The Legion Mapping Interface

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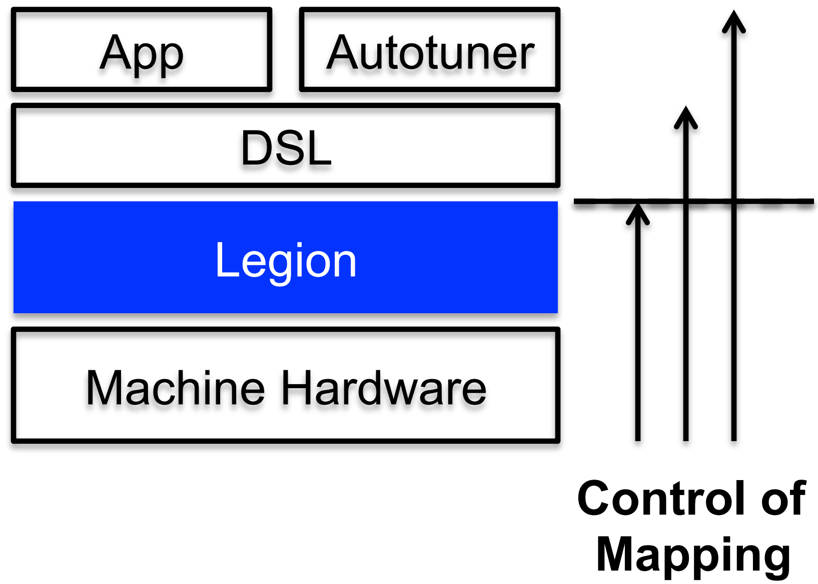
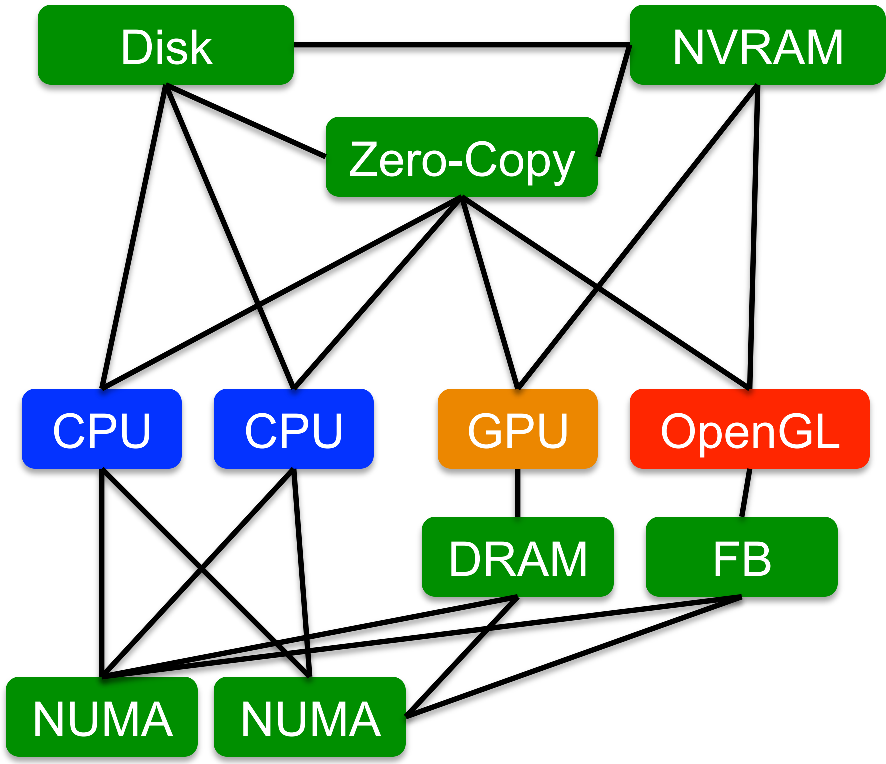
Philosophy

- Decouple specification from mapping
  - Performance portability
- Expose all mapping (perf) decisions to Legion user
  - Guessing is bad!
  - Don't want to fight Legion for performance
  - Propagate mapping control up through layers of abstraction
- Dynamic Mapping
  - React to machine changes
  - React to app. changes



