HIHAT MEMORY MANAGEMENT

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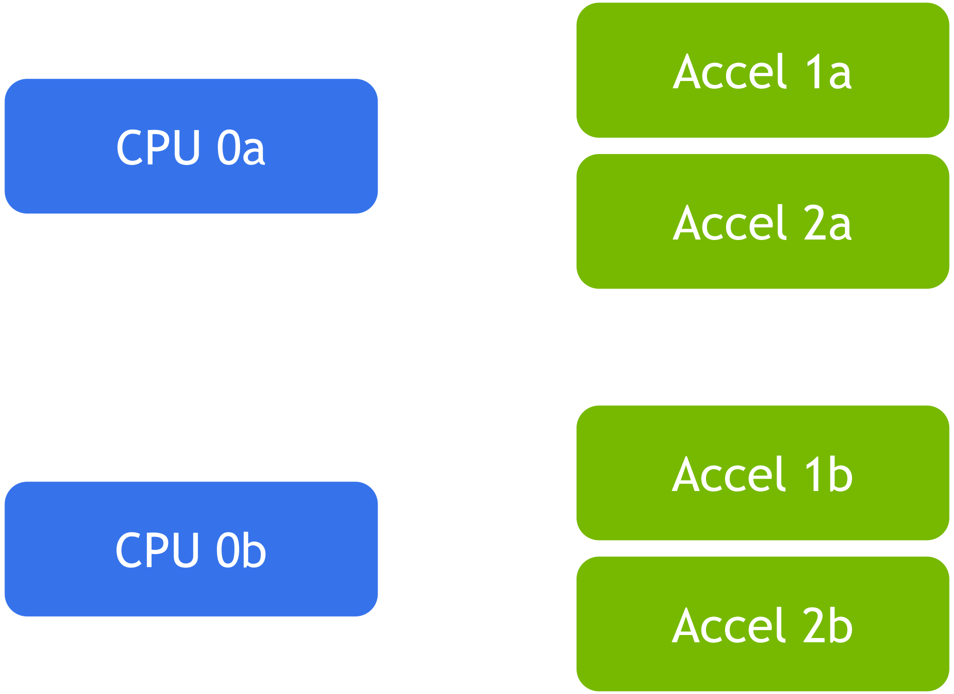
OUTLINE

- Purpose: inform and review

- Context
- Agents and targets
- Selection
- Access enumeration
- Registration
- Requirements

ALLOCATION CONTEXT

Agents do the allocating on targets



- Allocation agents
  - {CPU, Accel 1, Accel 2}
- Allocation targets
  - {CPU, Accel 1, Accel 2}

ALLOCATION: AGENTS AND TARGETS

Requirements, enhancements

- Allocation agent
  - Execution resource where code does the allocating
  - Named since it may not be the local source thread
  - Could be a specific resource or any one of a set of resources
- Allocation target
  - Memory resource to be allocated from
  - Supports a set of possible target resources
  - Ex: managed memory allows migration between {CPU, accel 1, accel 2}
- Resources could be all or part of a physical resource
  - Use something like bitsets to specify the subset [feedback]

ALLOCATION: SELECTION

Requirements, enhancements

- Memory may have several {kinds, locations, depths}
  - Each instance is its own resource handle
- There may be several kinds of allocators for the same resource
  - {shared or unique per memory resource}
  - {shared or unique per execution resource}
  - {any size or specific size}
  - {ability to support traits} (see below)
- Select of allocator
  - By computational and memory resource
  - By chooser, which is part of ExecPol (execution policy) parameter for all actions

ALLOCATOR REGISTRATION, INVOCATION

Requirements, initial implementation

- Review of how registration works
  - User or config files register implementations of all HiHAT-prescribed functionality
  - Actions query what's registered based on resource spec and policy, invoke it
- Registration and allocator querying share the same mapping
  - Based on compute resource agent(s), memory resource target(s), policy/selector
  - Each of these is registered to obtain an index, for a set or single entry
  - Possible implementation: 2D array [compute agent ID][memory target ID] of alloc funcs
  - If the same implementation is registered with ID values for however it's to be referenced (the whole set, relevant subsets, for each individual resource), then the speed-critical lookup is fast and direct. Trade off reference complexity for speed [feedback].

