Parallel computing memory models

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CMPT370
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Review last time

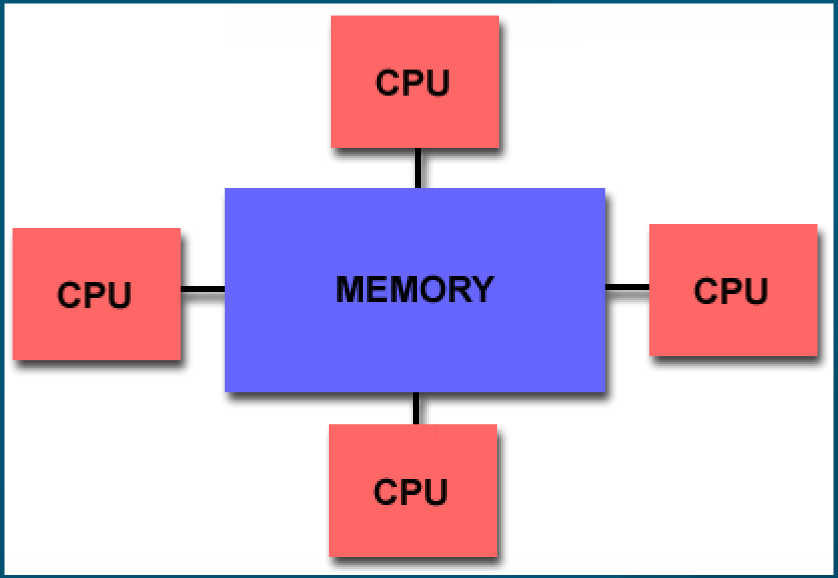
- Parallel computing concepts
  - Why do parallel?
  - vonNeumann abstraction: instructions, data
  - Instruction parallelism vs. data parallelism
    - Flynn's taxonomy: SISD, SIMD, MISD, MIMD
  - Measuring speedup
  - Design issues

- See tutorial from LLNL (Livermore) supercomputing centre

What's on for today

- Memory models:
  - Shared (SMP)
  - Distributed (cluster)
  - Hybrid
- Programming models:
  - Threads (PThreads, OpenMP)
  - Message passing (MPI)
  - Data-parallel (HPF)
  - Hybrids
- Automatic vs. manual parallelization

Shared memory

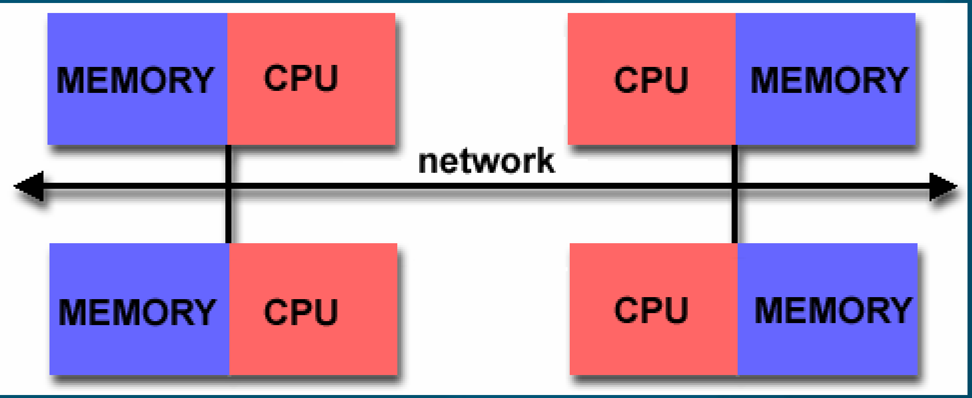


- All processors share a global memory space:
  - Uniform addressing
- Communication is easy: read/write to fixed addr
  - Still need locking/synchronization
- UMA: uniform memory access (SMP)
  - Equal latency, bandwidth to memory
- NUMA: non-uniform memory access
  - Access to local memory is faster
  - CC-NUMA: cache-coherent (SGI Origin hypercube)

