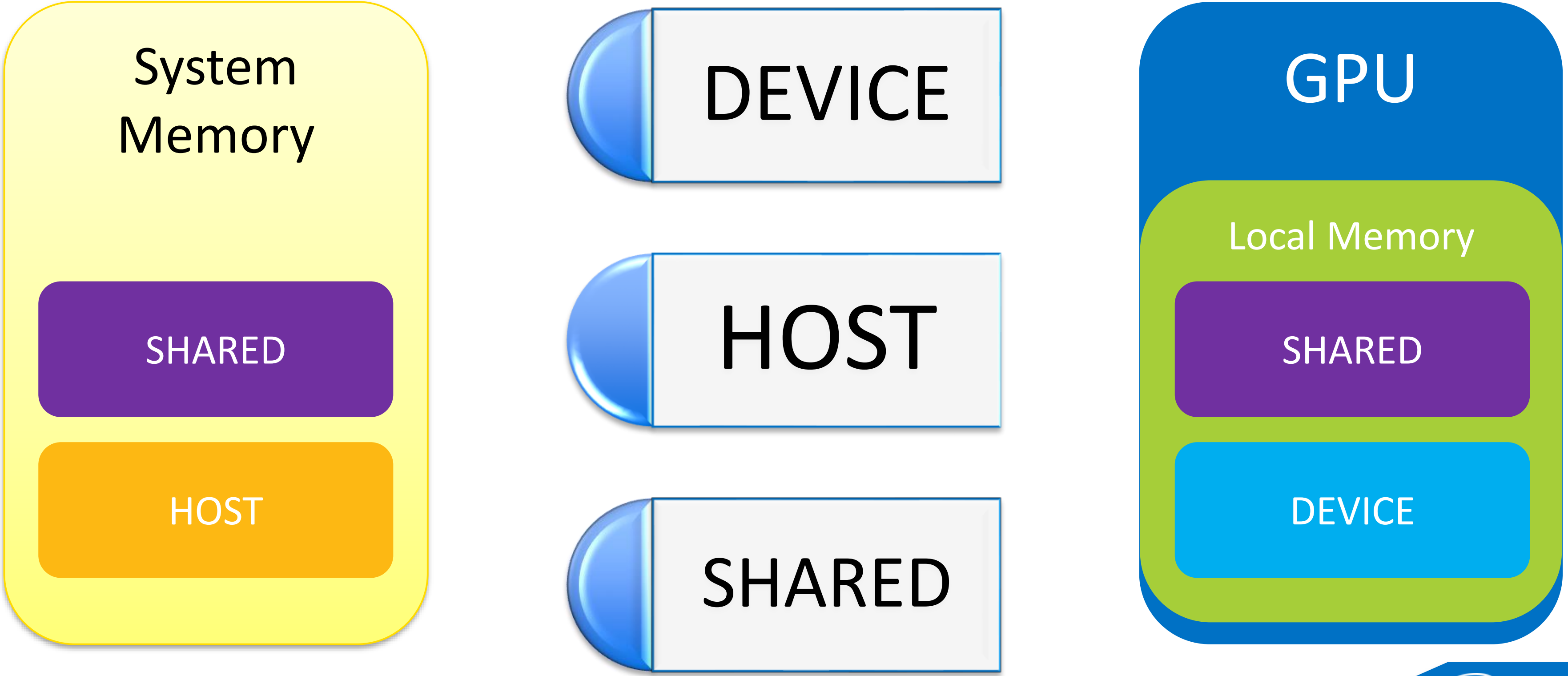
OpenCL 2.0 SVM: Programmer Convenience

(NOT Performance!)

	Coarse Grain	Fine Grain
Buffer	clSVMAlloc/Free, Pointer Representation, Good! Address Equivalence, Specify All Allocations, No Concurrent Access, Map/Unmap	clSVMAlloc/Free, Pointer Representation, Good! Address Equivalence, Specify All Allocations, Concurrent Access (Fine Grain) No Map/Unmap Good!
System	(N/A) Most Implementations Are Here ☹	malloc/free, Good! Pointer Representation, Good! Address Equivalence, Access Any Allocation, Good! Concurrent Access (Fine Grain) No Map/Unmap Good!

