Scalability evaluation of barrier algorithms for OpenMP

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Supported by NSF
under grant CCF – 0702775 and CCF - 0833201

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Agenda

- Motivation
- Overview of different barrier implementation.
- Methodology
- Experiment Results
- Conclusion
- Future Work

Motivation

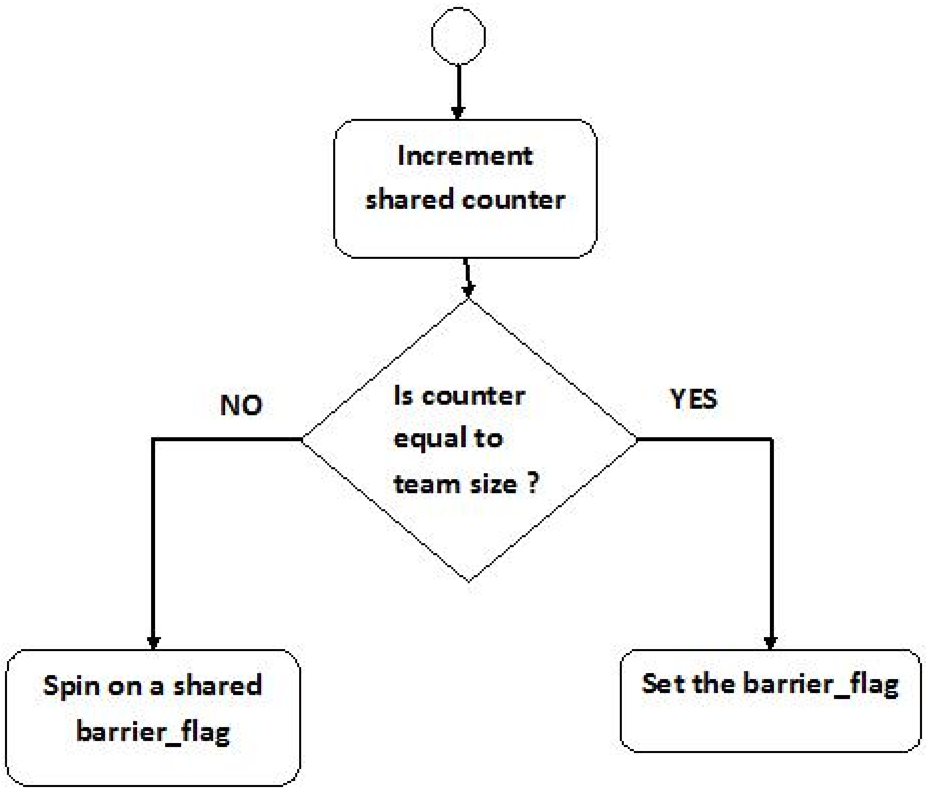
- The number of cores continues to grow…..
    - *OpenMP application scalability is critical.*
- Diverse architecture, memory hierarchy, network interconnect, applications…..
    - *Needs an adaptive runtime.*

OpenMP and Barriers

- OpenMP
  - Relies heavily on *explicit* barrier synchronization to coordinate the work of threads.
  - Most OpenMP constructs involve *implicit* barriers, and incur overhead because of it.