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ABOVE AND BELOW

- For a given set of execution and memory resources, may be several implementations
  - Can take the first, or pick a particular one using a selector
- The client/user of HiHAT sees both above and below the HiHAT dispatch layer
  - It registered the implementations, and can know what “#99” is capable of
  - It may select the implementation upon allocation, e.g. “#99”
  - Therefore it can understand semantics not explicitly exposed to HiHAT
  - HiHAT needn’t use traits/other capabilities as part of its lookup → simpler, faster
- This makes the client/user responsible for selecting a sufficient implementation

TRAITS

Some DataView properties are captured as Traits in its metadata

- A subset of traits require allocator implementation support
  - Pinned, cleared, materialized, affinitized – allocator implementation has to take action
- Traits are named with enumerated values, expressed as a bitset
- Allocator disclosed their subset of supported traits as implementation is registered
- Requested traits are expressed in alloc call
  - If debugging is enabled, that request can be checked against capability

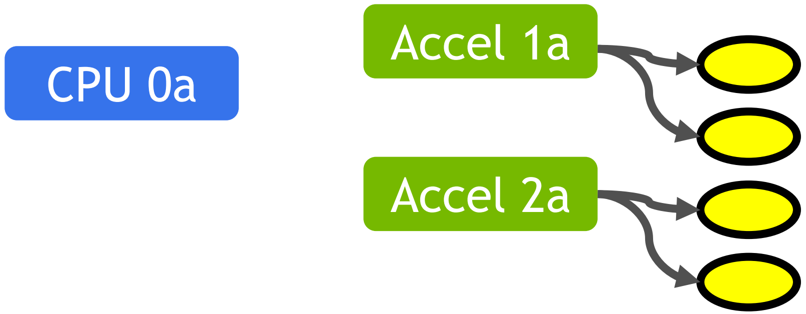
TYPES

- The content stored for a DataView is described in two ways
  - Data layout – structure, dimensions, extent, stride, block size
    - Includes how to access elements within a data collection
  - Element types – format, how to interpret the values
- Usage of types
  - Specified at allocation, but may be mutable since same storage could be reused
  - Queried to detect a mismatch between storage format and usage that triggers conversion
  - Type info may be used to guide allocator implementation but isn’t used to select it
- Enumeration and extensibility
  - HiHAT may not architecturally name types to begin with; could leave user-extensible
  - Field that carries type is a 64b integer, which could be a bitvector

MIGRATION & MIRRORING

Requirements

- Memory object could be read and written from multiple execution resources
- Object could reside on any of multiple memory resources: many local, many remote
- Options
  - Replication of read-only copies
    - From the start or as needed
  - Migration of writable or read-only instances
    - Suppressed – preference for remote, unmigrated
    - Based on proximity, e.g. near {CPU, accel 1, accel 2}
    - Based on prioritized need for capacity, e.g. HBM, nearby bulk DRAM, SysMem, NAS
    - Based on prioritized need specialized access, e.g. HBM vs. DRAM, texture cache



MIGRATION & MIRRORING

Implementation ideas

- Many policy choices to be made
  - Record policies as metadata in DataView
  - Can be specified at allocation, some may be mutable
  - Examples: cudaMemAdvise, mmap
- Metadata includes
  - Set of memory resource targets, pre-registration, migration policies
  - Current values for mutable characteristics
    - Current affinity – subset of execution and memory resources
    - Current access sets – subset of execution resources for each of read and write
- Can be communicated to underlying runtime via allocation request
  - Provide for that in alloc API interface using ExecPol

REGISTRATION AND QUERY APIS

- Registration and querying index by agent, target and chooser
- See below for discussion on nursery

```
hhRet hhnRegAlloc(
    void *task_ptr,                       // function pointer
    hhResrcHndlSet resrc_hndl,            // where this func pointer can execute
    hhMemHndlSet mem_hndl,                // which memory devices this func pointer is used for
    void *target_specific_config,         // target-specific config for function
    void *chooser,                        // value or pointer to blob that selects among registered implementations
    int supported_traits,                 // a bit vector of supported traits, based on hhMemTraitEnum values
    size_t nursery_bytes,                 // size of nursery; 0 if nursery not used or supported
    void *out_nursery_base_addr,          // base address obtained from initial allocation that happens at registration
);
hhRet hhnQueryRegAlloc(
    hhResrcHndlSet resrc_hndl,            // where this func pointer can execute
    hhMemHndlSet mem_hndl,                // which memory devices this func pointer is used for
    size_t function_idx,                  // index among registered tasks (another version of this API selects by chooser)
    int *out_supported_traits,            // a bit vector of supported traits, based on hhMemTraitEnum values
    /// expect to add more unique identifying parameters
    hhTaskHndl *out_task_hndl             // returned task handle
    size_t *out_nursery_bytes,            // size of nursery; 0 if nursery not used or supported
    void *out_nursery_base_addr,          // base address obtained from initial allocation that happens at registration
);
```

