Advanced Parallel Programming

Is there life beyond MPI?

Outline

- MPI vs. High Level Languages
- Declarative Languages
- Map Reduce and Hadoop
- Shared Global Address Space Languages
- Charm++
- ChaNGa
- ChaNGa on GPUs

Parallel Programming in MPI

- Good performance
- Highly portable: de facto standard
- Poor match to some architectures
  - Active Messages, Shared Memory
- New machines are hybrid architectures
  - Multicore, Vector, RDMA, Cell
- Parallel Assembly?

Parallel Programming in High Level Languages

- Abstraction allows easy expression of new algorithms
- Low level architecture is hidden (or abstracted)
- Integrated debugging/performance tools
- Sometimes a poor mapping of algorithm onto the language
- Steep learning curve

Parallel Programming Hierarchy

- Decomposition of computation into parallel components
  - Parallelizing compiler, Chapel
- Mapping of components to processors
  - Charm++
- Scheduling of components
  - OpenMP, HPF
- Expressing the above in data movement and thread execution
  - MPI

Language Requirements

- General Purpose
- Expressive for application domain
  - Including matching representations: *(a + i) vs a[i]
- High Level
- Efficiency/obvious cost model
- Modularity and Reusability
  - Context independent libraries
  - Similar to/interoperable with existing languages

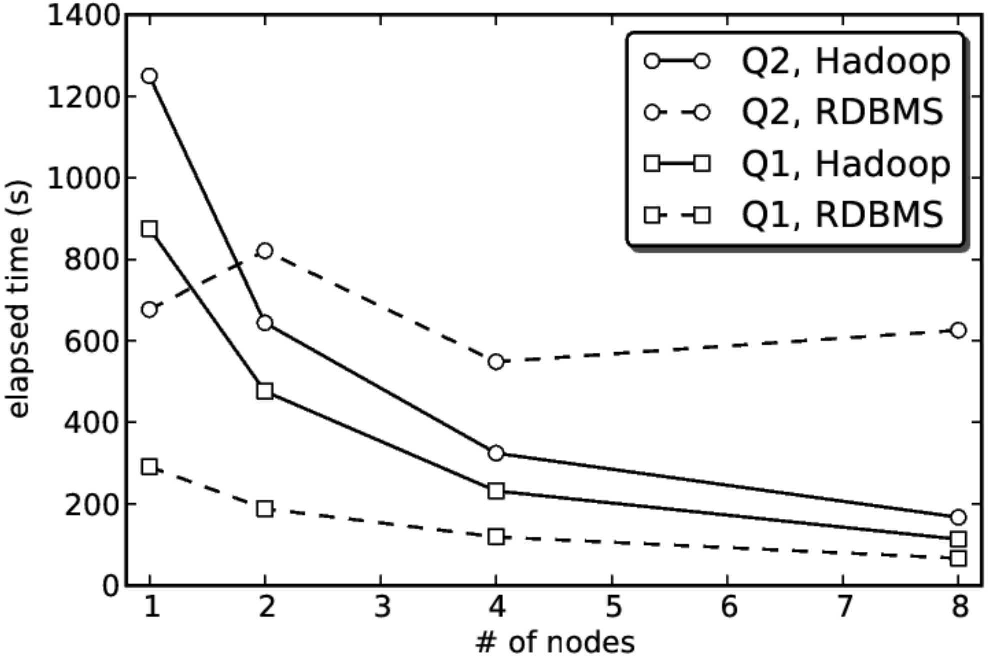
Declarative Languages

- SQL example:

  SELECT SUM(L_Bol) FROM stars WHERE tform > 12.0
- Performance through abstraction
- Limited expressivity, otherwise
  - Complicated
  - Slow (UDF)

Map Reduce & Hadoop

- Map: function produces (key, value) pairs
- Reduce: collects Map output
- Pig: SQL-like query language
- Effective data reduction framework
- Not suitable for HPC



Array Languages, e.g., CAF

- Arrays distributed across images
- Each processor can access data on other processors via co-array syntax

```
call sync_all(/up, down/)
new_A(1:ncol) = new_A(1:ncol)
+A(1:ncol)[up] + A(1:ncol)[down]
call sync_all(/up, down/)
```

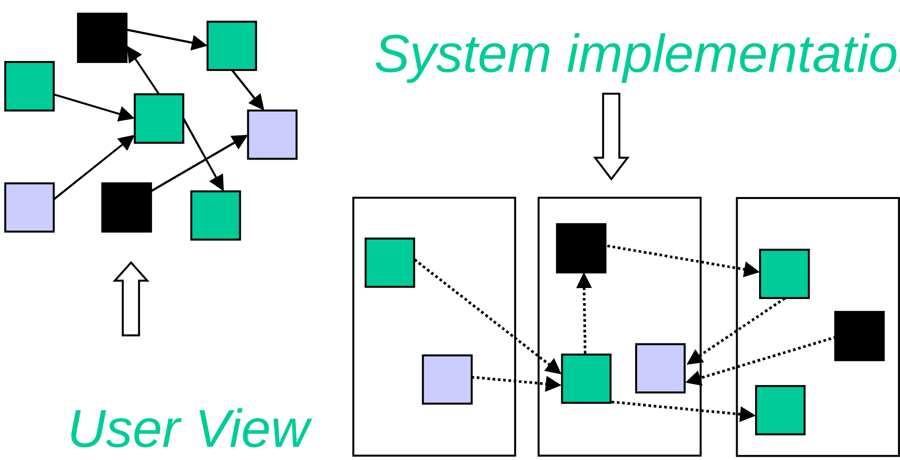
- Easy expression of array model
- Cost transparent