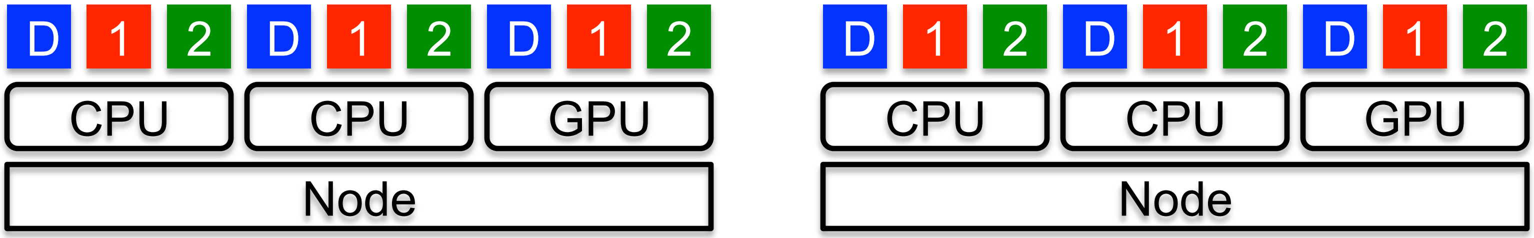
Machine Model

- Machine is a graph of processors and memories
- Nodes contain attributes
  - Processors: kind, speed
  - Memories: kind, capacity, “hardness”
- Edges describe relationships
  - Processor-Memory affinity
  - Memory-Memory affinity
  - Bandwidth, latency
- Machine object interface



Mapper Model

- Create a separate mapper for each processor
  - Mappers can specialize themselves
  - Avoid bottlenecks on mapping queries
- Support arbitrary number of mappers per application
  - Compose applications and libraries with different mappers
- Initialized at start-up of Legion runtime
  - `set_registration_callback` function
    - Add mappers with the `add_mapper` function
  - Default mapper is always given `MapperID` 0
    - Can be replaced with `replace_default_mapper` function



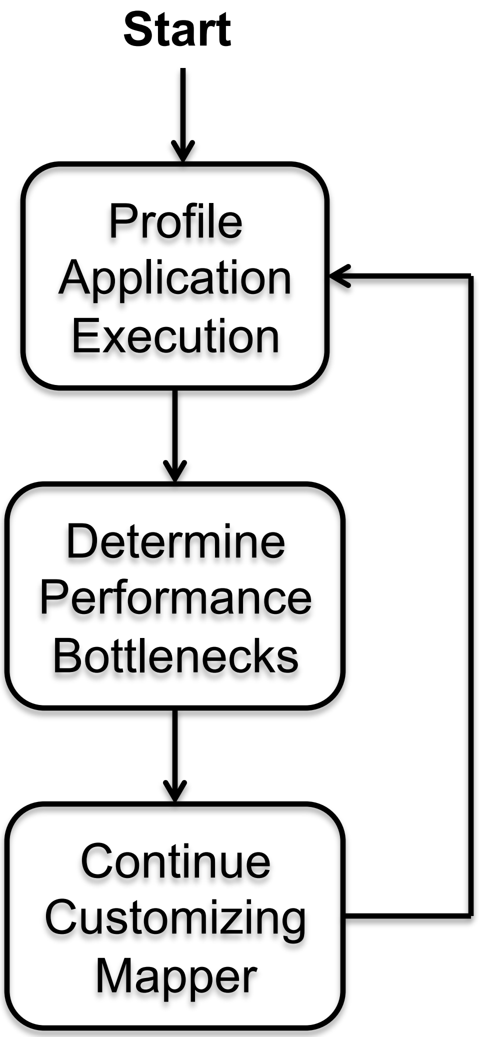
Mapper API

- Mapping API is a pure virtual interface
  - Easy to extend existing mappers
- Methods invoked by the runtime as queries
  - At most one invocation per mapper at a time
  - No need for locks
- Mappers can be stateful
  - Memoize information
  - State is distributed

```
class Mapper {
public:
  virtual void
select_task_options(Task*) = 0;
public:
  virtual void
      pre_map_task(Task*) = 0;
  virtual void
      map_task(Task*) = 0;
  virtual void
      post_map_task(Task*) = 0;
…
};
```

