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The Asynchronous Dynamic Load-Balancing Library

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Outline

- The Nuclear Physics problem - GFMC
- The CS problem: scalability, load balancing, simplicity for the application
- Approach: a portable, scalable library, implementing a simple programming model
- Status
  - Choices made
  - Lessons learned
  - Promising results
- Plans
  - Scaling up
  - Branching out
  - Using threads

} so far…

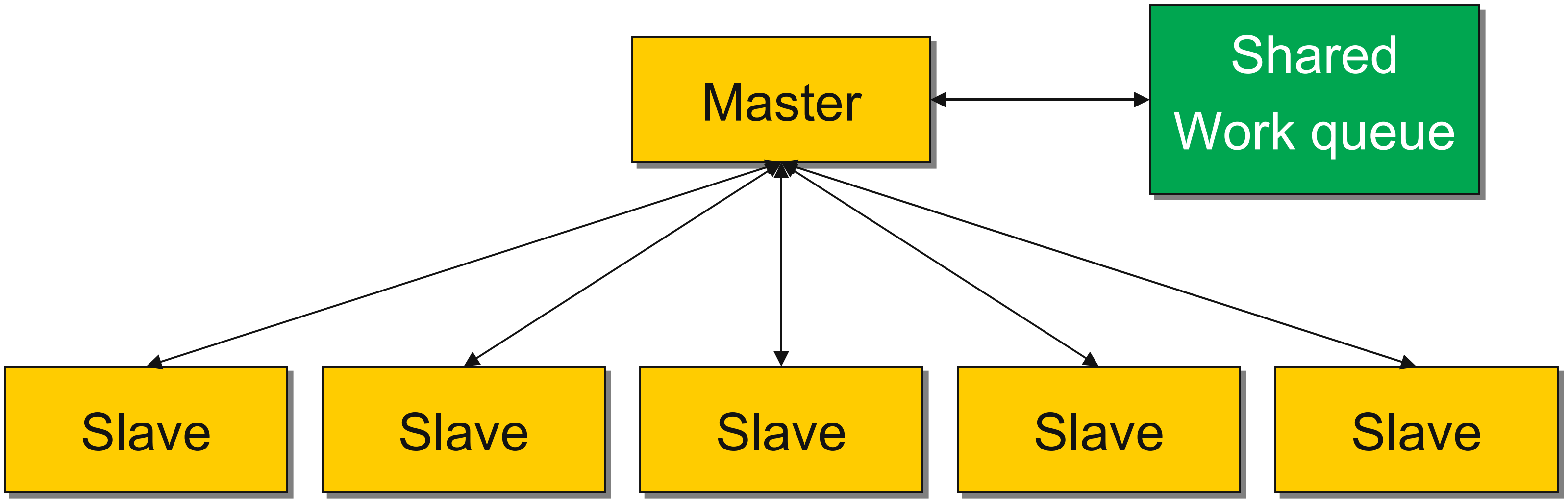
The Physics Project: Green's function Monte Carlo (GFMC)

- The benchmark for nuclei with 12 or fewer nucleons
- Starts with variational wave function containing non-central correlations
- Uses imaginary-time propagation to filter out excited-state contamination
  - Samples removed or multiplied during propagation -- work fluctuates
  - Local energies evaluated every 40 steps
  - For ^{12}C expect ~10,000 Monte Carlo samples to be propagated for ~1000 steps
- Non ADLB version:
  - Several samples per node; work on one sample not parallelized
- ADLB version:
  - Three-body potential and propagator parallelized
  - Wave functions for kinetic energy and two-body potential done in parallel
  - Can use many processors per sample
- Physics target: Properties of both ground and excited states of ^{12}C

The Computer Science Project: ADLB

- Specific Problem: to scale up GFMC, a master/slave code
- General Problem: scaling up the master/slave paradigm in general
  - Usually based on a single (or shared) data structure
- Goal for GFMC: scale to 160,000 processes (available on BG/P)
- General goal: provide simple yet scalable programming model for algorithms parallelized via master/slave structure
- General goal in GFMC setting: eliminate (most) MPI calls from GFMC and scale the general approach
- GFMC is not an easy case:
  - Multiple types of work
  - Any process can create work
  - Large work units (multi-megabyte)
  - Priorities and types used together to specify some sequencing without constraining parallelism ("workflow")