Charm++: Migratable Objects

Programmer: **[Over] decomposition into virtual processors**

Runtime: **Assigns VPs to processors**

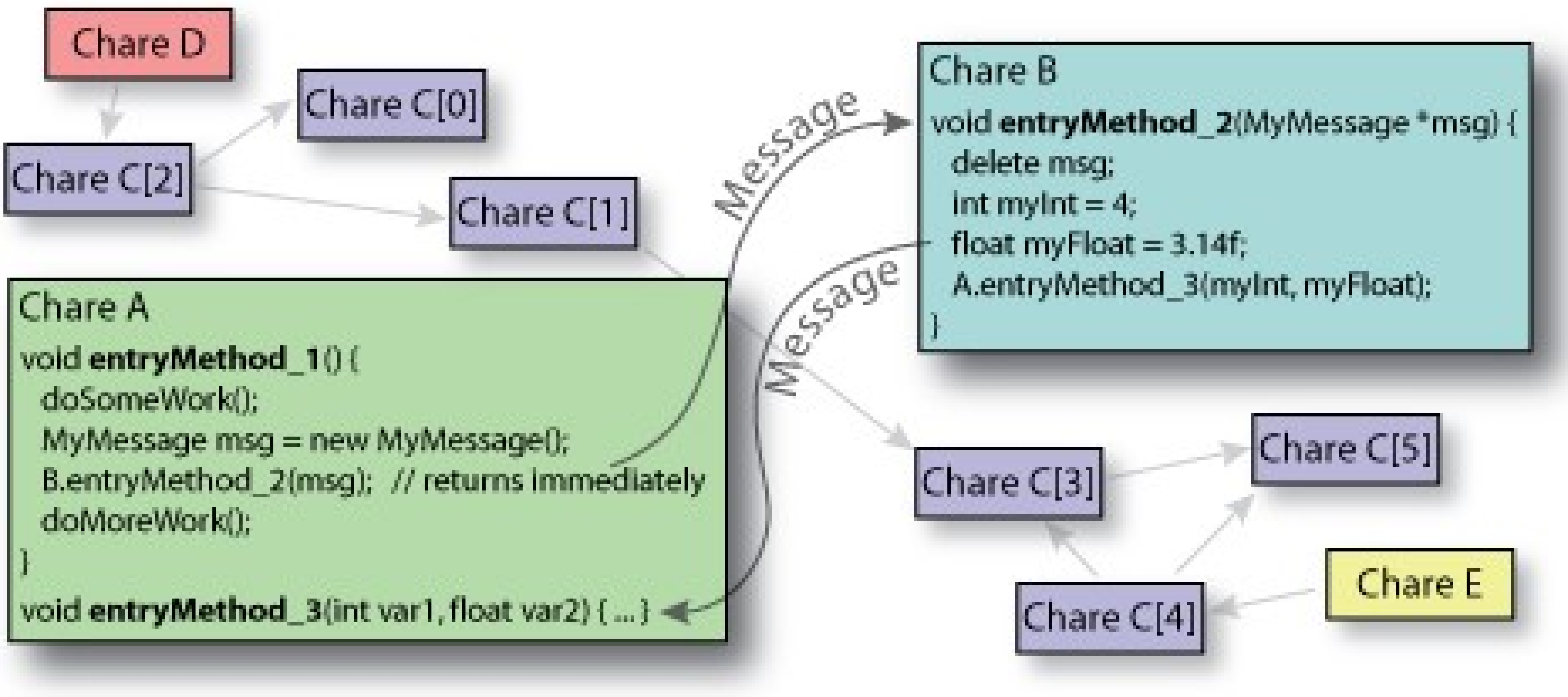
Enables *adaptive runtime strategies*



Benefits

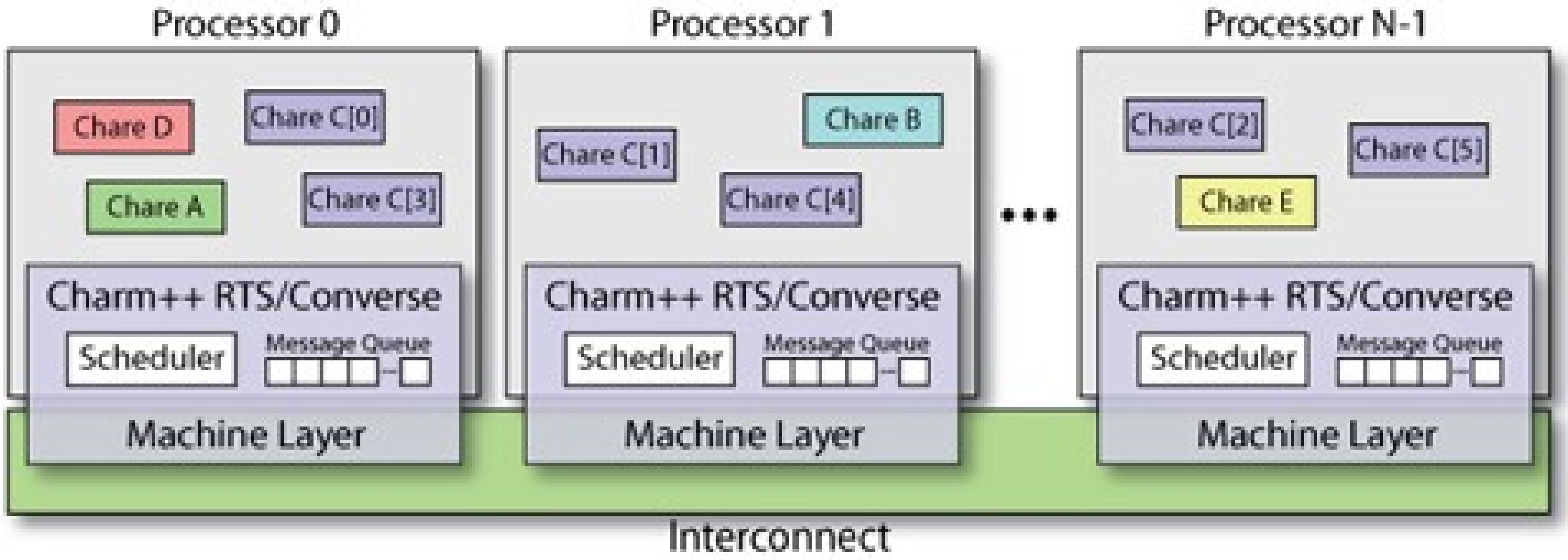
- Software engineering
  - Number of virtual processors can be independently controlled
  - Separate VPs for different modules
- Message driven execution
  - Adaptive overlap of communication
- Dynamic mapping
  - Heterogeneous clusters
    - Vacate, adjust to speed, share
  - Automatic checkpointing
  - Change set of processors used
  - Automatic dynamic load balancing
  - Communication optimization

User view



Chare D
Chare C[0]
Chare C[2]
Chare C[1]
Chare A
void entryMethod_1() {
doSomeWork();
MyMessage msg = new MyMessage();
B.entryMethod_2(msg); // returns immediately
doMoreWork();
}
void entryMethod_3(int var1, float var2) { ... }
Message
Message
Chare B
void entryMethod_2(MyMessage *msg) {
delete msg;
int myInt = 4;
float myFloat = 3.14f;
A.entryMethod_3(myInt, myFloat);
}
Chare C[3]
Chare C[5]
Chare C[4]
Chare E

System View


Processor 0
Processor 1
Processor N-1
Chare D
Chare C[0]
Chare A
Chare C[3]
Chare C[1]
Chare B
Chare C[4]
Chare C[2]
Chare C[5]
Chare E
Charm++ RTS/Converse
Scheduler
Message Queue
Machine Layer
Interconnect

