Adaptive MPI: Overview & Recent Work

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Motivation

- Main challenge for applications: variability
  - Hardware variation
    - Static/dynamic, heterogeneity, failures, power, etc.
  - Dynamic program behavior
    - AMR, particle movements, subscale simulations, …
- To deal with this:
  - Rewrite applications in new languages …
  - Or, implement existing APIs on different runtime systems

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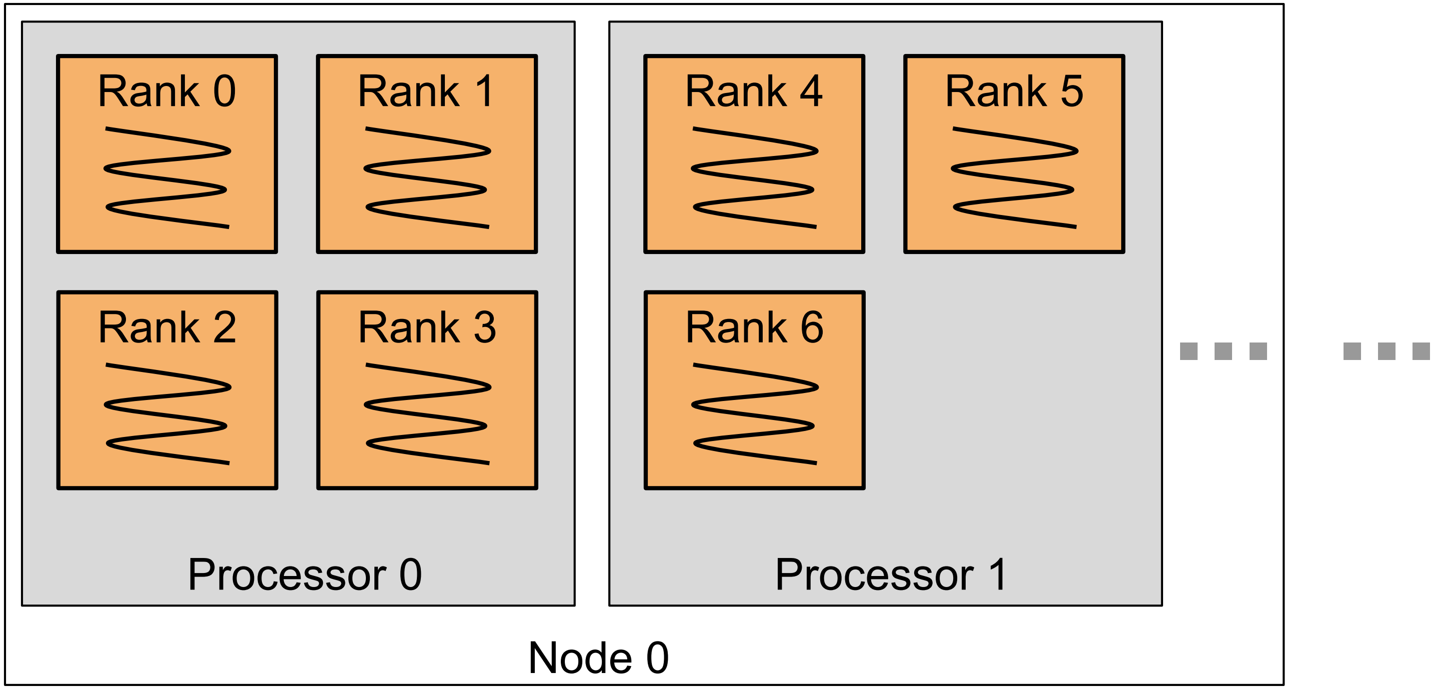
Adaptive MPI

- MPI-2.2 implementation on top of Charm++
  - MPI ranks are lightweight, migratable user-level threads associated with Charm++ objects



Adaptive MPI

- Q: What can Charm++ and its runtime system offer MPI programmers?
- A: Application-independent features for MPI codes:
  - Process virtualization
  - Automatic overlap of comm. & comp.
  - Static and dynamic mapping
  - Automatic fault tolerance
  - OpenMP runtime integration

Overdecomposition

- MPI programmers already decompose to MPI ranks:
  - One rank per node/core/…
- AMPI virtualizes MPI ranks, allowing multiple ranks to execute per node/core/…
  - Benefits: cache usage, comm. overlap, etc.
  - Issue: multiple ranks in same OS process now share all their global/static variables