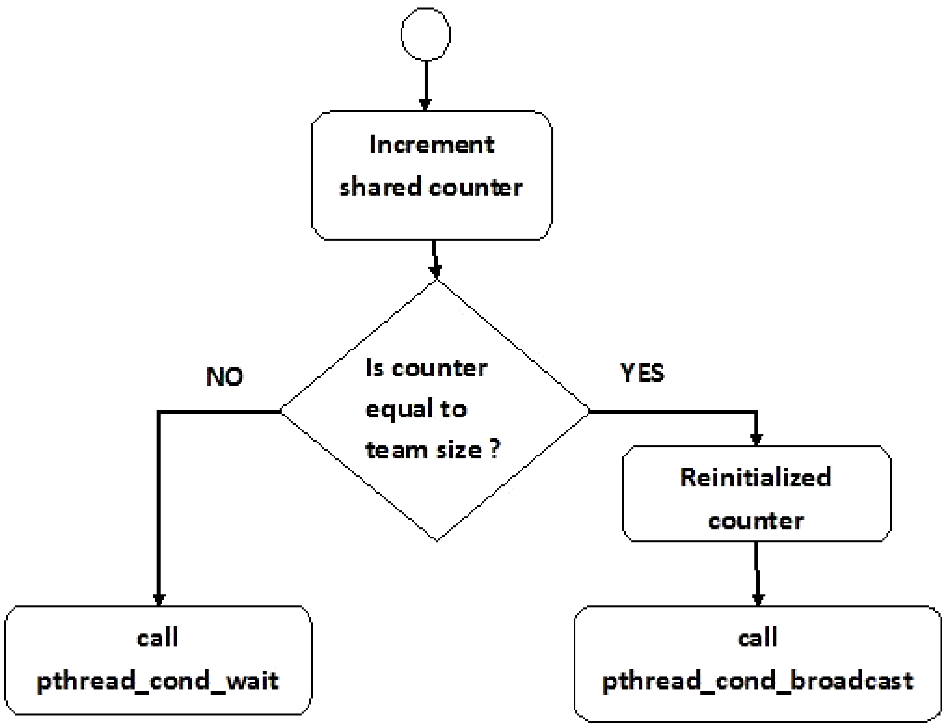
- Barrier algorithms classification:
  1. Centralized busy-wait : busy-wait on shared variable.
  2. Blocking : pthread call that de-schedules the waiting thread.
  3. Distributed busy-wait : busy-wait on a separate locally accessible variable.
     1. Dissemination barrier.
     2. Tournament barrier.
     3. Tree barrier.

Centralized barrier



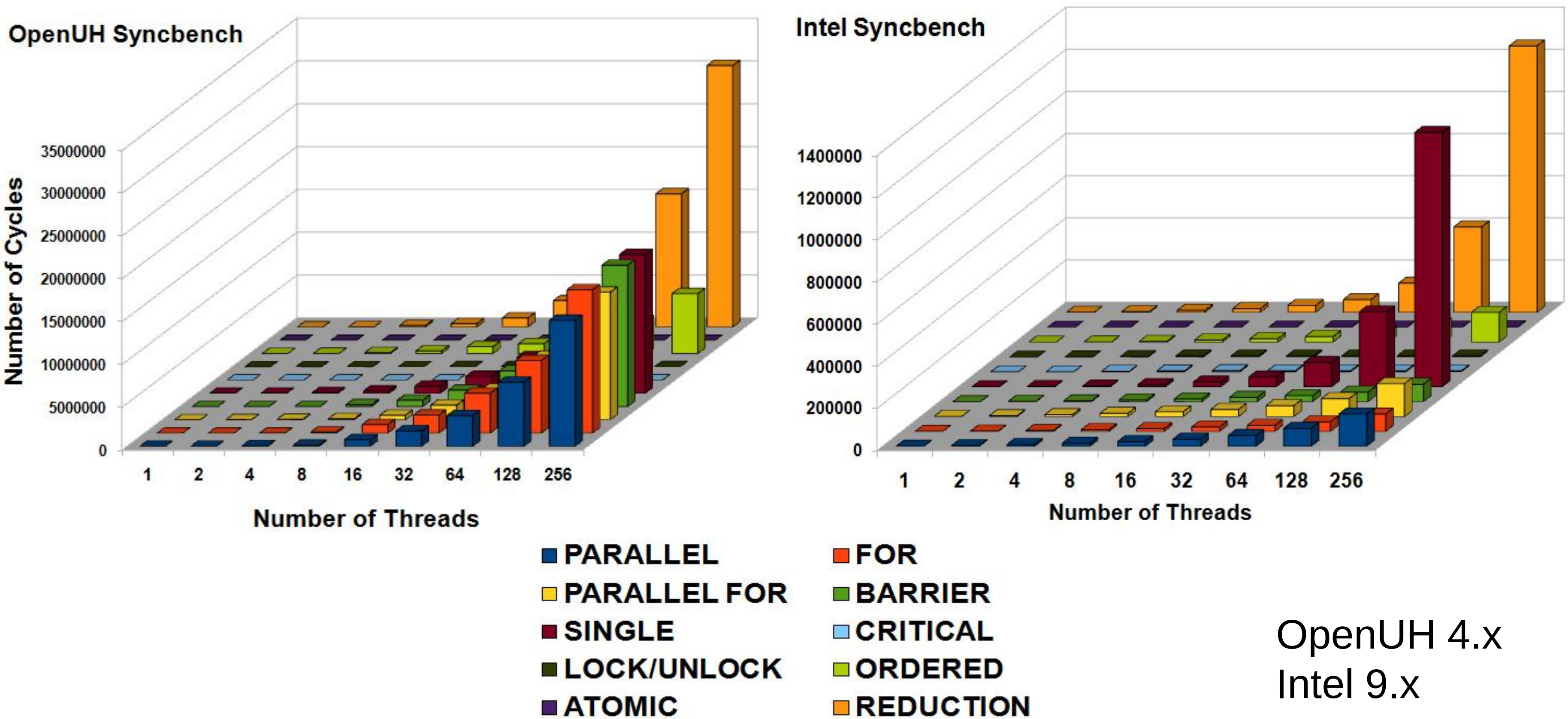
- The shared counter accessible by all threads is incremented atomically.
- Busy waiting on a single flag causes hot spots and large amounts of memory, and interconnect traffic.
- Effect is pronounced as application scales.