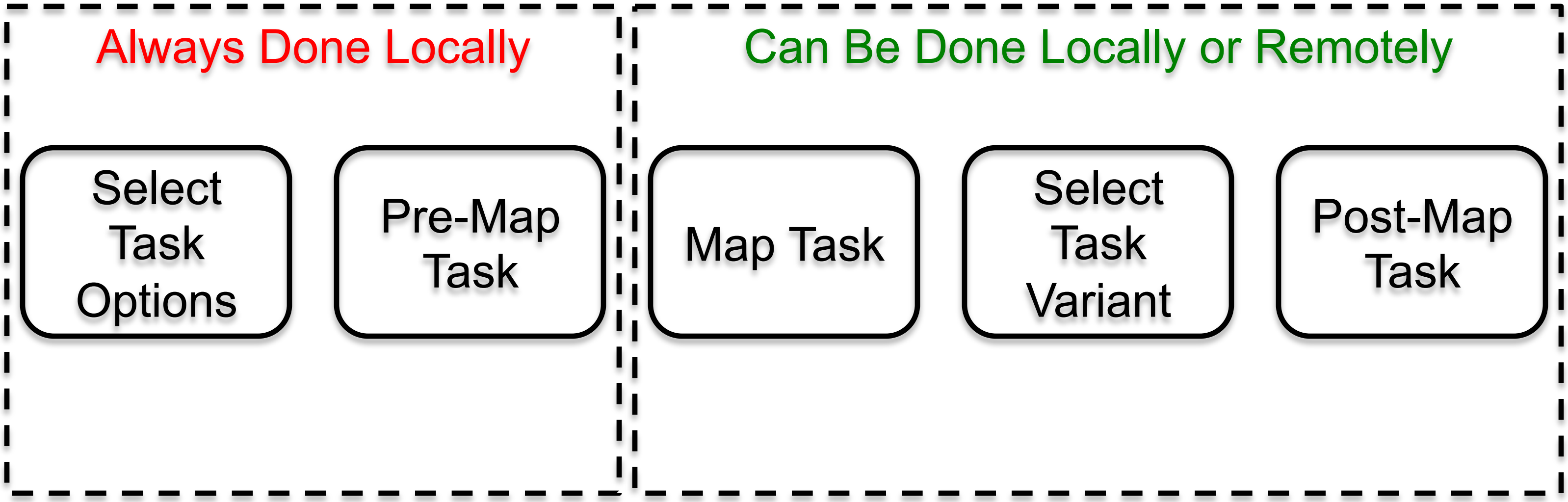
Default Mapper

- Legion comes with a default mapper
- Implement custom mappers that inherit from default mapper
  - Only need to customize specific mapper calls
  - Leverage open/closed principle of software engineering
- Lends itself to a natural performance tuning loop
  - Repeat for each application+architecture
  - Easy to autotune



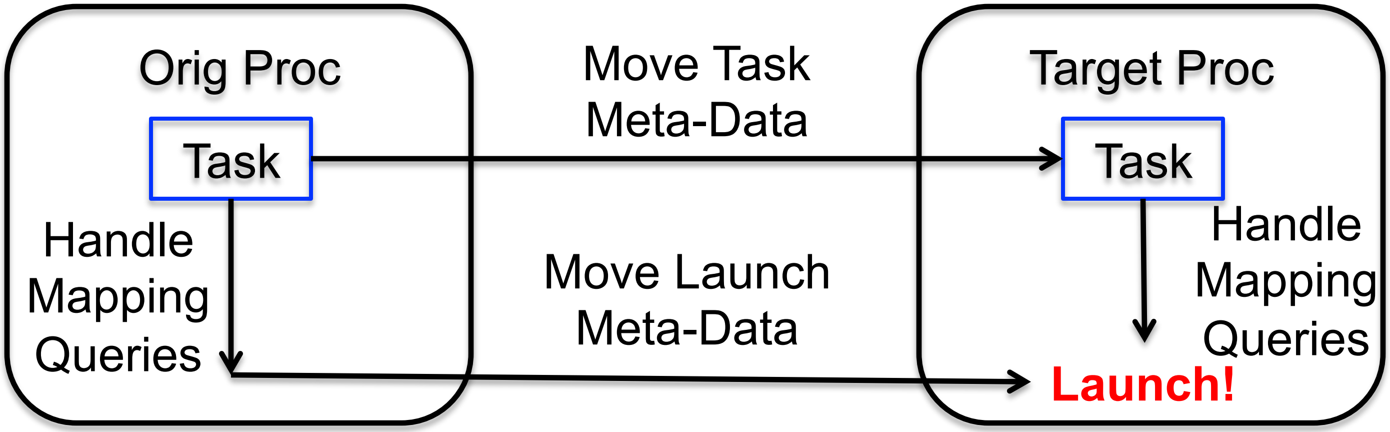
The Lifetime of a Task

- Mapper calls for tasks follow the task pipeline
- Not all calls handled by the same mapper object
  - Tasks can map both locally and remotely
  - Guaranteed to be handled by mappers of the same ID



Mapping Locally vs. Remotely

- Three important processors associated with `Task`
  - Origin Processor (`orig_proc`): where task was launched
  - Current Processor (`current_proc`): owner of the task
  - Target Processor (`target_proc`): current mapping target
- Tasks can be mapped locally or remotely
  - Locally: `current_proc == orig_proc`
  - Remotely: `current_proc == target_proc` (!= `orig_proc`)



Task Meta-Data >> Launch Meta-Data

Remote Mapping -> More Parallelism

Select Task Options

- `virtual void select_task_options(Task *task)`
  - Currently decorate fields of Task object
  - Planned: structure describing options

- Assign the following fields:
  - target_proc – pick the first owner processor
  - inline_task – inline using parent task's physical regions
  - spawn_task – make eligible for stealing
  - map_locally – map the task locally or remotely
  - profile_task – capture profiling information

Select Task Options | Pre-Map Task | Map Task | Select Task Variant | Post-Map Task

Task Mapping (Part 1)

- Tasks always have an "owner" processor
- Owner can be changed until a task is mapped
  - Once a task is mapped it will run on owner processor
- Mapping a task consists of three decisions
  - Fixing the owner processor
  - Selecting memories for physical instances of each region
  - Determining layout constraints for physical instances