NURSERIES

Enabling management of aggregated data structures

- Consider a tree, where all nodes in the tree are related but allocated one by one
- Moving a node at a time is cost prohibitive, but moving the whole tree is not
    - Move normally means changing physical address or attributes, VA is much harder
- One allocator may deal with several nurseries, as distinguished by chooser
    - There's a registration for each chooser value
    - Each of those can cause a nursery allocation of a given size

ALLOC API

- Alloc interface: specify agent(s), specify ExecPol in addition to specifying target(s), specify additional metadata – migration policies, initial affinity

```
hhRet hhuAlloc(
    hhDataView *out_mem_hndl,         // memory handle
    void **out_addr,                  // address of alloc'd address
    size_t num_bytes,                 // number of bytes to allocate for view
    hhMemTrait mem_trait,             // inherent memory traits
    hhMemType mem_type,               // (bit vector of) memory types
    hhExecPol exec_pol,               // provide for a rich set of execution policies (includes chooser)
    hhExecCfg exec_cfg,               // mode, profiling, exec scope, tag set
    hhResrcHndlSet resrc_hndl,        // where allocator may execute from
    hhMemHndlSet mem_hndl,            // which memory devices space is allocated from, migration scope
    hhActionHndl input_dep,           // single action this depends on
    hhActionHndl   *out_action_hndl   // used to obtain status, events
);
```

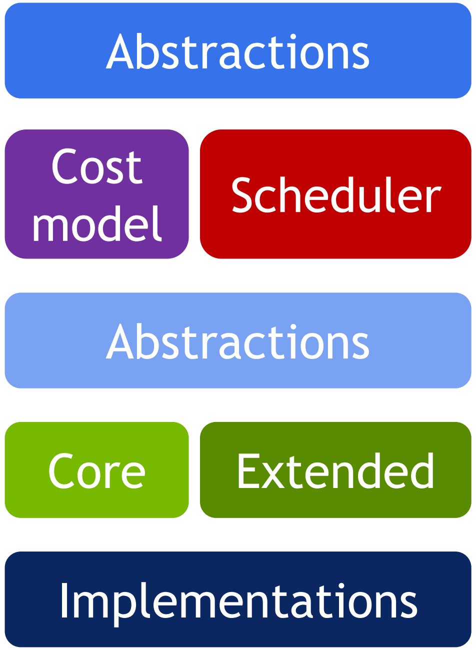
ALLOC API - EXTENDED VERSION

- Since reading may be shared or mutually exclusive, include readers & writers
- Consider including initial home

```
hhRet hhuAllocExt(
    hhDataView *out_mem_hndl,               // memory handle
    void **out_addr,                        // address of alloc'd address
    size_t num_bytes,                       // number of bytes to allocate for view
    hhMemTrait mem_trait,                   // inherent memory traits
    hhMemType mem_type,                     // (bit vector of) memory types
    hhExecPol exec_pol,                     // provide for a rich set of execution policies (includes chooser)
    hhExecCfg exec_cfg,                     // mode, profiling, exec scope, tag set
    hhResrcHndlSet resrc_hndl,              // where allocator may execute from
    hhResrcHndlSet resrc_hndl_readers,      // which execution resources may currently read the object
    hhResrcHndlSet resrc_hndl_writers,      // which execution resources may currently write the object
    hhMemHndlSet mem_hndl,                  // which memory devices space is allocated from, migration scope
    hhMemHndlSet mem_hndl_home,             // initial home that is a subset of migration scope
    hhActionHndl input_dep,                 // single action this depends on
    hhActionHndl   *out_action_hndl         // used to obtain status, events
);
```

RESOURCE ENUMERATION

Goals and Expectations



- Goals
  - What's there - enumerate it once, avoid double coverage
  - How it's connected – number and kinds and characteristics of links
  - Cost models – access characteristics, for unloaded and shared use
- Expectations
  - Core set of basic enumerations of what's there
  - Extended, target-specific enumeration of add'l features, e.g. connectivity, costs, order
  - Enumeration informs cost models, cost models are specialized for each scheduler

