P-Threads and Shared Memory Programming in PETSc

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Software Needs To Utilize Resources

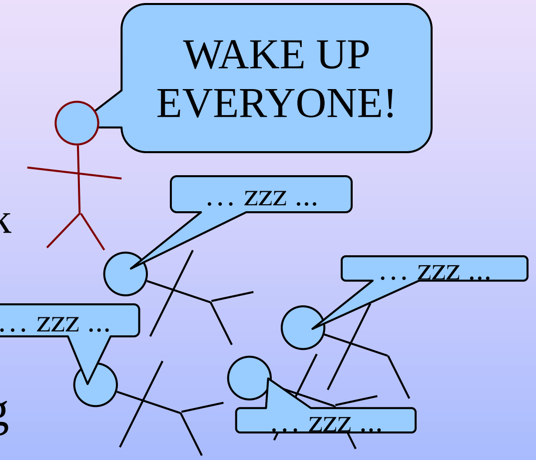
- Most HPC systems consist of many, many, many nodes networked together in a suitable topology
  - A node consists (most often) of multiple processors (sockets) that all have multiple cores
- Utilizing only 1 MPI process per node utilizes only 1 core of 1 processor
- P-Threads/OpenMP designed for shared memory parallel programming, coordinating work intra-node

Your basic supercomputer


Your basic desktop

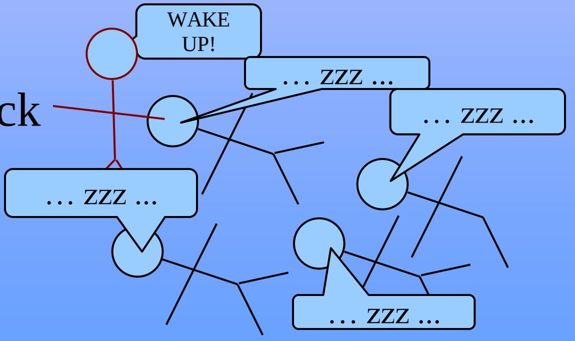
Communication Model

- P-Threads provides 2 routines to inform waiting threads that the state of some shared data structure has changed



- *pthread_cond_broadcast* awakens all the threads
  - initiates a 'thundering herd' all contending for the lock

- *pthread_cond_signal* awakens only 1 thread waiting
  - Can specify which thread is to be awoken by using a different condition variable for each thread



- *pthread_cond_wait* causes the thread to unlock the held mutex and sleep AUTOMICALLY

The Track Race Analogy

- Guy with the gun – the 'main' thread
- Runners – the posix threads

- The Event
  - All runners line up and get into position
  - The guy with the gun fires it off
  - Runners perform their task: run

- How can the above procedure be accomplished in software?

The Track Race Analogy Continued …

- Common track race events include the 100m, 200m, 400m, and 800m
- Track race events in software we term thread kernels and include vector dot product, matrix-vector multiply, etc.
  - Just as the 100m takes less time to complete than the 800m, different thread kernels take different amounts of time to complete

The Firing of the Starting Gun

- In real life the Starter fires the gun, the runners all hear it simultaneously, and everyone starts running
- The Starter firing the gun analogous to the 'main' thread issuing a pthread_cond_broadcast instruction

Implicit Synchronization
The Starter

- Must ensure all the runners are lined up and in position

- Must ensure all the runners have finished the race before commencing to set up a new race

- Must collect race results (sometimes)

Implicit Synchronization
The Runners

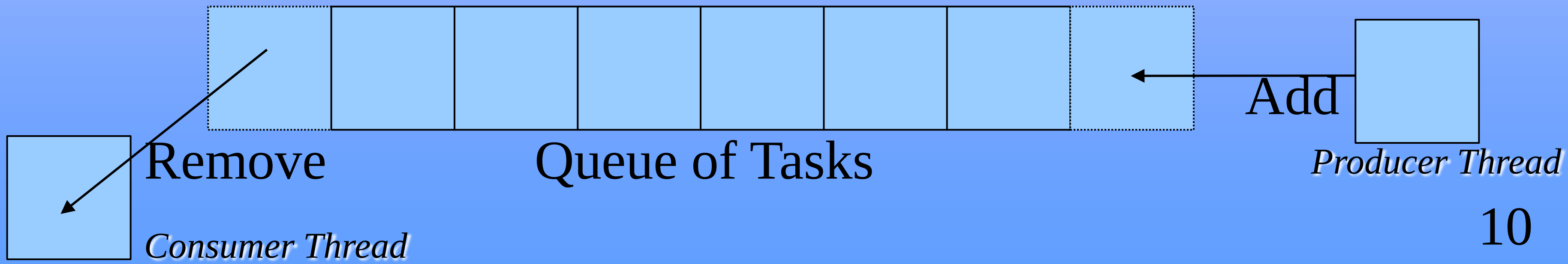
- In real life, unless running a relay, runners are completely independent of one another
- In software, a baton (mutex) enters
  - Depending on the implementation, threads may solely coordinate with the 'main' thread or could coordinate with multiple other threads
- The need for runner synchronization makes thread pool use much less appealing