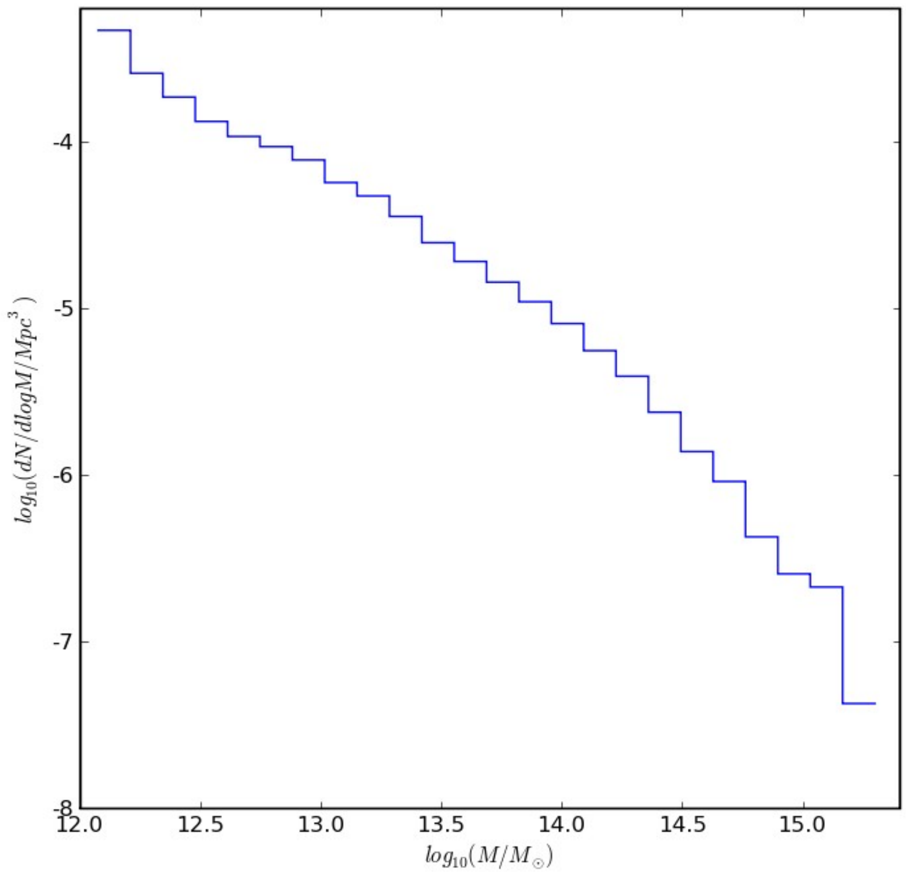
Gravity Implementations

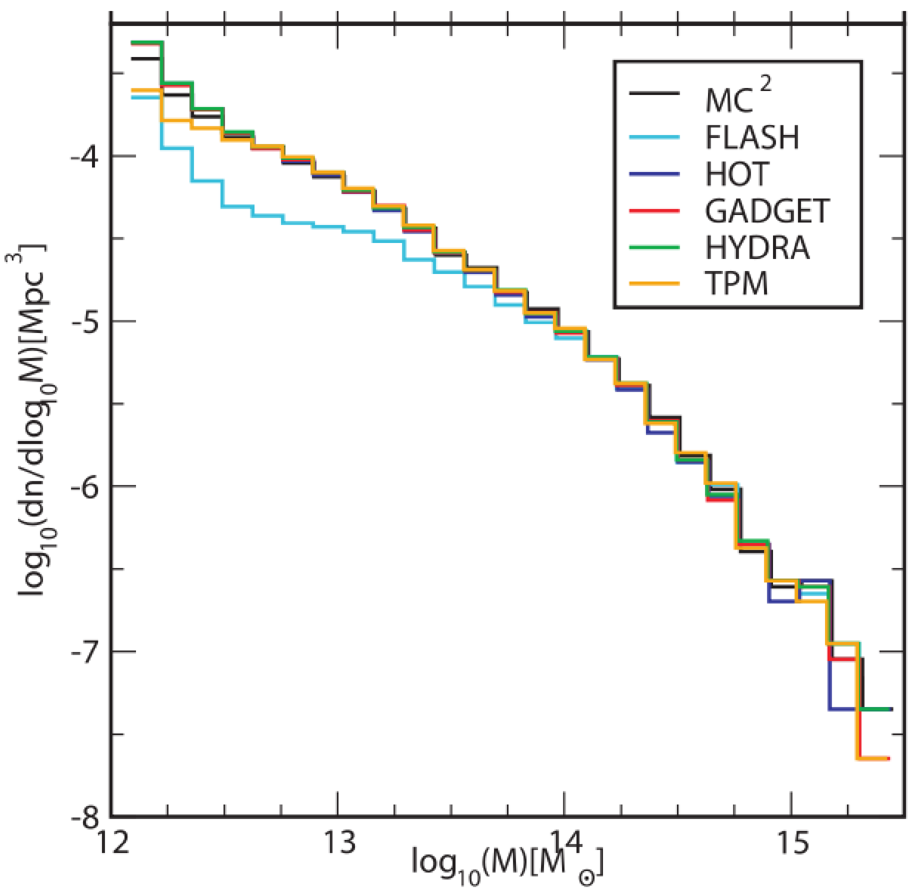
- Standard Tree-code
- “Send”: distribute particles to tree nodes as the walk proceeds.
  - Naturally expressed in Charm++
  - Extremely communication intensive
- “Cache”: request treenodes from off processor as they are needed.
  - More complicated programming
  - “Cache” is now part of the language

ChaNGa Features

- Tree-based gravity solver
- High order multipole expansion
- Periodic boundaries (if needed)
- SPH: (Gasoline compatible)
- Individual multiple timesteps
- Dynamic load balancing with choice of strategies
- Checkpointing (via migration to disk)
- Visualization

