Malleability for HPC

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The Role of the Future Computing Group at LRZ

User Requirements

Compute Demands | Ease of Use

Technology HW & SW

Cost-Effective | Sustainable/Green

Analyse, Predict

Future Computing Group

Recommend

Understand best options – not just t

Recommendations internally (for system pu
and externally (for supporting LRZ

Includes research on how to improve the operation and usage model, e.g. by adding **Malleability**

Outline

- Definition / Motivation
- LAIK: a runtime for elastic HPC codes
  - Overview
  - Examples
  - Directions
- Ongoing efforts

Definition "Malleable"

American Heritage Dictionary

Capable of being shaped or formed

For this talk (HPC context)

The property of a parallel code
to be able to take advantage of
changes in available compute resources
during run time

Benefits of Malleable Codes for Compute Centers

Improved usage model

- Quick job submission (for interactivity) by on-demand shrinking of running jobs
- Shrinking instead of killing running jobs if a high-priority jobs comes in

Better resource utilization

- Reduce fragmentation on a system (alternative to back-filling to use idle resources)
- Dynamic migration to more adequate resources when they become available

Better operation

- Dynamic migration to enable quick maintenance (similar to VMs)
- Ability to react on predicted node failures (”pro-active” fault tolerance)

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Original Context

- Envelope: German research project on self-organizing systems (2017 – 2019)
  KIT, TUM, JGU Mainz, RWTH Aachen
- Pro-active fault tolerance
  - Retreat application from node before (predicted) failure
  - Application-integrated approach: needs support for malleability

envelope

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

Original Focus

- Enable “easy” porting of MPI codes for malleability

- Shrink / expand based on external requests
  - Process IDs (ranks) not integral part of API
    - Library controls number of processes, knows how to distribute data (application specifies partitioner algorithm)
    - Constrain to iterative codes using “owner computes” paradigm
  - Automatic re-partitioning on resource size changes

- Enable fault tolerance
  - pro-active (react to predicted failure in the future)
  - reactive (cope with spontaneous failure)

Basic Idea

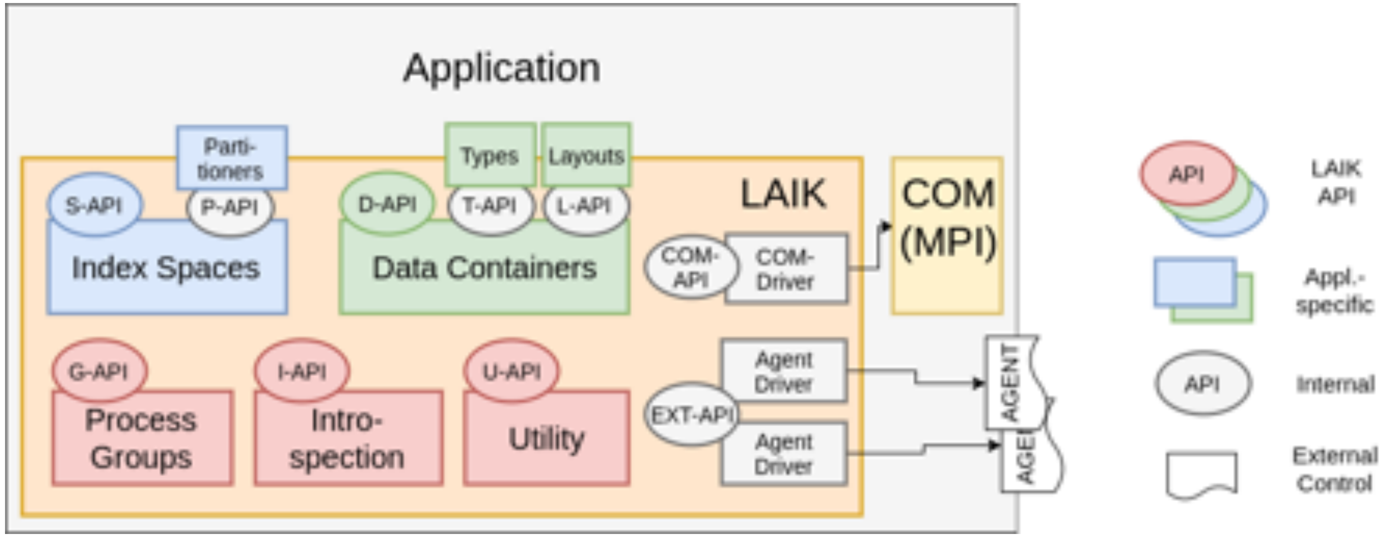
- Data is stored in multiple global (multi-dimensional) arrays, distributed over processes
  - Processes declare local access wish for array elements for compute phases
  - Value changes are globally propagated on demand

- Any communication = value updates of array elements

- We want to specify the communication requirements in an **abstract** way
  - Not based on MPI ranks, but: what data needs to be locally available for computation
  - Requirements declared once ➔ calculate communication schedules
    - executed multiple times on demand

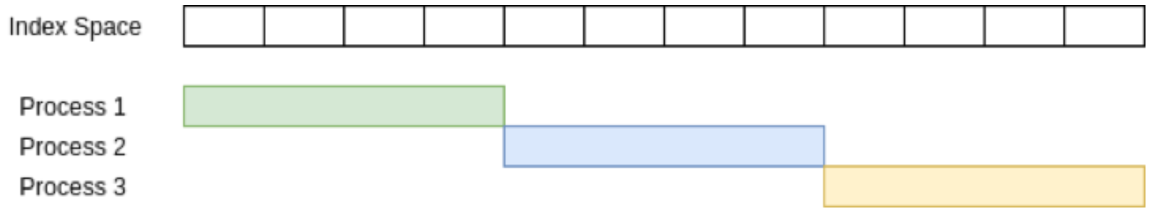
LAIK

- SPMD, can co-exist with MPI / OpenMP
  - a LAIK entity (process) is a Unix Process
- C API, runs on Linux & MacOS
- **github.com/envelope-project/laik**
- Communication backends as plugins: currently MPI, TCP