Pros/cons of shared memory

- Pros:
  - Simpler model: easier to program (OpenMP)
  - Multi-processor SMP boards make for fast memory access
    - Carmel's “8” processors: One board, two Intel Xeon chips, each with dual-core, each core with two HyperThreads
- Cons:
  - Doesn't scale well to hundreds of processors
    - Geometric explosion of communication links between CPUs and memory

Distributed memory



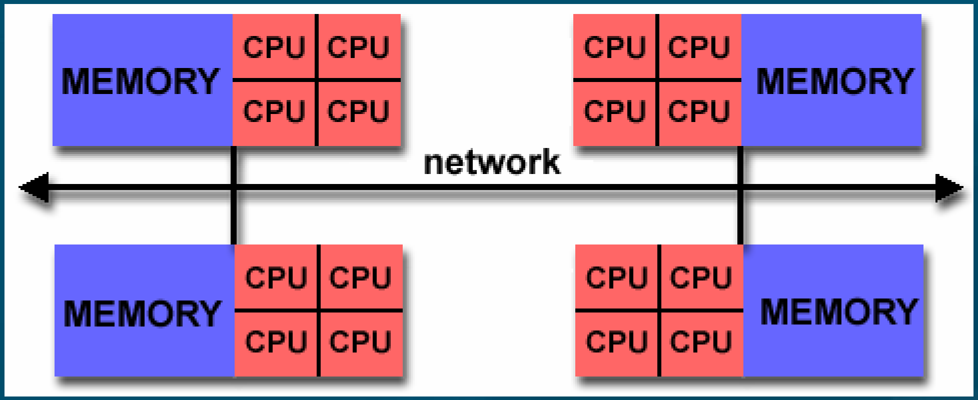
- Each processor has its own memory space
- Access other memory by passing messages to its controlling CPU
- Coarse-granularity parallelism is desired
- Network fabric is important:
  - Ethernet (802.3): CSMA-CD: doesn't scale well!
  - Myrinet: low latency, low packet overhead
  - InfiniBand: switched; has features like QoS
  - SCI (Scalable Coherent Interconnect): low overhead bus

Pros/cons of distributed memory

- Pros:
  - Scales well to hundreds or thousands of CPUs
    - LLNL BlueGene/L
- Cons:
  - Complex to program! (MPI)
    - Explicit parallelism: programmer's responsibility to coordinate communication between processors
    - How to span a big data structure across memories?
  - Memory access times very non-uniform
    - Importance of the network fabric: Sun: “the network is the computer”

Hybrid shared/distributed

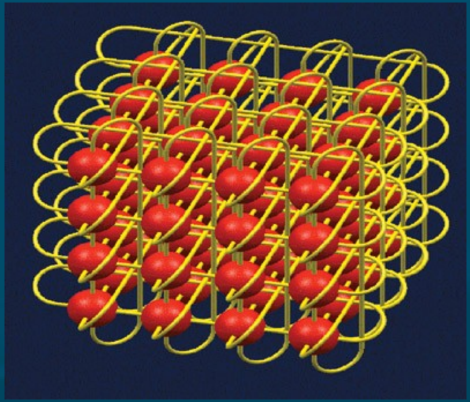
- Most large supercomputers today use a hybrid:
  - Each node is cache-coherent SMP (shared)
  - Link nodes via network (distributed)