Why can't all runners (threads) start simultaneously?

- Associated with the pthread_cond_wait() is a condition variable AND a mutex
- Any way that wake up & run can truly be simultaneous, not sequential?
  - NO! Unlock and wait needs to be atomic

Thread Pool & Use

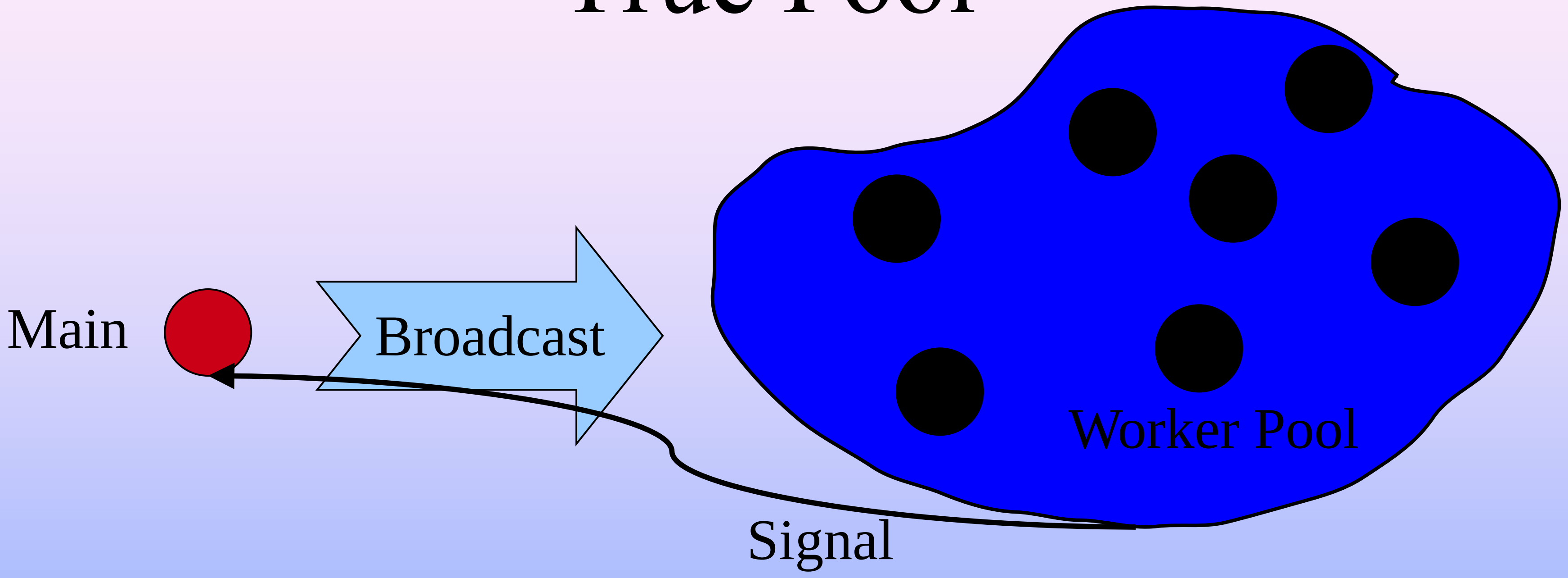
- Collection of threads
- Used often in producer/consumer model
    - Producer: add task to some shared data structure
    - Consumer: remove task from shared data structure and complete task
    - Lock must protect the shared data structure