Blocking barrier algorithm



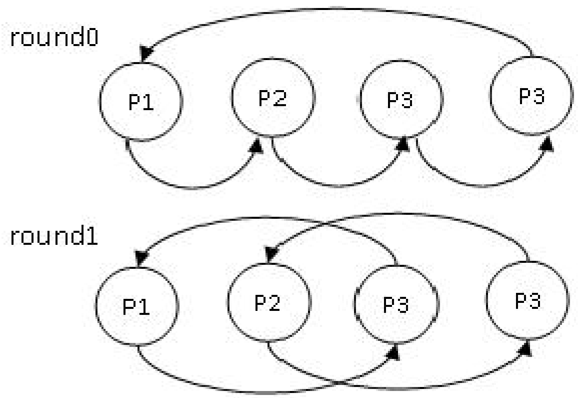
- Improves upon centralized shared counter algorithm.
- Involved rescheduling of threads.
- Suitable when there is frequent oversubscription of threads as in case of,
  - multiuser environment.
  - task support.
- Poor scalability because of,
  - Mutex and condition variables.
  - Context switching.

Overheads of blocking barrier (EPCC benchmark)



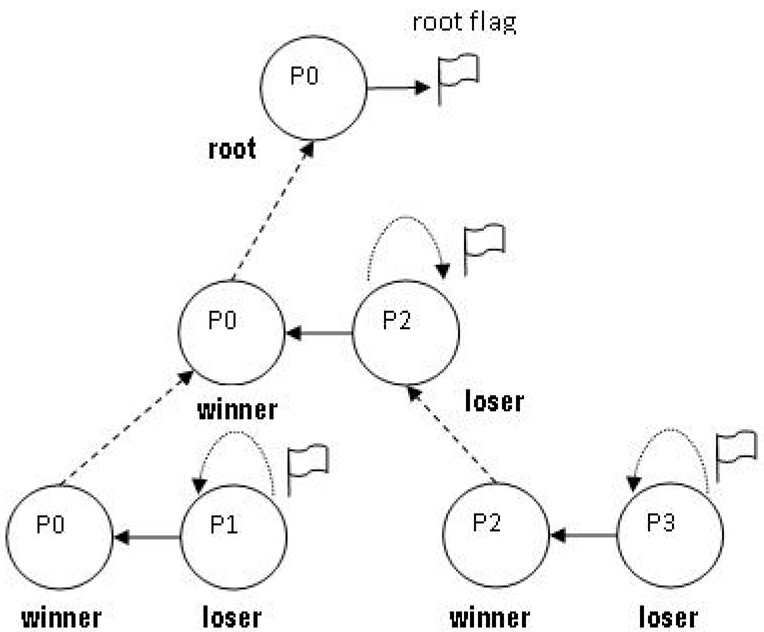
OpenUH 4.x
Intel 9.x

Dissemination Barrier



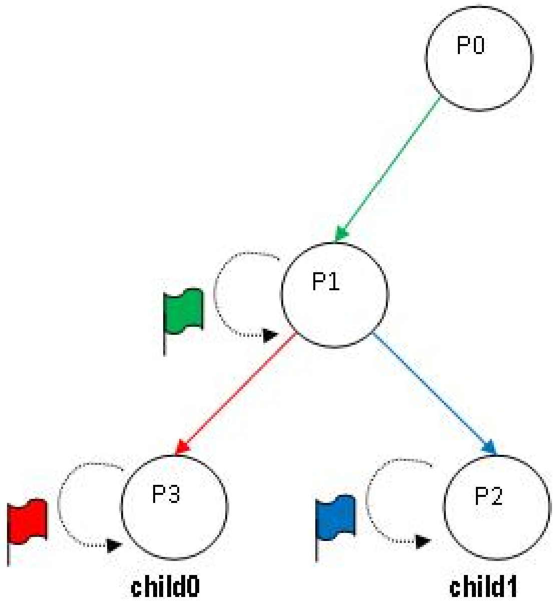
- Originally implemented in MPI environment.
- For each round n, thread i, waits for flag setting from i-2k and sets flag of thread i+2k
- Results
  - Gives good results for < 16 threads because of the simplicity.
  - Not as good on 16+ (constant interconnect communication in each round) and directory based cache (sun niagara)