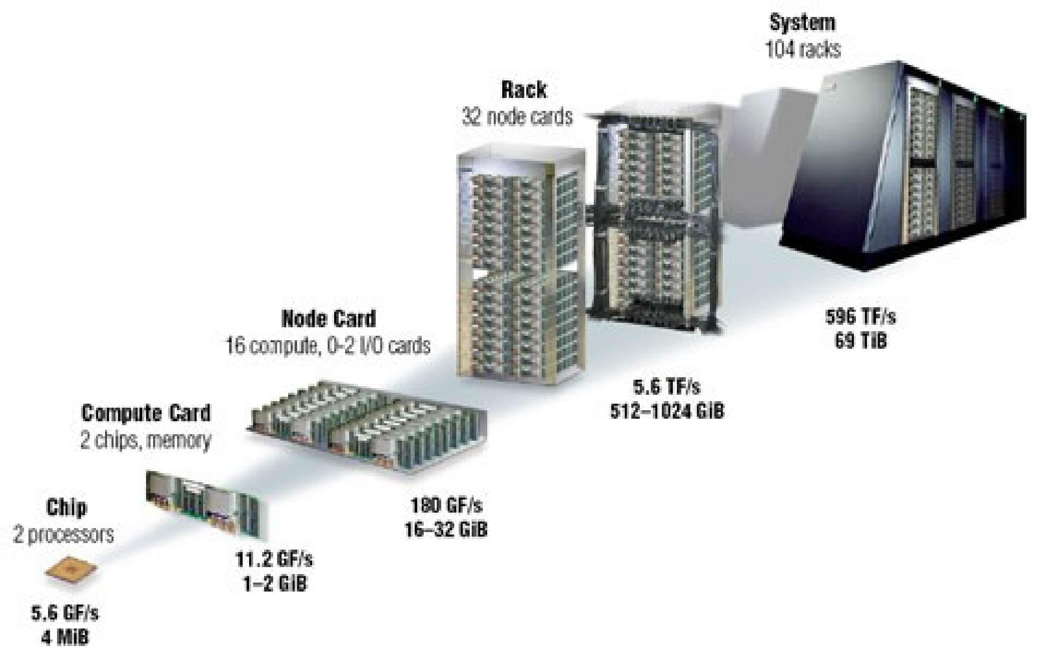


Case study: BlueGene/L

(BlueGene/L homepage)

- Made by IBM/Watson, site at LLNL
- Applications: fluid flow, nanotech, molecular biochemistry, etc.
- 106,496 nodes (dual-proc), 478 Tflops sustained, 69 TB RAM, 1.5 MW in 2500 sqft
- Nodes networked as a 32x32x64 3D torus



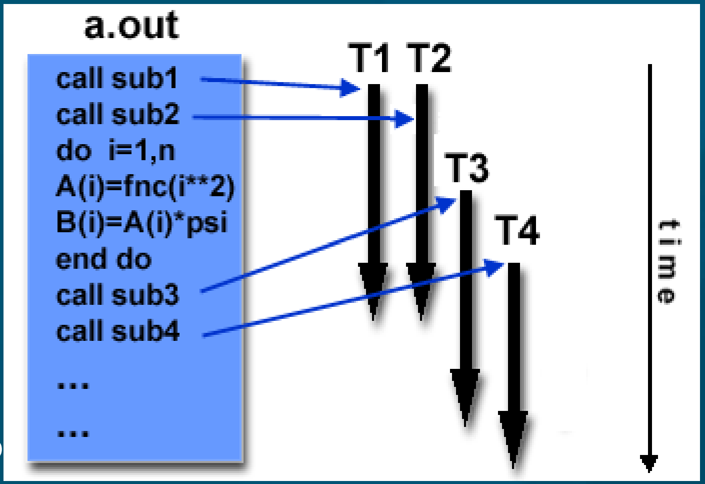


- Also 12 login nodes (SuSE) and 1204 disk I/O nodes (800 TB)

Programming a parallel machine

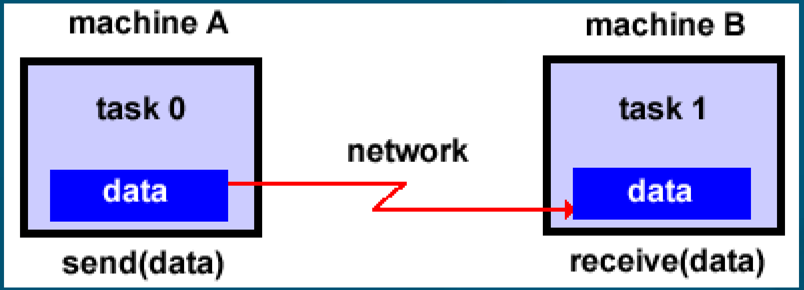
- The shared/distributed memory model deals with the address space visible by each processor
- The parallel programming model used is a separate issue:
  - Threads (PThreads, OpenMP)
  - Message passing (MPI)
  - Data parallel (HPF)
  - Hybrids of these models

