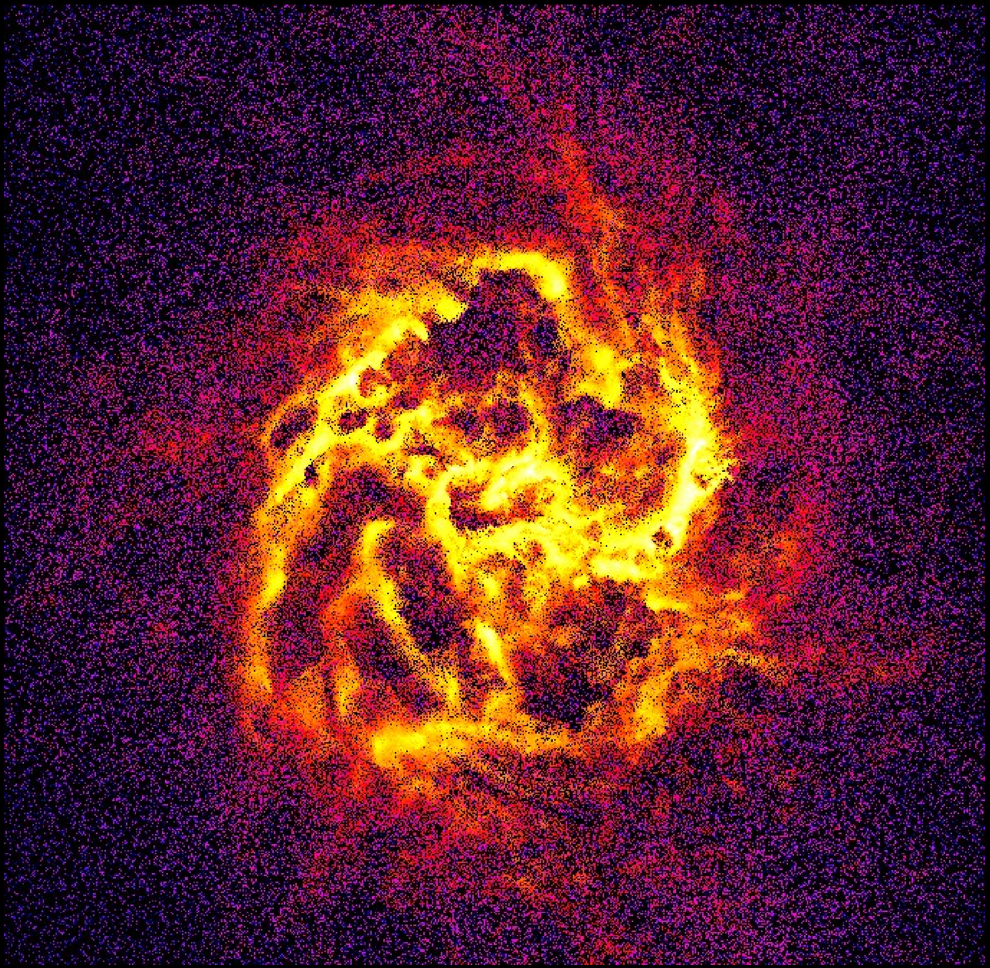
ChaNGa



CHArm N-body GrAvity

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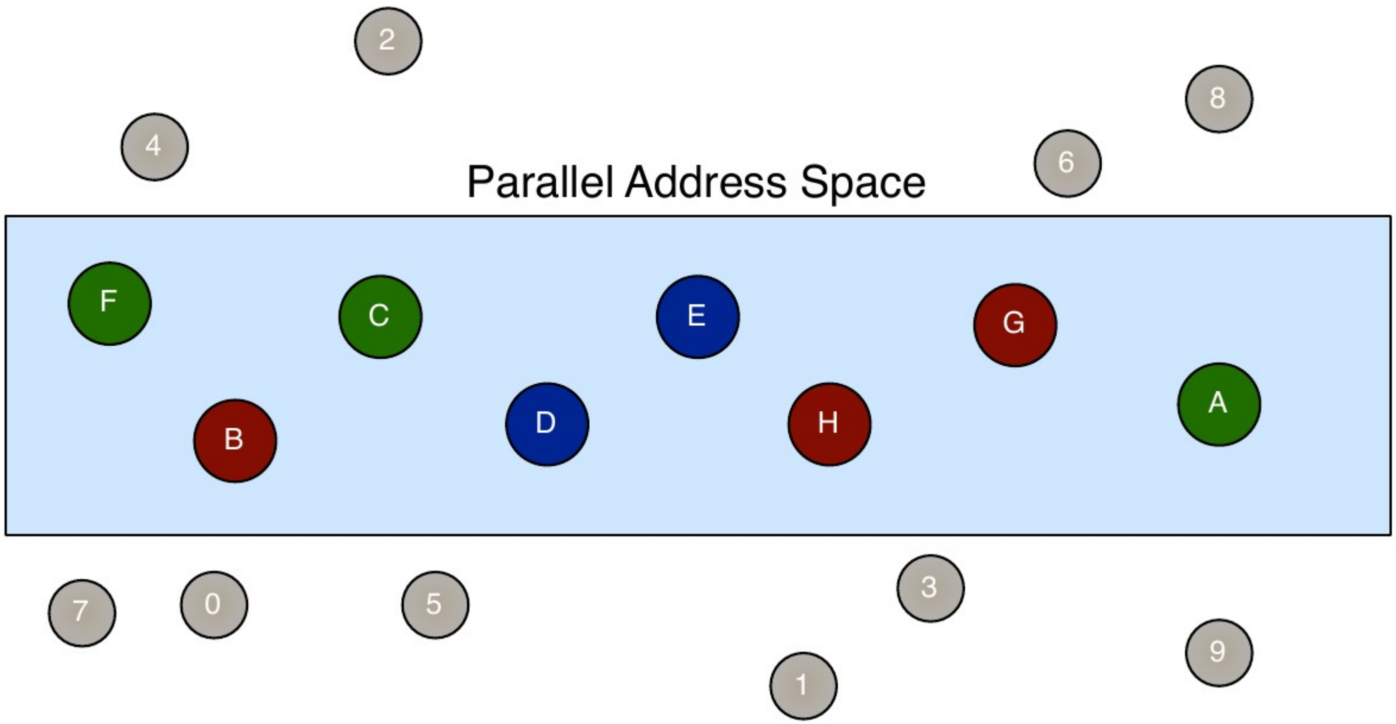
Outline

- Basic concepts of Charm++
  - Tutorial by S. Kale and the UIUC PPL group
- Charm++ paradigms: Chare arrays, method invocations, broadcasts, reductions
- Architecture of ChaNGa.
- Compiling and running Charm++ programs

Charm++

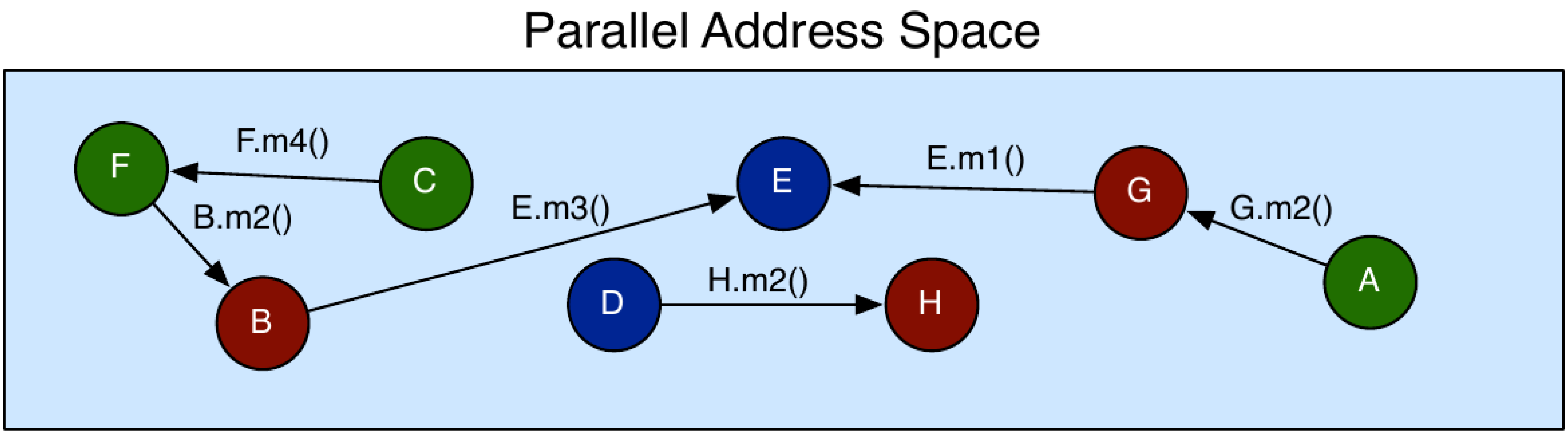
- C++-based parallel runtime system
  - Composed of a set of globally-visible parallel objects that interact
  - The objects interact by asynchronously invoking methods on each other
- Charm++ runtime
  - Manages the parallel objects and (re)maps them to processes
  - Provides scheduling, load balancing, and a host of other features, requiring little user intervention