Tournament barrier



- Based on the idea of tournament game.
- For each round n, loser sets the flag of winner before spinning on root flag.
- Better performance on higher number of threads because of faster initialization as compared to tree algorithm.
- The interconnect traffic caused by root flag can cause performance bottleneck in which case the tree implementation would be better.

Tree barrier

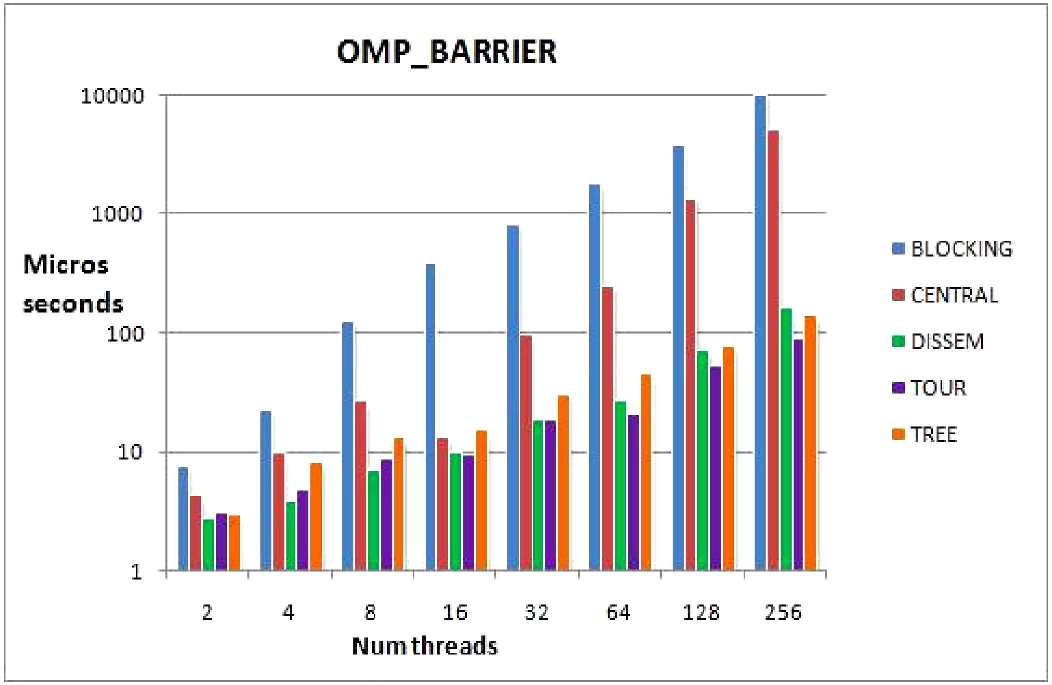


- Binary tree communication between threads.
- All non-root threads wait on local flags during arrival phase. (leaves to root)
- The parent sets the flag of the children during wakeup phase (root to leaves).
- Better performance in some cases because it eliminates the root flag.
- Involves complexity of building the tree structure.