Introducing Unified Shared Memory (USM)

Introducing 3 new memory types



System Memory

SHARED

HOST

DEVICE

HOST

SHARED

GPU

Local Memory

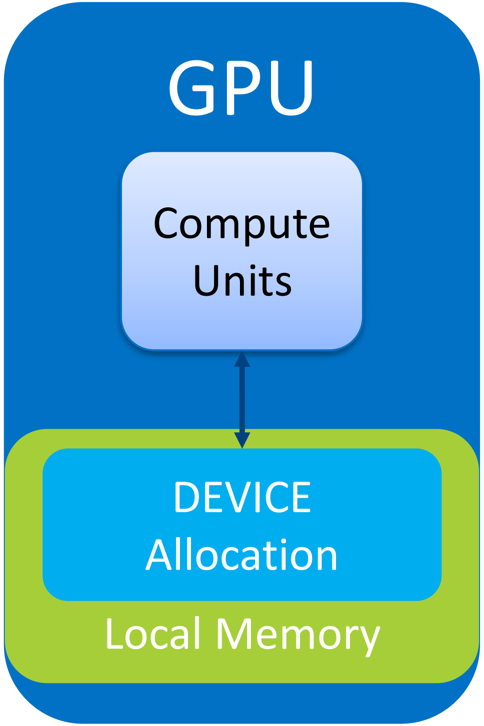
SHARED

DEVICE

Device Allocations: Performance

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

```
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);
```