Thread Pool Implementation in PETSc

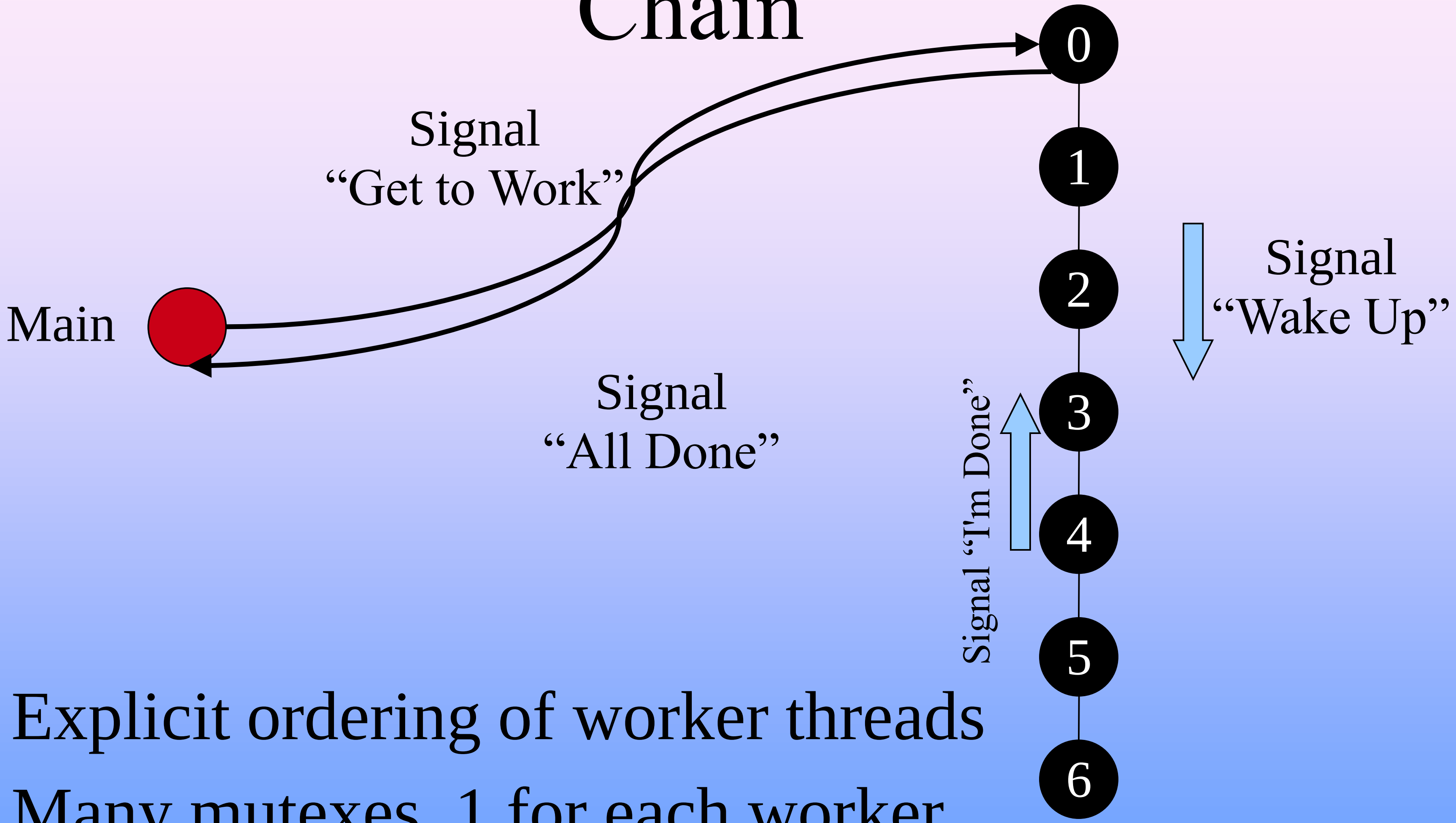
- Thread pools designed for programs comprised of many short tasks
- Run time consists of combining computation and P-Thread overhead time
- Small jobs can take longer using P-Threads due to (comparatively) large amount of time for thread creation
- Thread creation occurs on startup, thread termination occurs at shutdown

Thread Pool Implementations
"True Pool"