Methodology

- Platforms:
  - SGI 4700 Altix: 1024 dual core Intel processor.
  - Sun Fire X4600: 8 dual core AMD Opteron.
  - Fujitsu-Siemens RX600S4: 4 quad core Intel Xeon processors.
  - Sun T5120: 8 processor cores each with 8 hardware threads.
- Benchmarks
  - The EPCC microbenchmark suite.
  - NAS Parallel Benchmark 3.0, LU-HP benchmark.
  - OpenMP application ASPCG kernel and GENIDLEST.
  - An hand-crafted pthread application.
- Compilers and Tools
  - OpenUH, OpenMP Collector API tool, GCC

EPCC Results



OMP_BARRIER

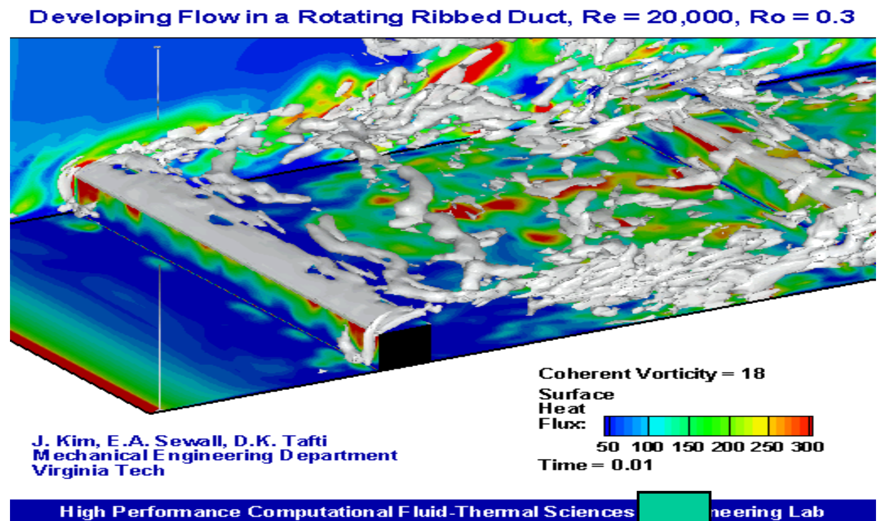
- The centralized and blocking barrier do not perform as well as other algorithms.
- Dissemination barrier has the least overhead on 16 threads or less.
- Tournament barrier resulted in lowest overhead for more than 16 threads

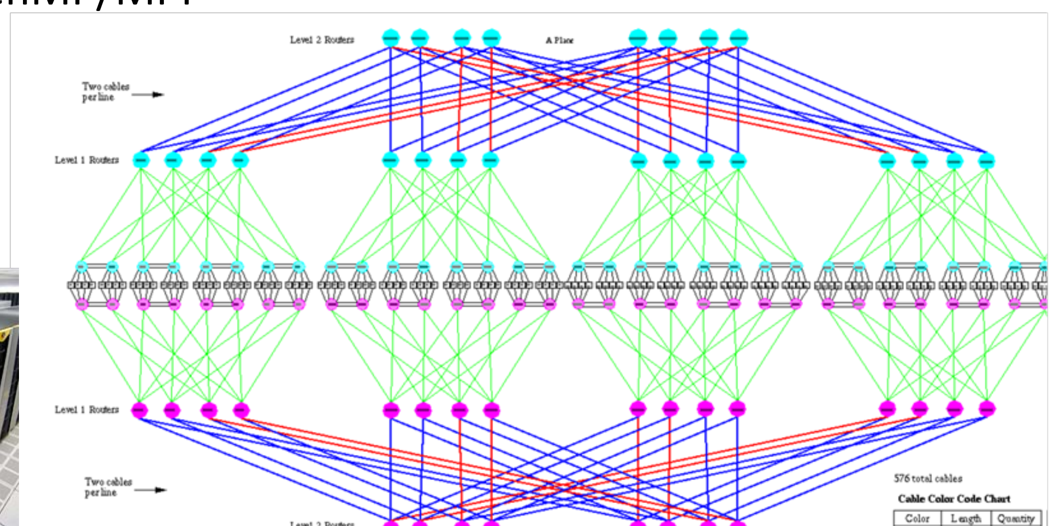
```
for (k=0; k<=OUTERREPS; k++){
  start  = getclock();
#pragma omp parallel private(j)
  {
   for (j=0; j<innerreps; j++){
     delay(delaylength);
     #pragma omp barrier
   }
  }
  end = getclock();
}
```