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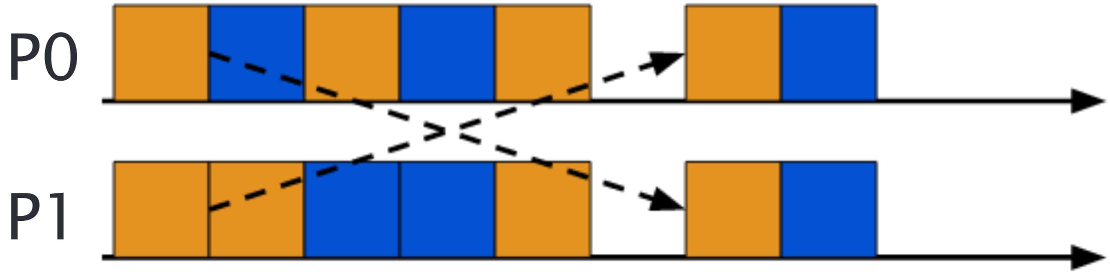
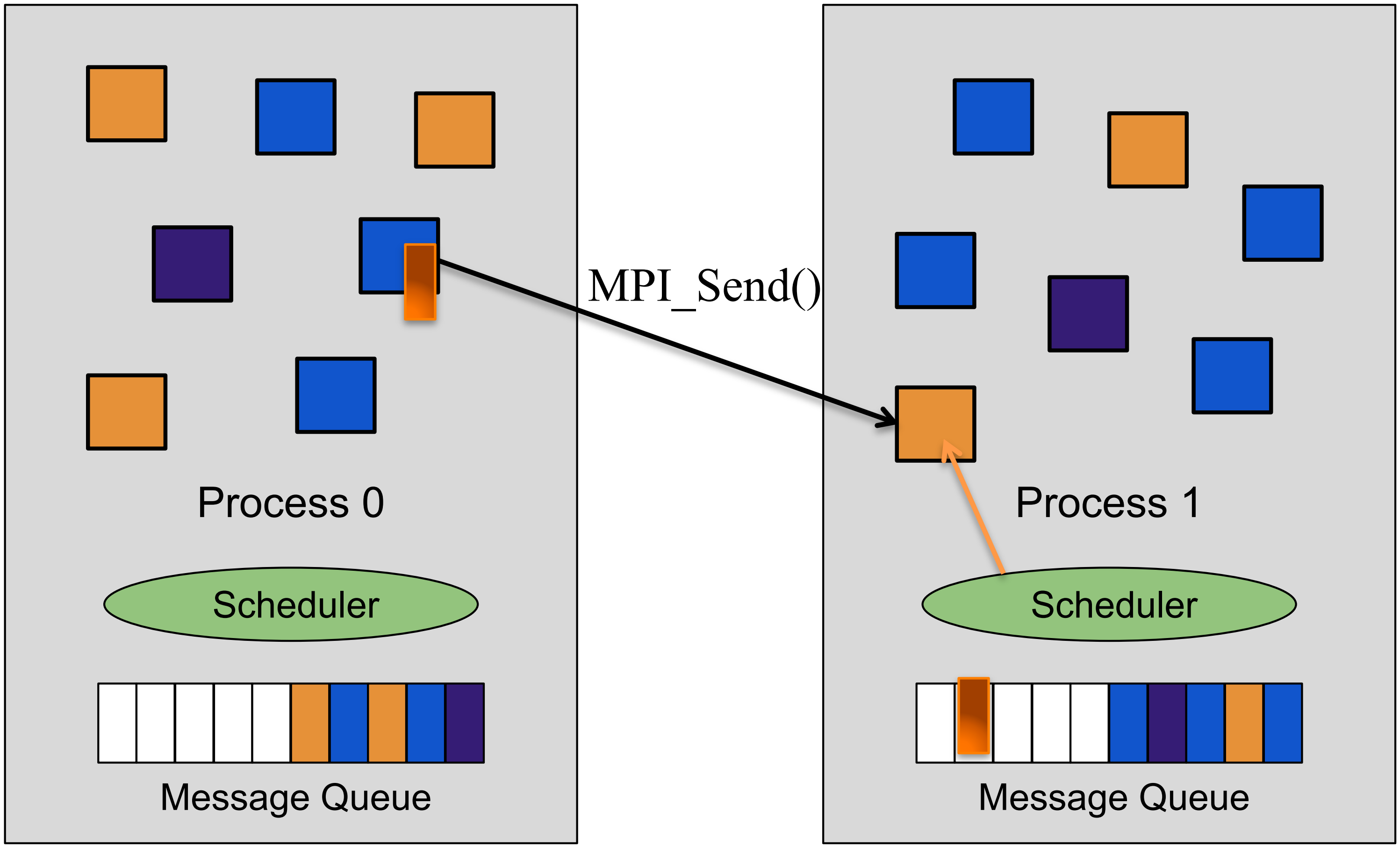
  - Benefits: cache usage, comm. overlap, etc.
  - Issue: multiple ranks in same OS process now share all their global/static variables
    - AMPI programs are MPI programs without mutable global/static variables
    - Compiler support for automating this privatization

Asynchrony

- With multiple MPI ranks per core, how do we schedule them?
- Message-driven execution:
  - Let the work-unit that happens to have data (a matching message) available for it execute next
  - Let the RTS select among ready work units

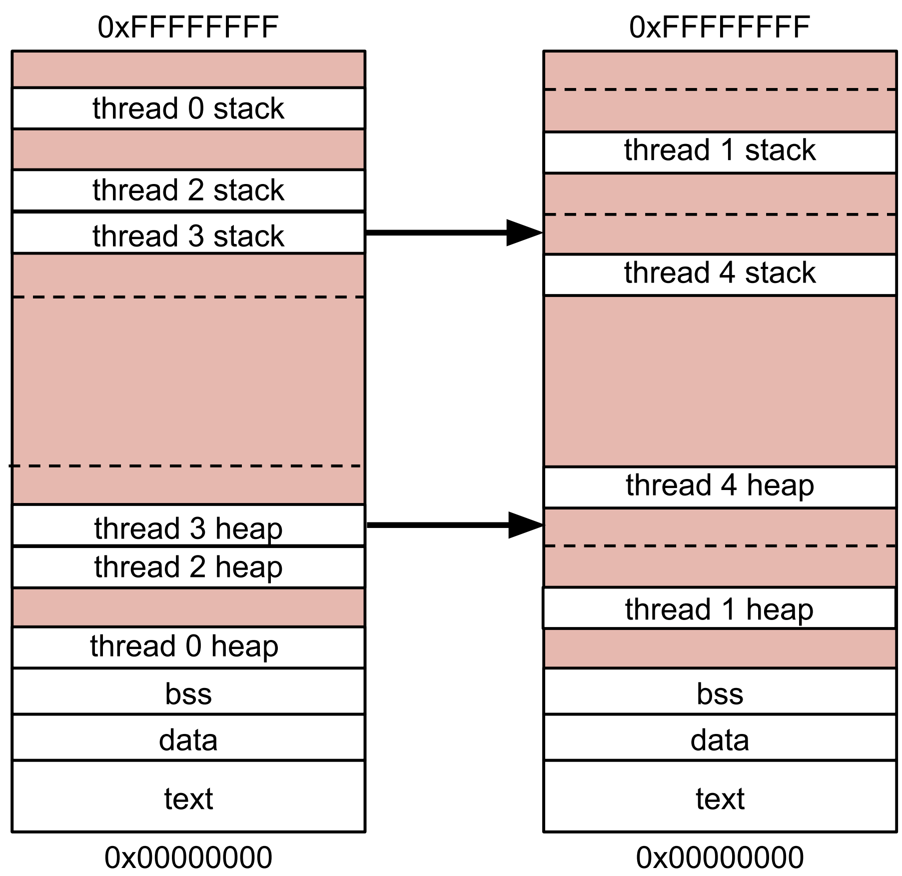


Message-driven Execution



Migratability

- AMPI ranks are migratable at runtime
  - Thread stack + heap



Migratability

- AMPI ranks are migratable at runtime
  - Thread stack + heap
- Isomalloc makes migration automatic
  - No application Pack-UnPack (PUP) code needed
  - Productive, easy to experiment with
- PUP routines are only an optimization
  - Portability: no need for 64-bit VM
  - Performance: only migrate the data that will be needed after migration