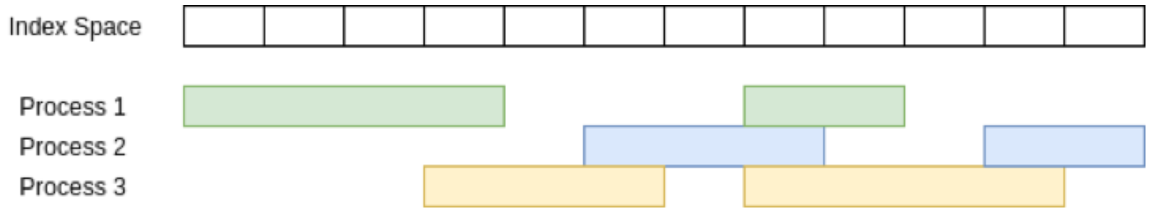


Index Spaces, Partitionings, Partitioners

- Example: disjunctive partitioning

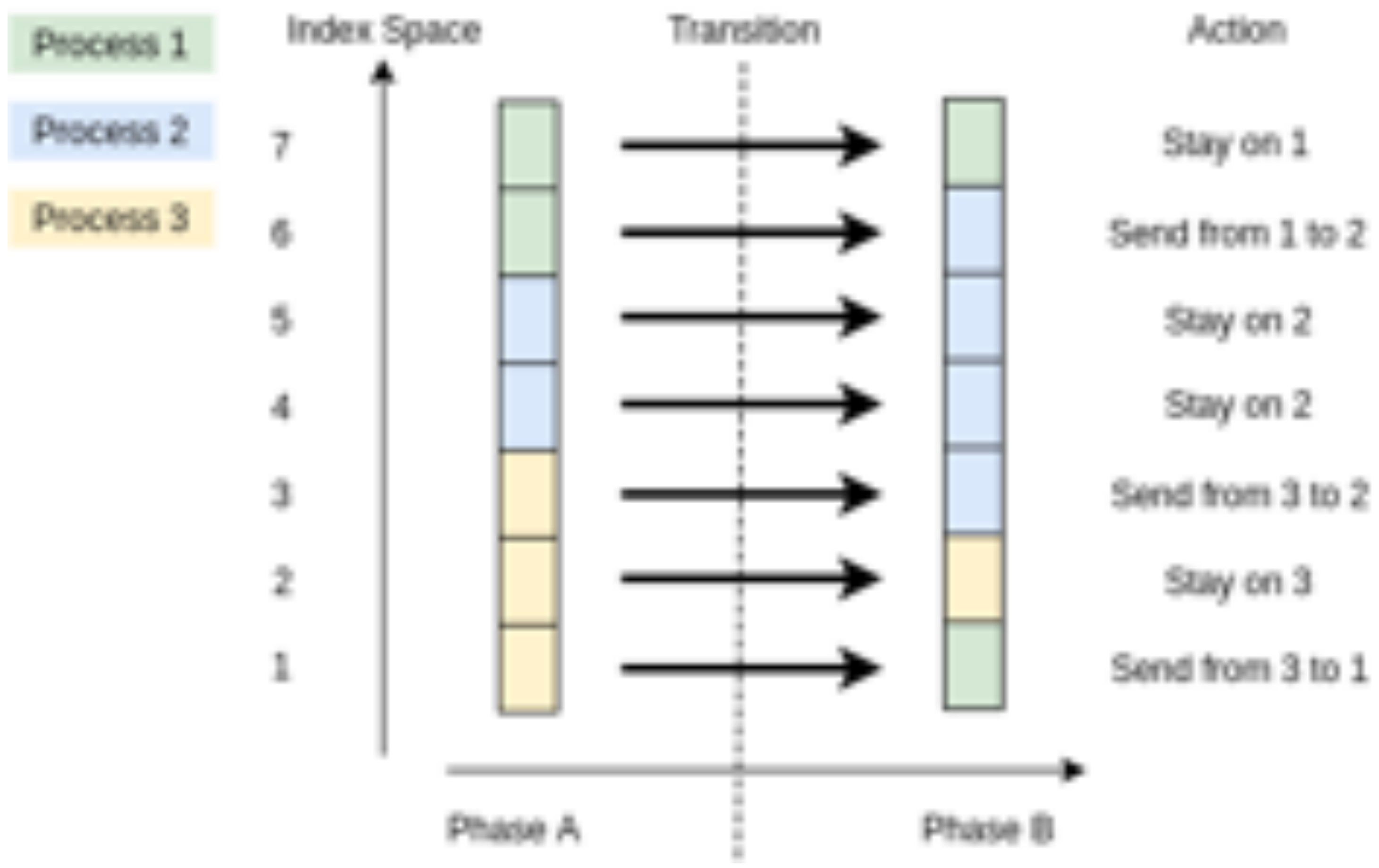


- General partitioning: multiple processes per index

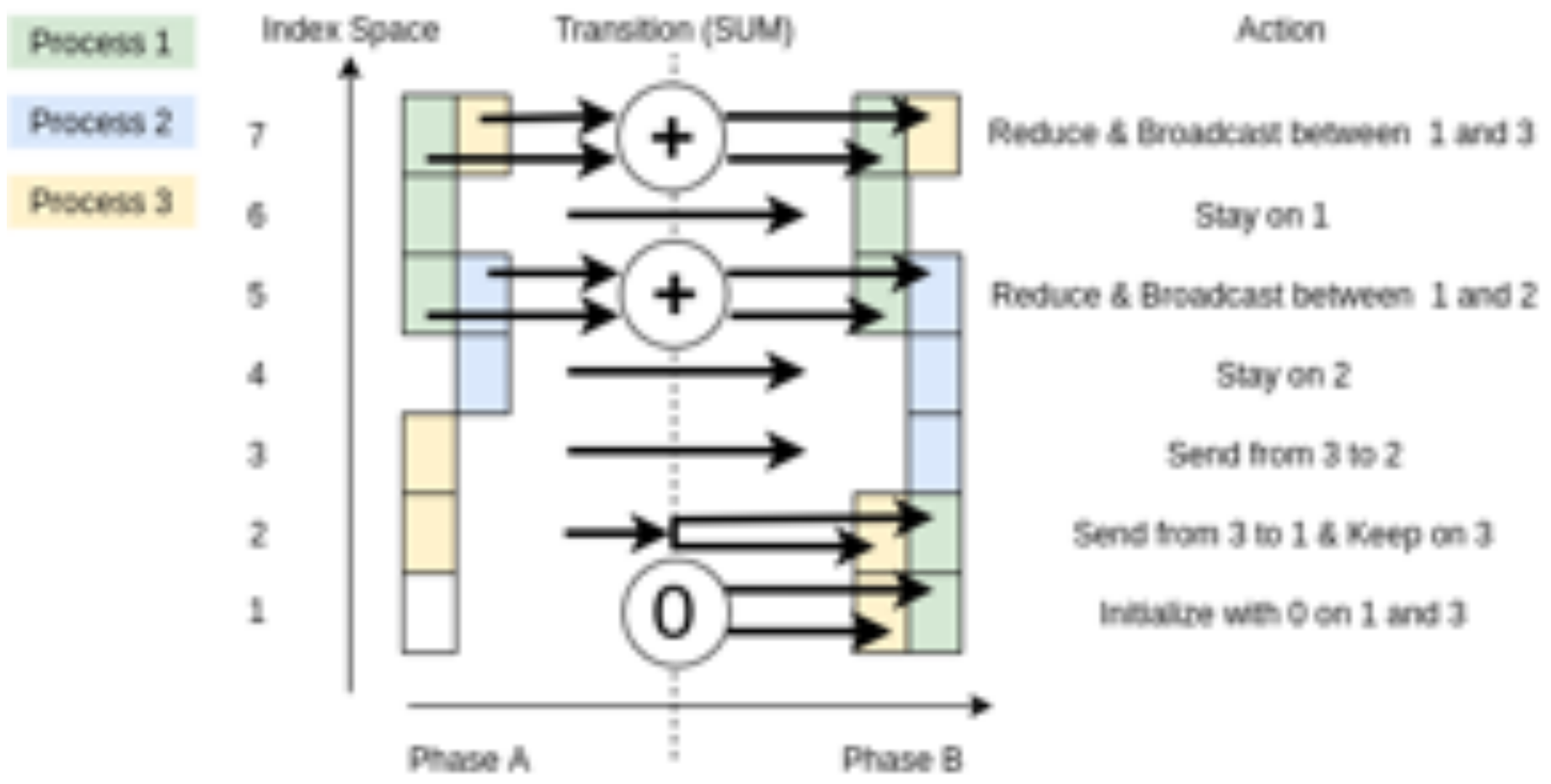


- Custom partitioner algorithms supported
  - can use another partitioning as input (e.g. with ghost layer)

Communication Schedule on Update, same Container



Communication Schedule on Update, same Container (2)



Needed: reduction operation (can be custom)