GenIDLEST / ASPCG

- Generalized Incompressible Direct and Large-Eddy Simulations of Turbulence
- Solves the incompressible Navier-Stokes and energy equations
- Overlapping multi-block body-fitted structured mesh topology combined with an unstructured inter-block topology.
- ASPCG is a small CG kernel of GenIDLEST
- OpenMP, MPI and OpenMP/MPI

  Versions of code.





The Altix 3700 512-processor system

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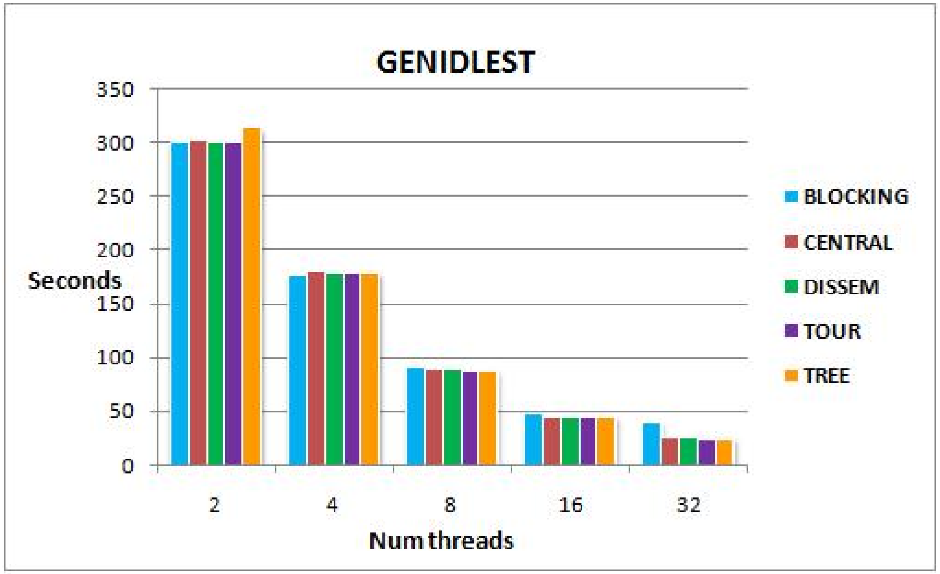
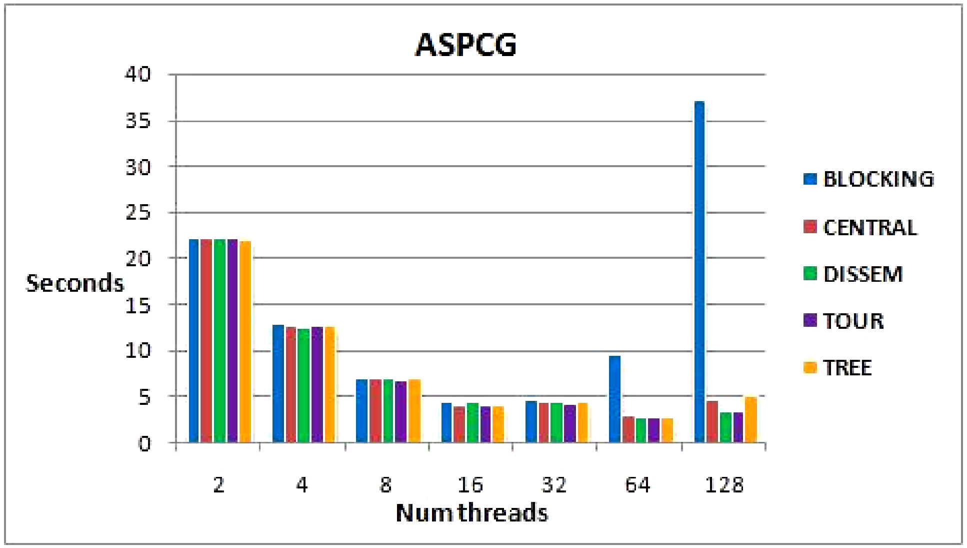
Application Results