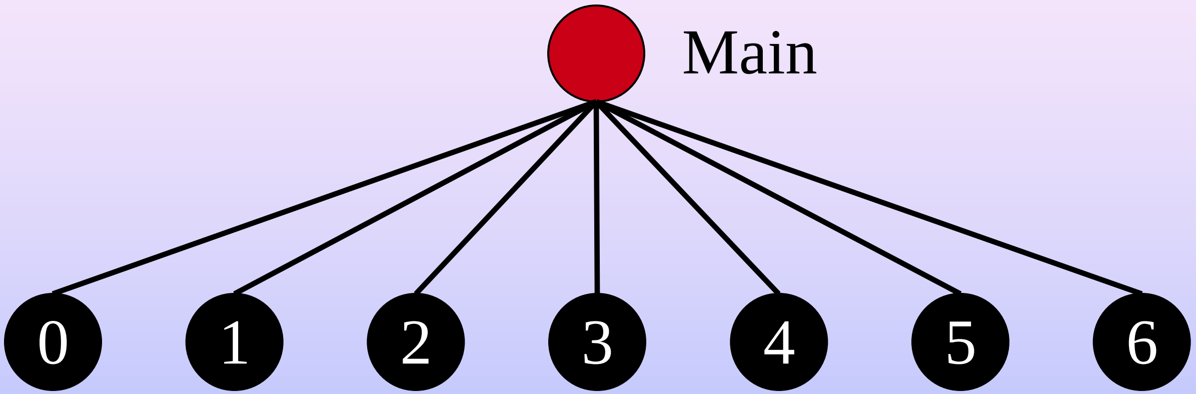
- 1 mutex coordinates/synchronizes everyone
- "Thundering herd" for mutex control
- Last worker to finish signals Main

Thread Pool Implementations
"Chain"



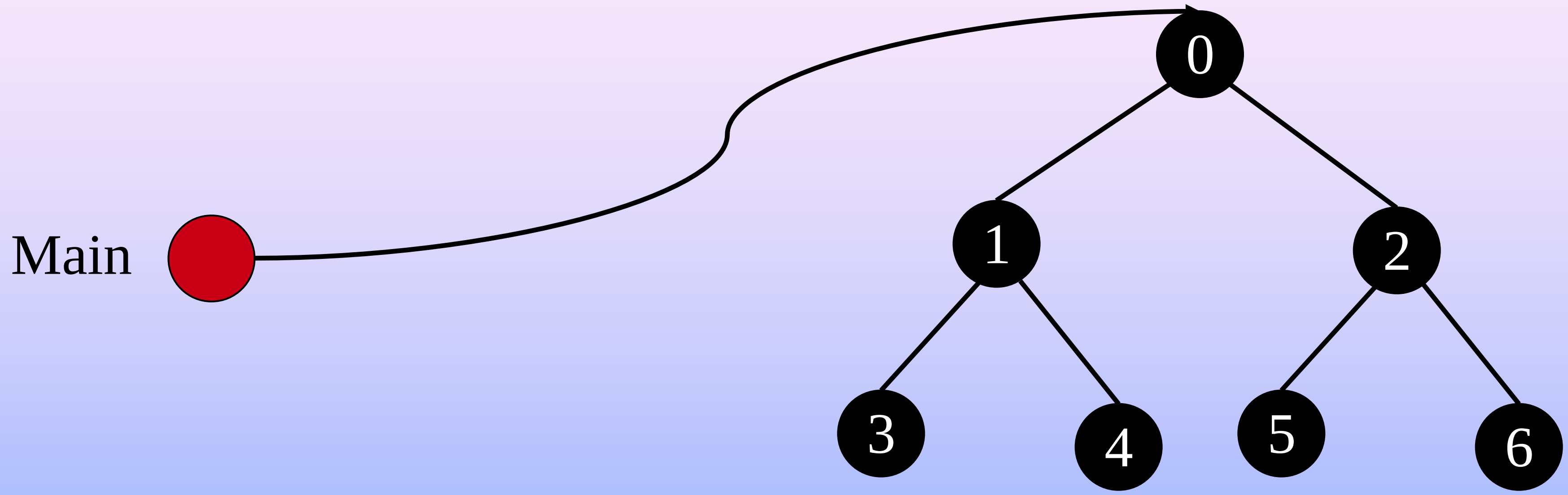
- Explicit ordering of worker threads
- Many mutexes, 1 for each worker
- Sequentiality explicit

Thread Pool Implementations "Dictatorship"