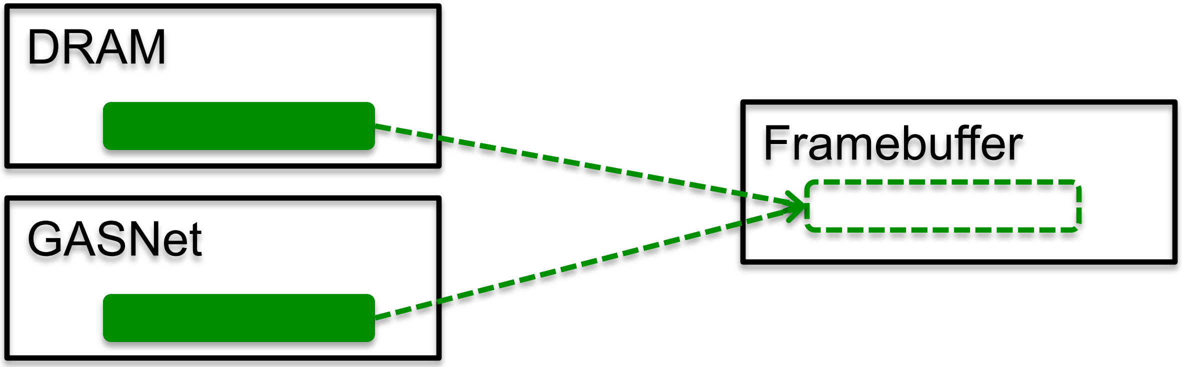
Task Mapping (Part 2)

- `virtual bool map_task(Task *task)`
  - Choose memory ordering for each region requirement
  - Return ‘true’ to be notified of mapping result
- Task has a vector of application-specified regions
  - Represented by region requirements
  - Called `regions`
- Legion provides list of current memories with data
  - Called `current_instances`
  - Boolean indicates if contains valid data for all fields
- Mapper ranks target memories in `target_ranking`
  - Runtime tries to find or create instance in each memory
  - Will issue necessary copies and synchronization
  - Choose layout by selecting `blocking_factor`

Task Mapping (Part 3)

- **Legion automatically computes copies based on mapping decisions**
  - **Sometimes there might be multiple valid sources**
  - **Never guess! (Legion knows what to do if only one source)**

- **`virtual void rank_copy_sources(…)`**
  - **Set of possible source memories**
  - **Memory containing physical instance**
  - **Populate a vector ranking source memories by preference**



Task Mapping (Future)

- New mapping API in progress
  - Switch from memory centric to physical instance centric
  - Be field aware
  - Support more data layout formats
- map_task will not change much
  - Legion will provide information about physical instances
    - Layout, field sizes, which fields are valid
  - Mappers provide ranking of physical instances
- Physical instances specified as a set of constraints
  - Order of index space dimensions + field interleaving
  - Constraints on specific pointers and offsets

Selecting Task Variants

- **Task variant selected based on mapping decisions**
- **Legion examines all constraints and picks variant**
  - **Processor kind, physical instance memories and layouts**
- **If there are multiple valid variants then query mapper**
  - `virtual void select_task_variant(Task *task)`
- **Might require many variants. Is there a better way?**
  - **Yes! Task generator functions (using meta-programming)**

Select Task Options | Pre-Map Task | Map Task | **Select Task Variant** | Post-Map Task

Dealing with Failed Mappings

- Mappings can fail for many reasons
  - Resource utilization
  - Memories not visible from target processor
  - No registered task variant based on constraints
- `virtual void notify_mapping_failed(…)`
  - Region requirements annotated by `mapping_failed` field
- Failed tasks automatically ready to map again
  - Mappers can try mapping them again later
  - Watch out for repeated failures (looks like livelock)
  - Future work: establish conditions for re-mapping

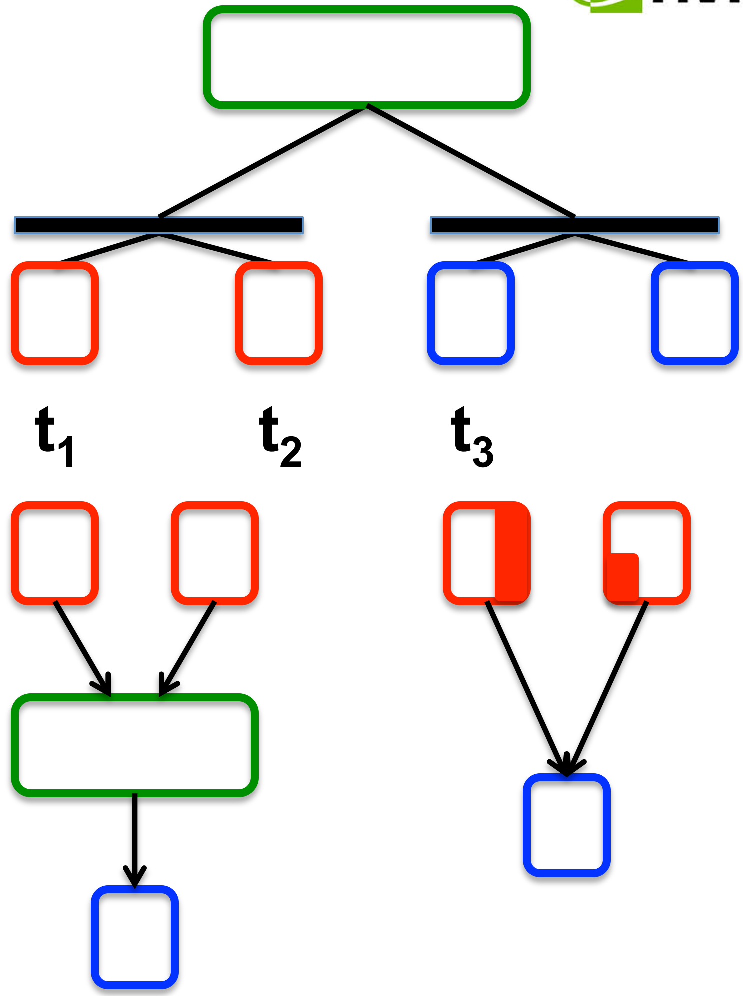
Pre-Map Task (Part 1)