Data Containers

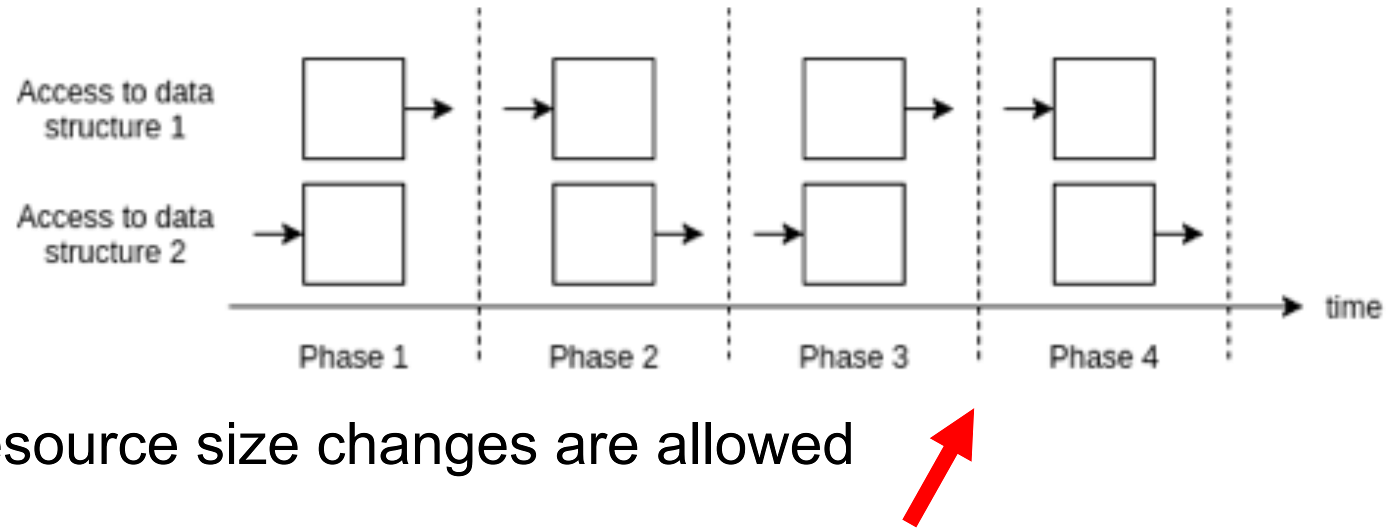
- Memory for data arrays, known to LAIK
- Same type for each index in a container
  - Type needed for reductions
- Layout: how are indexes locally ordered in memory
  - Application can specify custom layouts

- Explicit allocation
  - Specify set of partitionings to reserve space for, LAIK allocates
  - Get memory address for a local index (application knows layout)
  - Trigger Update: can only involve partitionings specified in allocation

- Repartitioning: allocate new, copy (= Update), free old

Application Structure (suggested, not enforced)

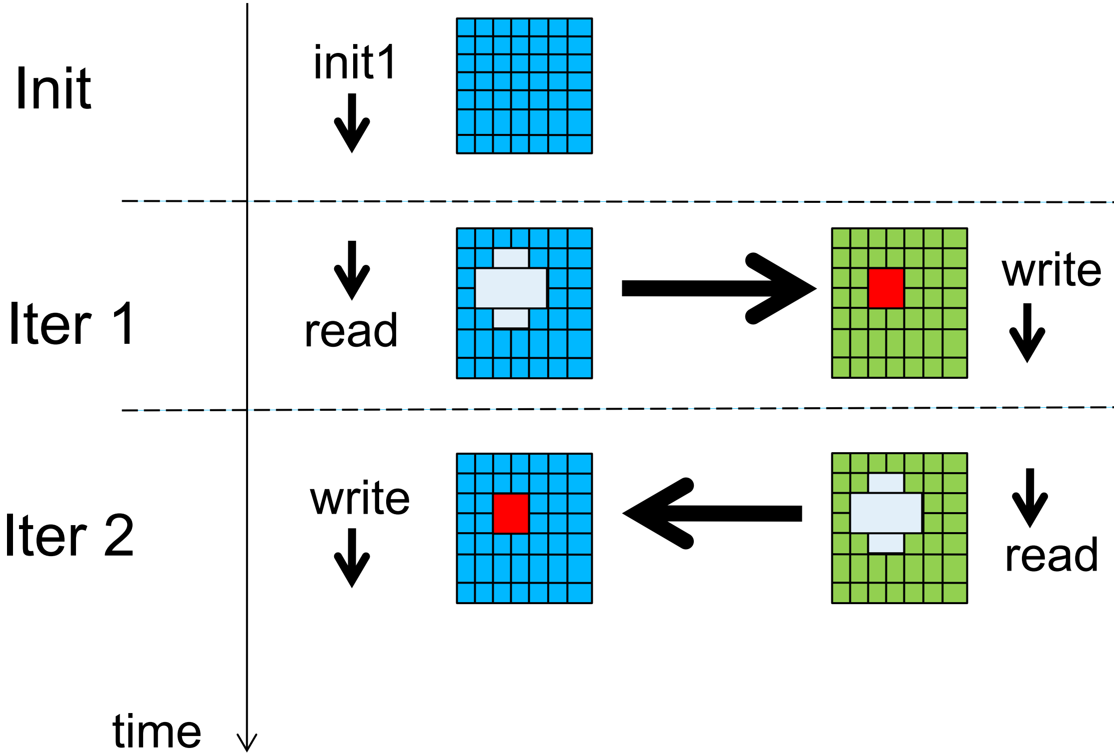
- Sequence of compute phases
  - Trigger adequate updates on phases changes



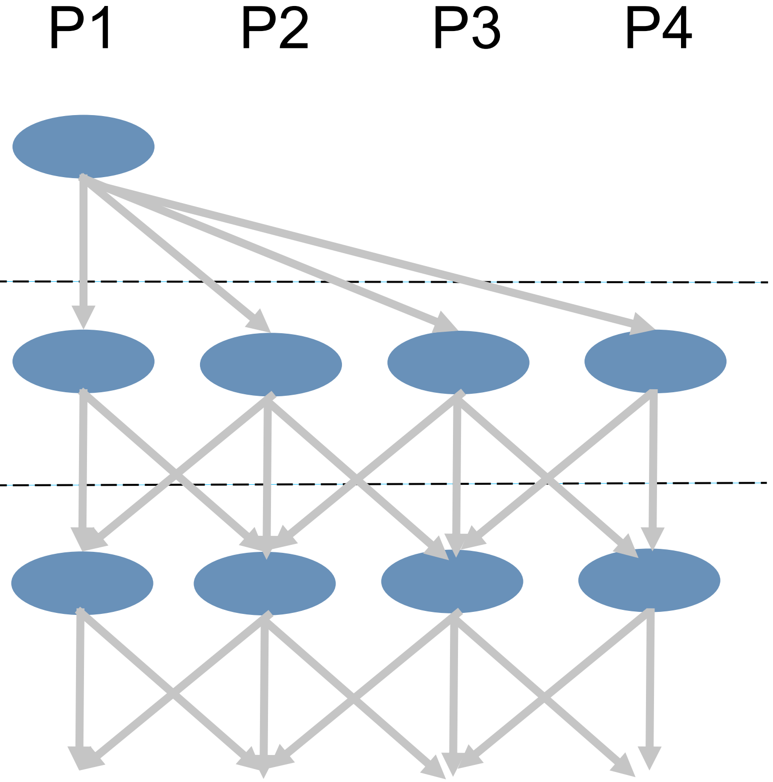
- Mark program points where resource size changes are allowed
  - Global synchronization
  - Results in re-runs of partitioner algorithms
    - Take joining / leaving processes into account
    - Data redistribution is “just” an update from old to new partitioning