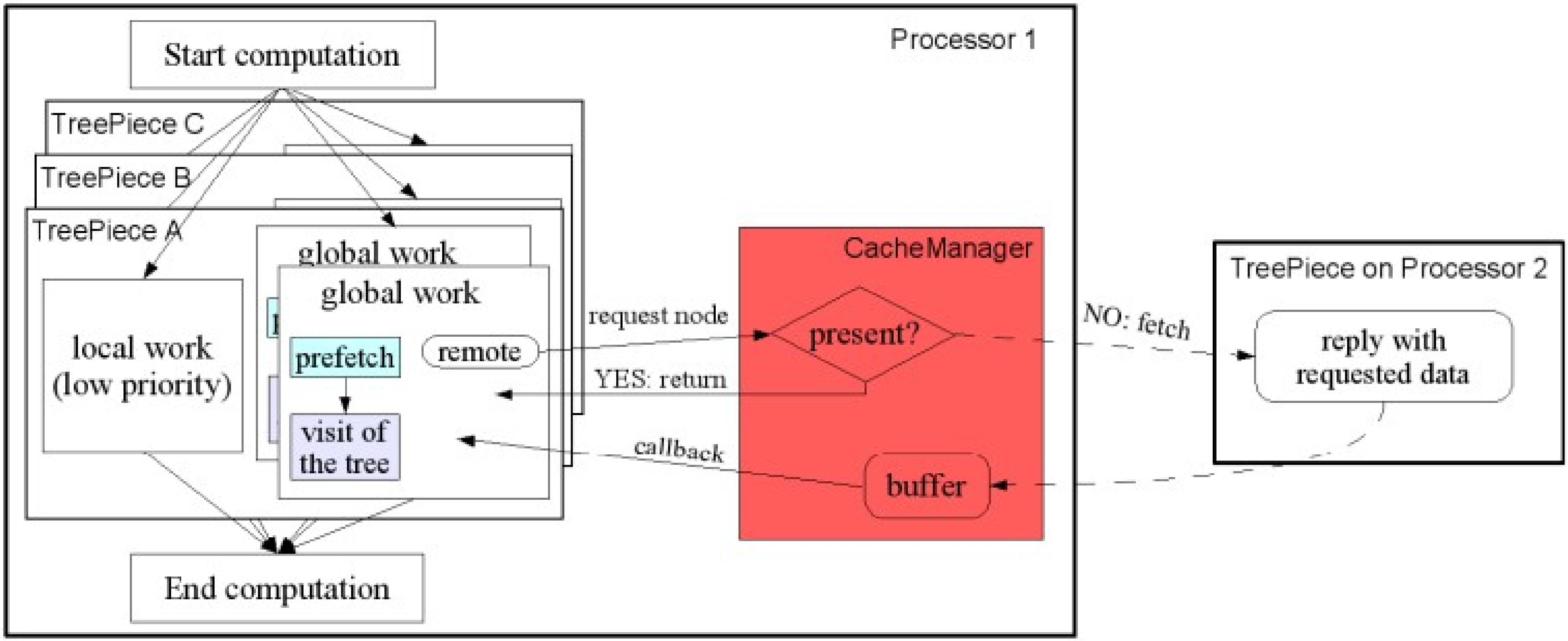
Cosmological Comparisons: Mass Function





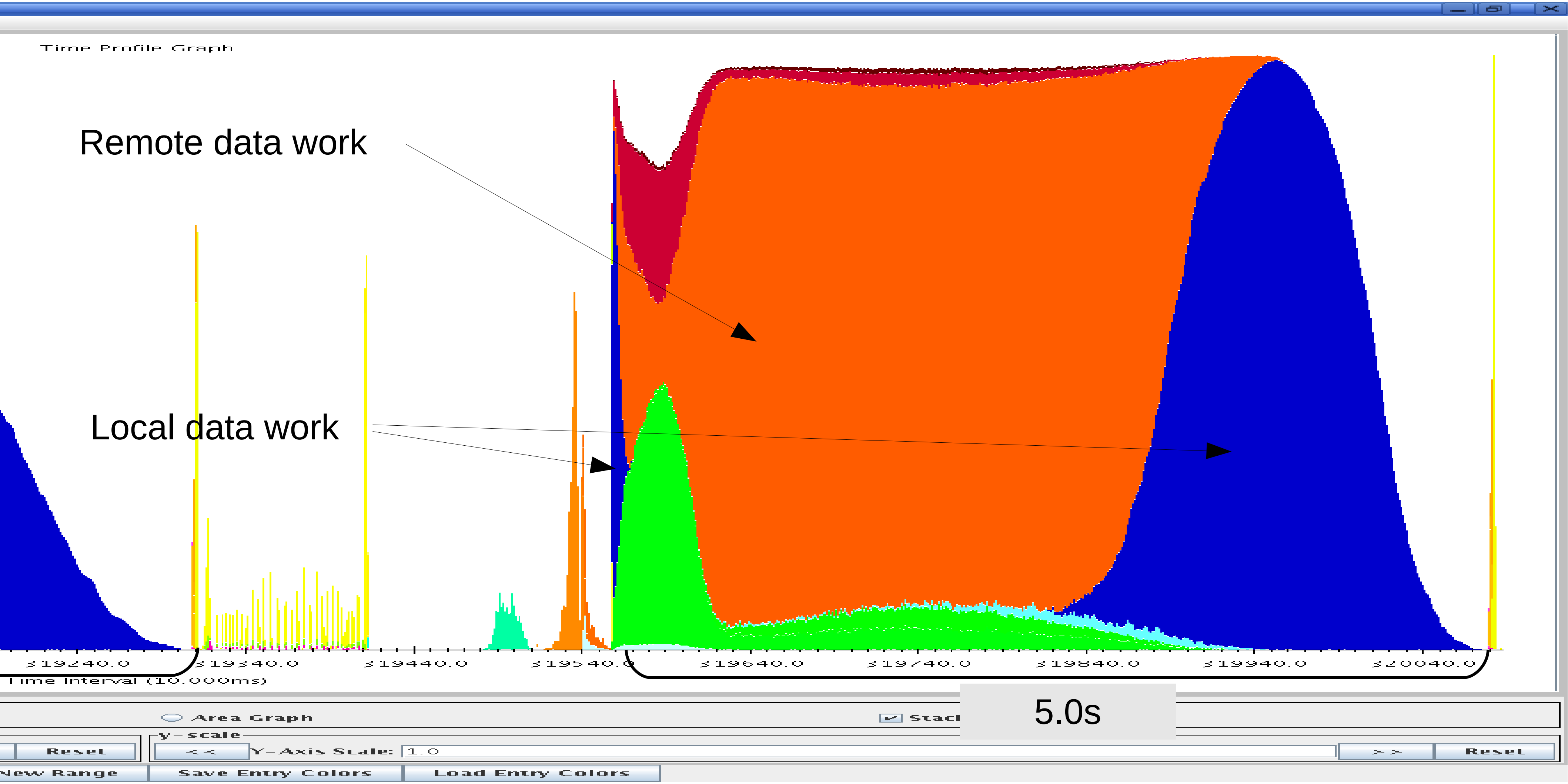
Heitmann, et al. 2005

Overall structure



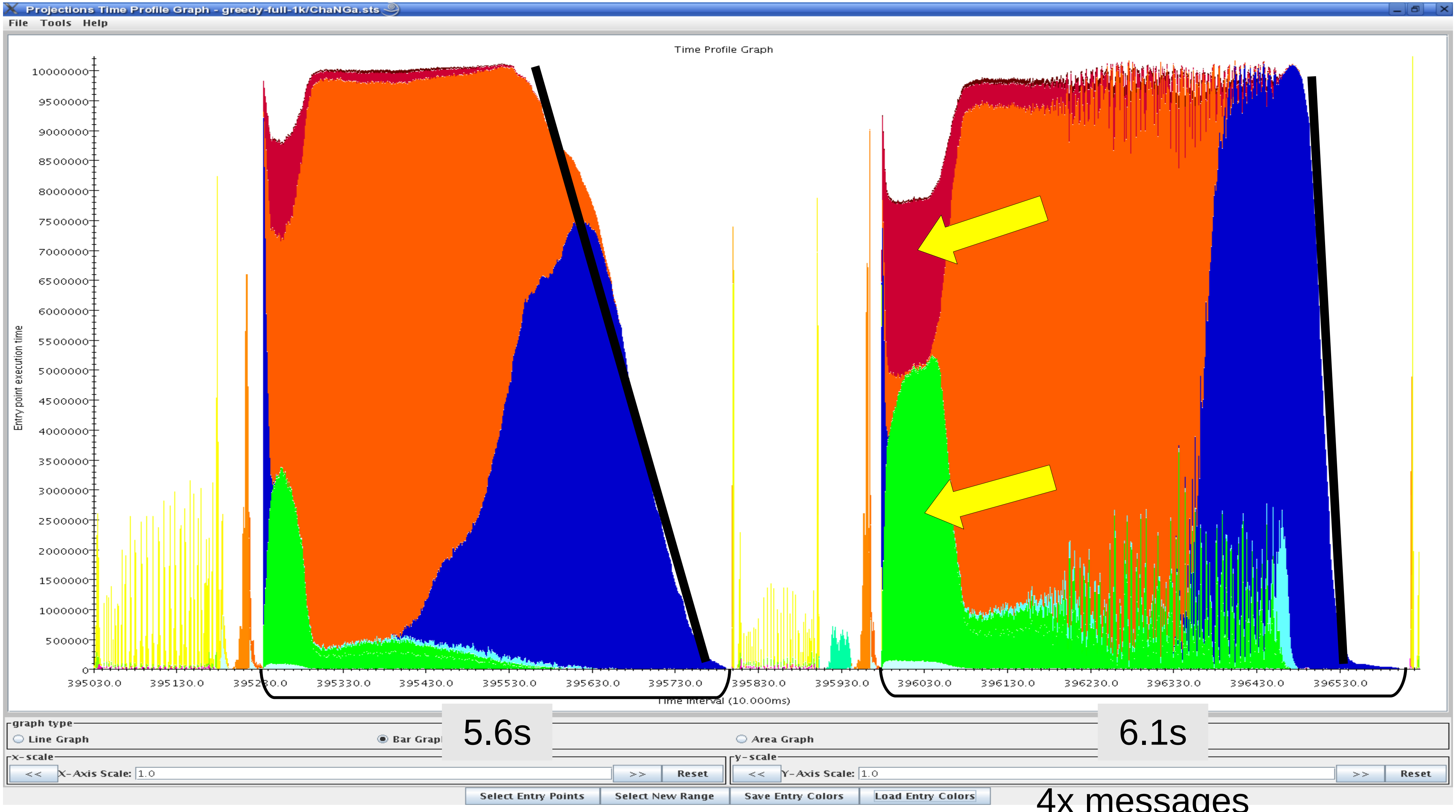
Remote/local latency hiding

Clustered data on 1,024 BlueGene/L processors