Globally Visible Objects



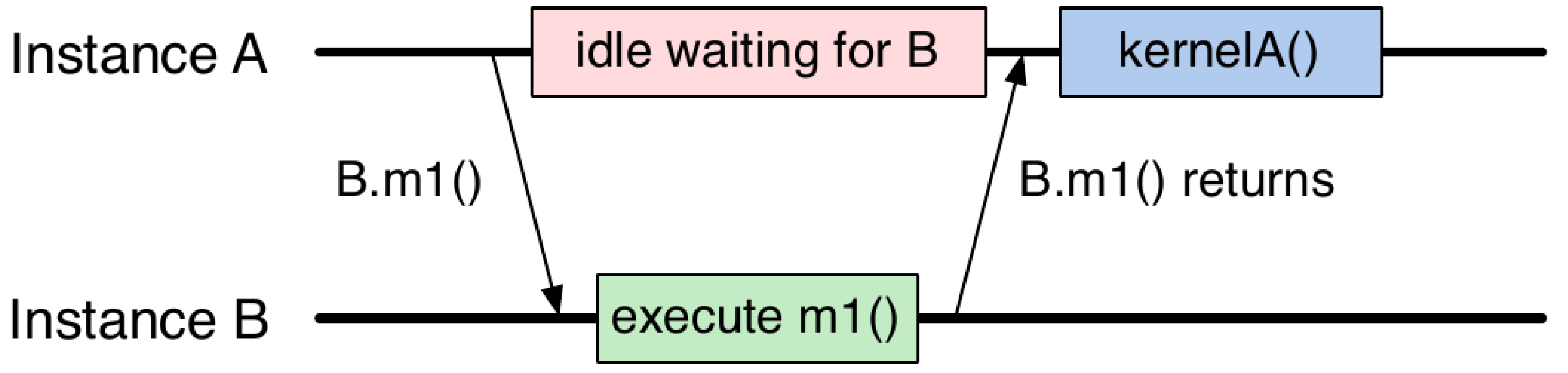
- Certain “special” object instances are
  - First-class citizens in the parallel address space
  - With unique location-independent names
- Under the hood, the runtime handles locality and provides mechanisms to promote objects to the parallel space

Globally-Visible Methods



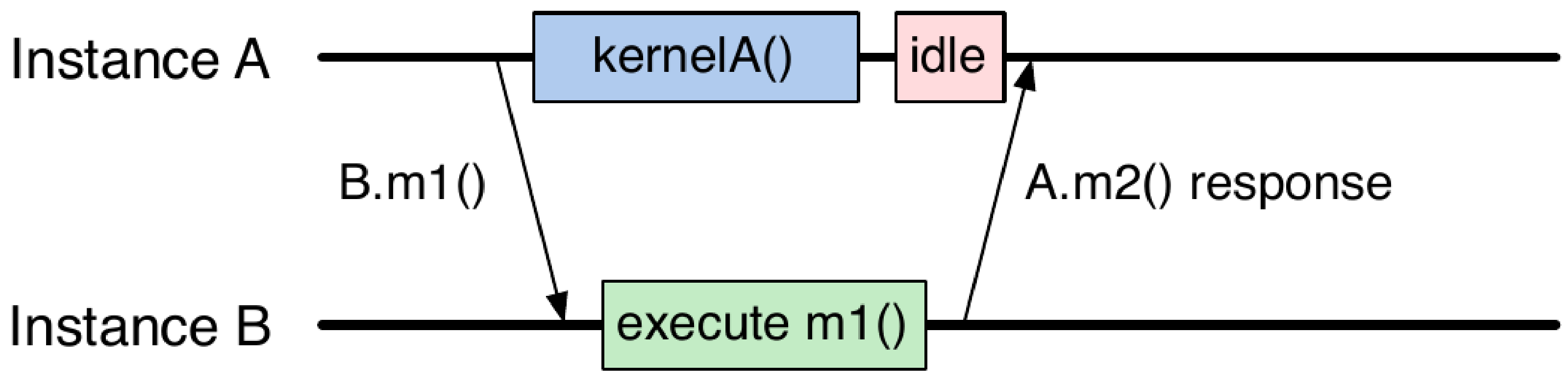
- How can objects communicate across address spaces?
  - Just like a sequential language: use object reference to invoke a method
  - Location independent handle
  - Method invocation becomes a communication

Method-Driven Asynchronous Communication



- What happens if an object waits for a return value from a method invocation?
  - Performance
  - Latency

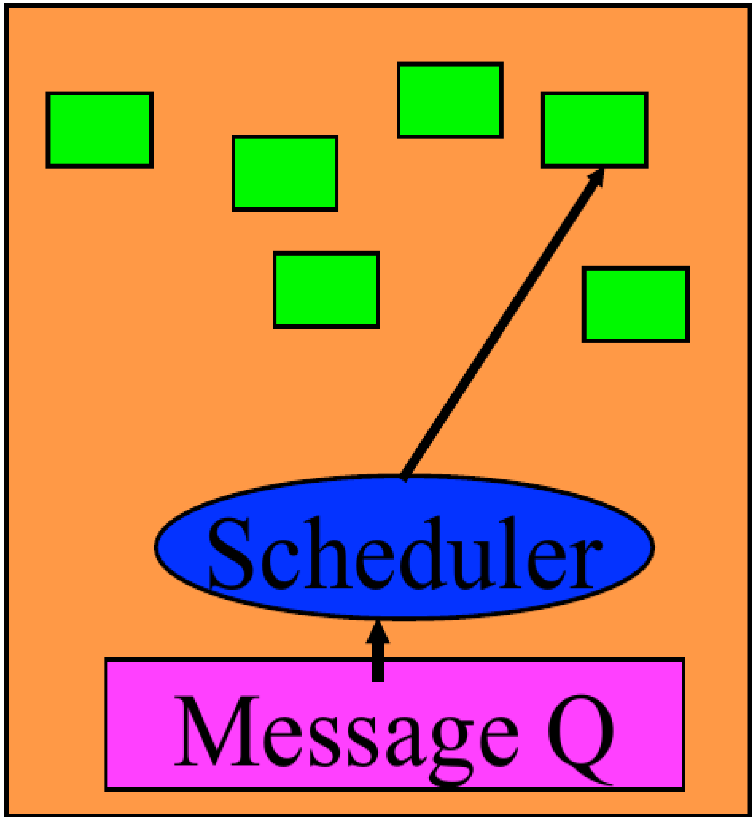
Design Principle: Do not wait for remote completion



- Hence, method invocations should be asynchronous
    - No return values
- Computations are driven by the incoming data
    - Initiated by the sender or method caller

The Execution Model

- Several objects live on a single PE
  - I.e. Core or processor
- As a result
  - Method invocations directed at objects on that processor will have to be stored in a pool,
  - And a user-level scheduler will select one invocation from the queue and runs it to completion
  - A PE is the entity that has one scheduler instance associated with it.