Dynamic Load Balancing

- AMPI ranks can be dynamically load balanced between nodes/cores
  - Based on measured idle time, or user-level information
  - Suite of built-in Charm++ strategies available
  - Application developers can write their own strategies too
- User code needs to call AMPI_Migrate() and choose balancer at runtime:
  - srun -n 100 ./pgm +vp 1000 +balancer RefineLB

Fault Tolerance

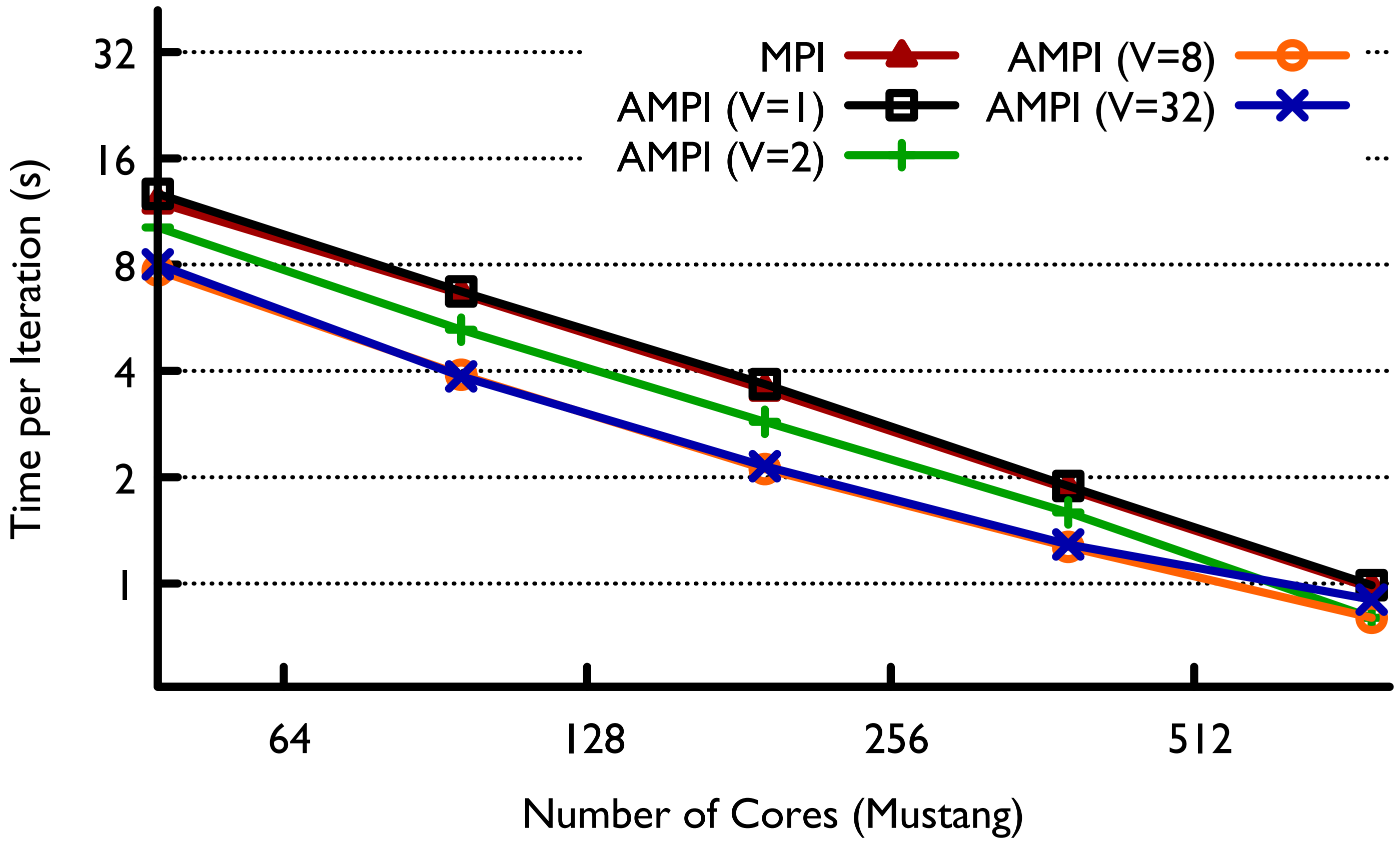
- Basic ideas:
  - Checkpoints are just migrations to storage
  - Underlying storage can be various things
  - Can be used in concert with load balancing
- Four approaches available:
  - Disk-based checkpoint/restart
  - In-memory double checkpoint w/ auto restart
  - Proactive object migration
  - Message-logging

PlasComCM

- The Center for Exascale Simulation of Plasma-Coupled Combustion (XPACC)
  - PSAAPII center at UIUC
  - Collaboration of experimentalists, computational scientists, and computer scientists
- Main simulation code: PlasComCM
  - 150K lines of Fortran90/MPI: runs on AMPI
    - Benefits from overdecomposition
    - Fault tolerance demonstrated
    - Dynamic load imbalance coming in future

PlasComCM Strong Scaling

- Virtualization benefits (V=ranks/core)