Example: 2D Jacobi

- Two matrices, 5 point stencil
- Partitionings: “Init”, “Read with halos”, “Write” (disjunctive)
- Phases



Task Graph



LAIK Update Object

- Declaration
  - Before/after partitionings of same index space
  - Do update into same or different allocation?
  - Reduction operation
- Contains calculated communication schedule as instruction stream
  - Different abstractions possible: <RunUpdate>, <MPISend, …>
  - To be run by the communication backend (or stack of backends)
- Pre-optimize as much as possible
  - Can include code generation
  - Can be done off-line using pre-calculated partitionings in files (Metis runs)

LAIK Update Object (2)

Partial Specialization

- Information which may not be known at declaration time
  - backend to use, hardware available, machine topology
  - data container (from/to), type info, layout, memory addresses
- whenever new info becomes available, run optimization
  - can be done locally, as long as all LAIK processes agree on basics

LAIK Update Object (3)

Benefits of instruction stream approach

- Optimization passes are decoupled code
- Application-specific passes possible
- easy selection via external configuration
- Instructions can be backend-specific (backend executes instruction stream)
  - Enables layers of backends, which pass instruction stream down
    e.g. Smart NIC-support: reduction offloading, resource reservation
- Variants of instruction streams to react dynamically
  - Change of job priority from job scheduler

LAIK Update Object (4): Optimization Passes

Examples

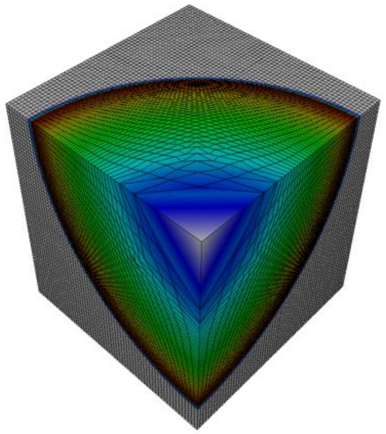
- Lower abstraction:
  “send indexes 1-5 from container X” → “send 5 ints at 0xX”
- Merge multiple sends between same peers into one send
- Copy pieces into pre-allocated network buffers
- Different reduction algorithms depending on size / topology
- Detect Pattern & replace with MPI collective (All-to-All)

Provided functionality for Passes

- Can create backend-specific calls to early resource alloc/free
- Reordering via attaching ordering labels

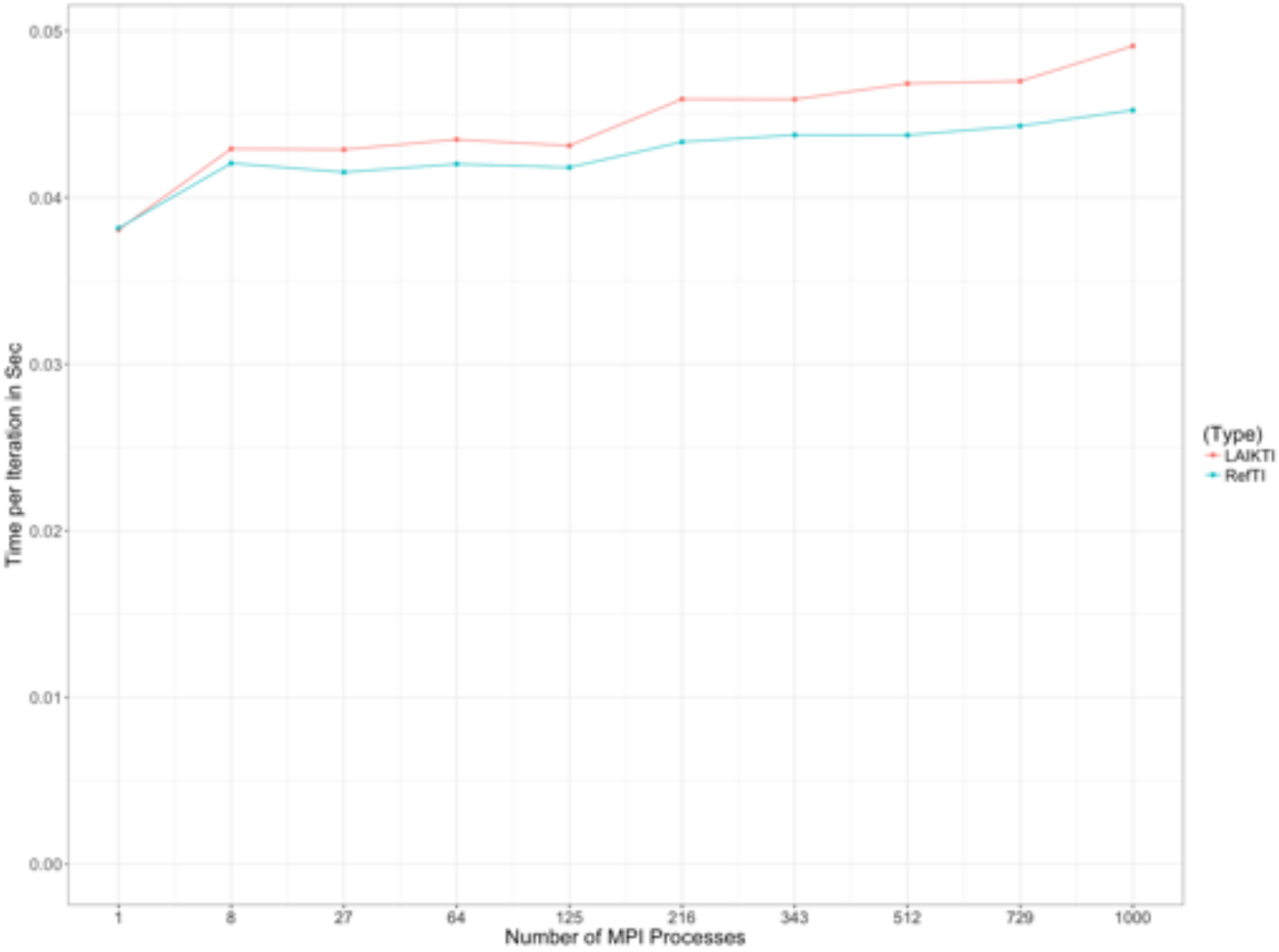
Porting of LULESH (Shock Hydrodynamics)

- Incremental porting from MPI code
  - Small steps, easy to check for correctness
  - Eliminate 2800 lines of comm code (~50%)
  - Almost no changes in main loop of reference code
- Performance/scalability similar to MPI
- Added elasticity and external control