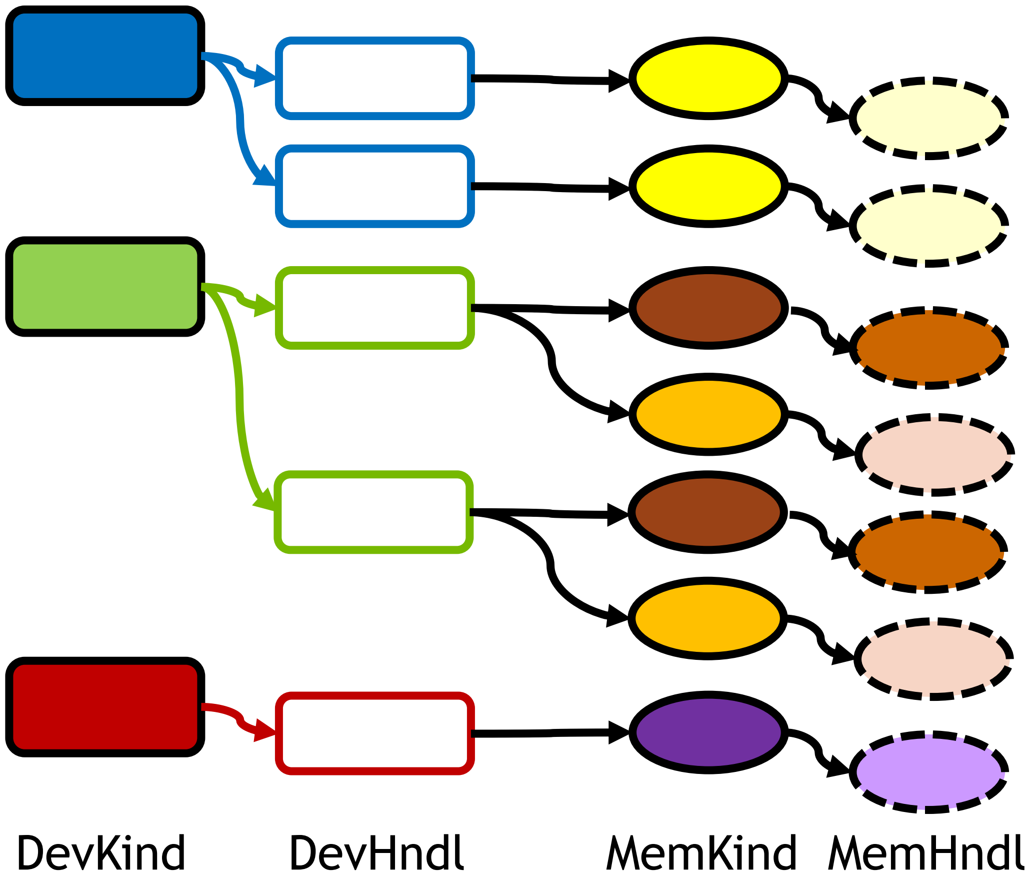
ENUMERATION

Requirements, enhancements

- Enumeration of compute resources
- Enumeration of memory resources
  - Hang off of compute resources
  - Enumerated once even if it's associated with multiple compute resources (ok'd for hwloc)
- Partial overlap is supportable
  - Example: >1/4 of resource X could go to each of A and B, and they could fight over 2/4
- Enumeration of connectivity between compute and memory resources [feedback]
  - Design and implementation not yet complete
  - Unlikely for the community to agree, so offer a flexible & extensible interface
  - Priority among equivalence classes – guide selection via priority, could include "whether"
  - Cost – could depend on direction, read/write mix, granularity, queue depth