Message-driven Execution

- Execution is triggered by availability of a “message” (method invocation)
- When an entry method executes
  - It may generate messages for other objects
  - The RTS deposits them in the message Q on the target processor

Migratability

- Once the programmer has written the code without reference to processors, all of the communication is expressed among objects
- The system is free to migrate the objects across processors as and when it pleases
    - It must ensure it can deliver method invocations to the objects, where ever they go
    - This migratability turns out to be a key attribute for empowering an adaptive runtime system

Load balancing

- Static
  - Requires accurate cost model
- Dynamic
  - Demanded by adaptive algorithms
  - Work needs to be migrated with, e.g., particles
- Migratable Objects a natural solution
  - Coupled with a load measurement infrastructure

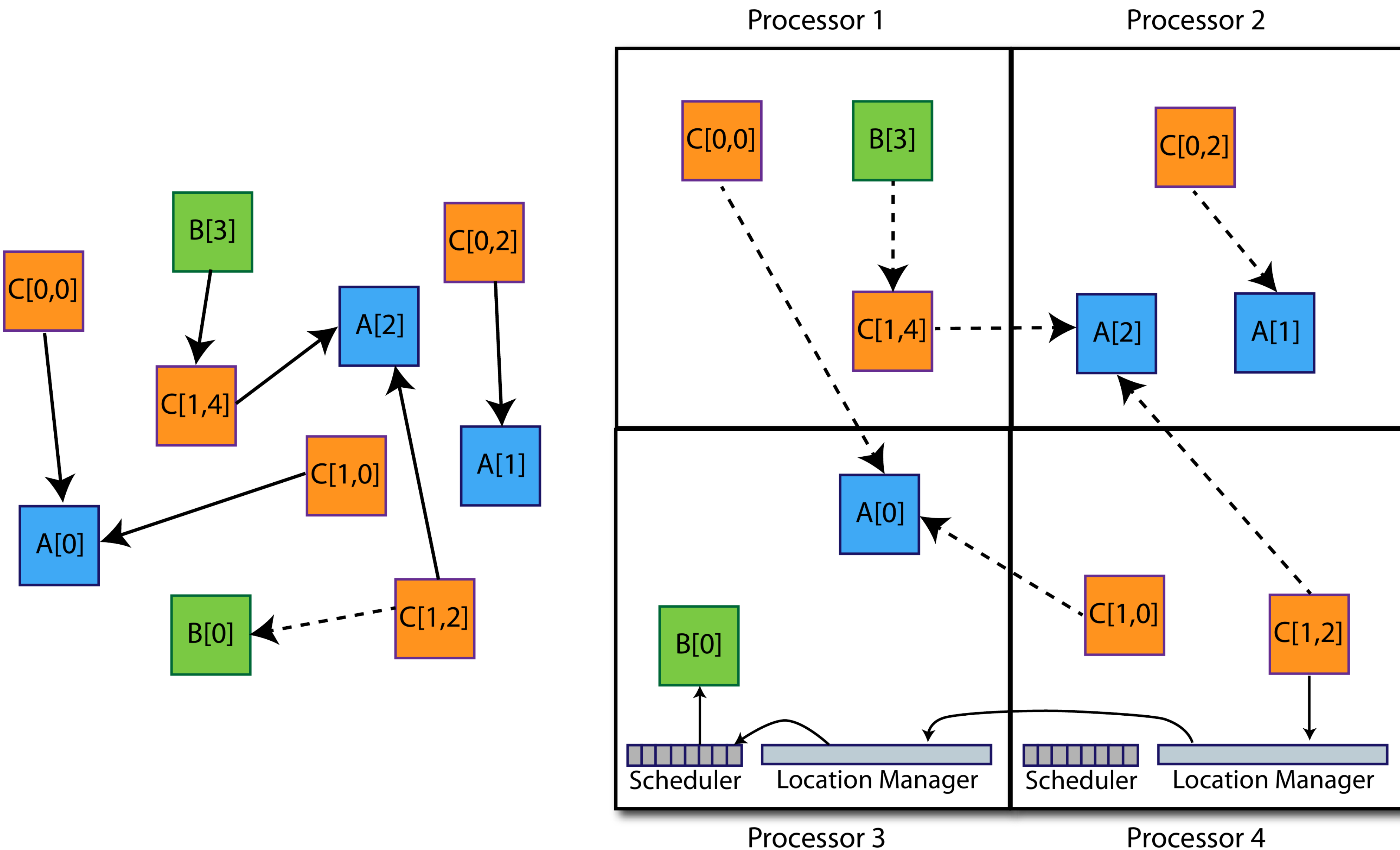
Collections of Objects

- "Chare arrays"
  - Structured: 1D, 2D, ..., 6D
  - Unstructured: anything hashable
  - Dense or Sparse
  - Static – all created at once
  - Dynamic – elements come and go
- Shadow arrays: share data but allow separate flow

Collections of Objects: Communication

- Point-to-point: to one element of a collection
- Broadcast: message to whole collection
- Multicast: message to subset of collection
- Reductions: message from (part of) collection
- Runtime system provides efficient delivery for all

Collections of Objects: user and machine view



Groups and NodeGroups

- Non-migratable chare array
- One element per PE (Group) or SMP node (NodeGroup)
- Share data among objects on a PE or node
  - E.g. Cooling table
- NodeGroups can have races.

Charm Array: Hello Example

```
mainmodule arr {
    readonly int arraySize;
    mainchare Main {
      entry Main(CkArgMsg*);
      }
    array [1D] hello {
      entry hello();
      entry void printHello();
      }
}
```

Charm Array: Hello Example

```
#include ”arr.decl.h”
/*readonly*/ int arraySize;
struct Main : CBase Main {
   Main(CkArgMsg* msg) {
     arraySize = atoi(msg−>argv[1]);
     CProxy hello p = CProxy hello::ckNew(arraySize);
     p[0].printHello();
     }
};
struct hello : CBase hello {
   hello() { }
   hello(CkMigrateMessage*) { }
   void printHello() {
      CkPrintf(”%d: hello from %d\n”, CkMyPe(), thisIndex);
      if (thisIndex == arraySize − 1) CkExit();
      else thisProxy[thisIndex + 1].printHello();
      }
};
#include ”arr.def.h”
```

Migration: packing/unpacking data

```
class MyChare : public
        CBase MyChare {
  int a;
  float b;
  char c;
  float
  localArray[LOCAL_SIZE];
};
```

```
void pup(PUP::er &p) {
  Cbase_MyChare::pup(p);
  p | a;
  p | b;
  p | c;
  p(localArray,
LOCAL_SIZE);
}
```

Measurement Based Load Balancing

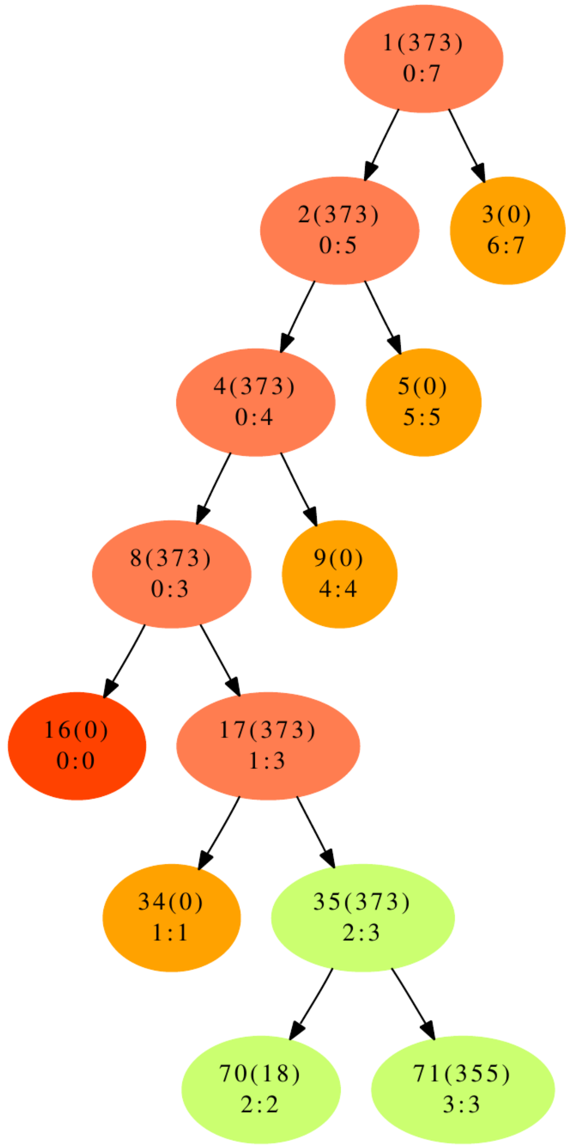
- Principle of Persistence
  - Object communication patterns and computational loads tend to persist over time
  - In spite of dynamic behavior
    - Abrupt but infrequent changes
    - Slow and small changes
- Runtime instrumentation
  - Measures communication volume and computation time
- Measurement based load balancers
  - Use the instrumented data-base periodically to make new decisions
  - Many alternative strategies can use the database