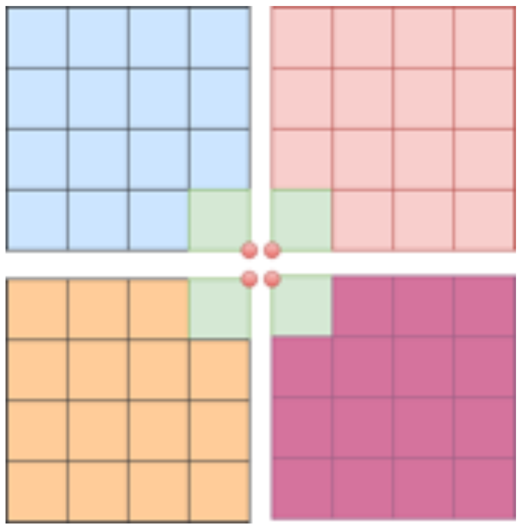
LULESH: Weak Scaling

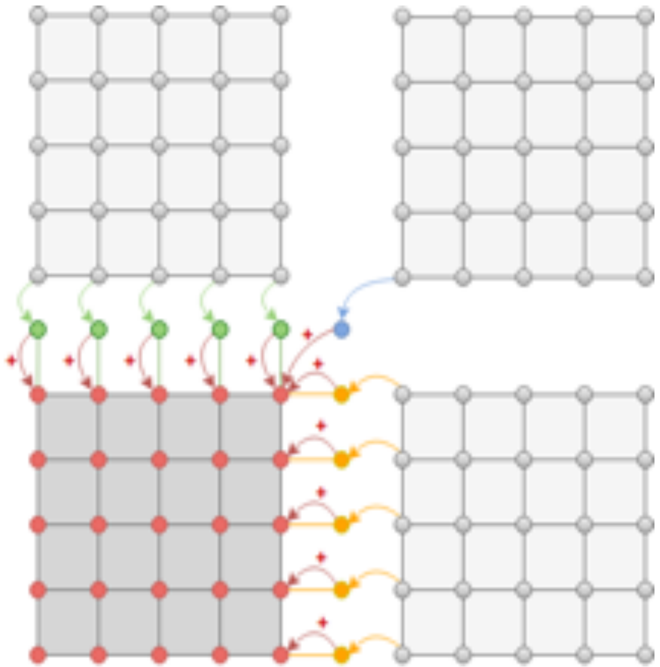
- Normalized time per Iteration



MPI Communication for Kernels

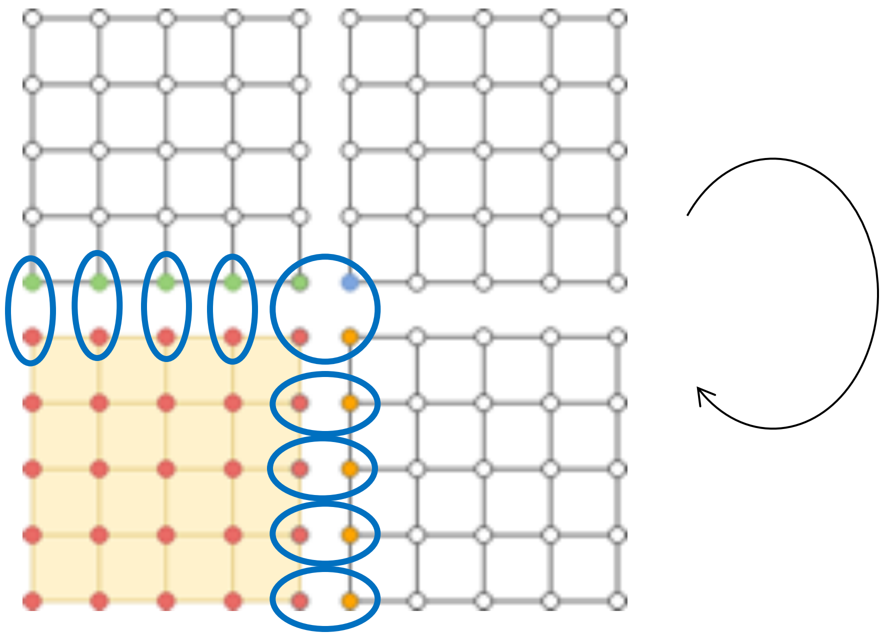
- Kernel 2: communicate neighbors’ corner data, and do local reduction (sum)





LAIK Model: Just Update

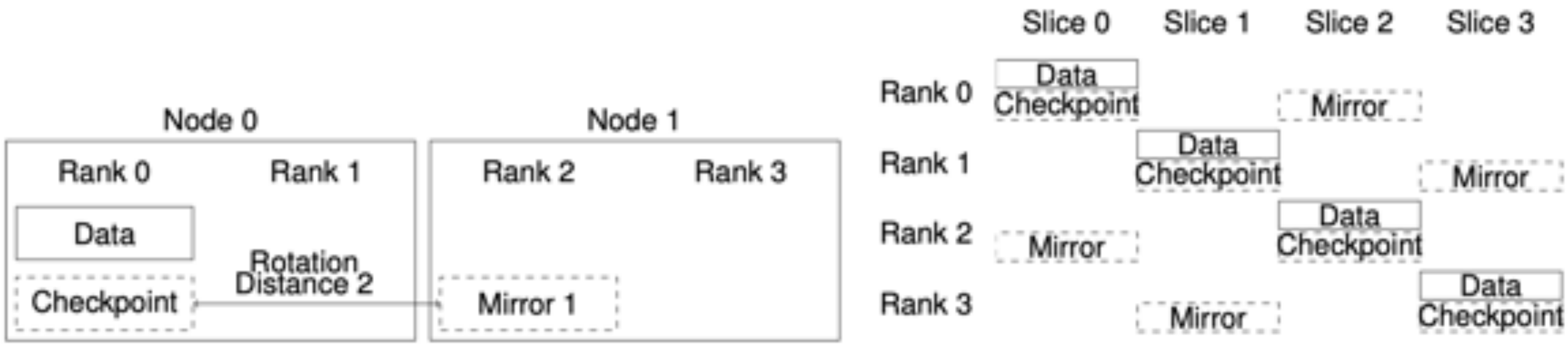
- Kernel 2: one partitioning with overlapping access at edges: triggers reduction on update



use SUM
reduction

Fault Tolerance for spontaneous Failures

Regular “in-memory” checkpointing, to neighbor node
Extend partitioning for redundancy, copy into “checkpoint” containers



Fault Tolerance for spontaneous Failures

1) Regular “in-memory” checkpointing, to neighbor node
   Extend partitioning for redundancy, copy into “checkpoint” containers

2) Node failure: Transition execution only partially completed
   - Values do not get updated correctly
   - Still, application can proceed (just “wrong values”)
     - Failure handling can be delayed to later point
       (or skips computation)

Fault Tolerance for spontaneous Failures

1) Regular “in-memory” checkpointing, to neighbor node
   Extend partitioning for redundancy, copy into “checkpoint” containers