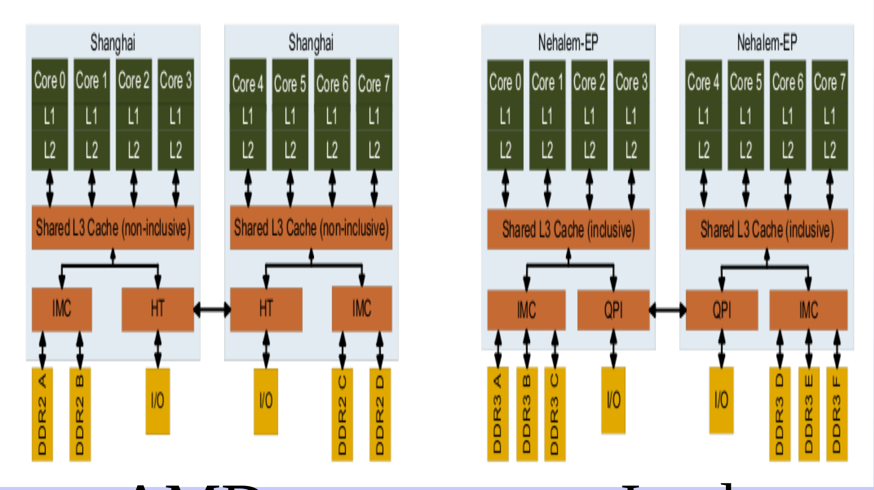
- Many mutexes, 1 for each worker thread
- Main sends signals sequentially
- Each worker thread signals Main
- Workers truly independent

Thread Pool Implementations
"Corporate" or "Tree"



- Threads tell their subordinates to get to work
- Subordinates inform their bosses that they're done
- "Parallelization" of wake up procedure

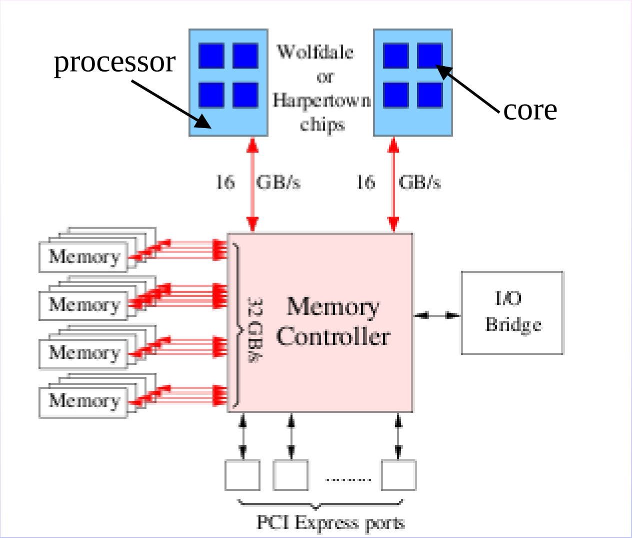
Threads And Core Affinity



AMD Intel

- Which core does Main run on? Which do my threads run on?
- Process-to-processor and thread-to-core mappings greatly affect performance
  - "Task mapping problem" heavily researched

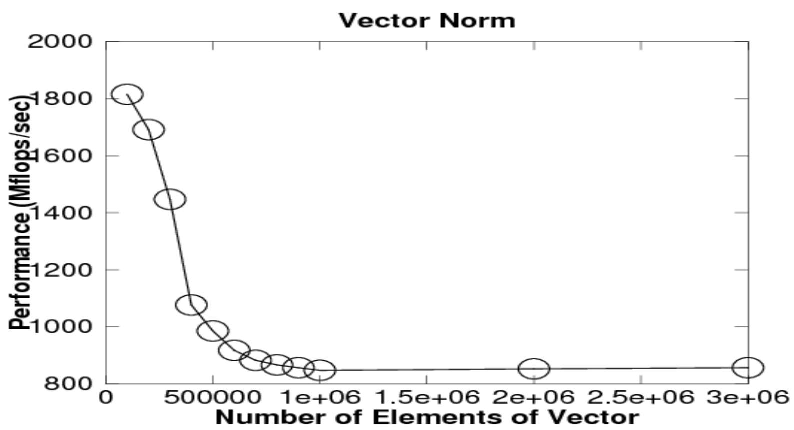
Parallel Performance



- All tests conducted on MCS's PETSC machine (see schematic)
- What's the Bottleneck?
  - Compute bound: program execution time determined by speed at which floating operations can be retired
  - Memory bound: program execution time determined by speed at which cores can obtain data from memory
- Important questions to ask:
  - Can we double sequential performance by using 2 threads?
  - Can we quadruple sequential performance by using 4 threads?
  - Can we octuple sequential performance by using 8 threads?