Master/Slave Algorithms and Load Balancing

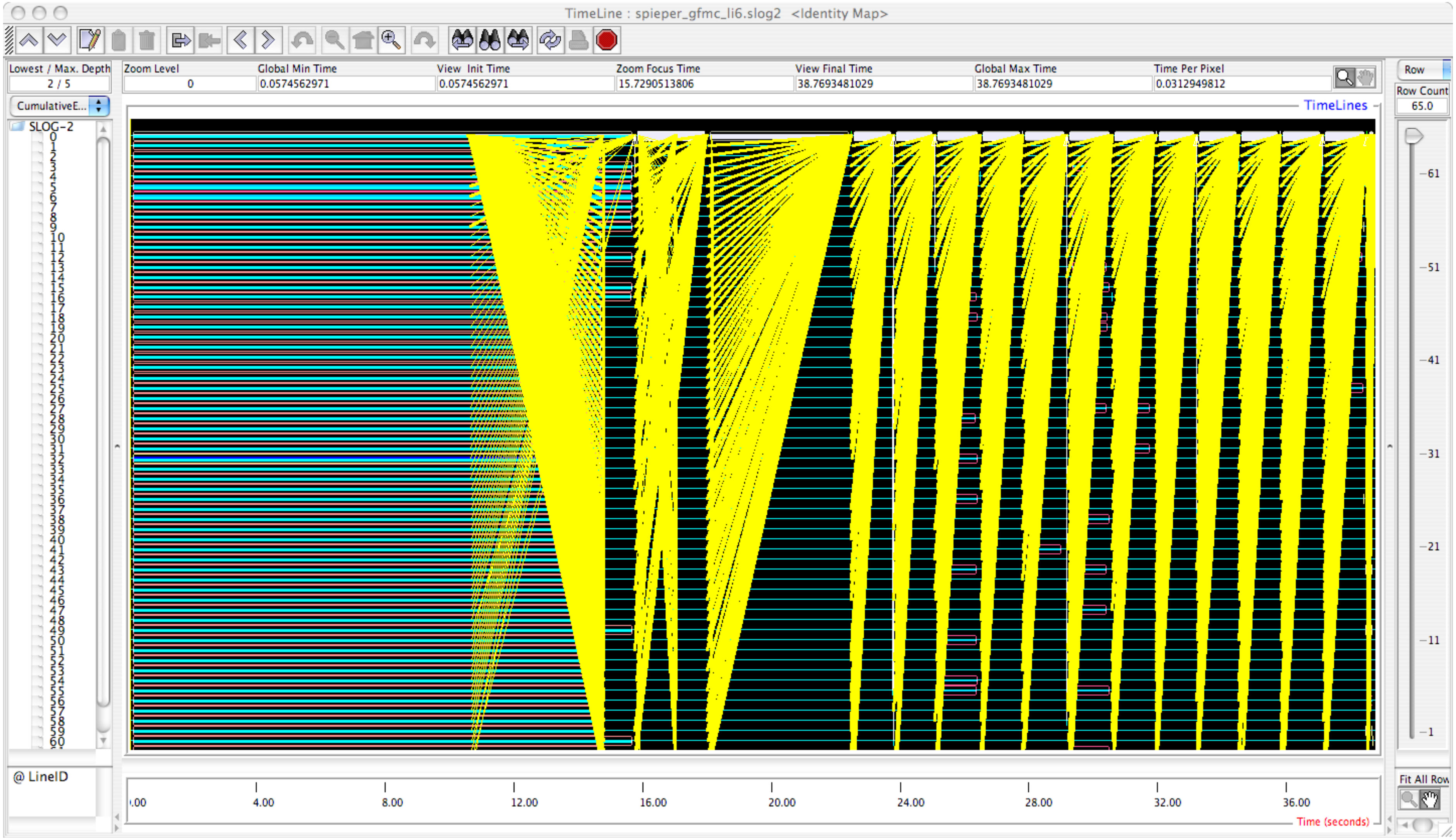


- Advantages
  - Automatic load balancing
- Disadvantages
  - Scalability - master can become bottleneck
- Wrinkles
  - Slaves may create new work
  - Multiple work types and priorities that impose ordering