GENIDLEST

- GENIDLEST solves incompressible Navier-stokes and energy equations.
- Total 35% improvement in the execution time on 32 threads.
- Blocking barrier performs equally well because of nature of the application, which is memory intensive.

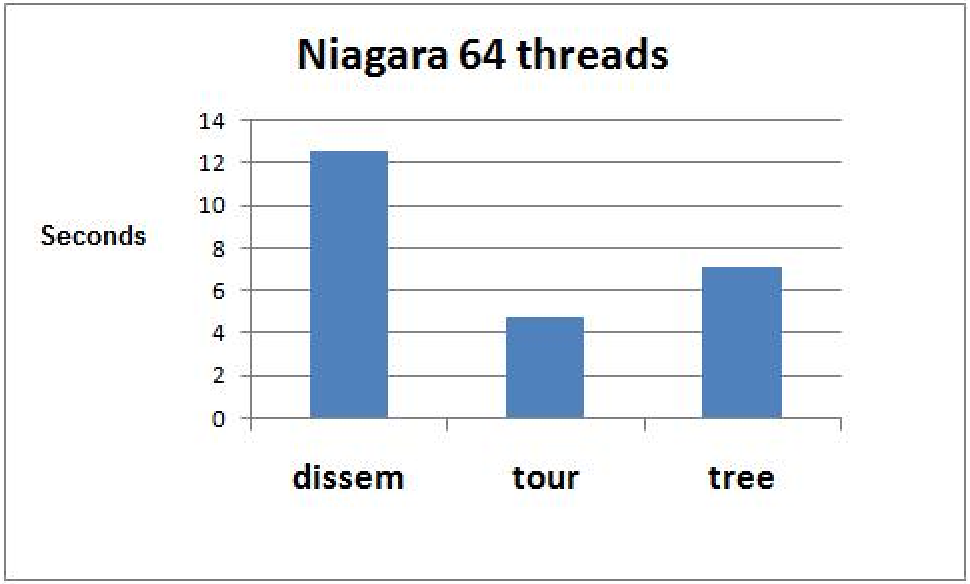
Application Results (cont…)