Sequential (Uni-core) Performance Hardware Limited

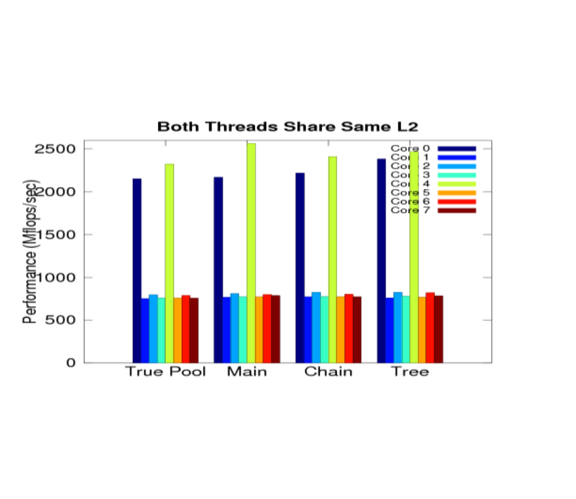
- Argonne “PETSC” machine
  - 32KB L1 Data & Instruction
  - 6144KB L2 Unified
- Working Set
  - Amount of physical memory needed by program
  - As size increases, L2 cannot hold it all and must utilize DRAM



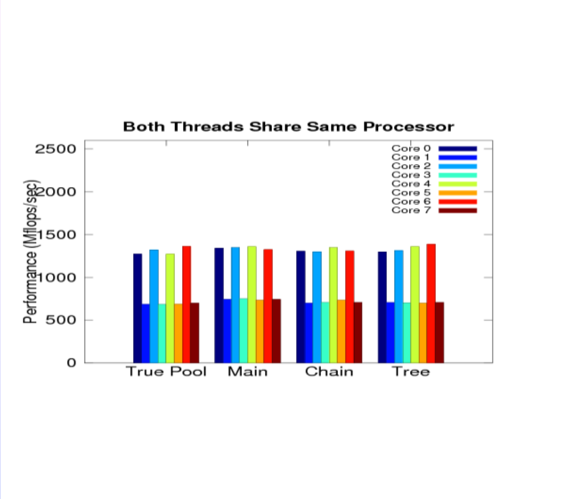
Vector Dot Product Results
Vector of Size 100,000 Elements

- Sequential
  - Runs made using different cores
    - As expected, the particular core utilized did not make a difference
  - Results ranged from 1868 to 1983 Mflops/sec with 1960 Mflops/sec as the median
- Thread Creation/Destruction (2 Threads)
  - Results varied widely between 860 to 1300 Mflops/sec
    - Indicative of current inability to control where threads are placed

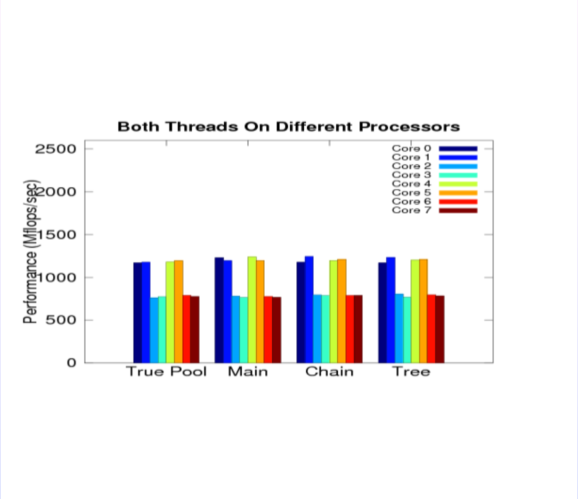
Thread Pool Vector Dot Product Results
Vector of Size 100,000 Elements