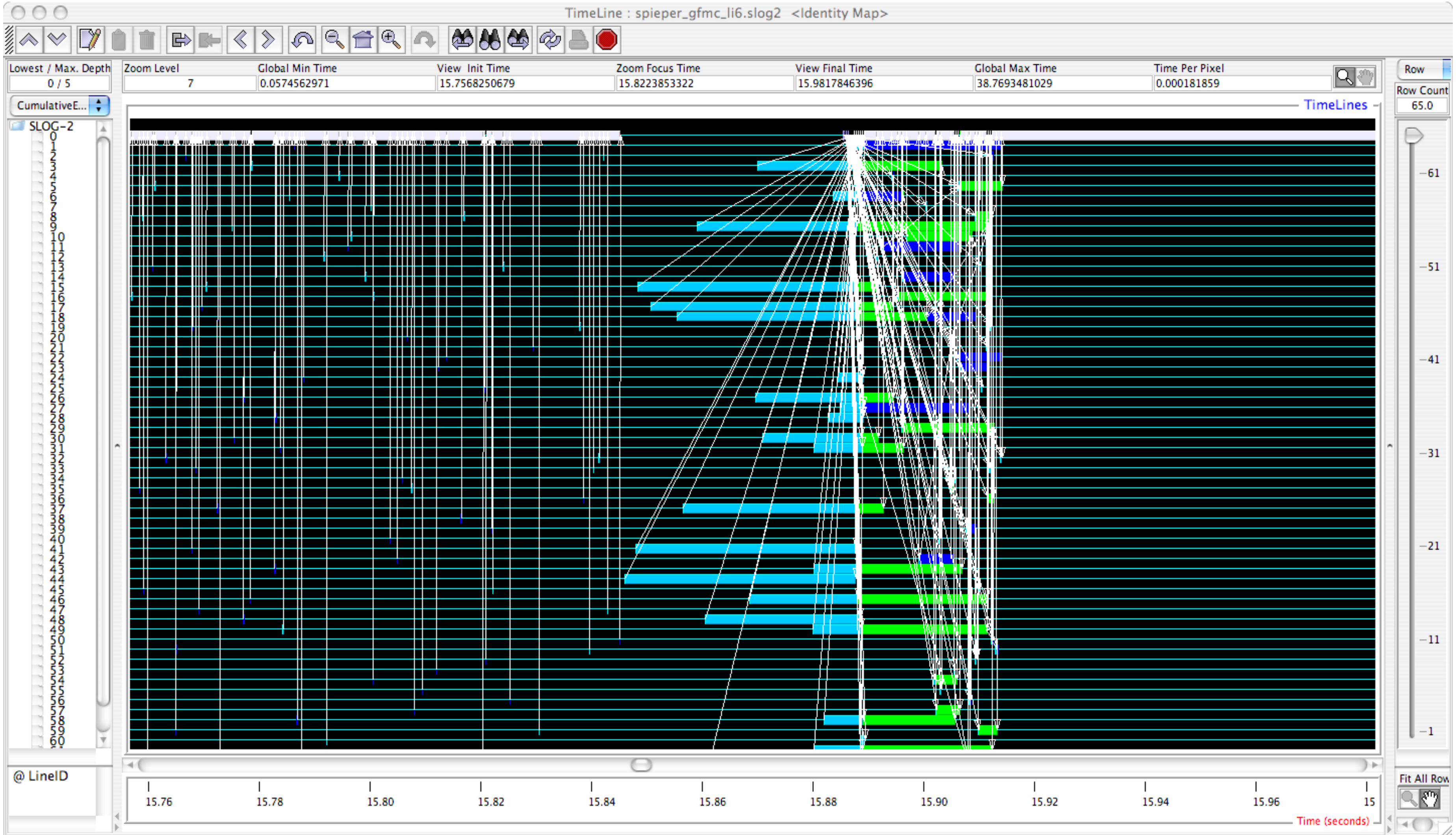
Load Balancing in GFMC Before ADLB

- Master/Slave algorithm
- Slaves do create work dynamically
- Newly created work stored locally
- Periodic load balancing
  - Done by master
  - Slaves communicate work queue lengths to master
  - Master determines reallocation of work
  - Master tells slaves to reallocate work
  - Slaves communicate work to one another
  - Computation continues with balanced work queues

GFMC Before ADLB



Zoomed in



TimeLine : spieper_gfmc_li6.slog2 <Identity Map>
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0 / 5
Zoom Level
7
Global Min Time
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View Init Time
15.7568250679