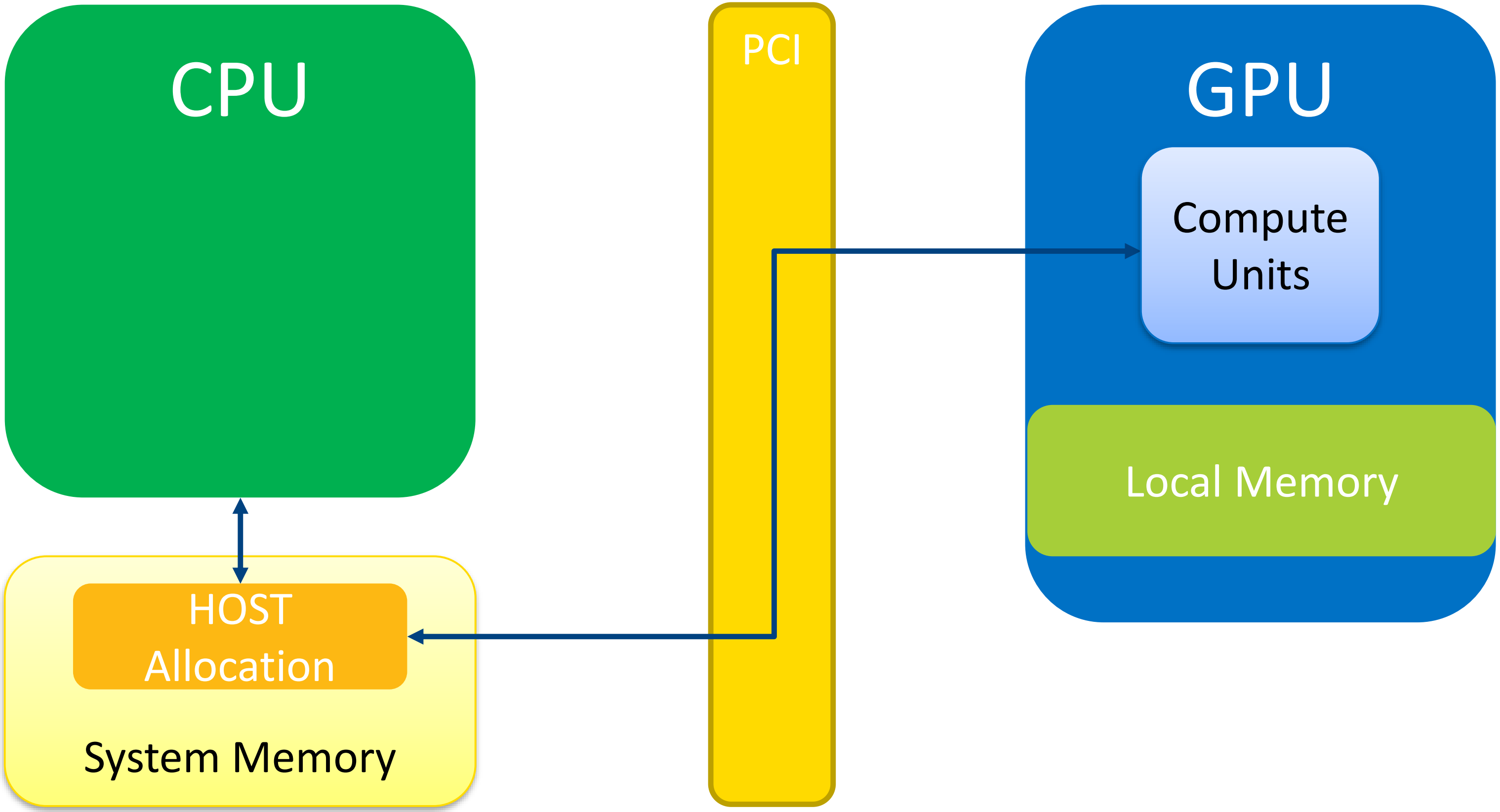


Host Allocations: Zero Copy Sharing (no Migration)

- 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

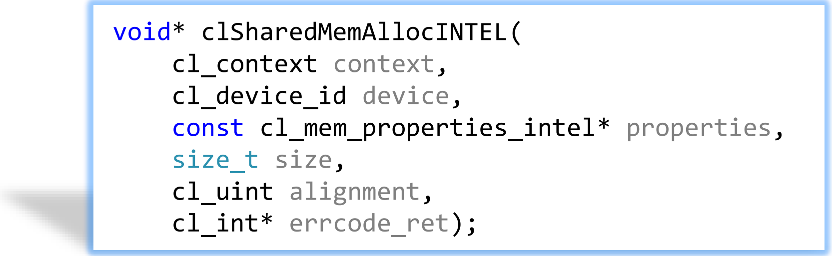
```
void* clHostMemAllocINTEL(
    cl_context context,
    const cl_mem_properties_intel* properties,
    size_t size,
    cl_uint alignment,
    cl_int* errcode_ret);
```