Thread 0, Core 0; Thread 1, Core 4



Thread 0, Core 0; Thread 1, Core 2



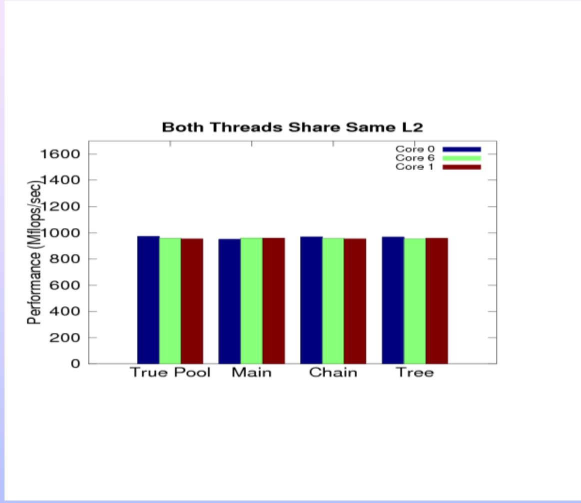
Thread 0, Core 0; Thread 1, Core 1

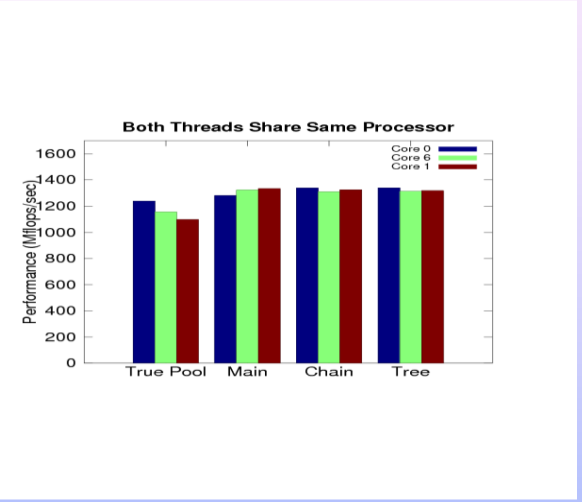
- Performance shows how much data movement matters

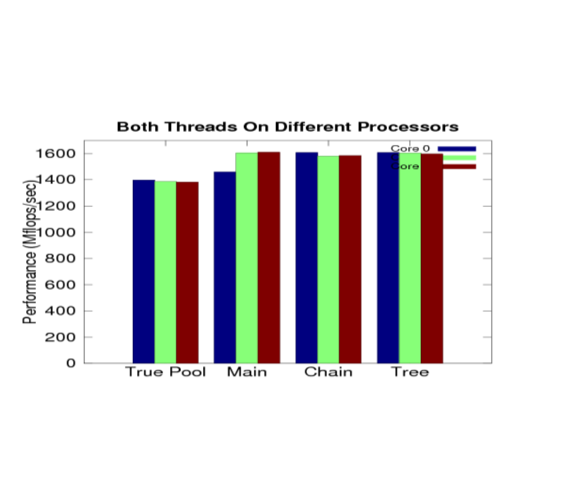
Vector Norm Results
Vector of Size 1,000,000 Elements

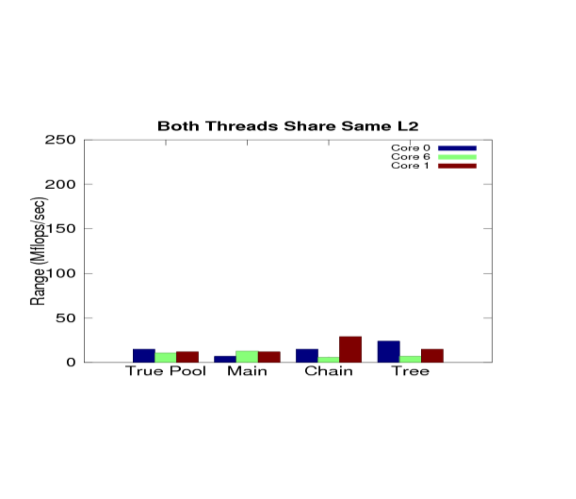
- Sequential
  - Median of 850 Mflops/sec
  - Working set overflow of L2 means core has to wait for data to arrive from DRAM
- Thread Creation/Destruction (2 Threads)
  - Comparable performance to sequential

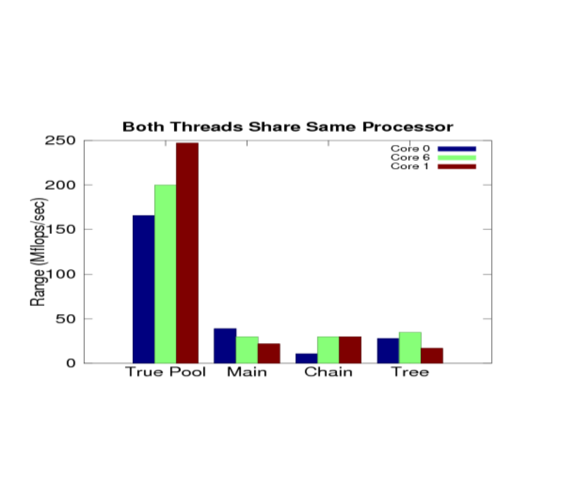
Thread Pool Vector Norm Results
Vector of Size 1,000,000 Elements