ChaNGa Features

- N-body/SPH solver
- Very latency tolerant
- SMP aware
- Dynamic load balancing with choice of strategies
- Checkpointing (via migration to disk)
- Visualization

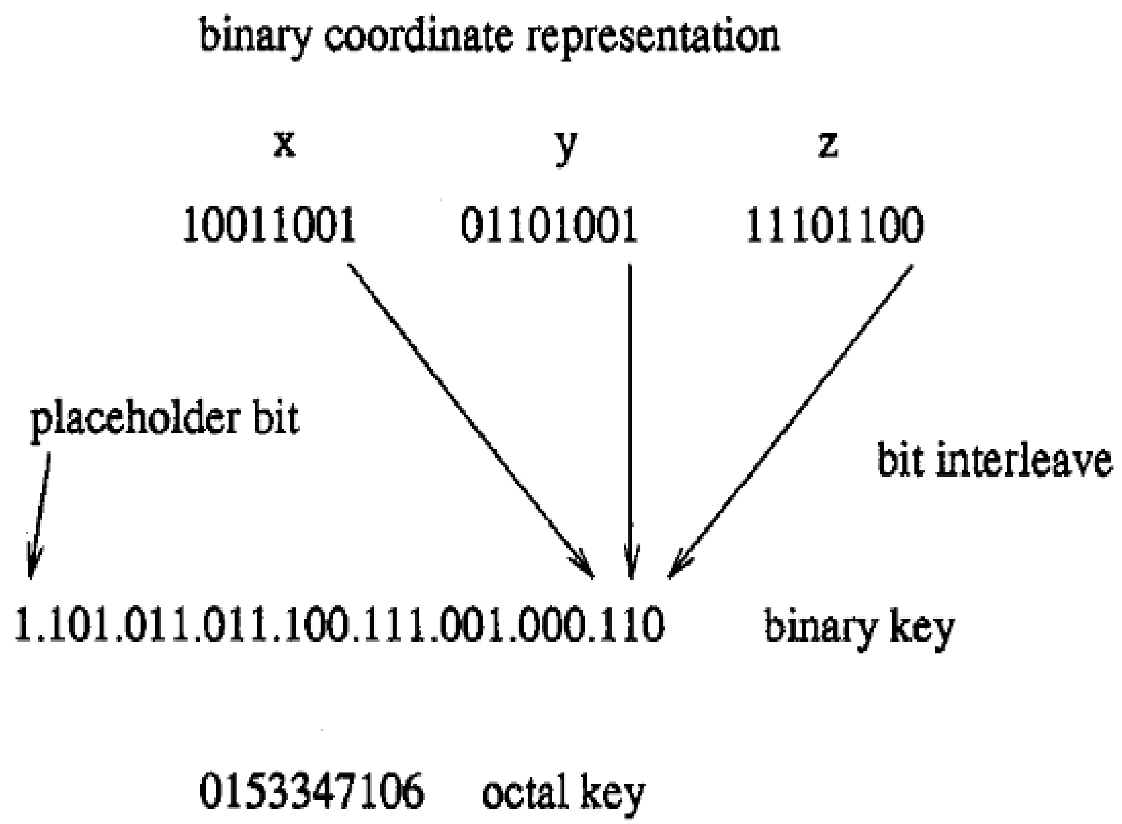
TreePiece: basic data structure

- A “vertical slice” of the tree, all the way to the root.
- Nodes are either:
  - Internal
  - External
  - Boundary (shared)

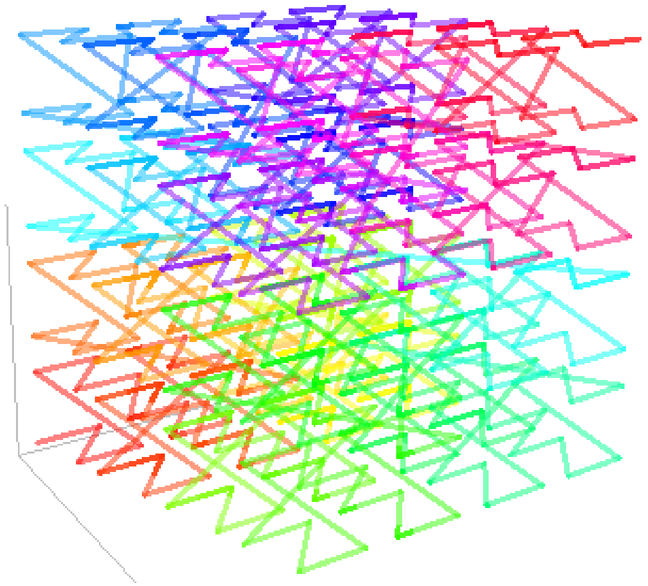


Domain Decomposition

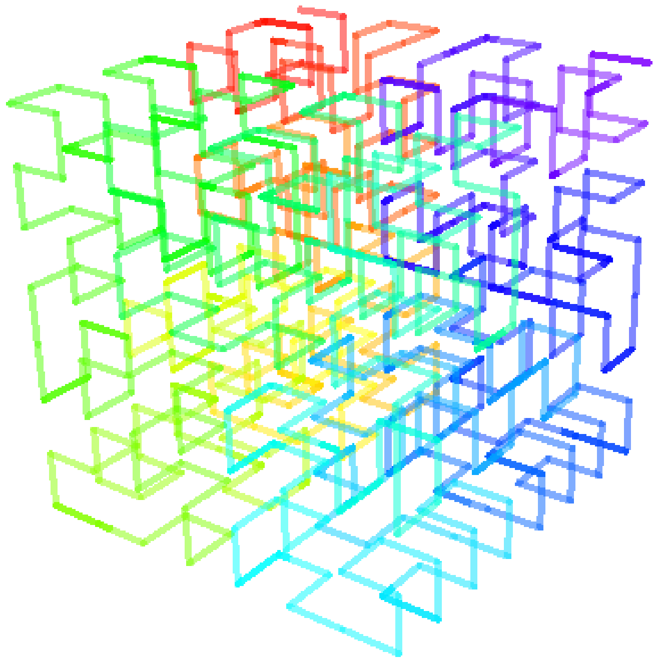
- Particles are identified by “Keys” (Warren & Salmon, 1993)
- Keys also define domains
- Decomposition is a “sort”.



Domain Decomposition Options



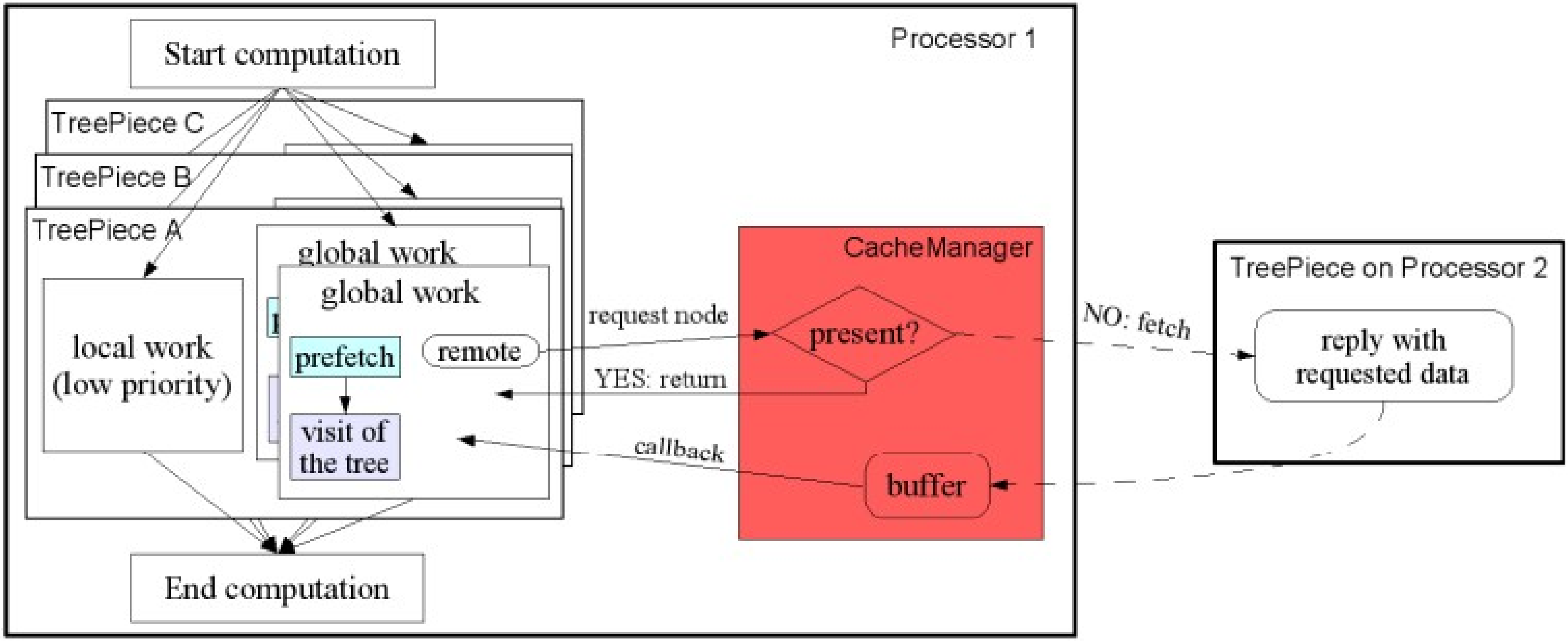
- Space-filling curves
  - Morton ordering
  - Peano-Hilbert
- “Oct”: fully contained nodes
  - Less communication
  - Harder load balancing
- ORB (orthogonal recursive bisection)
  - Poor gravity