- `virtual bool pre_map_task(Task *task)`
  - Can early-map region requirements to physical instances
  - Performed on origin processor before task can be moved
  - Return ‘true’ to be notified of pre-mapping result
- Handle some special cases
  - Read-Write coherence on index space task region

Select Task Options | **Pre-Map Task** | Map Task | Select Task Variant | Post-Map Task

Pre-Map Task (Part 2)

- Runtime performs "close operations" as part of pre-mapping task
- Handle translation between different views
- Two options:
  - Concrete Instance
  - Composite Instance
- Composite Instances
  - Memoize intersection tests to amortize cost

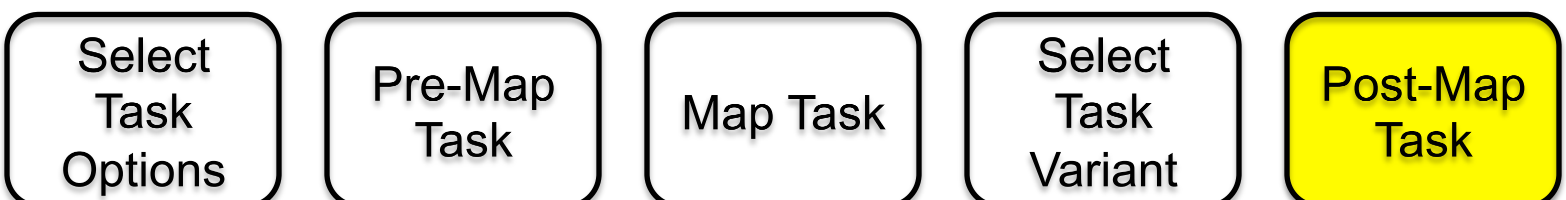


virtual bool rank_copy_targets(…)

return true for composite instance

Post-Map Task (In Progress)

- Create optional checkpoints of logical regions
  - Generate physical instances in hardened memories
  - Copies automatically issued by Legion runtime
  - Control which logical regions and fields are saved



Mapping Other Operations

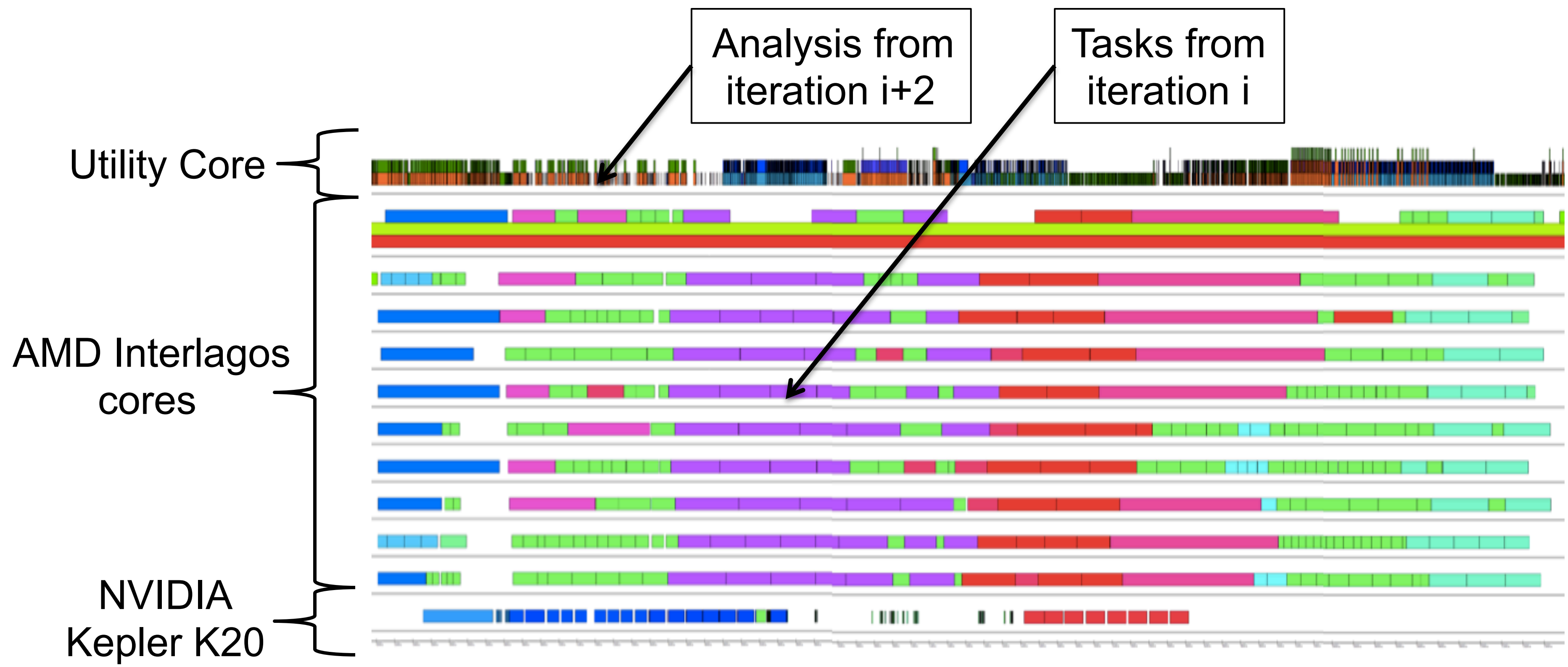
- Legion maps many operations other than tasks
  - Inline mappings
  - Explicit region-to-region copies