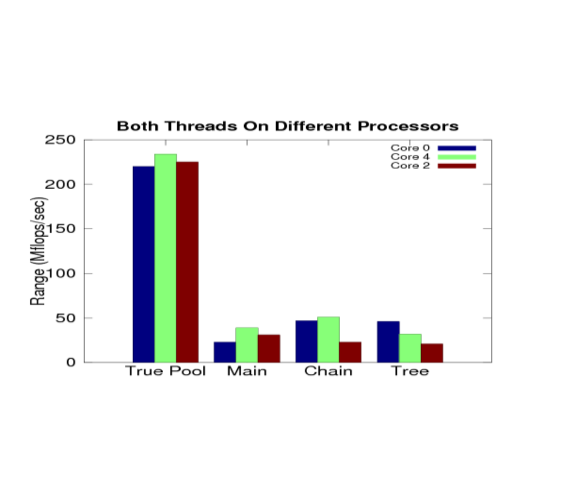








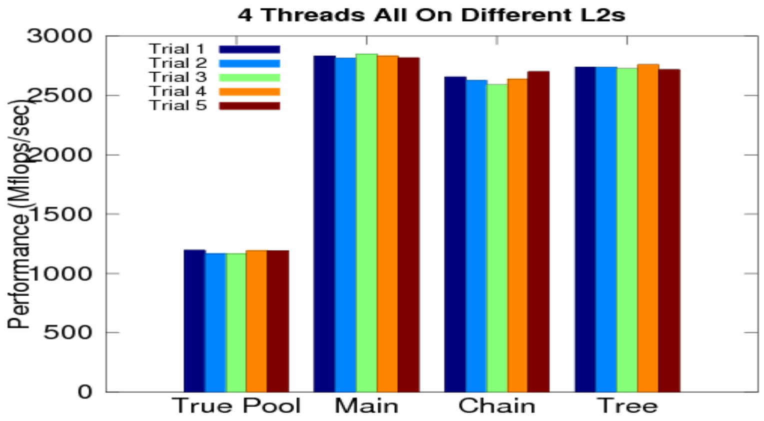


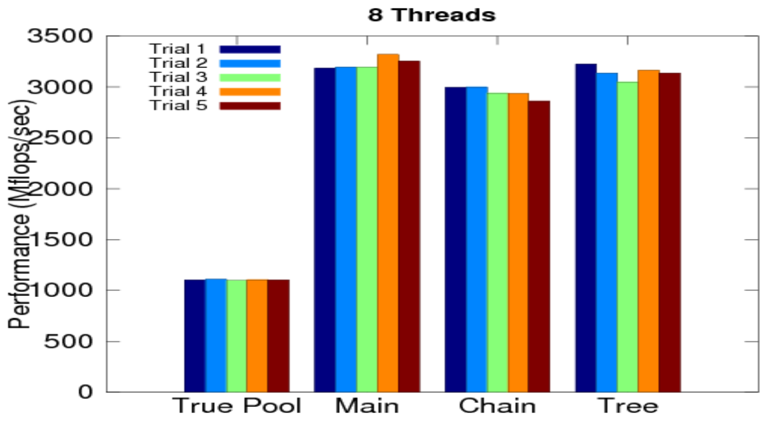


Thread 0, Core 0; Thread 1, Core 4 | **Thread 0, Core 0; Thread 1, Core 2** | **Thread 0, Core 0; Thread 1, Core 1**

Matrix-Vector Multiplication SNES ex19, dmmg_nlevels = 6

- Sequential implementation sees 585 Mflops/sec performance





References

- Documentation: http://www.mcs.anl.gov/petsc/docs
- PETSc Users manual
- Manual pages
- Many hyperlinked examples
- FAQ, Troubleshooting info, installation info, etc.
- Publications: http://www.mcs.anl.gov/petsc/publications
- Research and publications that make use PETSc
- ***Programming with POSIX Threads***, by Butenhof