ASPCG

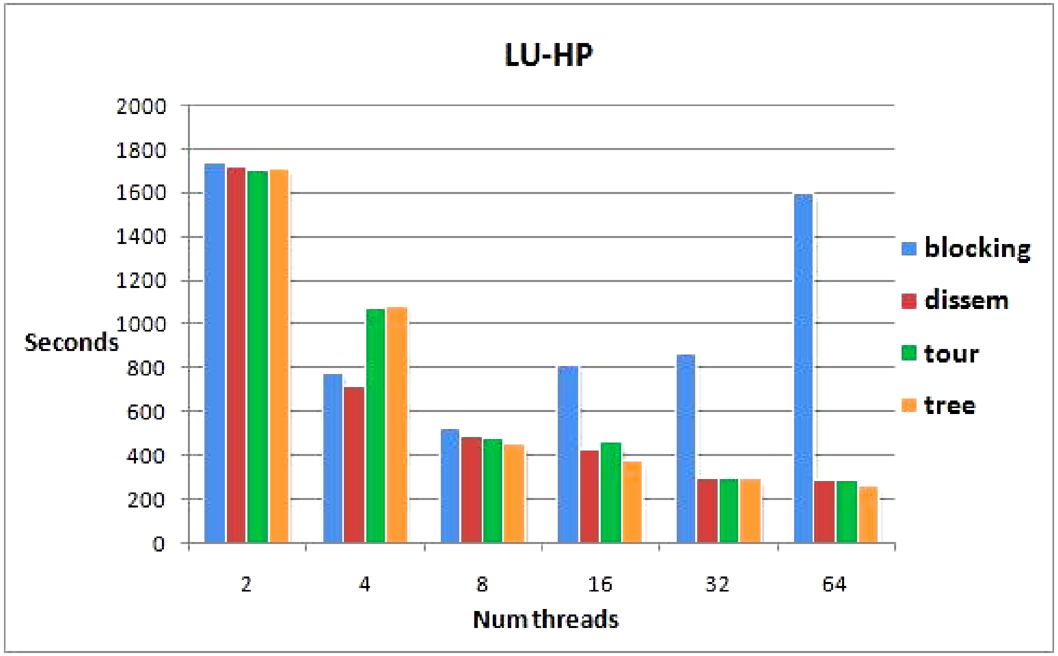
- ASPCG solves a linear system of equations generated by a Laplace equation in cartesian coordinates.
- All busy wait algorithms scale, some with better performance than other.
- Nearly 12x improvement when compared to blocking barrier on 128 threads.
- Tree barrier incurs nearly 20% more execution time than the tournament and dissemination.

Sun Niagara Results



- Employed an hand crafter pthread application for testing, due to lack of OpenUH implementation on Solaris.
- The cache coherence protocol causes poor performance of dissemination.

NAS PB results



- Explored the behavior of LU-HP NAS Parallel benchmark
- LU-HP is CFD application that invokes 739426 implicit barriers on 4 threads. (Data obtained using OpenMP collector API tool)
- Shows considerable performance benefit of tree barrier over others (10% better).

Conclusion

- Achieved good scalability and performance using the new algorithms.

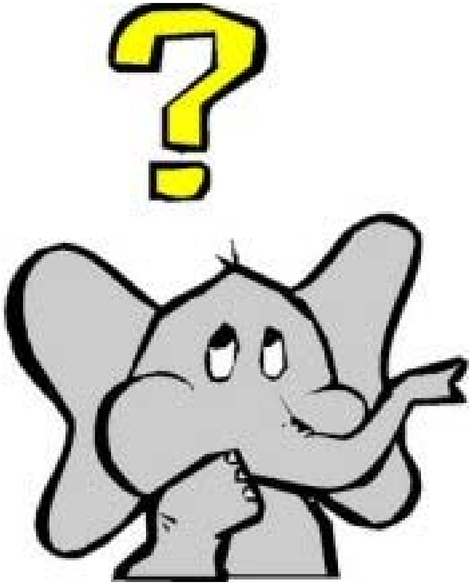
- In general, the performance of a given barrier implementation is dependent on
  - The number of threads used.
  - The number of barriers.
  - The application.
  - The OpenMP directive.
  - The architecture (memory layout/interconnect)
  - And possibly system load (on small scale multicore).

- An OpenMP runtime library should ideally, adapt to different barrier implementations during runtime.

Future Work

- Further testing of these algorithms on even larger system (in particular, with 2048 cores)
- As OpenMP 3.0 implementation becomes available in OpenUH we would like to evaluate how these algorithms affect the tasking feature.
- Implement similar enhancements for the reduction operation.
- Cost model for adaptive runtime.
- Integrate these work with the Adaptive OpenMP and Dynamic compiler work.

Questions?



Backup slides

Dynamic Optimizer and OpenMP

- DO checks if collector is present
- DO requests collector for initialization.
- Thread states are kept by the OpenMP RTL
- DO registers thread events with callbacks to the OpenMP RTL
- DO requests for parallel region replacement, change of schedulers, implementations.