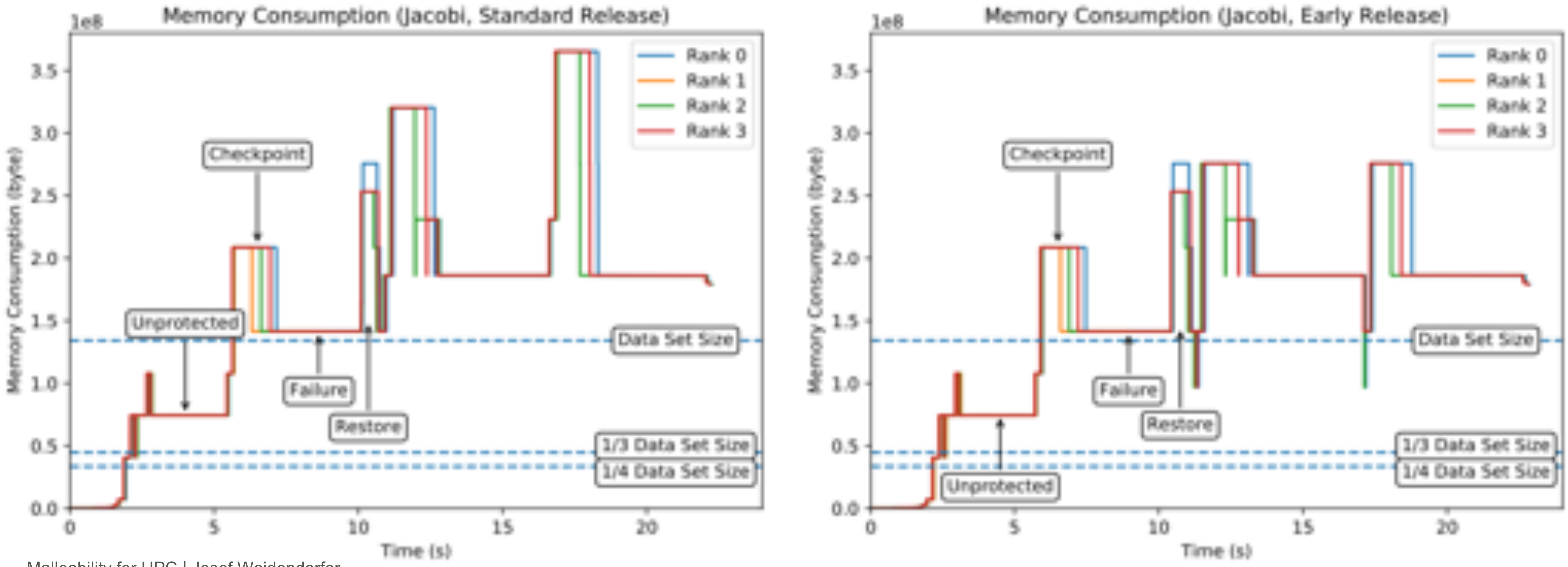
2) Node failure: Transition execution only partially completed
   Failure handling can be delayed to later point

3) Rollback to previous checkpoint
   Copy back, only working if redundancy was enough
   - Without failed processes, data distribution may be different, but can proceed
   - Eventually with Re-balancing step

Evaluated via (1) “TCP backend”, (2) ULFM MPI implementation

Memory Consumption

- ”Standard Release”: delete old checkpoint only after next checkpoint successful
- “Early Release”: delete old checkpoint before creating next checkpoint (higher risk!)



At SC19

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Other Directions LAIK

- Automatic load balancing
- Alternative for virtual topology
  - LAIK knows communication matrix for updates
  - Developer can specify which updates should be as fast as possible
- Other communication backends
  - Shared memory: 2-copy → 1-copy → 0-copy
  - RDMA on libfabric (allows direct resource reservation): less handshakes, better asynchronity
- Show that API works with requirements from real-world applications
  - More ports

Understand what is needed in MPI to best support these features

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Efforts

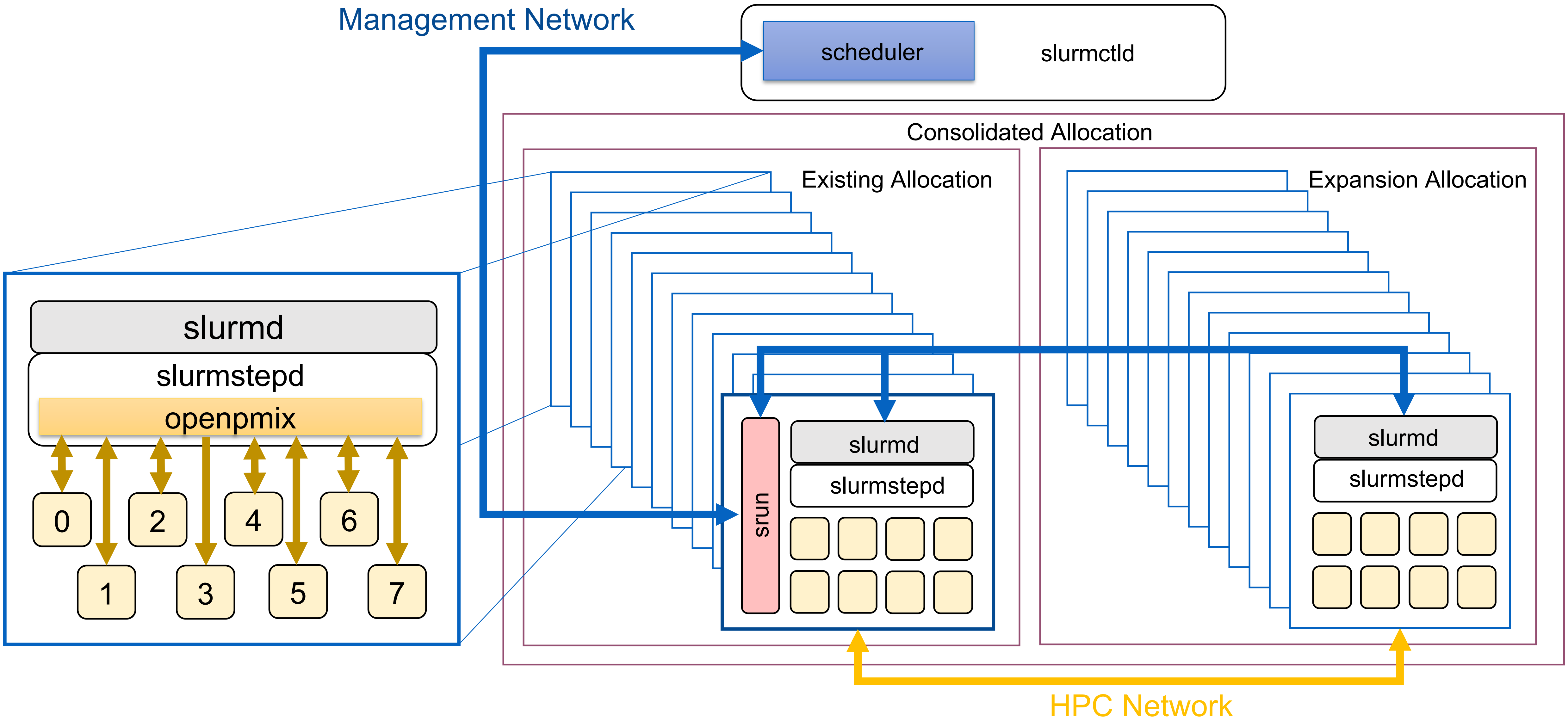
MPI

- TRR Invasic / EU DEEP-SEA
  Research on extending MPI for elasticity, proposal to MPI forum
  (by Isaias Compress Urena, Michael Gerndt)
- Ongoing discussion in MPI WG Malleability
  - Very flexible, covers different use cases