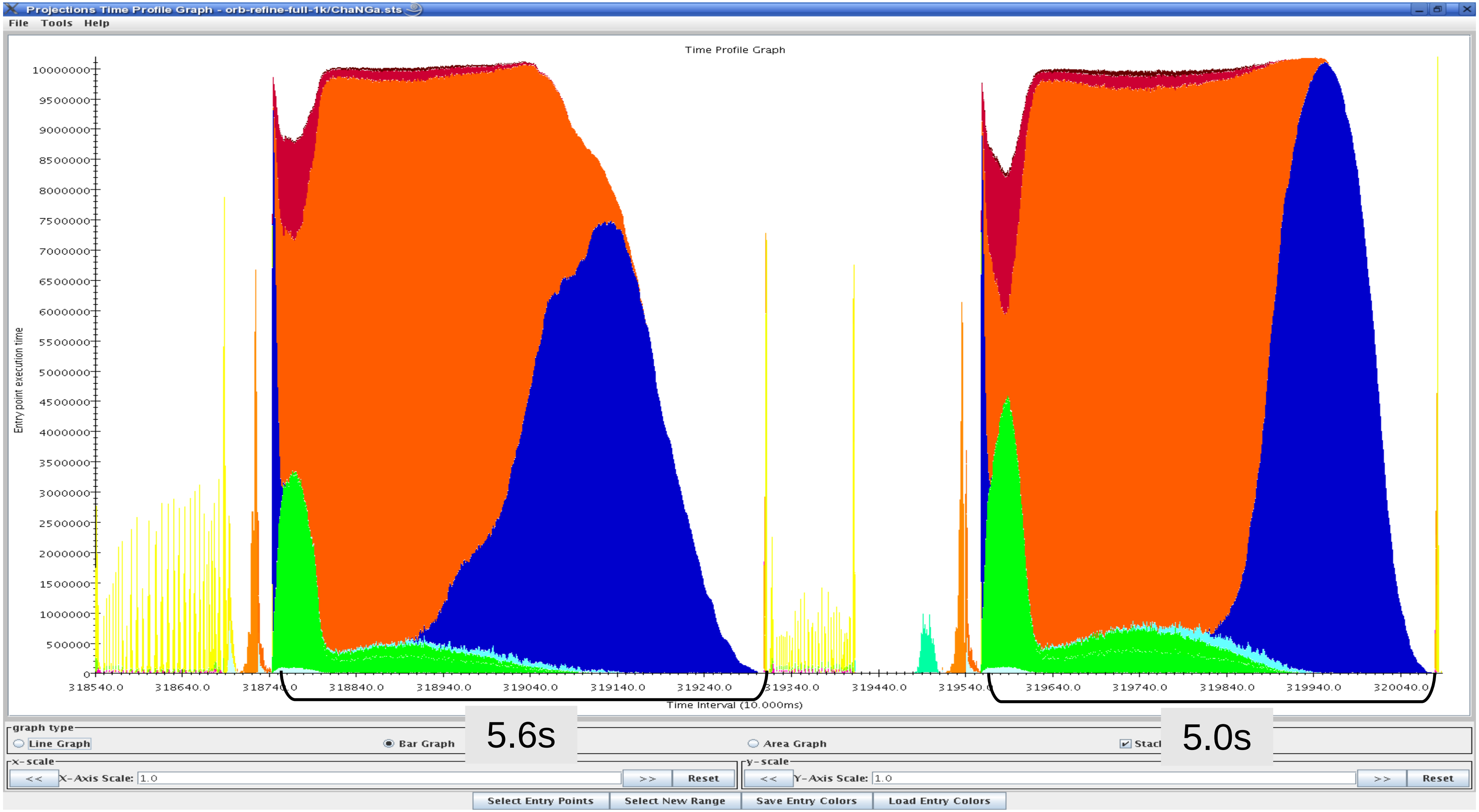
Load balancing with GreedyLB

Zoom In 5M on 1,024 BlueGene/L processors

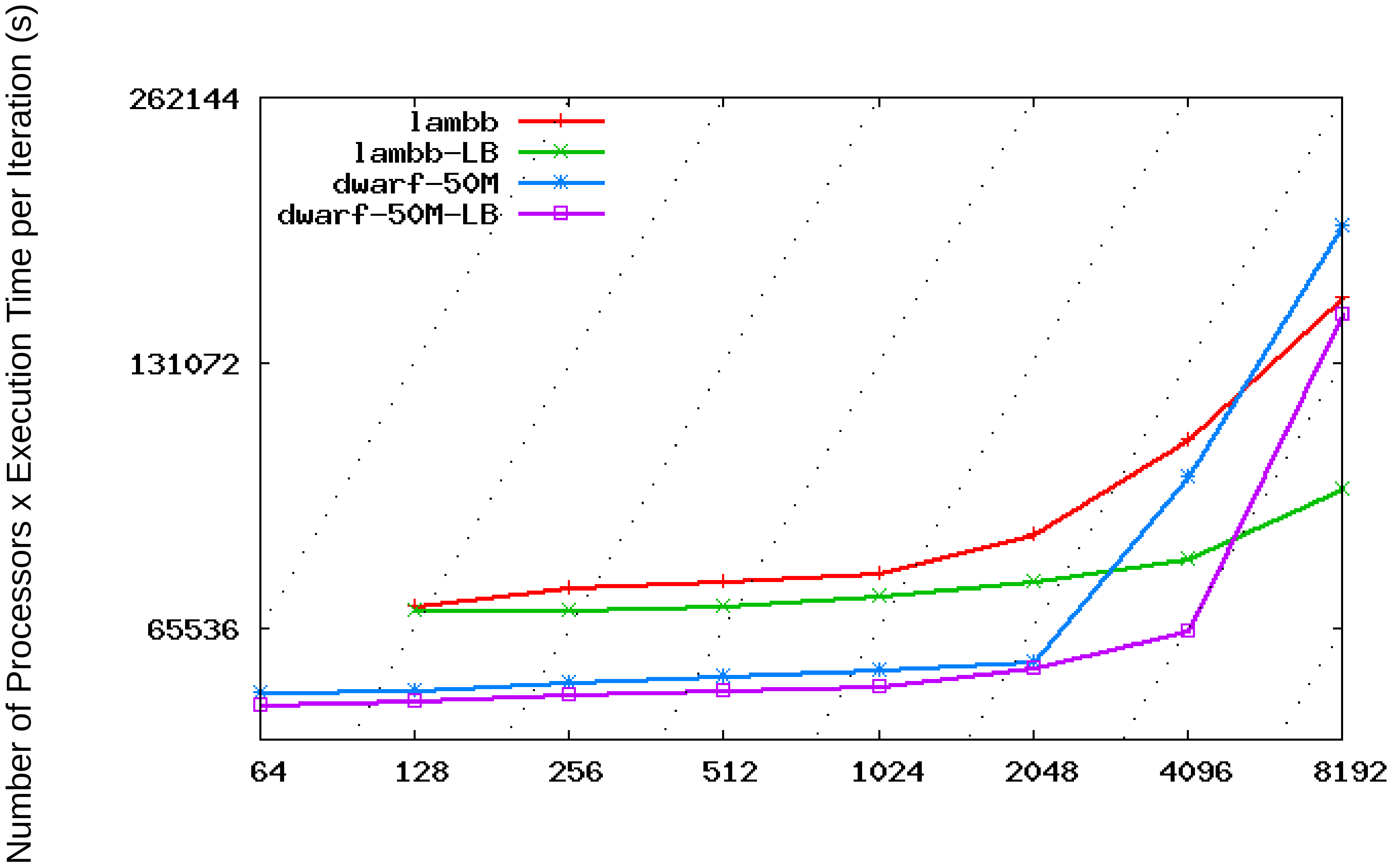


Load balancing with OrbRefineLB

Zoom in 5M on 1,024 BlueGene/L processors



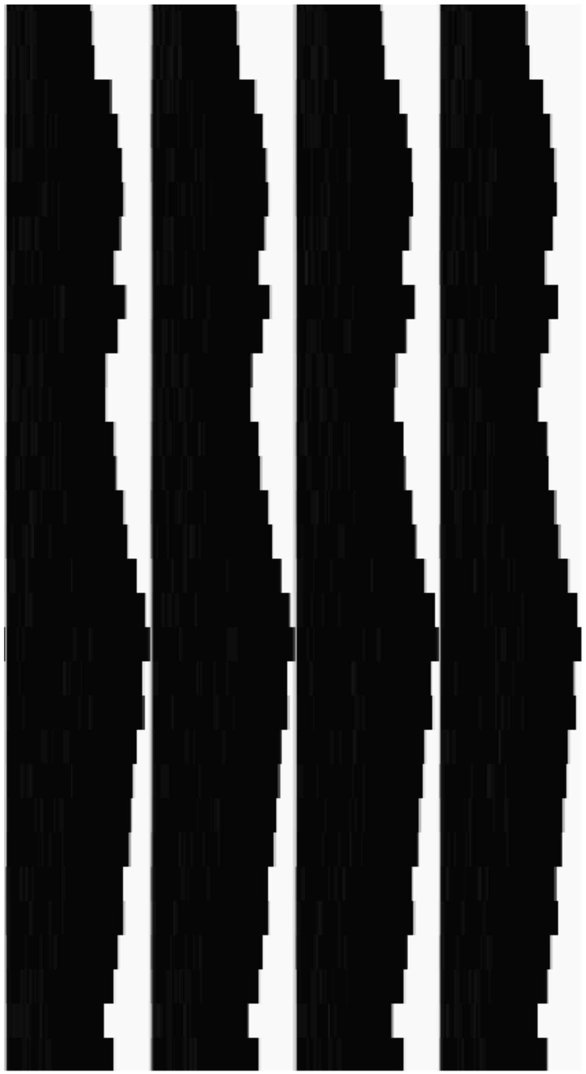
Scaling with load balancing