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Fault Tolerance

```
PlasComCM: iteration =      96, dt =  0.870094D-02, time =  0.835290D+00, cfl =  0.500000D+00, maxT =  0.298000D+03
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1. Checkpoint

Fault Tolerance

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Socket 4 failed
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1. Checkpoint

2. Failure

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Charmrun finished launching new process in 1.153346 seconds
Charmrun says Processor 1 failed on Node 1
[1] Restarting after crash
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2. Failure

3. Recover

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2. Failure
3. Recover
4. Resume execution

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CharmLB> RefineLB: PE [0] starting at 69.353145
CharmLB> RefineLB: PE [0] #Objects migrating: 7
CharmLB> RefineLB: PE [0] finished at 69.355673 duration 0.002528 s
```

5. Load balance

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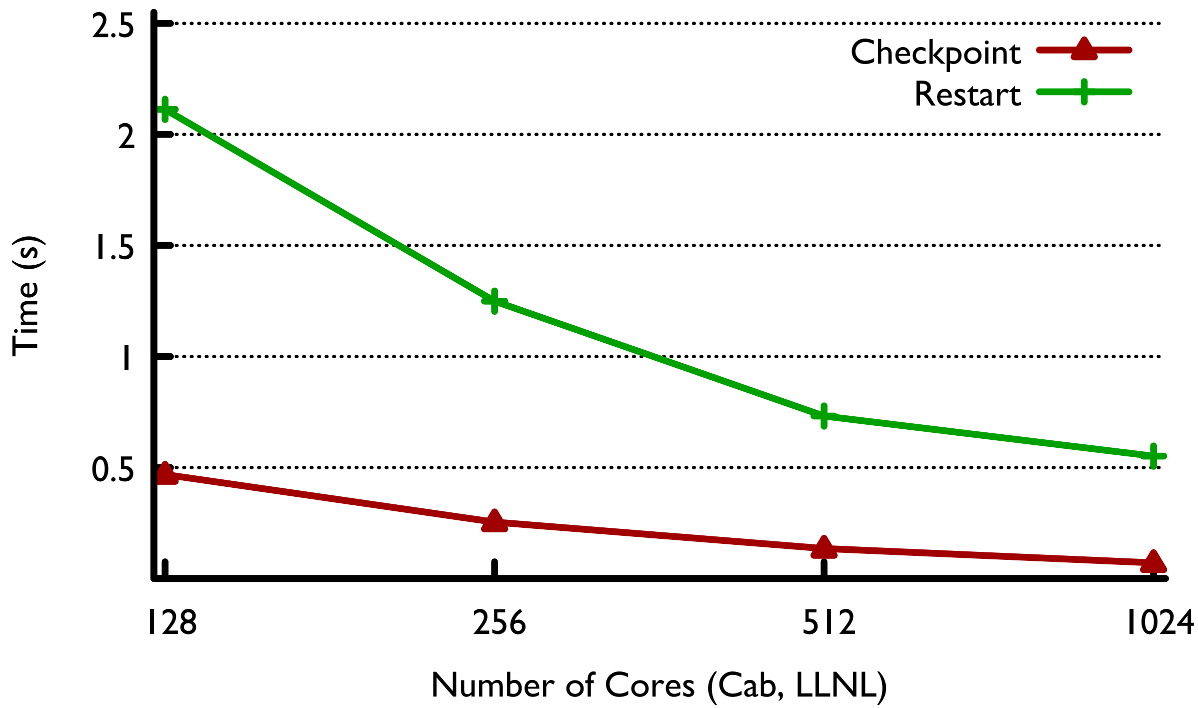
PlasComCM: iteration =      107, dt =  0.870094D-02, time =  0.931001D+00, cfl =  0.500000D+00, maxT =  0.298000D+03
```

Fault Tolerance

- Double in-memory checkpoint is scalable



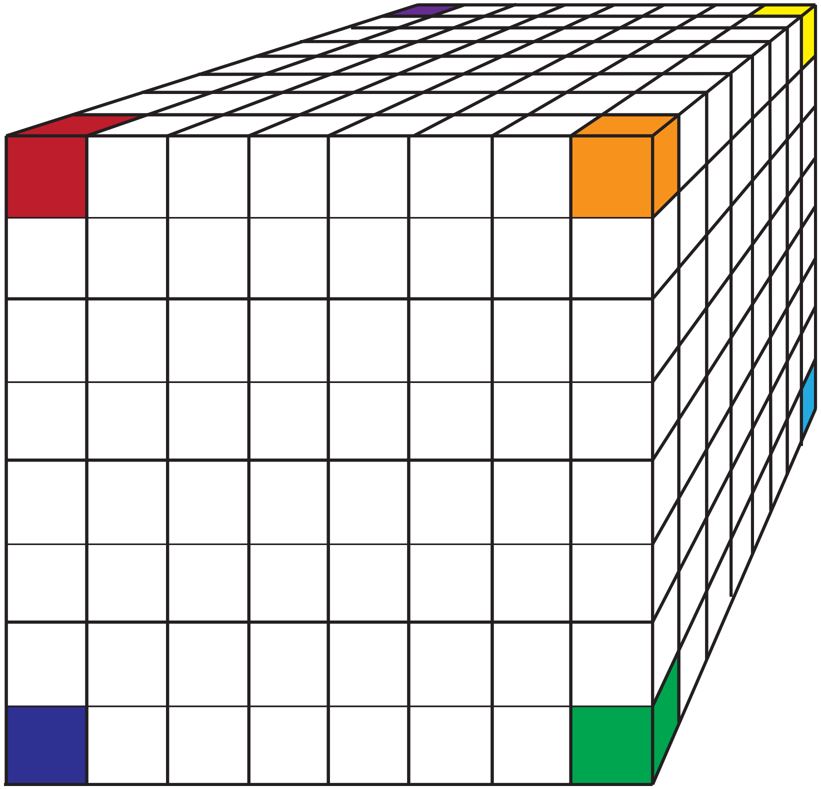
- Minimal changes needed to *PlasComCM*

Kripke

- LLNL ASC proxy app for deterministic particle transport codes
  - Solves the Boltzmann transport equation using parallel sweeps over a 3D domain space
- Given:
  - 3D domain of known materials