PMIx

- Updates for malleability
- Pushed by work in EU DEEP-SEA

Process Interactions on Malleable Allocations



D3

Adaptation Step 1

D3

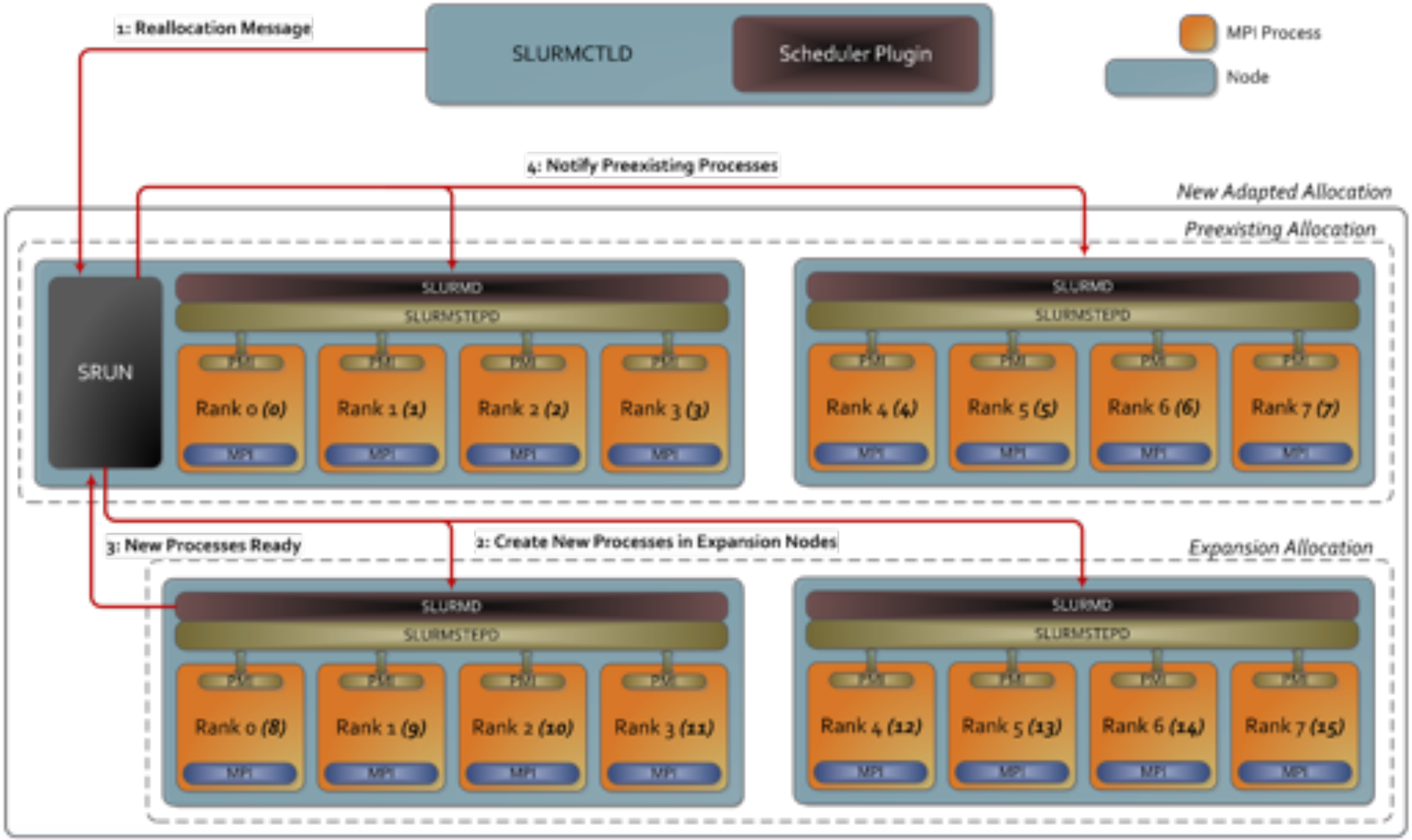
Adaptation Step 2

D3

Adaptation Step 3

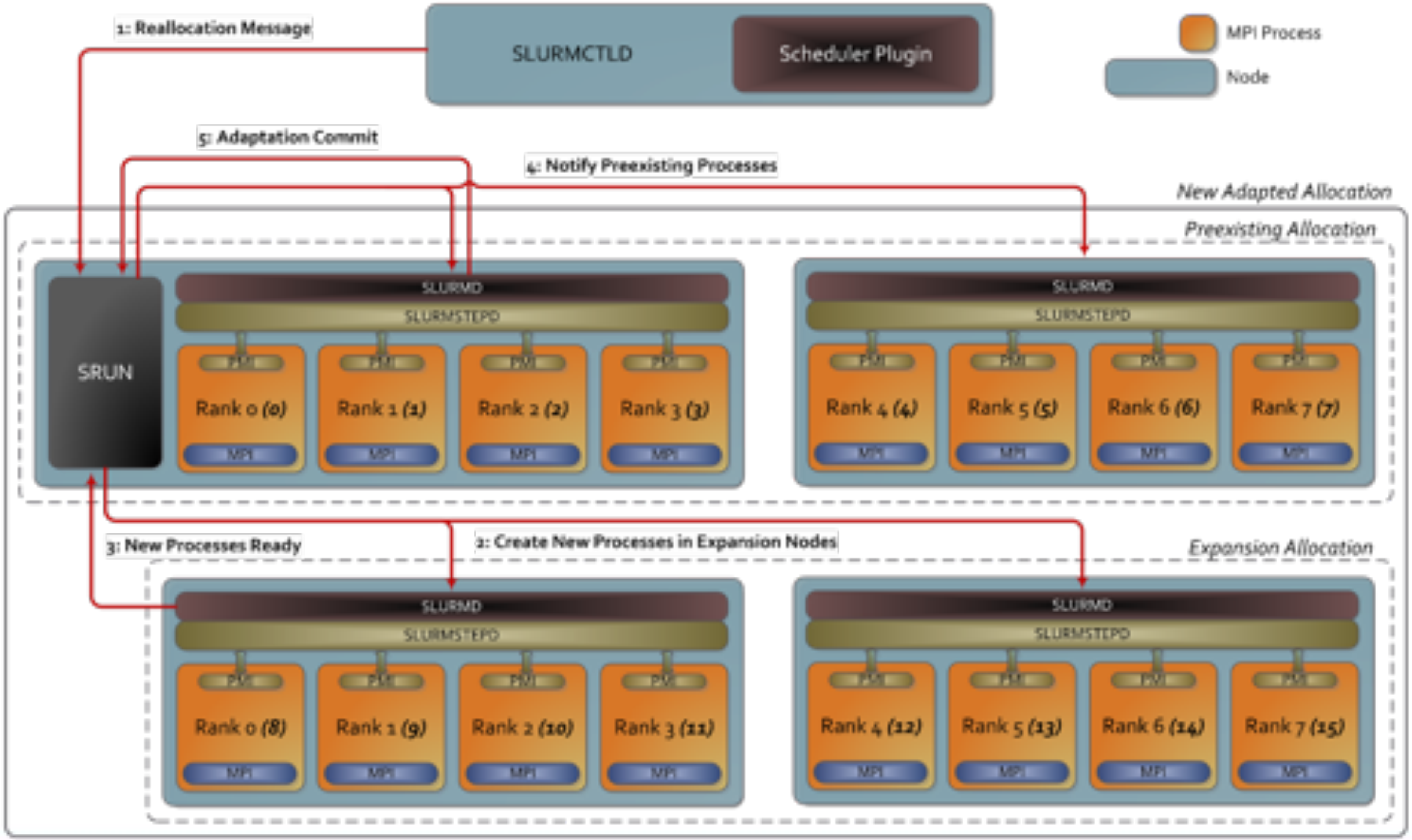
Adaptation Step 4

D3



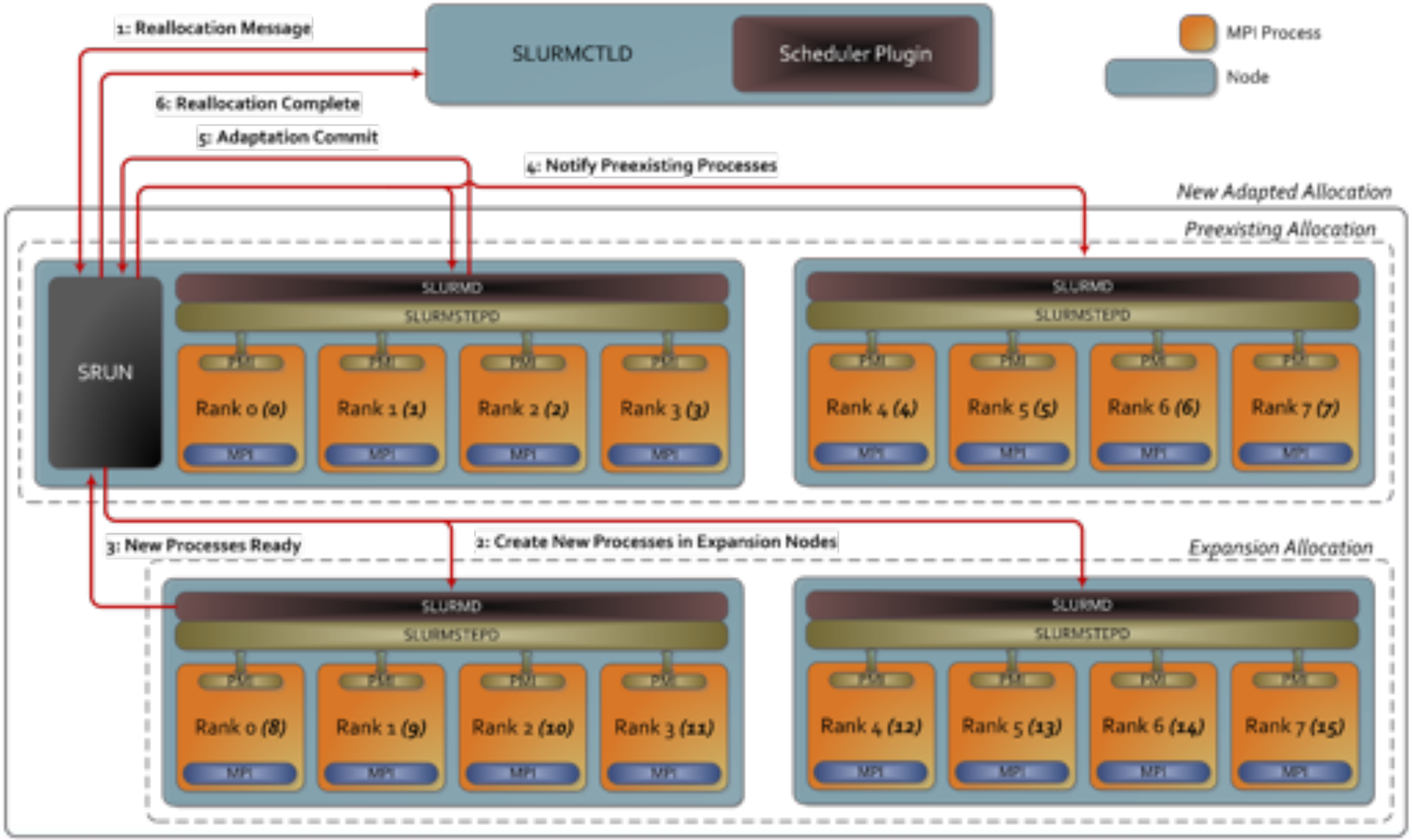
D3

Adaptation Step 5



D3

Adaptation Step 6



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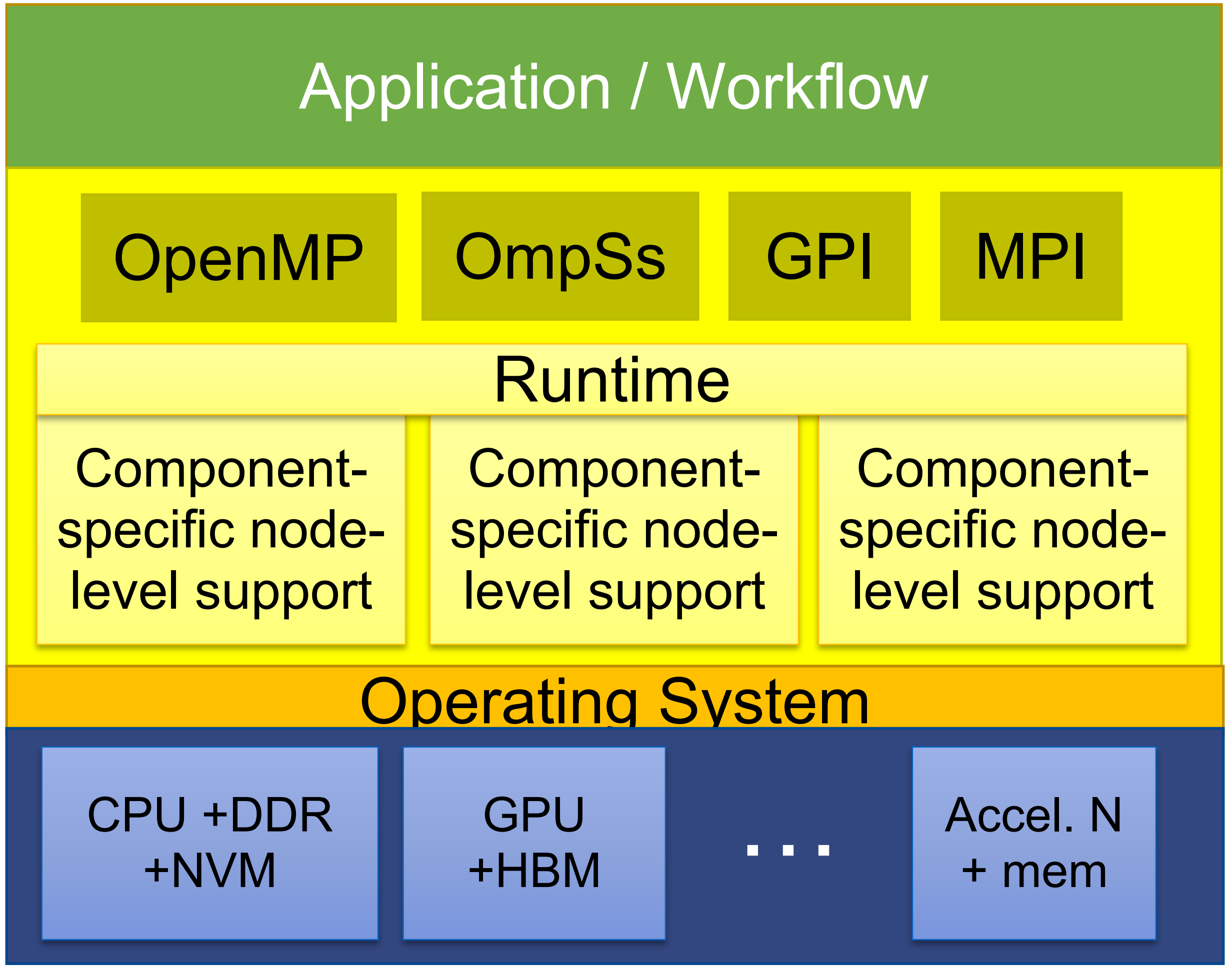
PMIx in DEEP-SEA System Software

- PMIx enables interoperability
  - Programming models:
    - *MPI, GPI2, GPI-Space, OmpSS*
  - Tools support:
    - *Trace analyzers, memory analyzers, monitors*
  - Network endpoints setup:
    - *Tools over management network*
    - *HPC network*
  - Heterogeneous task mappings
- Integration primarily with Slurm



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