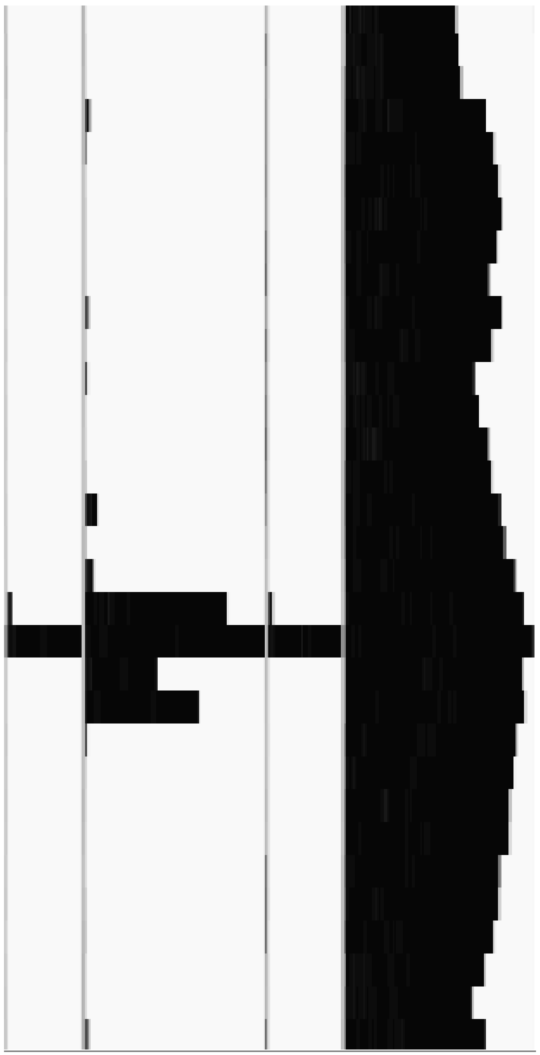
Cosmo Loadbalancer

- Use Charm++ measurement based load balancer
- Modification: provide LB database with information about timestepping.
  - “Large timestep”: balance based on previous Large step
  - “Small step” balance based on previous small step