- Similar mapping calls, all on origin processor
  - `virtual void map_copy(Copy *copy)`
  - `virtual void map_inline(Inline *inline_op)`

- Map region requirements the same as tasks

Managing Deferred Execution

- **Legion is an out-of-order task processor**
  - **How far do we run ahead (into the future)?**
  - **Machine and application dependent -> mapper decision**



Managing Deferred Execution (2)

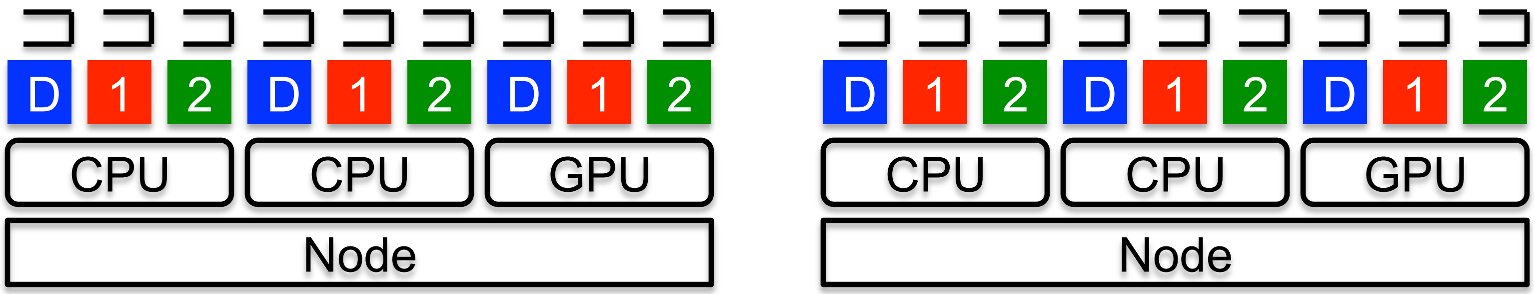
- Two components of managing run-ahead
  - How many sub-tasks outstanding per task?
  - When should tasks begin the mapping process?

- Control max outstanding sub-tasks with window size
  - virtual void configure_context(Task *task)
  - Set `max_window_size` (default 1024)
  - Can be unbounded (any negative value)
  - Trade-off parallelism discovery with memory usage

- Control max outstanding sub-tasks with frames
  - Call `issue_frame` at the start of each iteration
  - Set `max_outstanding_frames`

Managing Deferred Execution (3)

- **Legion maintains ready queue for each mapper**
  - **Contains tasks that are ready to map**

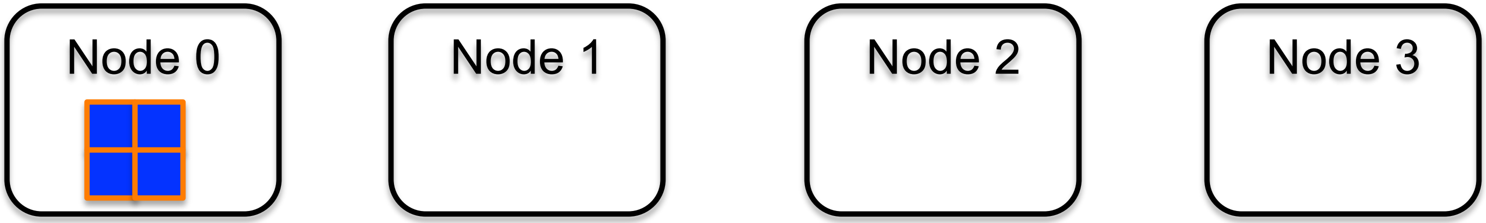


- **Mappers decide when to start mapping tasks**
  - virtual void select_tasks_to_schedule(list<Task*>)
  - **Open question: when to stop invocation?**
    - **Right now: when "enough" tasks outstanding (-hl:sched)**