Zoom Focus Time
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View Final Time
15.9817846396
Global Max Time
38.7693481029
Time Per Pixel
0.000181859
Row
Row Count
65.0
CumulativeE...
SLOG-2
TimeLines
@ LineID
Fit All Row
15.76
15.78
15.80
15.82
15.84
15.86
15.88
15.90
15.92
15.94
15.96
15
Time (seconds)

BlueGene P

- 4 cpus per node
- 4 threads or processes per node
- 160,000 cpus
- Efficient MPI communication
- Original GFMC not expected to continue to scale past 2000 processors
  - More parallelism needed to exploit BG/P for Carbon 12
  - Existing load-balancing mechanism will not scale
- A general-purpose load-balancing library should
  - Enable GFMC to scale
  - Be of use to other codes as well
  - Simplify parallel programming of applications

The Vision

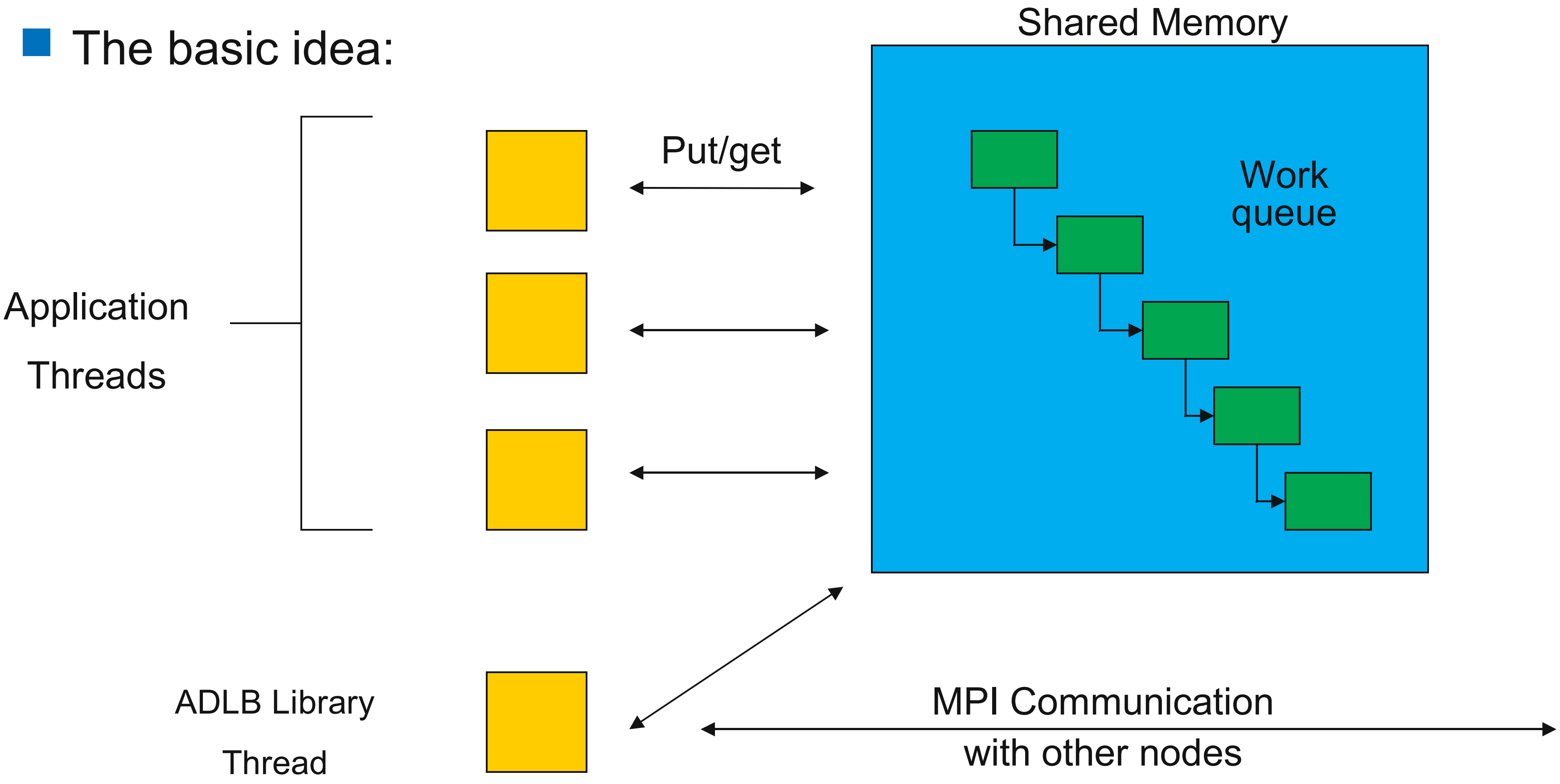
- No explicit master for load balancing; slaves make calls to ADLB library; those subroutines access local and remote data structures (remote ones via MPI).
- Simple Put/Get interface from application code to distributed work queue hides most MPI calls
  - Advantage: multiple applications may benefit
  - Wrinkle: variable-size work units, in Fortran, introduce some complexity in memory management
- Proactive load balancing in background
  - Advantage: application never delayed by search for work from other slaves
  - Wrinkle: scalable work-stealing algorithms not obvious