Host Allocation: Direct GPU access to System Memory



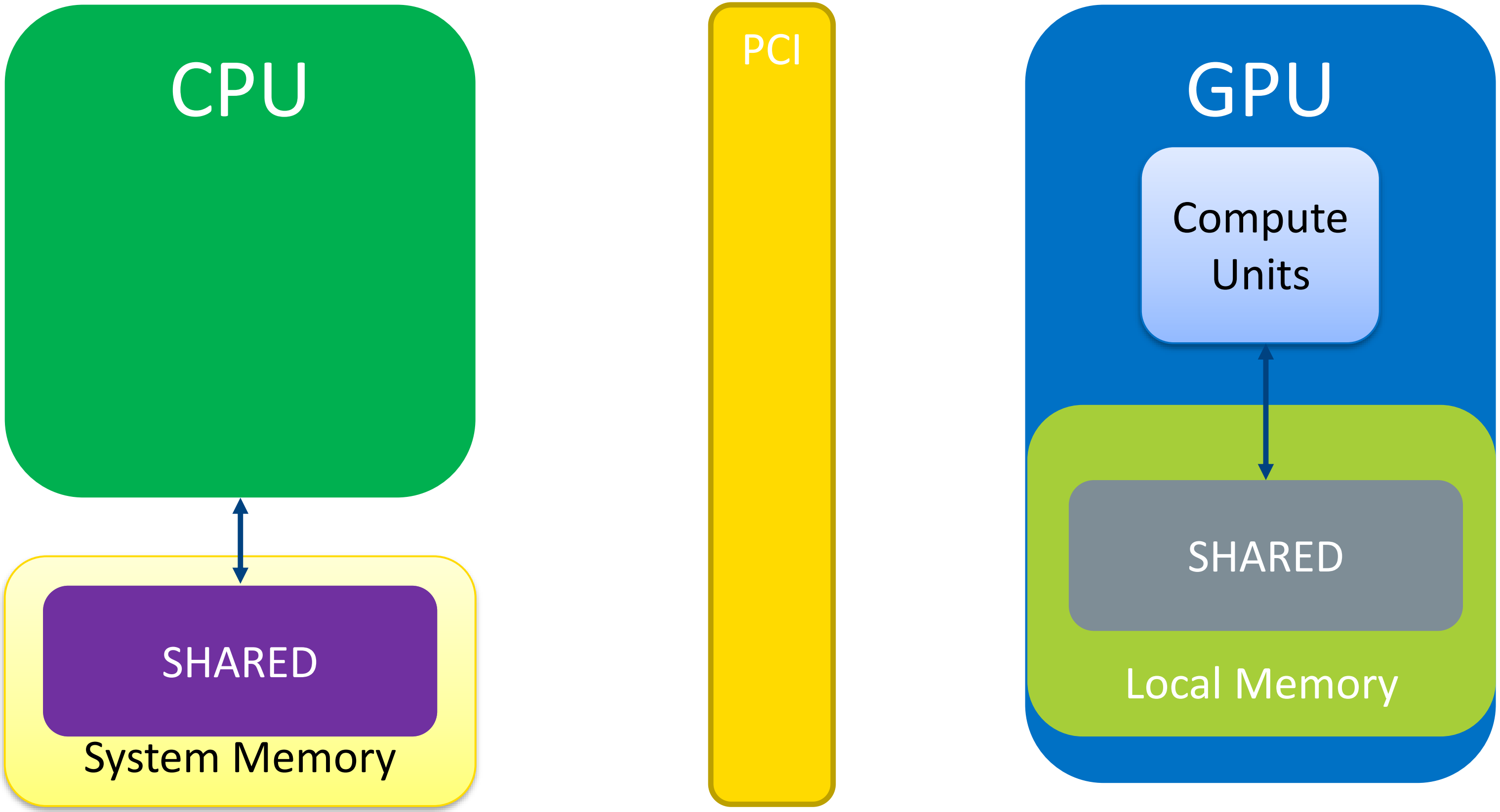
Shared Allocations: Programmer **Convenience**