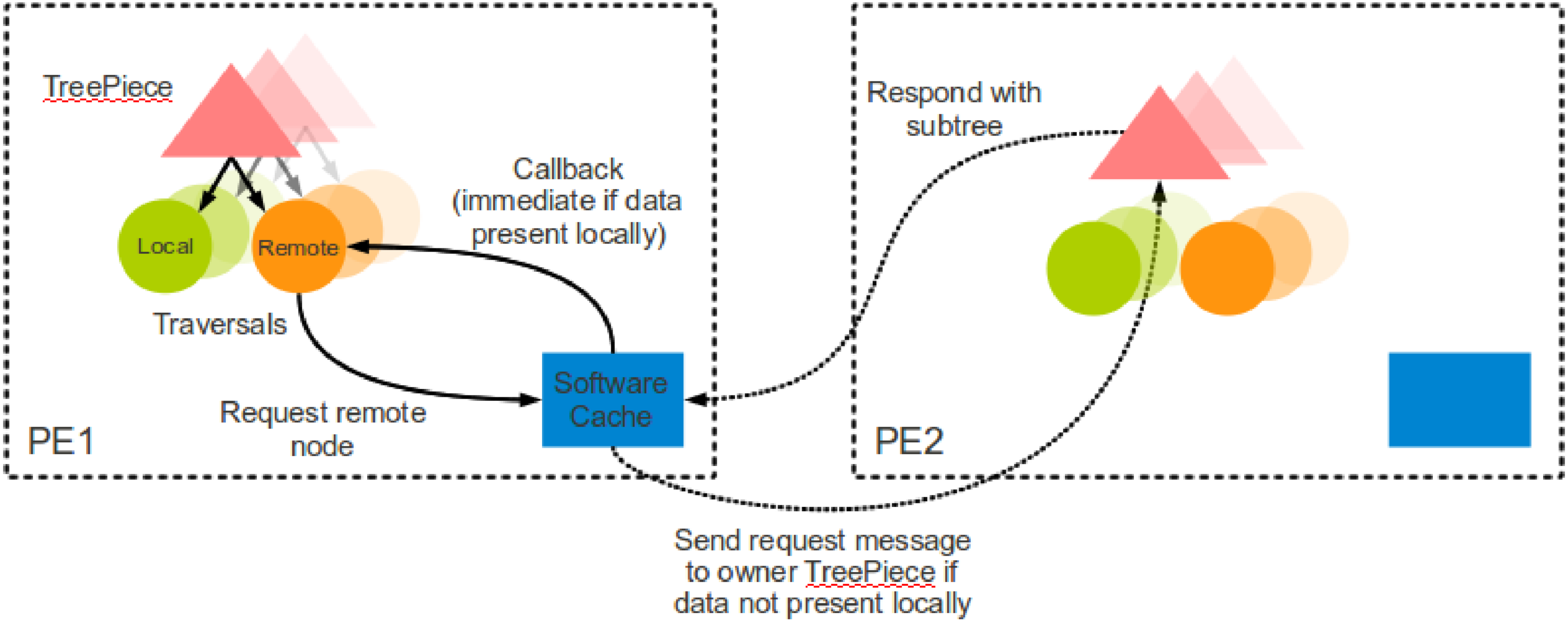
Tree Building

- Sort on Keys: particles are in tree order
- Determine count of particles in each Node
- Assign NodeKey: each bit a left-right branch
- Stop at “buckets”: each leaf contains a few particles.
- Construct multipole moments
  - Request moments of External Nodes
- Merge pieces on same address space.

Overall treewalk structure



Cache control flow



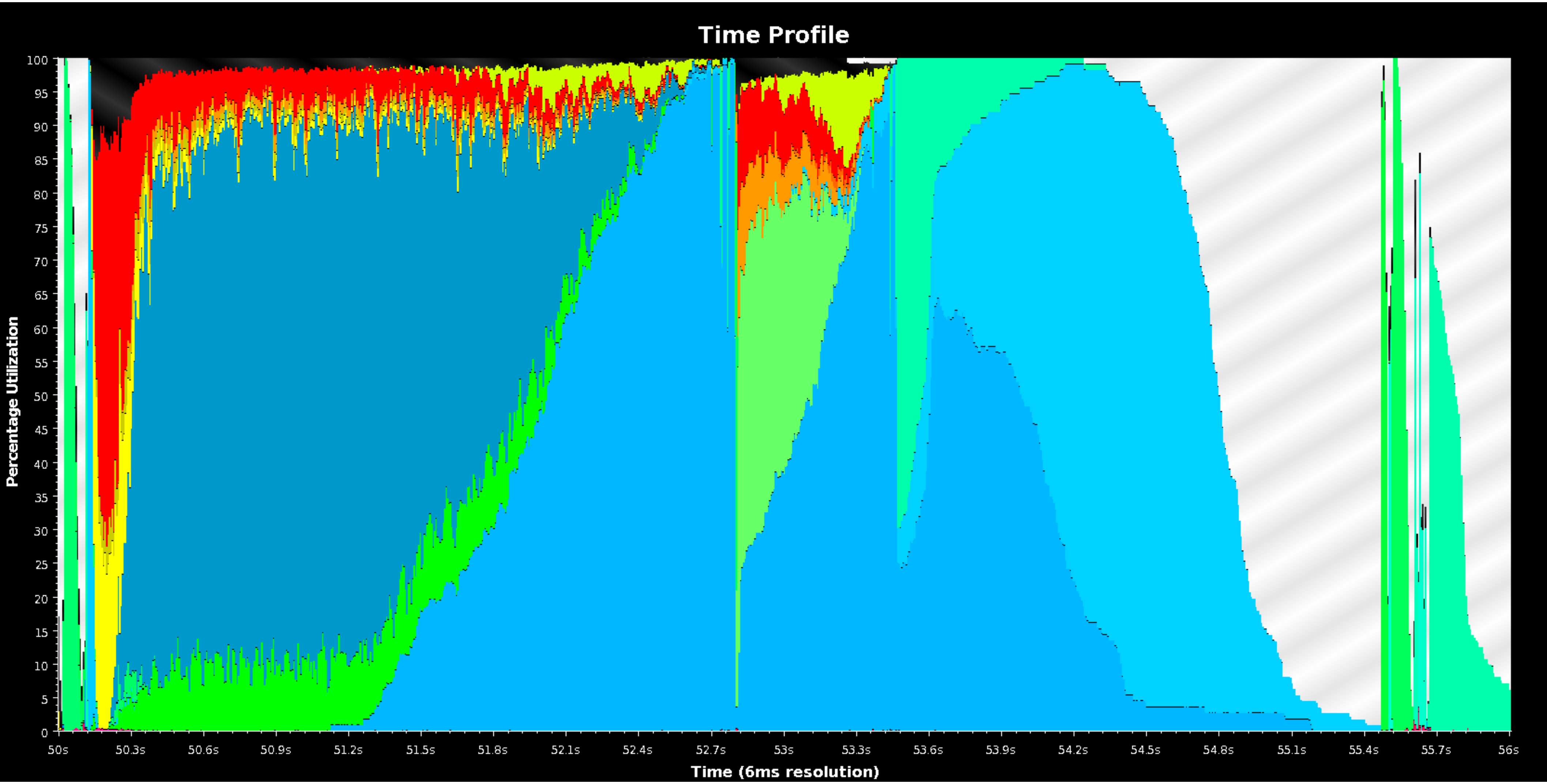
SPH Walks

- Two phases: density then pressure
- Symmetric forces => Cached data is written back to home piece.
- Multistepping: still need density of neighbors and particles for which I am a neighbor
  - Inverse neighbor search