Results on 3 rung example



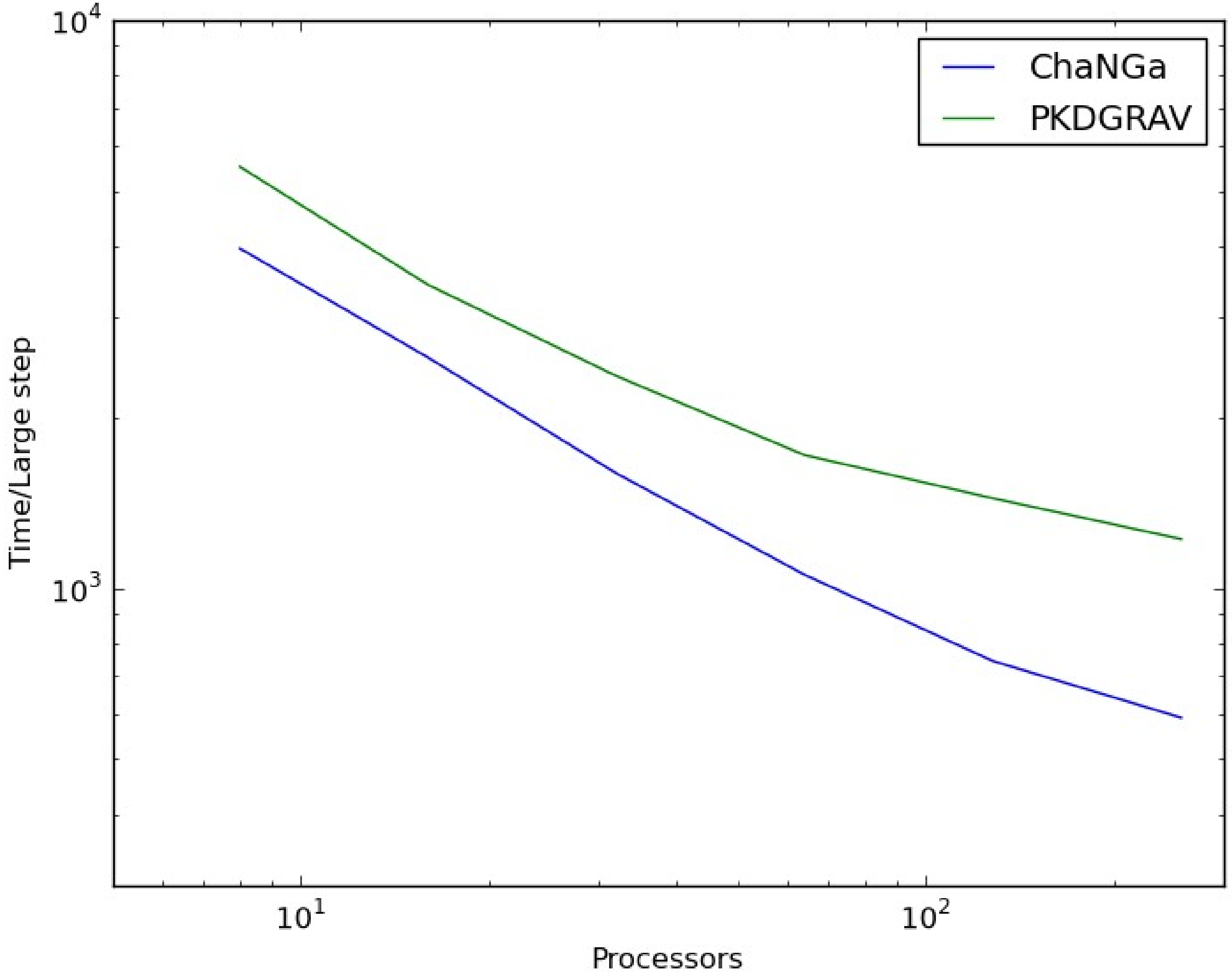
613s



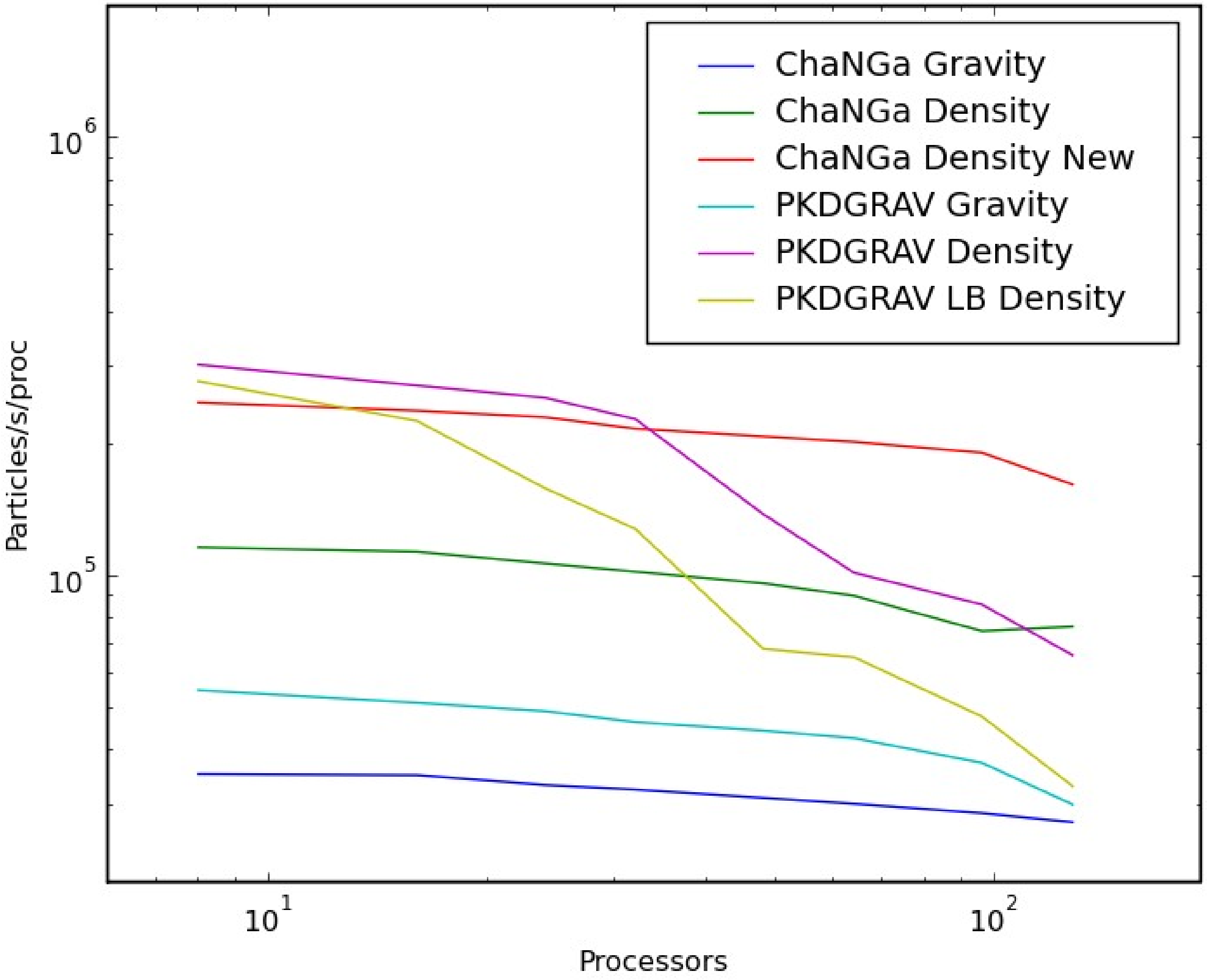
429s

228s

Multistep Scaling



SPH Scaling

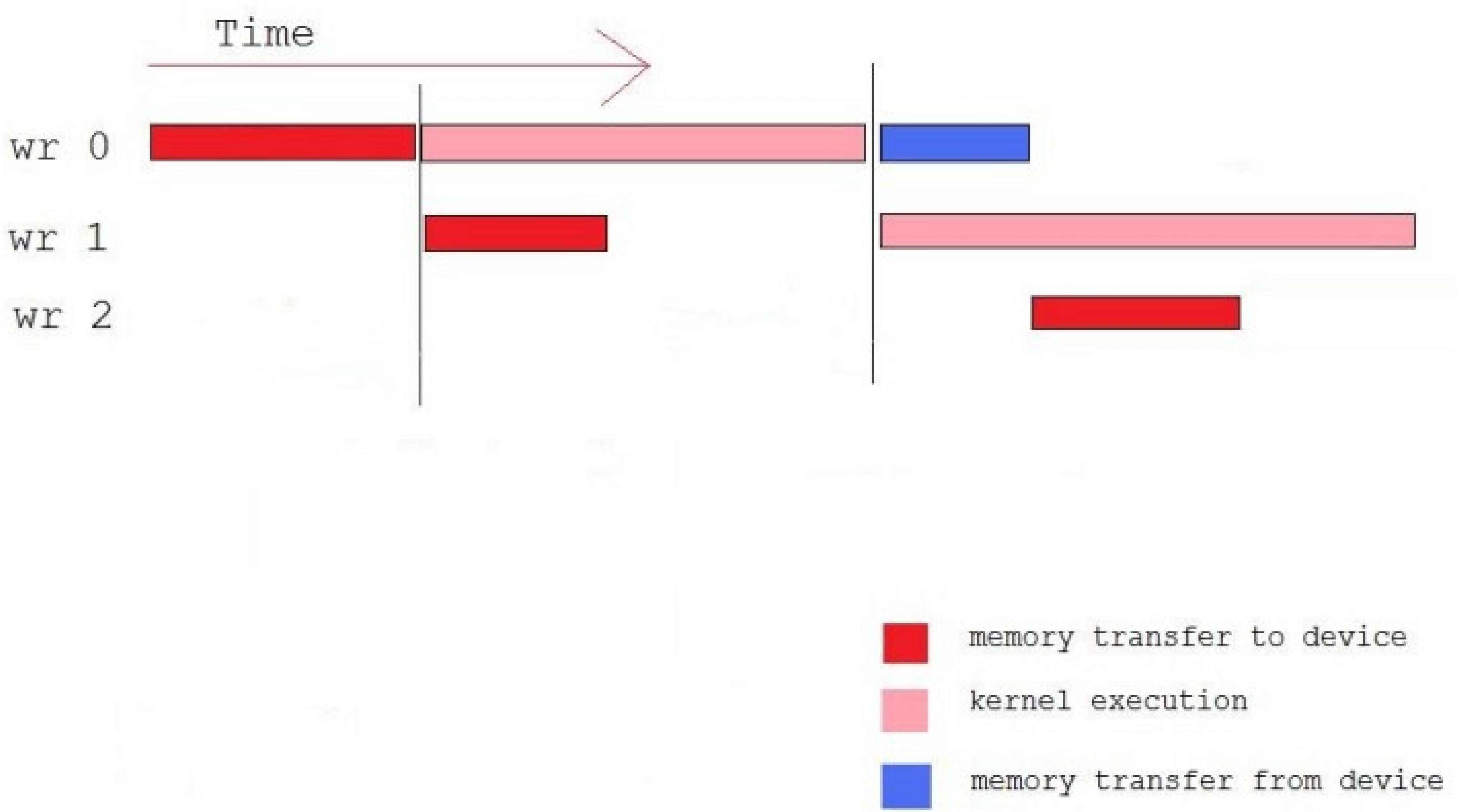


ChaNGa Gravity
ChaNGa Density
ChaNGa Density New
PKDGRAV Gravity
PKDGRAV Density
PKDGRAV LB Density
10^6
10^5
Particles/s/proc
10^1
10^2
Processors