- **Can perform one of three operations for each task**
  - **Start mapping (set `schedule` field of `Task*` to true)**
  - **Change `current_proc` to new processor to send remotely**
  - **Do nothing: important for loading balancing**

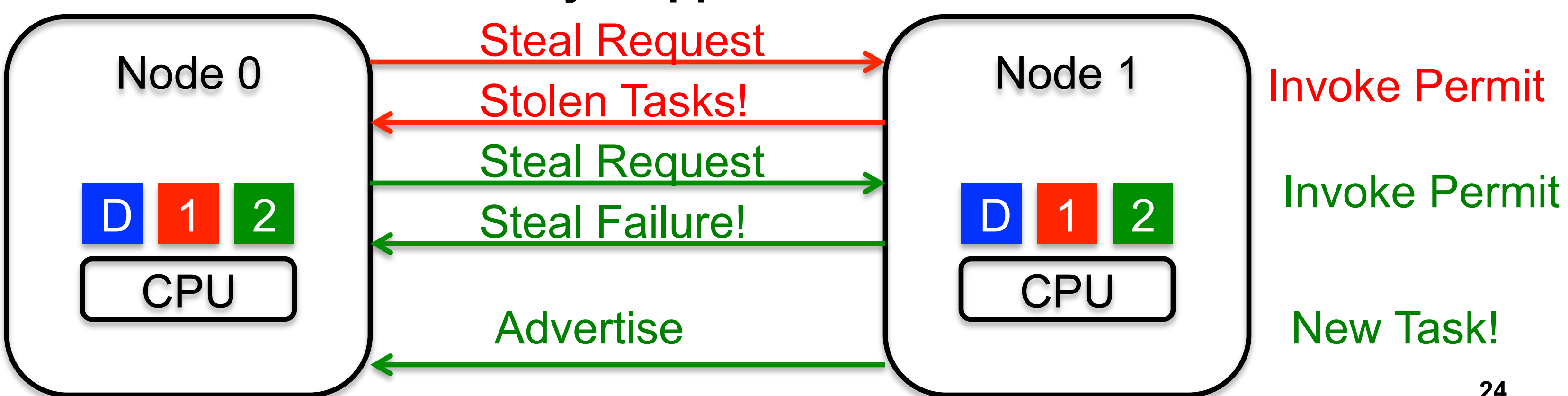
Inter-Node Load Balancing

- Legion supports both push and pull load balancing
  - Push tasks to other nodes
  - Pull work from other nodes (e.g. stealing)
- Two forms of push
  - Change `current_proc` in `select_tasks_to_schedule`
  - virtual void slice_domain(…)
    - Decompose index space into subsets and distribute
    - Recursively slice subsets, specify target processor
  - Index space tasks: slice into subsets of points
    - Look at is_index_space to determine if slice or single task
    - index_domain gives bounds of slice



Task Stealing

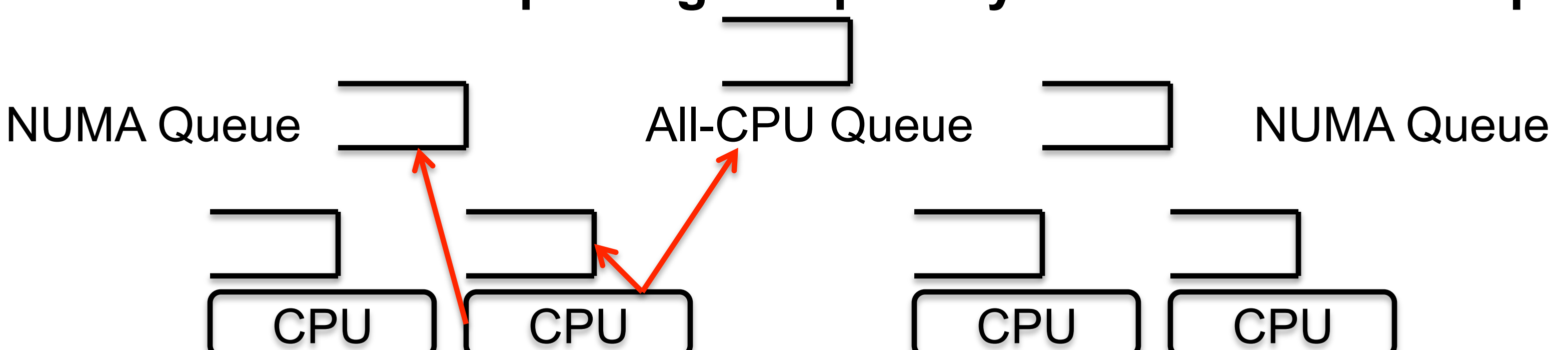
- Legion also supports pull load balancing via stealing
  - Stealing is totally under control of mappers
  - Mappers can only steal tasks from mappers of the same kind
- Stealing in Legion is two-phase
  - Send requests: virtual void target_task_steal(…)
    - Choose targets for stealing (no guessing by Legion)
  - Approve requests: virtual void permit_task_steal(…)
  - Tasks can only be stolen from ready queues
    - Cannot steal already mapped tasks