Latency hiding strategies

- Multiple “treepieces” per core
- Division into multiple work units (*all concurrently*)
  - Off processor gravity treewalk
  - SPH treewalk
  - Local gravity treewalk
  - Ewald summation
- Method prioritization
  - Data requests get high priority

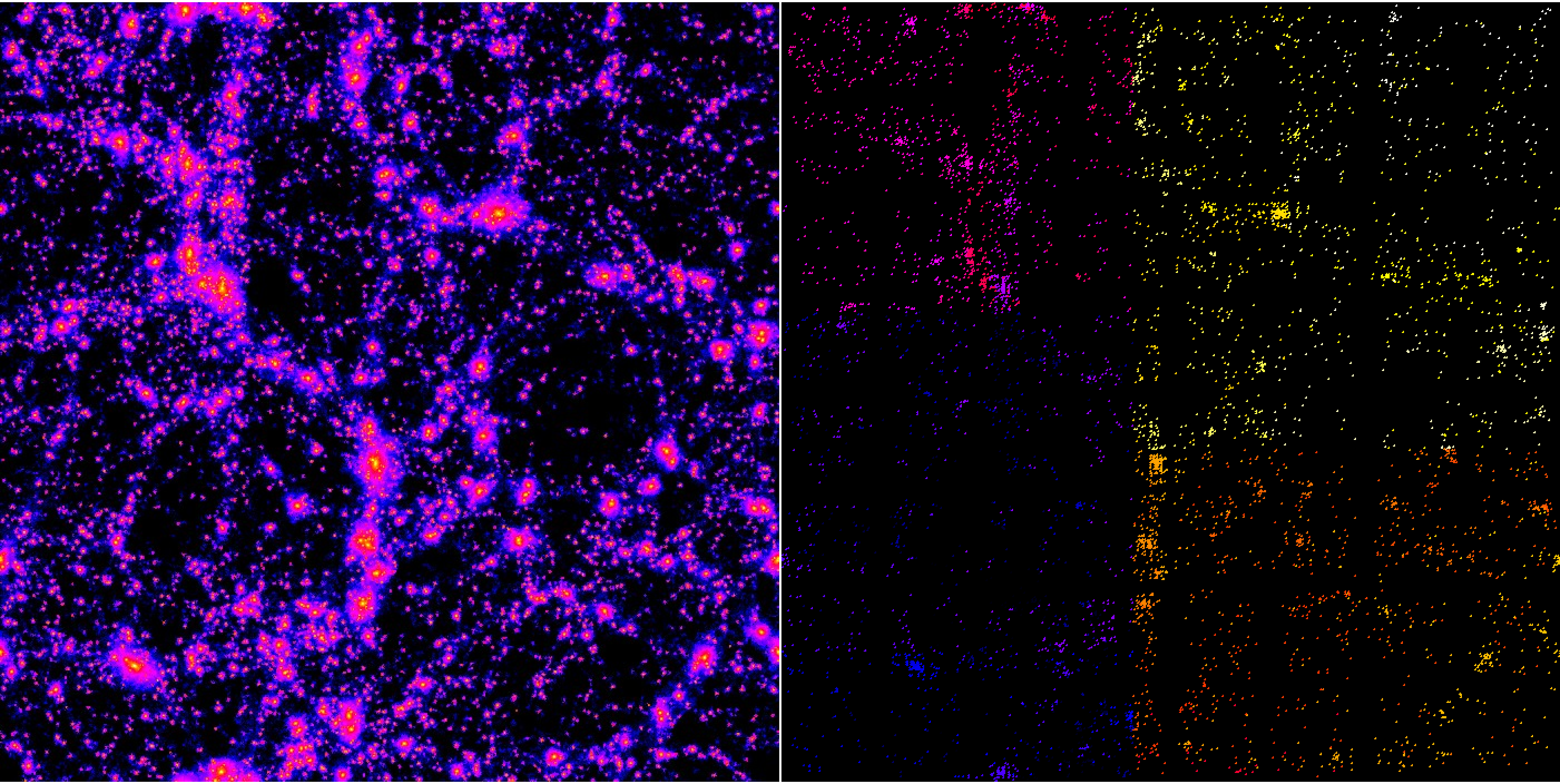
Overlap of Phases



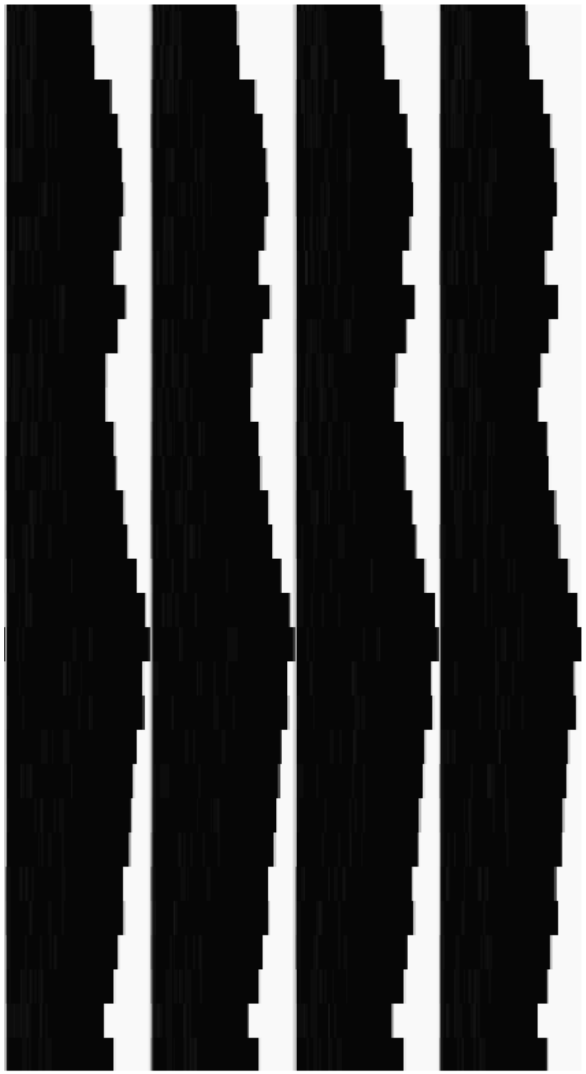
Load Balancing

- ORB load balancing:
  - Treepiece centroids sent to load balancer
  - Load balancer evenly divides work across x, y or z split.
  - Minimizes communication
- MultistepLB
  - Use load information from last timestep at current “rung”.