The API (Application Programming Interface)

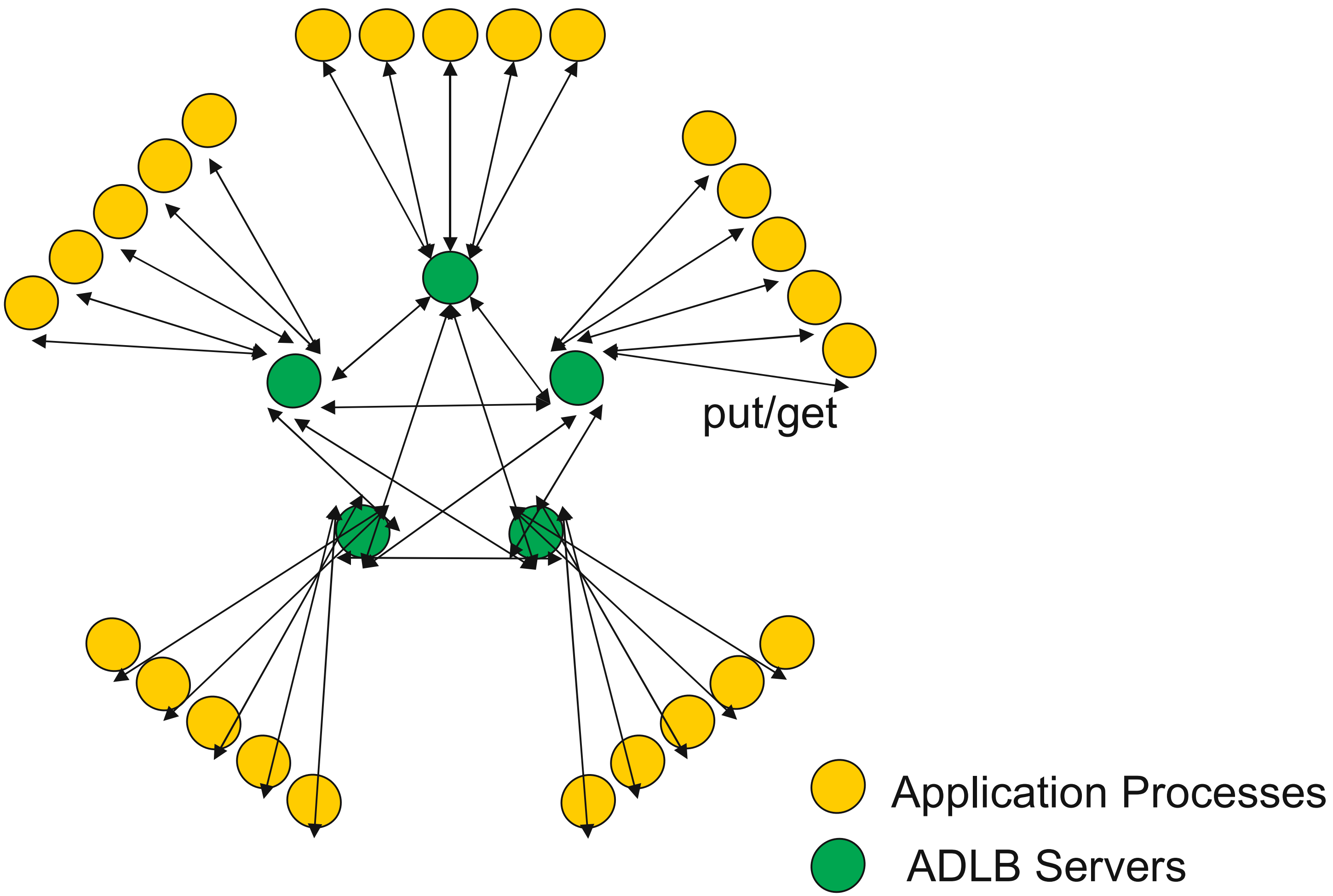
- Basic calls
  - ADLB_Init(num_servers, am_server, app_comm)
  - ADLB_Server()
  - ADLB_Put(type, priority, len, buf, answer_dest)
  - ADLB_Reserve(req_types, work_handle, work_len, work_type, work_prio, answer_dest)
  - ADLB_Ireserve(…)
  - ADLB_Get_Reserved(…)
  - ADLB_Set_done()
  - ADLB_Finalize()
- A few others, for tuning and debugging
  - (still at experimental stage)