Intra-Node Load Balancing

- Stealing is inefficient within a node
  - Support mapping tasks onto multiple processors in a node

- Can assign `additional_procs` in `map_task`
  - Must be of the same kind as `target_proc`, on same node
  - Must be able to access all physical instances
  - Legion automatically checks these properties
    - Will ignore bad processors and issue warning
- Create internal queues for running these tasks
  - Processors pull highest priority task from all their queues



Program Introspection

- Mappers can (immutably) introspect data structures
  - Region tree forest: index space trees, logical region trees
  - Task variant collections
  - Semantic tags describing tasks and regions
  - Dynamic dependence graph (computed by runtime)

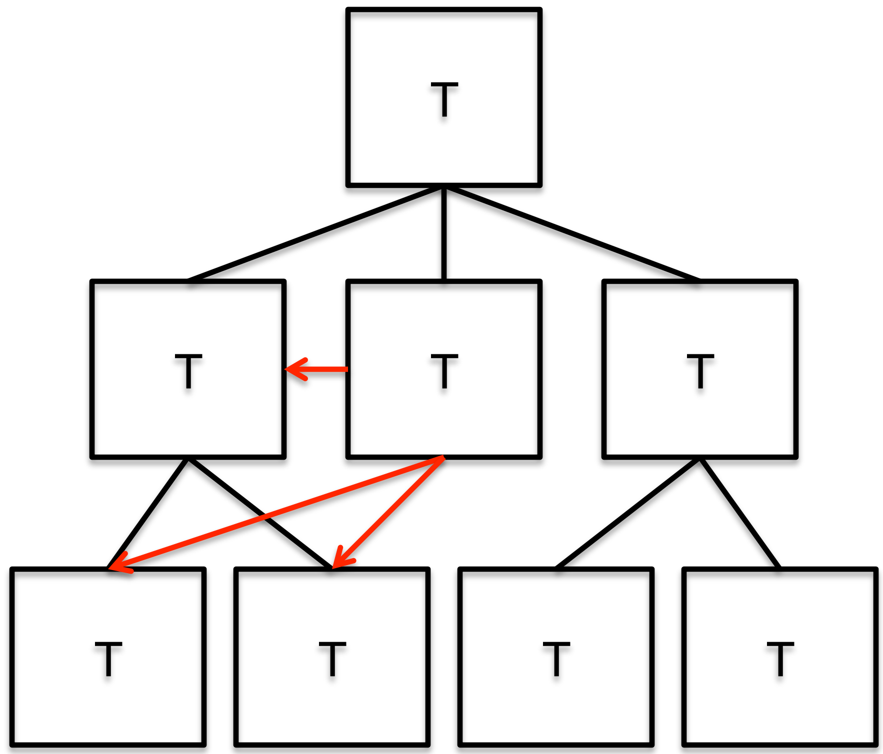
- Mappers can profile task execution
  - Set `profile_task` to true in `select_task_options`
  - `virtual void notify_profiling_info(Task *task)`
  - Currently profile basic properties (e.g. execution time)
  - What else do we need?

Other Mapping Features

- Tunable variables
  - Abstract variables that depend on machine (e.g. # of partitions)
  - `virtual int get_tunable_variable(…)`
- Virtual mappings
  - Some tasks only need privileges, don't need a physical inst.
  - Virtually map region requirement by setting `virtual_map`
  - Child task mapping flows back into parent context
- Controlling speculation
  - Mapper controls speculation on predicated tasks
  - `virtual void speculate_on_predicate(…)`
  - Don't speculate for now, available soon ☺

Avoiding Resource Deadlocks

- Sibling tasks with a dependence cannot map until all children have mapped
  - Enforced automatically by the runtime
- Necessary to avoid resource deadlock
- Is there a better way?



Open Mapping Questions

- Resource constrained mapping
  - Right now we map one task at a time
  - Map multiple tasks together to optimize resource usage
  - Trade-off parallelism with resource usage
- Task fusion + mutation of dynamic dependence graph
  - Fuse operations to support better data re-use
    - More on this in meta-programming talk later today
  - Other manipulations on dynamic dependence graph?
- Task replication
  - Why move data when you can compute it multiple times?
  - Replicate tasks to reduce overall data movement costs