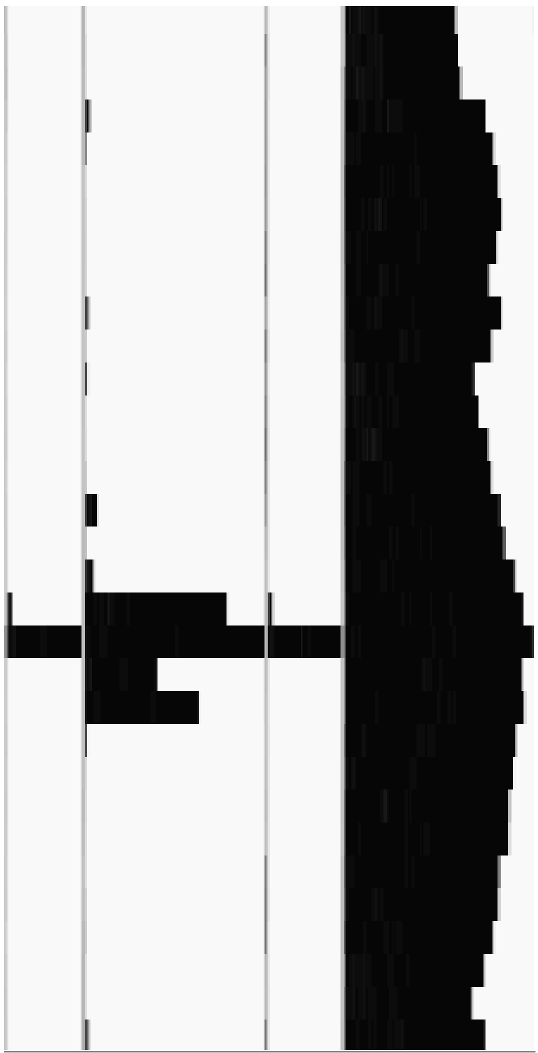
ORB3D Load Balancing



Multistepping: 3 rung example



613s



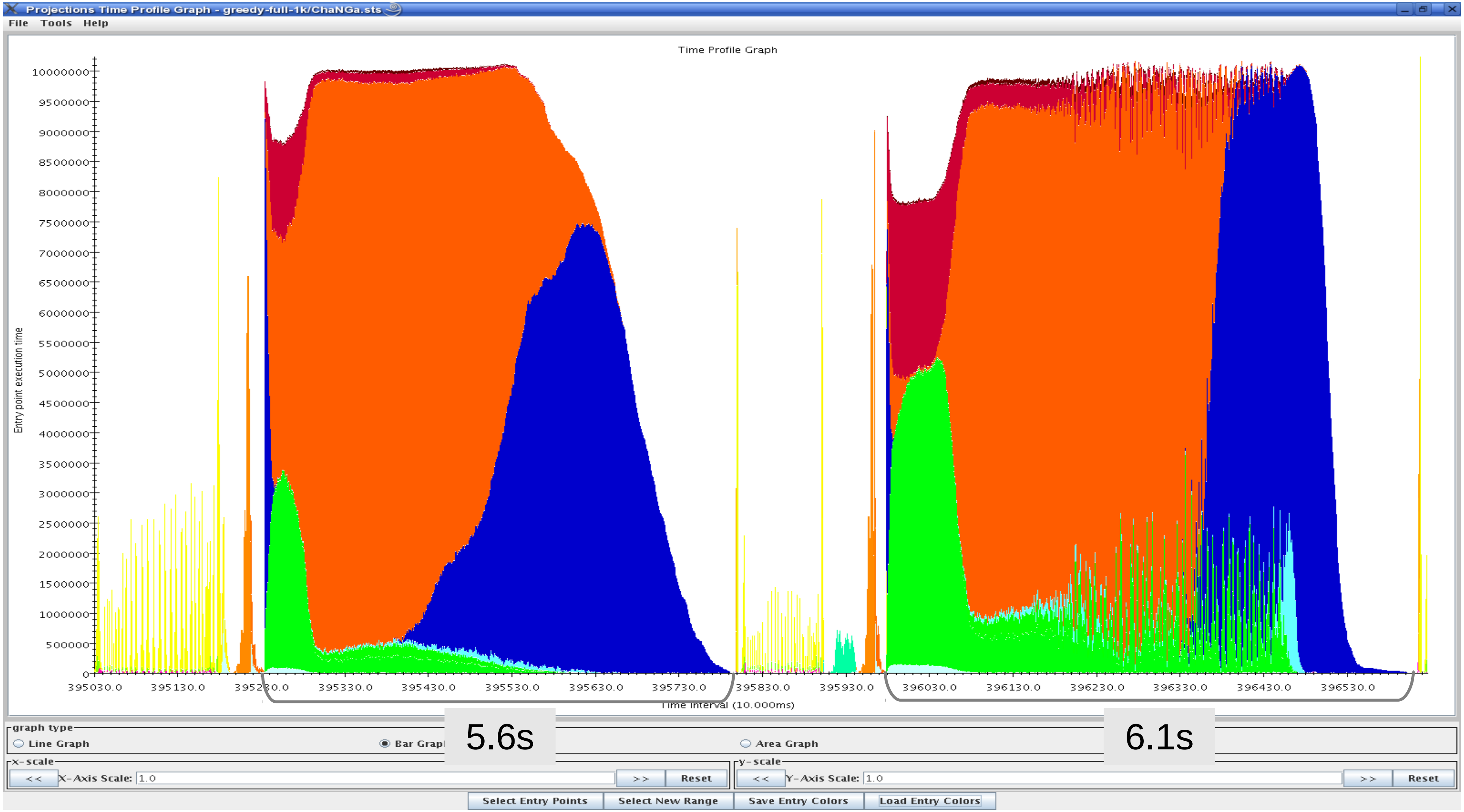
429s

228s

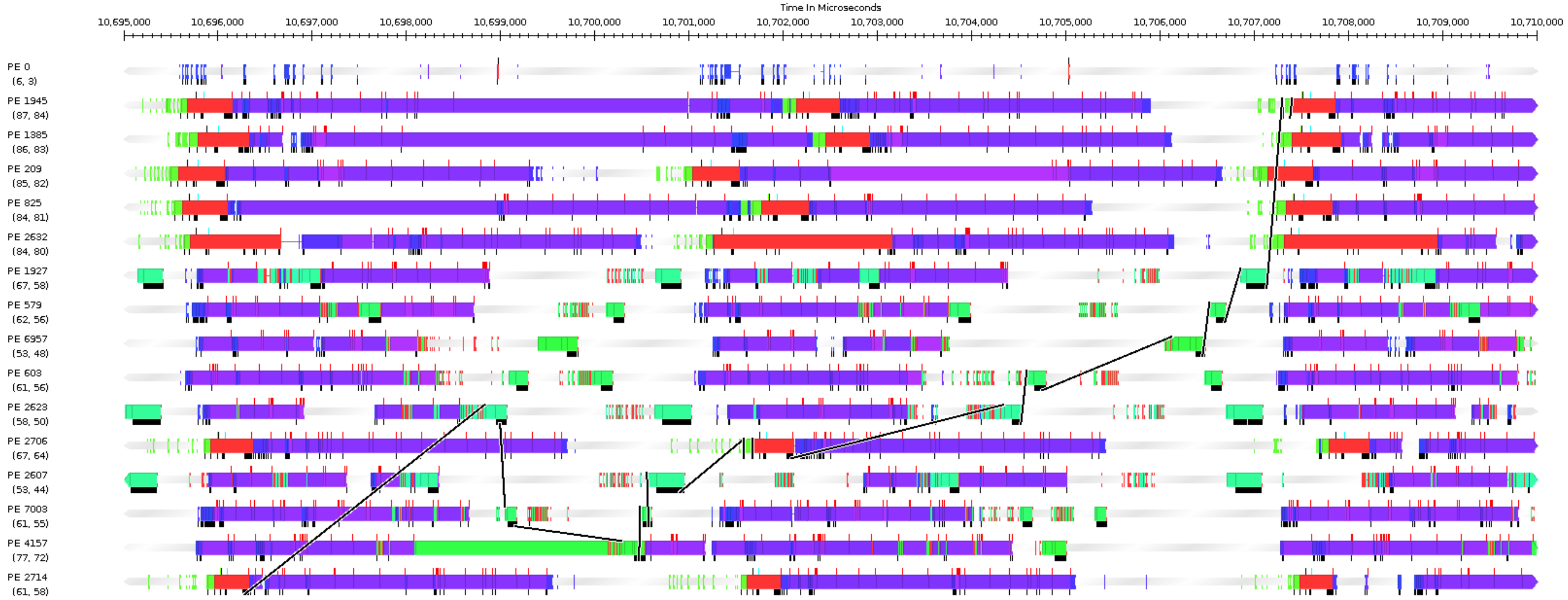
Performance Analysis Using Projections

- Instrumentation and measurement
  - Link program with -tracemode projections or summary
  - Trace data is generated automatically during run
  - User events can be easily inserted as needed
- Projections: visualization and analysis
  - Scalable tool to analyze up to 300,000 log files
  - A rich set of tool features : time profile, time lines, usage profile, histogram, extrema tool
  - Detect performance problems: load imbalance, grain size, communication bottleneck, etc

Projections example:
Testing load balancing on 1024 processors



Time Lines with Message Back Tracing



Charm++ features in ChaNGa

- Computation/communication overlap
- Entry method prioritization
- Flexible, customizable load balancing framework
- Composability
- Object Oriented: reuse of existing code.
- Porting to new architectures
  - Including GPGPUs