Asynchronous Dynamic Load Balancing - Thread Approach

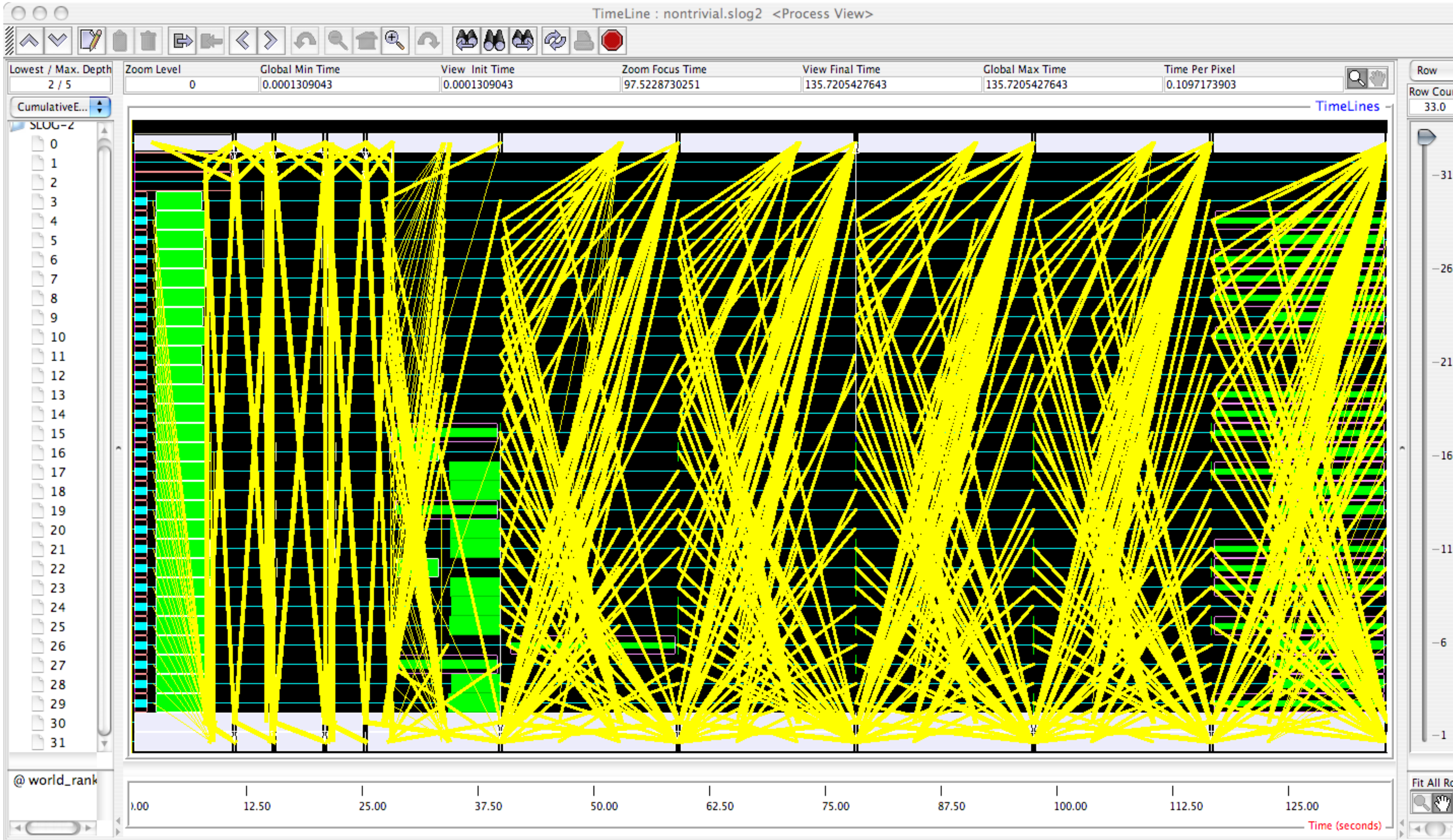
- The basic idea:



ADLB - Process Approach



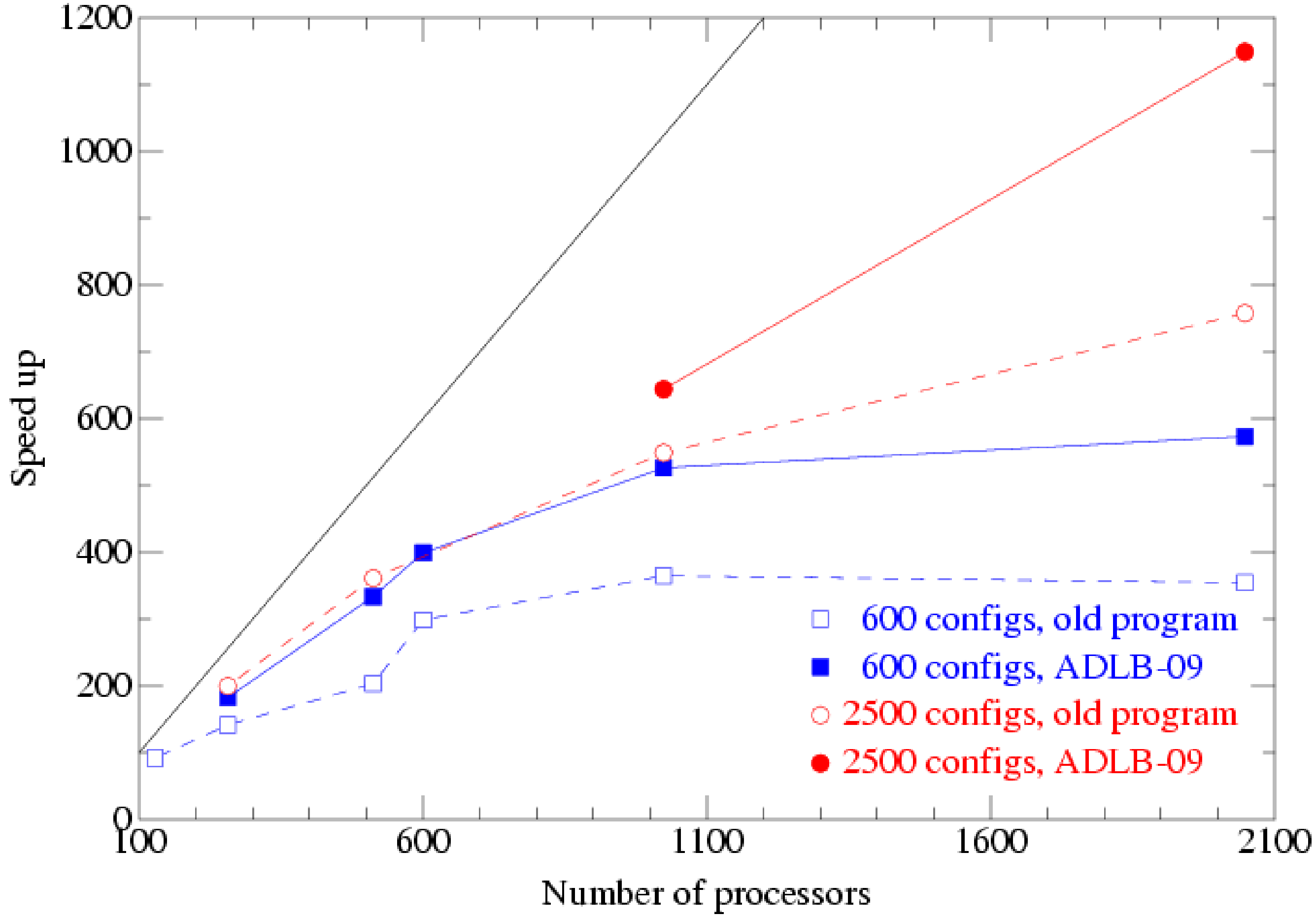
Early Version of ADLB in GFMC on BG/L



History and Status

- Year 1: learned the application; worked out first version of API; did thread version of implementation
- Year 2: Switched to process version, began experiments at scale
  - On BG/L (4096), SiCortex (5800), and BG/P (16K so far)
  - Variational Monte Carlo (part of GFMC)
  - Full GFMC (see following performance graph)
  - Latest: GFMC for neutron drop at large scale
- Some additions to the API for increased scalability, memory management
- Internal changes to manage memory
- Still working on memory management for full GMFC with fine-grain parallelism, needed for ^{12}C
- Basic API not changing

Comparing Speedup



Most Recent Runs

- 14-neutron drop on 16,384 processors of BG/P
- Speedup of 13,634 (83% efficiency)
- No microparallization since more configurations
- ADLB processes 171 million work packages of size 129KB each, total of 20.5 terabytes of data moved
- Heretofore uncomputed level of accuracy for the computed energy and density
- Also some benchmarking runs for ^{9}Be and ^{7}Li

Future Plans

- Shortdetour into scalable debugging tools for understanding behavior, particularly memory usage
- Further microparallelization of GFMC using ADLB
- Scaling up on BG/P
- Revisit the thread model for ADLB implementation, particularly in anticipation of Q and experimental compute-node Linux on P
- Help with multithreading the application (locally parallel execution of work units via OpenMP)
- Work with others in the project who use manager/worker patterns in their codes
- Work with others outside the project in other SciDACs

Summary

- We have designed a simple programming model for a class of applications
- We are working on this in the context of a specific UNEDF application, which is a challenging one
- We have done two implementations
- Performance results are promising so far
- Still have not completely conquered the problem
- Needed: tools for understanding behavior, particularly to help with application-level debugging

The End