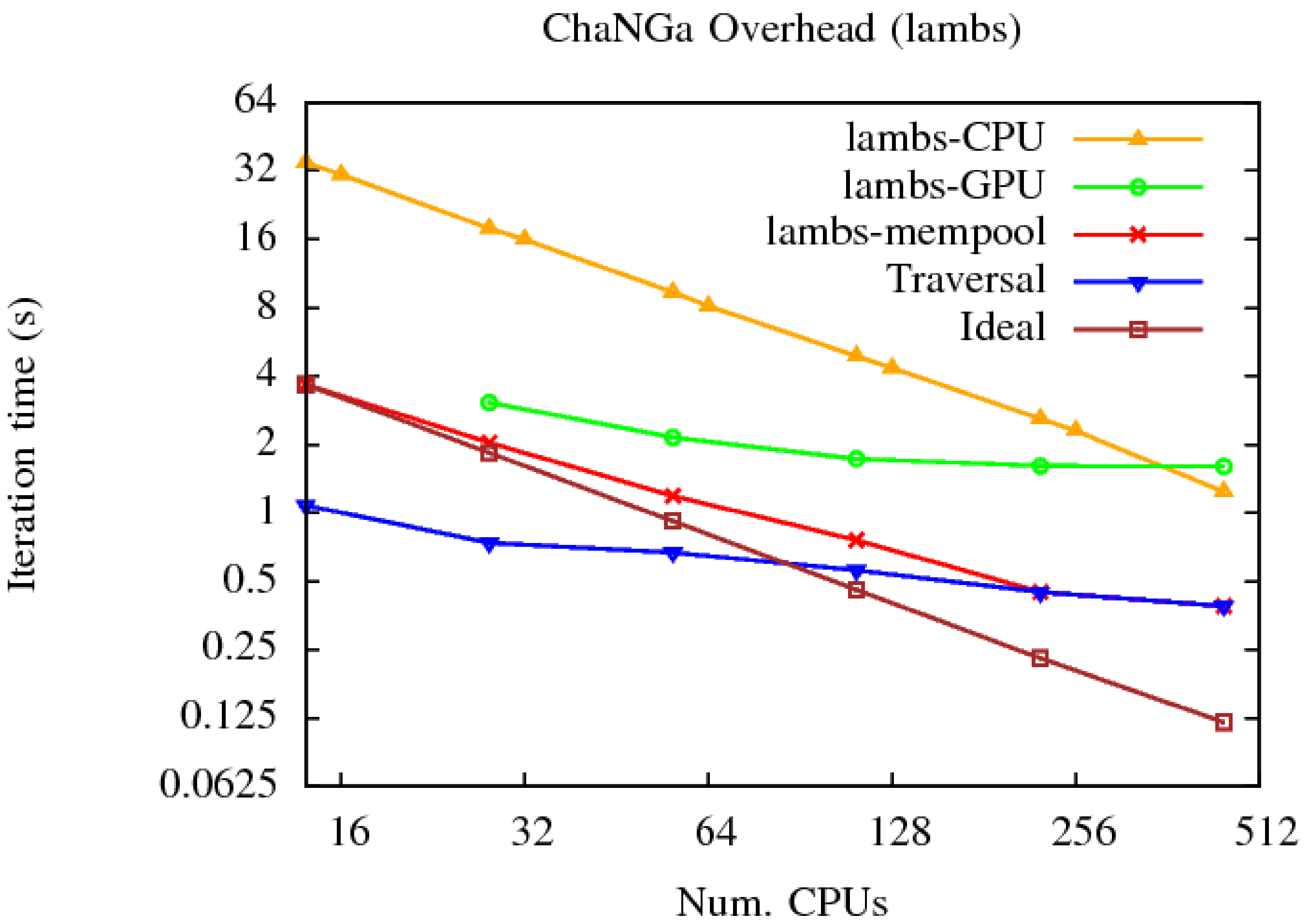
ChaNGa on GPU clusters

- Immense computational power
- Feeding the monster is a problem
- Charm++ GPU Manager
  - User submits work requests with callback
  - System transfers memory, executes, returns via callback
  - GPU operates asynchronously
  - Pipelined execution

Execution of Work Requests

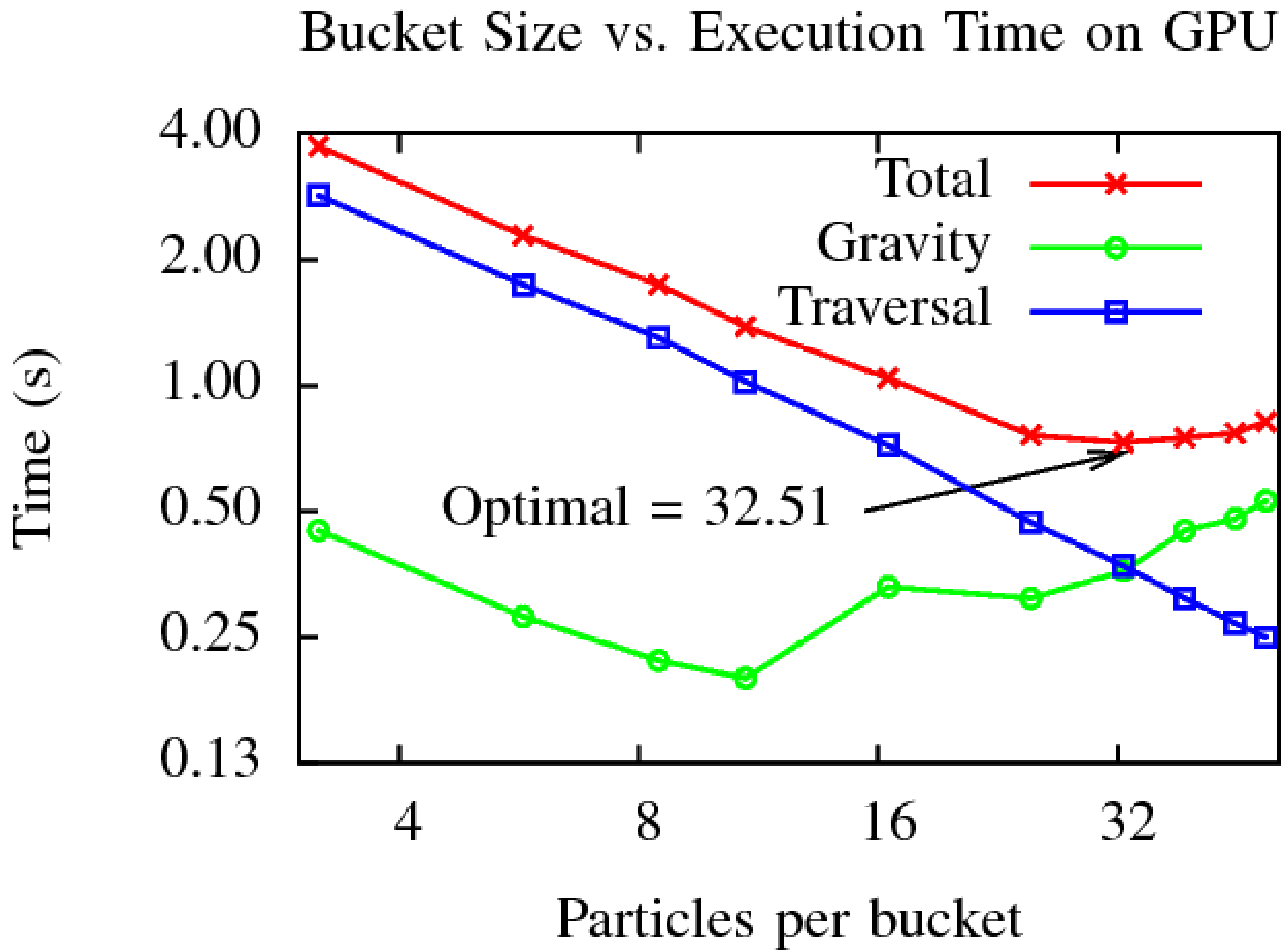


GPU Scaling



ChaNGa Overhead (lambs)
Iteration time (s)
64
32
16
8
4
2
1
0.5
0.25
0.125
0.0625
16
32
64
128
256
512
Num. CPUs
lambs-CPU
lambs-GPU
lambs-mempool
Traversal
Ideal

GPU optimization



Summary

- Successfully created highly scalable code in HLL
  - Computation/communication overlap
  - Object migration for LB and Checkpoints
  - Method prioritization
  - GPU Manager framework
- HLL not a silver bullet
  - Communication needs to be considered
  - “Productivity” unclear
    - Real Programmers write Fortran in any language

PPL PARALLEL PROGRAMMING LAB
DEPT OF COMPUTER SCIENCE, UNIVERSITY OF ILLINOIS

Thomas Quinn
Graeme Lufkin
Joachim Stadel
James Wadsley

Laxmikant Kale
Filippo Gioachin
Pritish Jetley
Celso Mendes
Amit Sharma
Lukasz Wesolowski
Edgar Solomonik

Availability

- Charm++: http://charm.cs.uiuc.edu
- ChaNGa download: http://software.astro.washington.edu/nchilada/
- Release information: http://hpcc.astro.washington.edu/tools/changa.htm
- Mailing list: changa-users@u.washington.edu