  - Initial flow of particles through domain
  - Particle-generating sources inside the domain
  - Boundary conditions
- Solution:
  - Particle flux at every point inside the domain at a later time

Kripke

- Key communication pattern: parallel sweep



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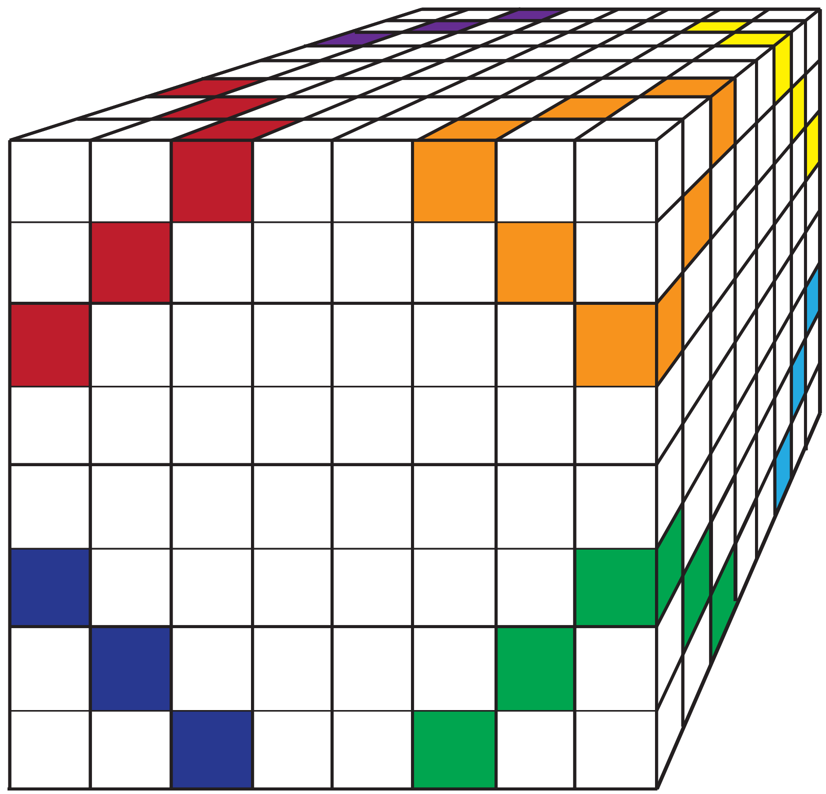

Kripke

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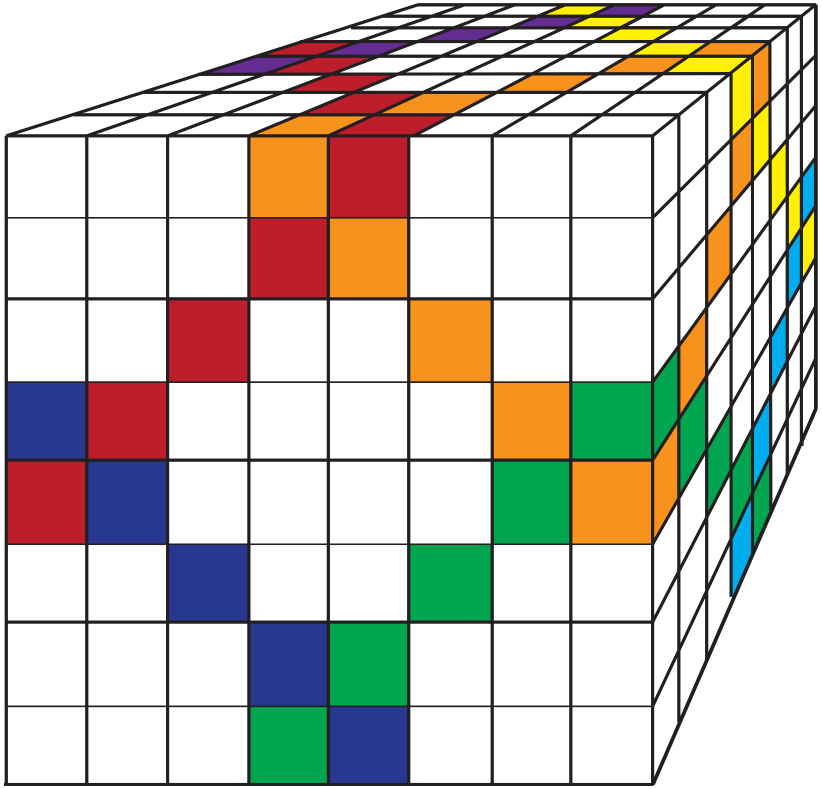
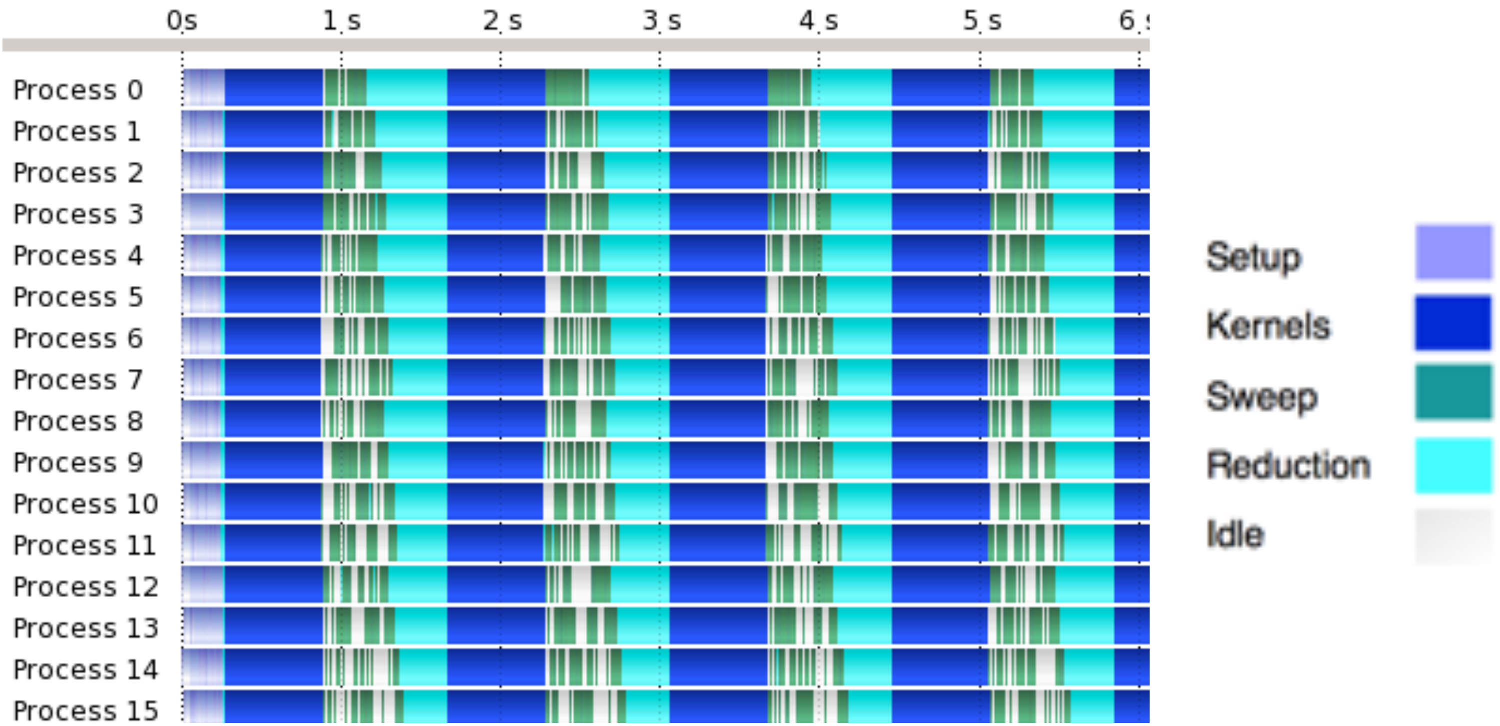


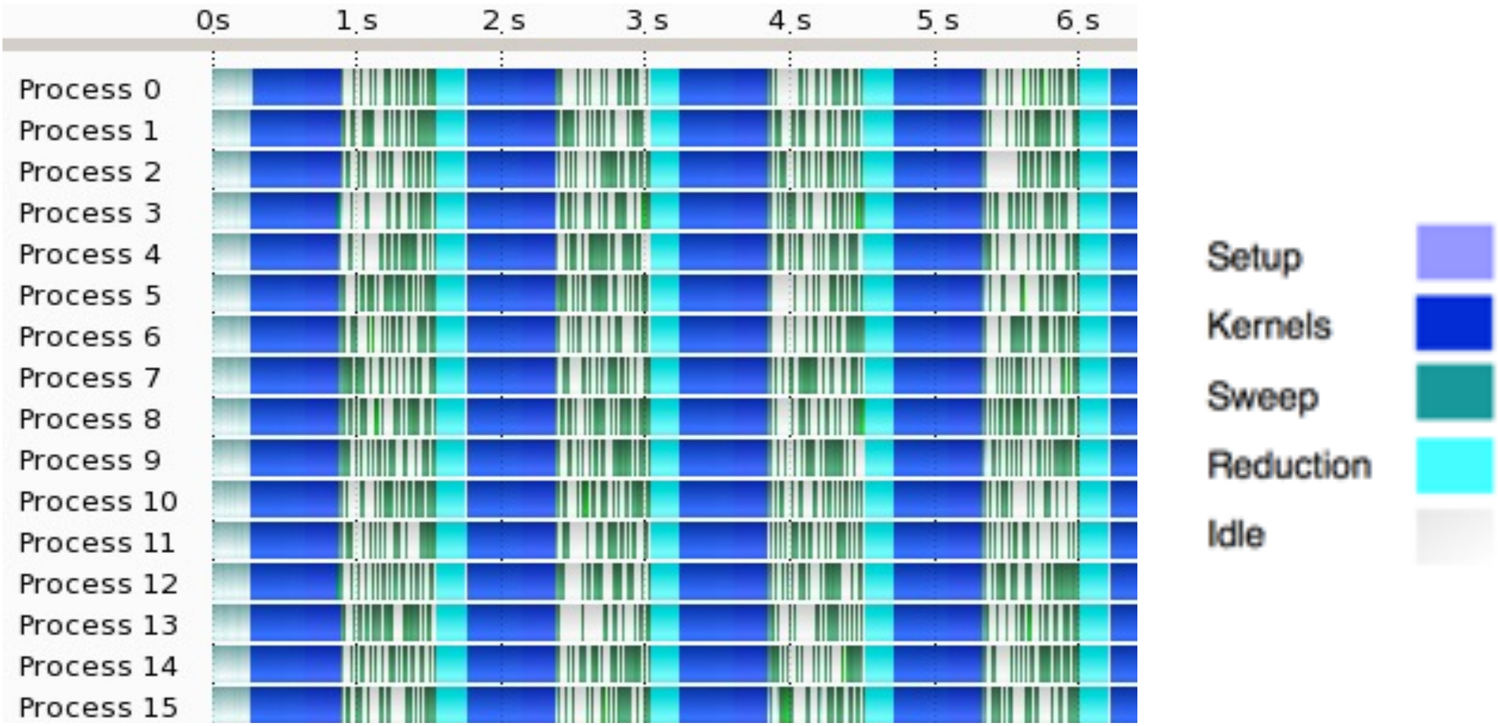
Mapping

- Blocked mapping of subdomains to ranks is efficient within-node



Mapping

- Scattered mapping increases concurrency
  - 5-10% improvement at scale



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OpenMP Integration

- Charm++ version of GNU OpenMP 4.0 works with AMPI