Availability

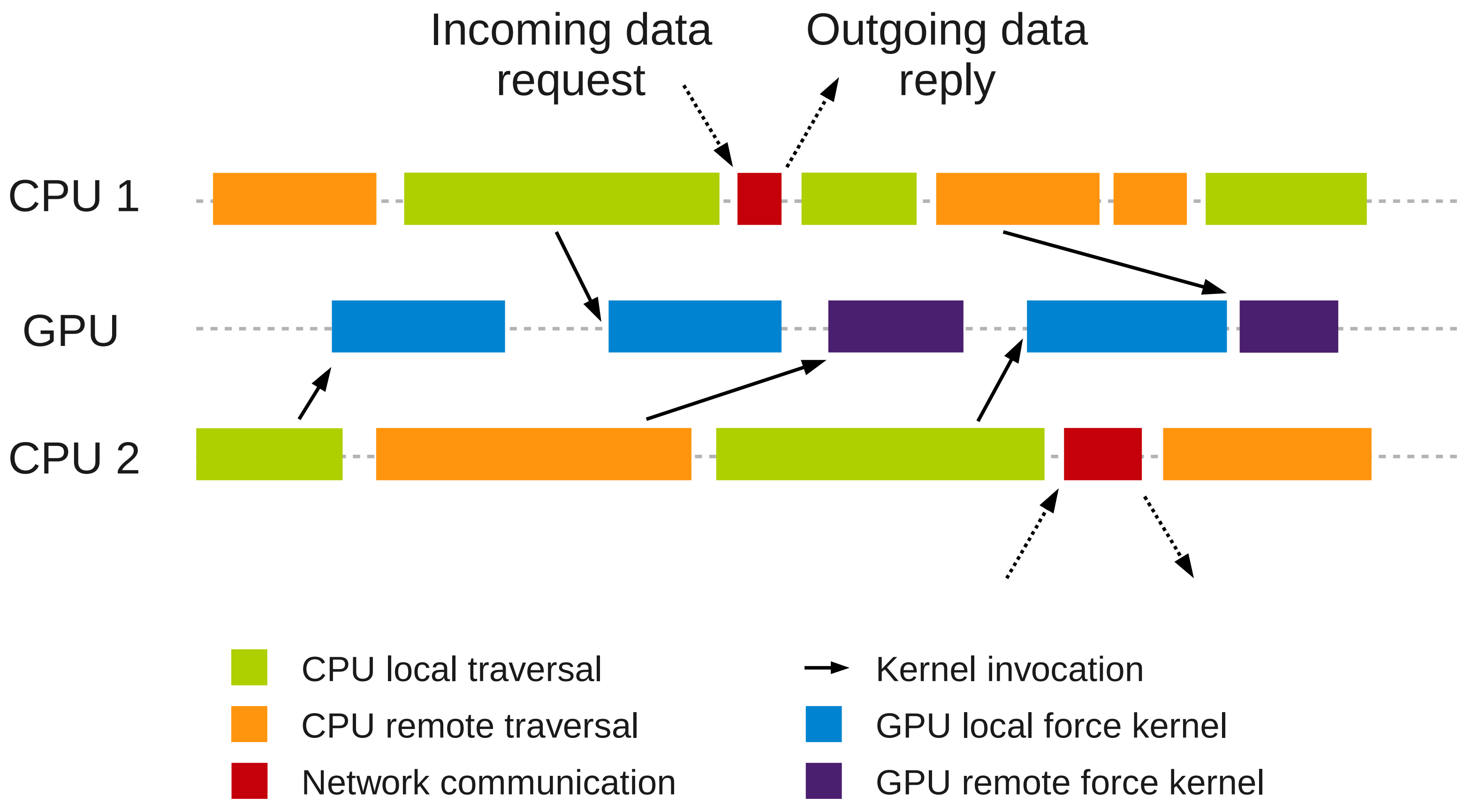
- Charm++: http://charm.cs.uiuc.edu
- ChaNGa download: http://software.astro.washington.edu/nchilada/
- Release information: http://hpcc.astro.washington.edu/tools/changa.html
- Mailing list: changa-users@u.washington.edu

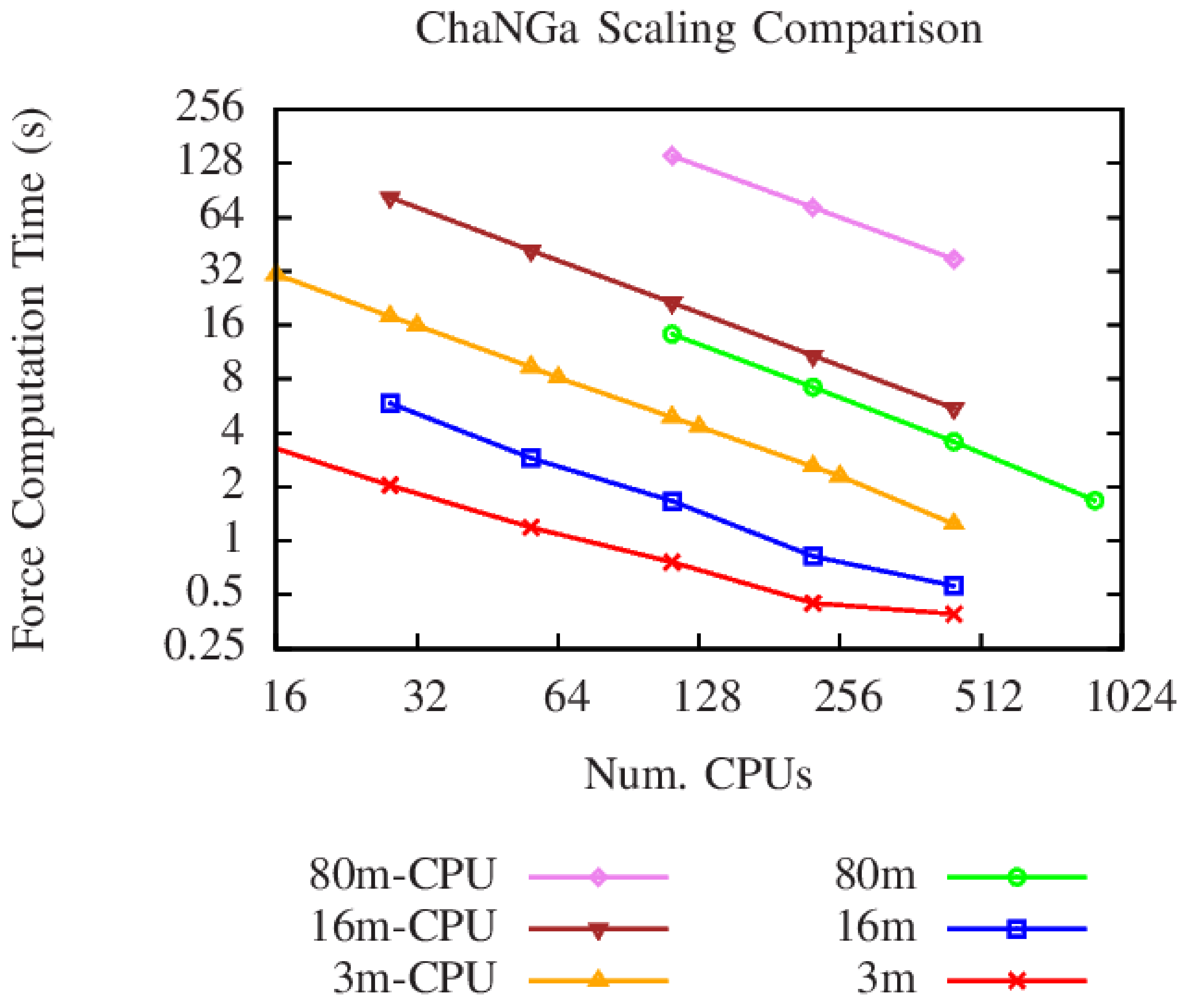
Acknowledgment: NSF-ITR, NSF-PRAC, NASA-AISR

GPU Manager

- User submits “work requests” with GPU kernel, associated buffers and callback
- System transfers memory between CPU and GPU, executes kernel, and returns via a callback
- GPU operations performed asynchronously
- Pipelined execution
- Consistent with Charm++ model
- Charm++ tools (profiler) available

GPU/CPU Timeline





ChaNGa Scaling Comparison
Force Computation Time (s)
256
128
64
32
16
8
4
2
1
0.5
0.25
16
32
64
128
256
512
1024
Num. CPUs
80m-CPU
16m-CPU
3m-CPU
80m
16m
3m