Threads



- Start with master thread
- Master forks off worker threads
  - Each thread can be running same code or different code (e.g., subroutines)
- Scatter/gather: when worker threads complete, send results back to master thread
- Two implementations:
  - POSIX Threads: library-based, explicit parallel
  - OpenMP: compiler directives, easier to "add-on" to serial code
    - #pragma omp parallel

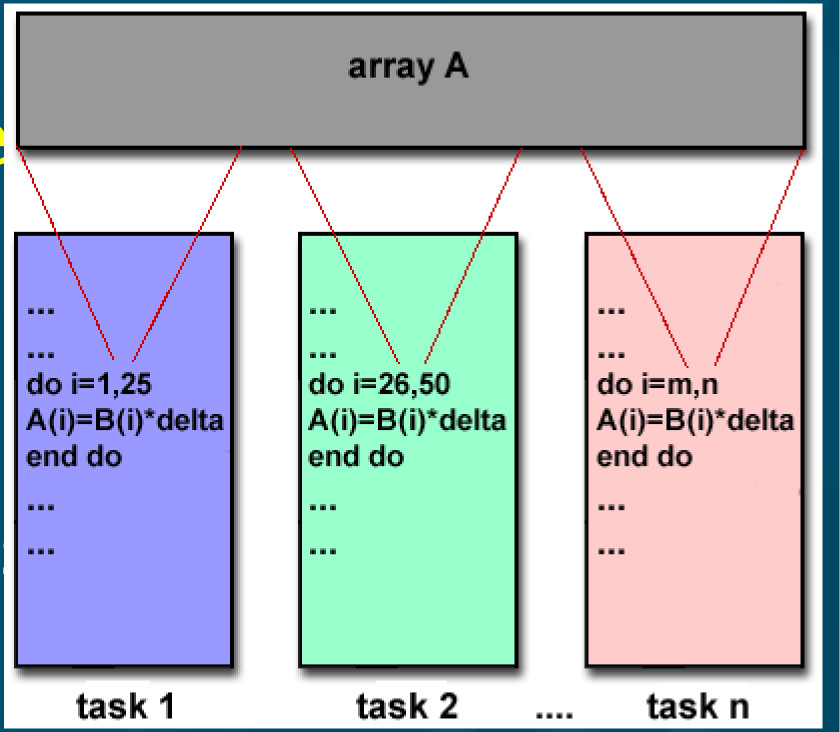
Message passing



- All communication between nodes is via messages
- Explicit parallelism:
  - Serial program must be restructured by programmer
- One unified standard implementation: MPI (Message Passing Interface)
  - Library routines: MPI_Bcast(), MPI_Reduce()
- MPI homepage

Data parallel model

- Each parallel task does same work on a different portion of a large regular data structure
  - Vector, n-D array, etc.
- Use either compiler directives or library routines to specify parallelism
- Implementations: HPF (High performance Fortran)



Hybrid programming models

- Memory models: shared vs. distributed
- Programming models: threads, MPI, data-parallel
- For clusters (distributed memory model), MPI is most commonly used
- However, hybrid programming models exist:
  - OpenMP to the programmer (ease of use)
  - MPI at lower layer (cluster communications)
- HPF (data-parallel) on clusters often uses MPI as a transparent back-end

Writing a parallel program

- Designing a program to work and make full use of multiple processors is tough
- Fully automatic parallelizing compilers exist:
  - Analyzes your code for parallel opportunities
  - For loops, iteration over arrays, etc.
- Directives can make the compiler's job easier:
  - #pragma delimits portions of code that have minimal dependencies (coarse granularity)
- The most control and speedup is from manually programming it: explicit parallelism

Summary of today

- Memory models:
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- Programming models:
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  - Data-parallel (HPF)
  - Hybrids
- Automatic vs. manual parallelization