  - (A)MPI+OpenMP configurations on P cores/node:

Notation	Ranks/Node	Threads/Rank	MPI(+OpenMP)	AMPI(+OpenMP)
P:1	P	1	✔	✔
1:P	1	P	✔	✔
P:P	P	P		✔

  - AMPI+OpenMP can do P:P without oversubscription of system resources

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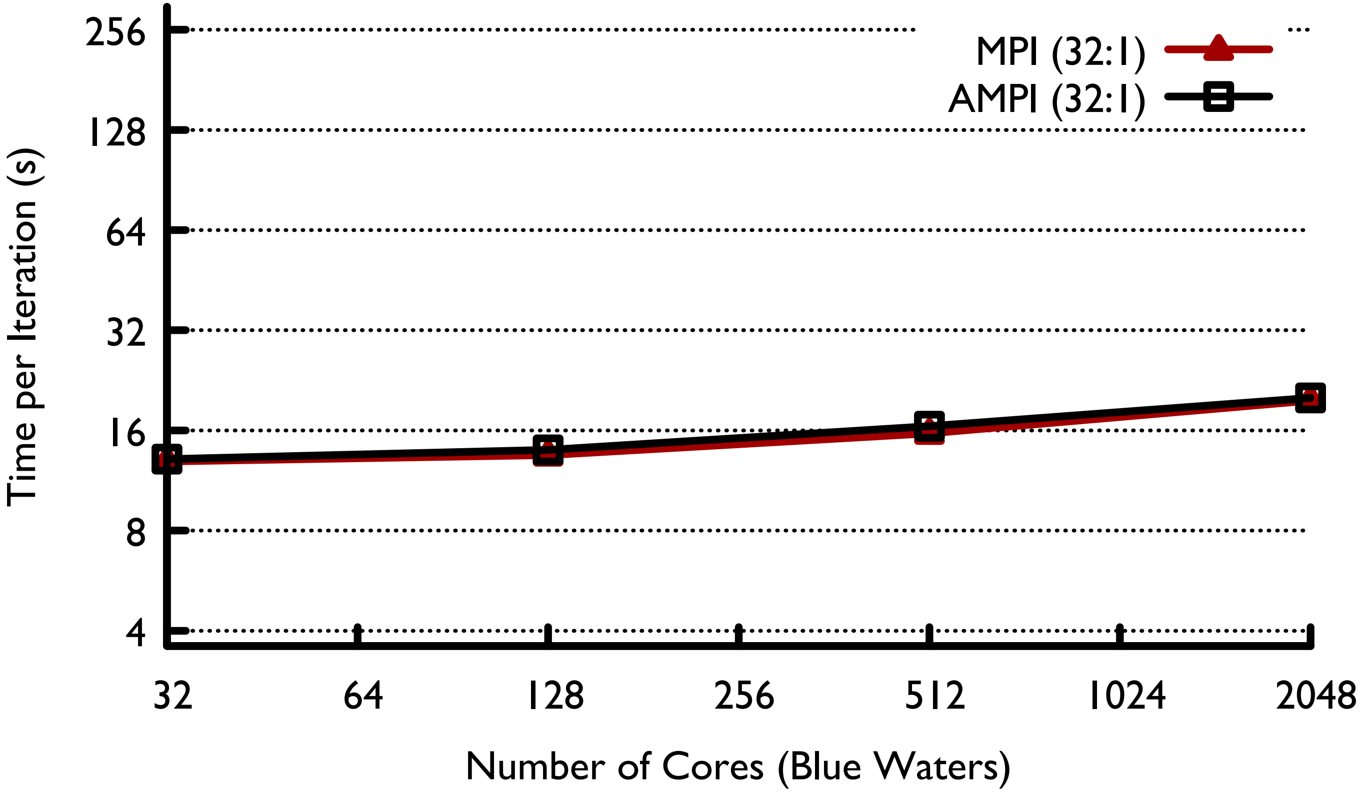
Kripke Weak Scaling

- (A)MPI-only suffers from transient load imbalance during the sweep



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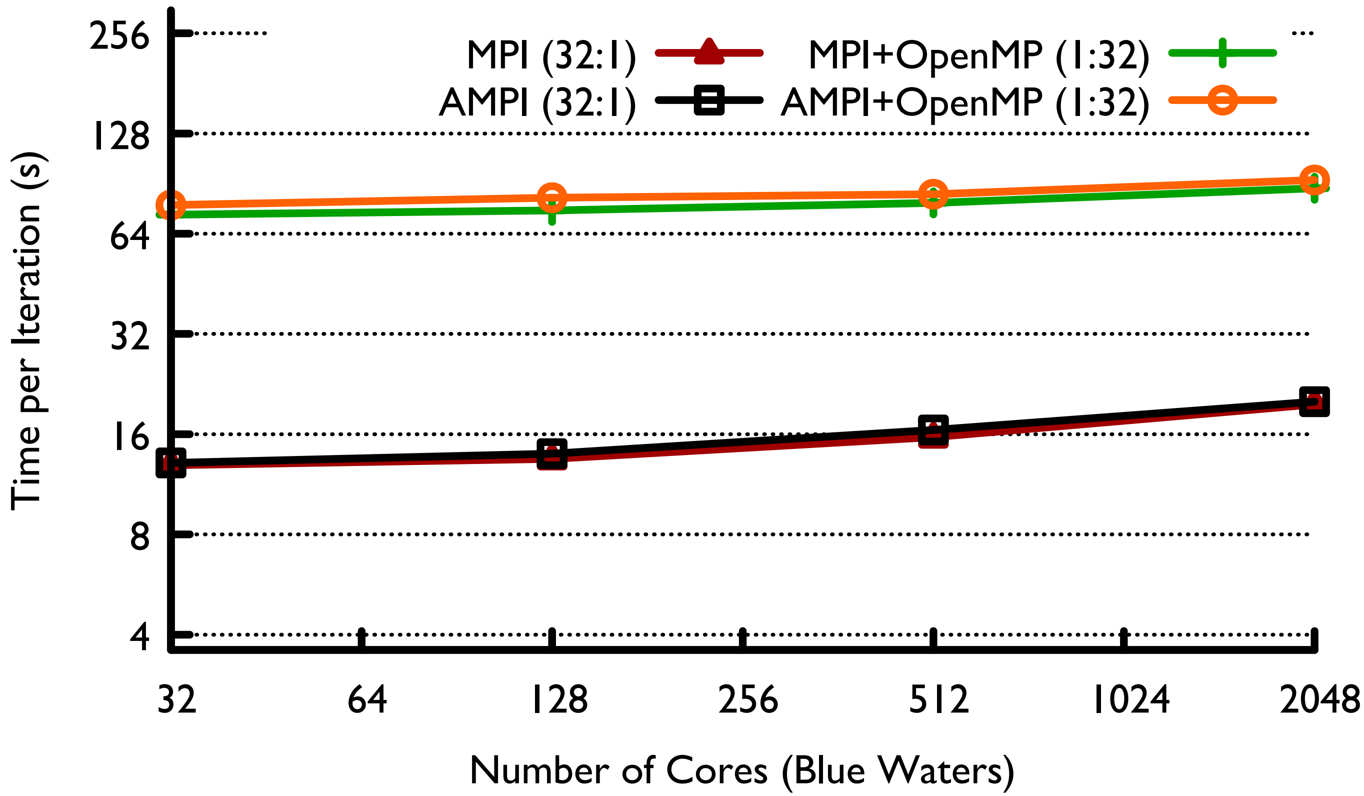
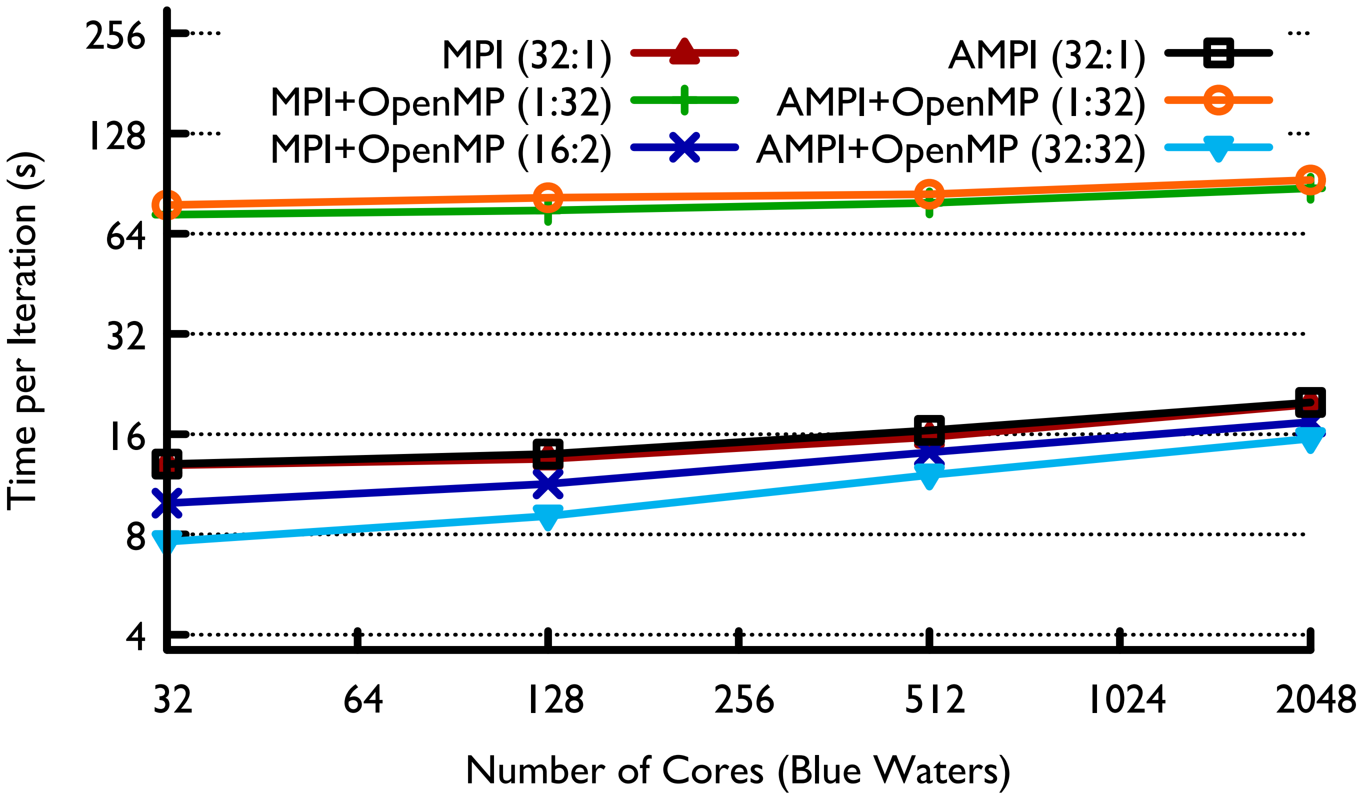
OpenMP Interoperation

- (A)MPI+OpenMP (1:P) loses out on the sweep's pipeline parallelism



OpenMP Integration

- Kripke benefits from AMPI+OpenMP (P:P)
  - Pipeline parallelism + within-node load balancing



Recent Progress

- Charm++ 6.7.1 is a feature release for AMPI
  - AMPI extensions now prefixed with ‘AMPI_’
  - MPI-2.2 compliance
  - MPI-3.1 nonblocking & neighborhood collectives
  - Improved performance for test, wait routines
  - *ampicc* is more compatible with autoconf/cmake
- Ongoing work:
  - Conformance to MPI-3.1
  - True RDMA for MPI’s RMA routines
  - Optimization of AMPI+OpenMP integration

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Summary

- Adaptive MPI provides Charm++'s high-level features to pre-existing MPI applications
  - Overdecomposition
  - Overlap of communication and computation
  - Configurable static mapping
  - Dynamic load balancing
  - Automatic fault tolerance
  - OpenMP runtime integration

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Thank you