- 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

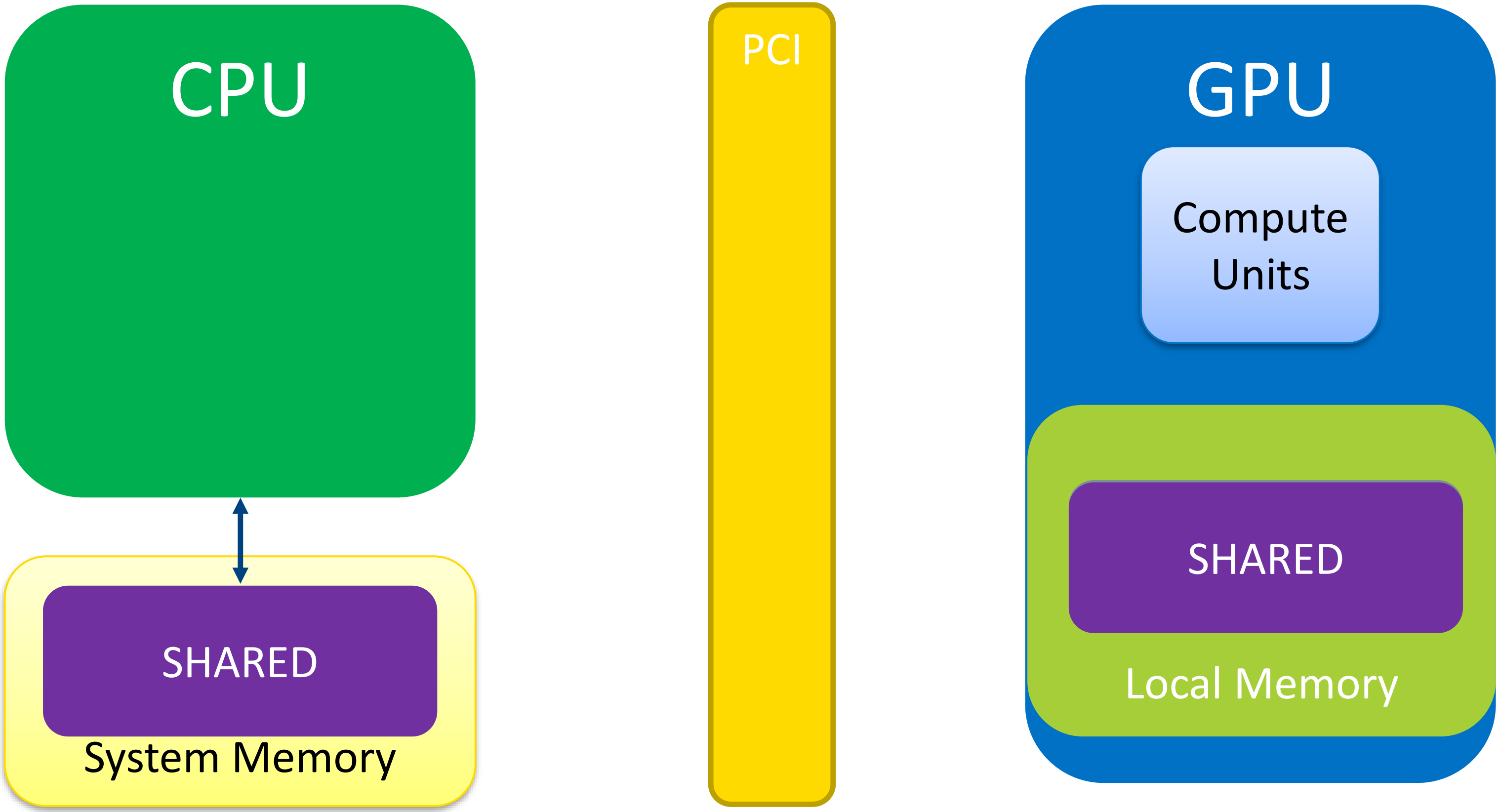


```
void* clSharedMemAllocINTEL(
    cl_context context,
    cl_device_id device,
    const cl_mem_properties_intel* properties,
    size_t size,
    cl_uint alignment,
    cl_int* errcode_ret);
```

Shared allocation – automatic migration to GPU



Shared allocation – automatic migration to CPU



Freeing the memory

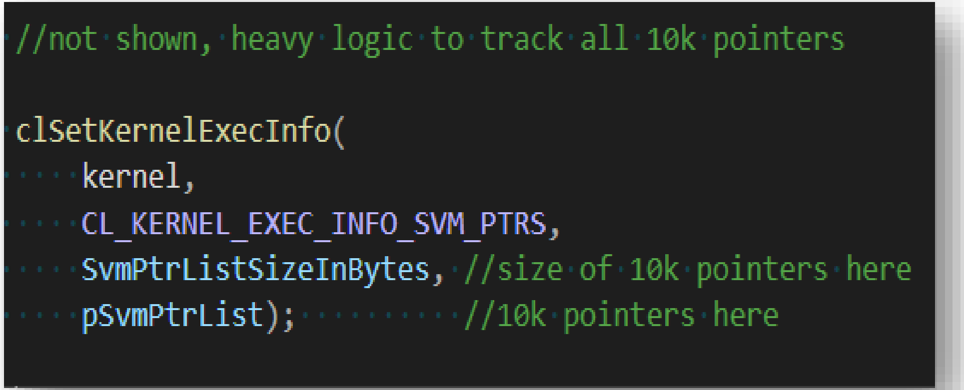
- Blocking version introduced for convenience,
    - Waits for completion of all associated submissions
    - Useful when application do not want to track what is used where
- Non-Blocking version requires synchronization from application