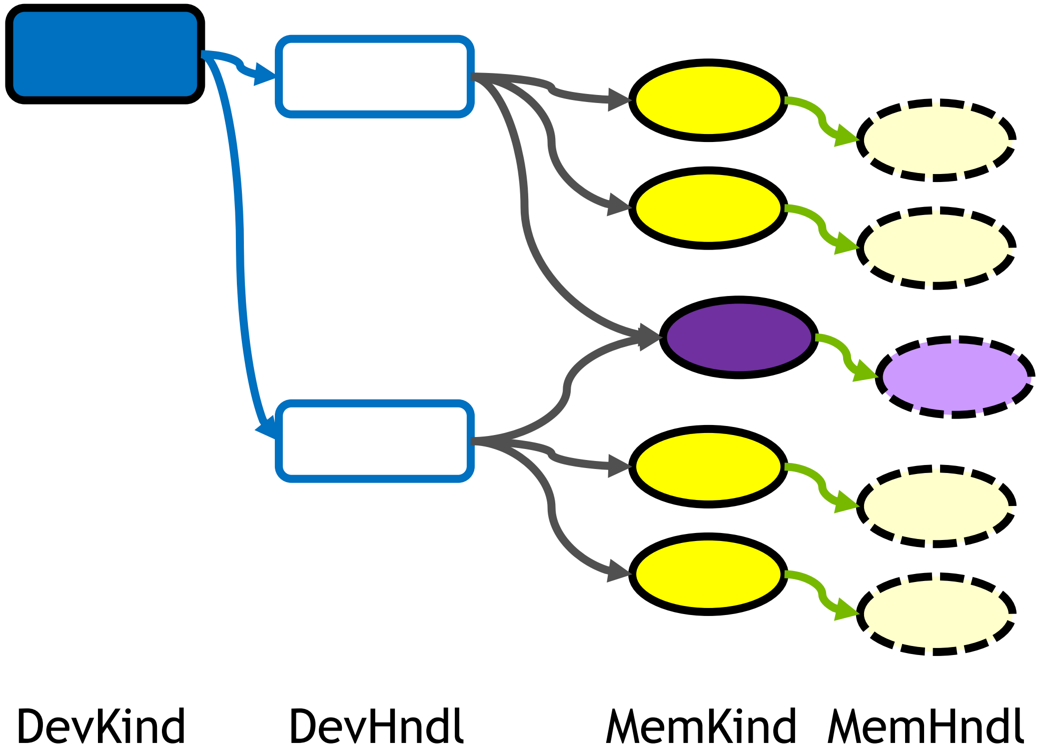
RESOURCE ENUMERATION

Device and memory hierarchy



RESOURCE ENUMERATION

Both one to many and many to one



ENUMERATION

- Enumeration of connectivity between compute and memory resources
  - Not yet supported: in API, not implementation
  - Unlikely for the community to agree, so offer a flexible & extensible interface
  - Priority among equivalence classes – guide selection via priority, could include “whether”
  - Cost – could depend on direction, read/write mix, granularity, queue depth

```
///  Exactly two of the four Resrc/MemHndlSets must be non-null
hhRet hhnQueryConnectionBasic(
   hhResrcHndlSet resrc_hndl_from,    ///< execution resource the transfer is coming from (could be empty)
   hhResrcHndlSet resrc_hndl_to,      ///< execution resource the transfer is going to (could be empty)
   hhMemHndlSet  mem_hndl_from,       ///< memory resource the transfer is coming from (could be empty)
   hhMemHndlSet  mem_hndl_to,         ///< memory resource the transfer is going to (could be empty)
   size_t        *out_read_bandwidth,  ///< bytes/s of typical read bandwidth
   size_t        *out_write_bandwidth, ///< bytes/s of typical write bandwidth
   size_t        *out_read_latency,    ///< nanoseconds for typical read latency
   size_t        *out_write_latency    ///< nanoseconds for typical write latency
};
hhRet hhnQueryConnectionExtended(
   hhResrcHndlSet resrc_hndl_from,    ///< execution resource the transfer is coming from (could be empty)
   hhResrcHndlSet resrc_hndl_to,      ///< execution resource the transfer is going to (could be empty)
   hhMemHndlSet  mem_hndl_from,       ///< memory resource the transfer is coming from (could be empty)
   hhMemHndlSet  mem_hndl_to,         ///< memory resource the transfer is going to (could be empty)
   int selector,                      ///< selector among potential cost structures, default 0
   size_t cost_structure_bytes,       ///< max permissible bytes to copy in
   void *out_ConnectionCost           ///< user-defined object that describes connectivity/costs to copy into
);
```

THINGS TO PONDER

- Support copy on write?
  - Could add that support as a trait
- Support is limited to least common denominator for multiple targets?
  - Maybe. Can use different allocators for different subsets of resources
- How is exclusive access managed?
  - The implementation of the HiHAT dispatch code itself will not track where instances are, nor which are valid or close by. That'd be left to what's layered above or below.
  - Could be managed either in implementations plugged in from below, or functionality layered on top of HiHAT. We'll need to carefully choose between those two.