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

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

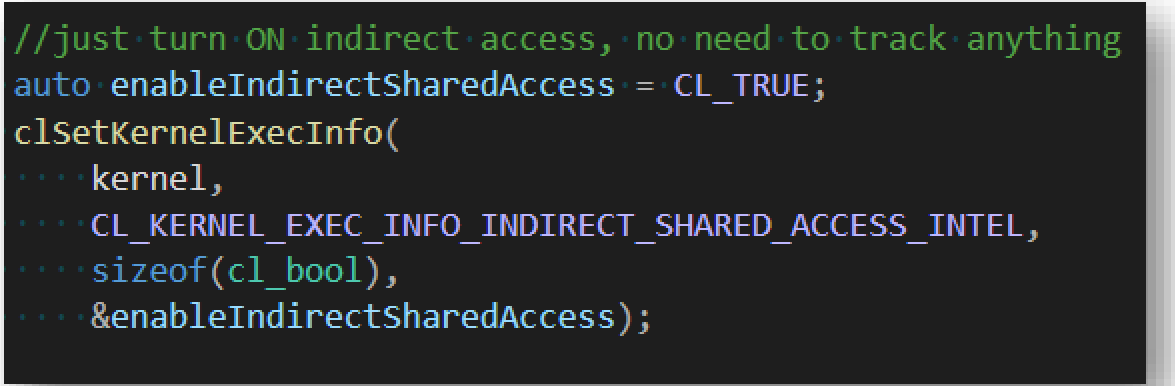
Indirect Access

- 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



```
//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

```
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

USM Code Walk-Through

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

q.wait();
```

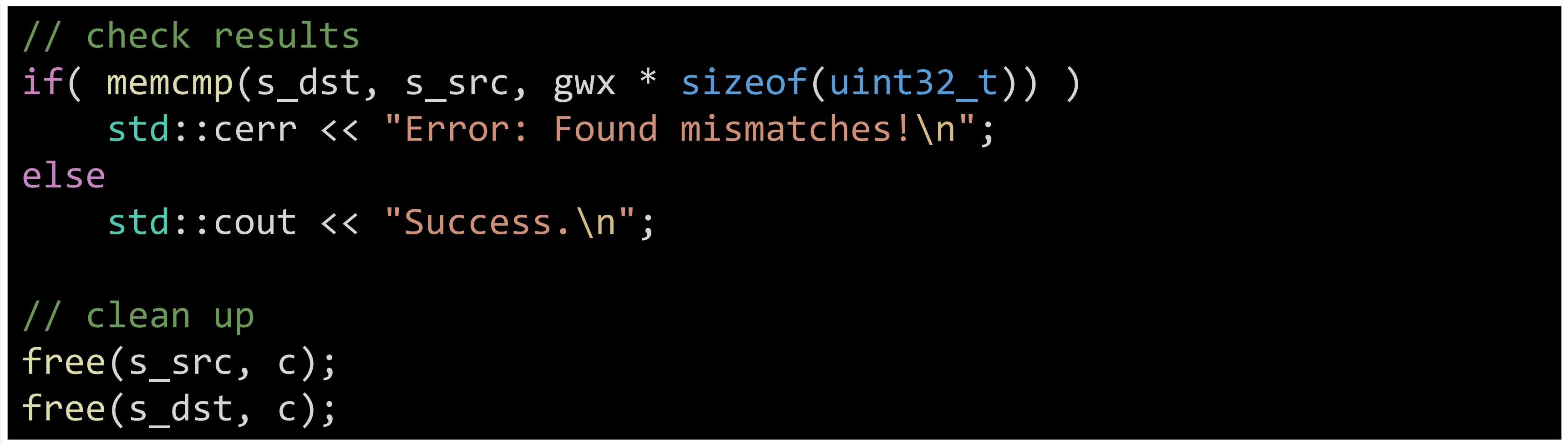
Kernel lambda can capture and use USM pointers directly!

- 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

USM Code Walk-Through



```
// 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);
```

Checking results and freeing allocations is straightforward

- Free function requires the same SYCL context used for allocation

Complete Example

```
// 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:

- https://github.com/intel/llvm/blob/sycl/sycl/doc/extensions/USM/USM.adoc
- https://github.com/intel/llvm/blob/sycl/sycl/doc/extensions/USM/cl_intel_unified_shared_memory.asciidoc

USM Implementations:

- https://software.intel.com/en-us/oneapi/base-kit
- 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