Announcements
Topologies (cont)

- tree - needs to increase bandwidth near the top

- mesh - two or three dimensions

- hypercube - needs a power of number of nodes
Memory Systems

- **Key Performance Issues**
  - latency: time for first byte
  - throughput: average bytes/second

- **Design Issues**
  - Where is the memory
    - divided among each node
    - centrally located (on communication network)
  - Access by processors
    - can all processors get to all memory?
    - is the access time uniform?
Coordination

- **Synchronization**
  - protection of a single object (locks)
  - coordination of processors (barriers)

- **Size of a unit of work by a processor**
  - need to manage two issues
    - load balance - processors have equal work
    - coordination overhead - communication and sync.
  - often called “grain” size - large grain vs. fine grain
Sources of Parallelism

- **Statements**
  - called “control parallel”
  - can perform a series of steps in parallel

- **Loops**
  - called “data parallel”
  - most common source of parallelism
  - each processor gets one (or more) iterations to perform
Example of Parallelism

- **Easy (embarrassingly parallel)**
  - multiple independent jobs (i.e..., different simulations)

- **Scientific**
  - Largest users of parallel computing
  - dense linear algebra (divide up matrix)
  - physical system simulations (divide physical space)

- **Databases**
  - biggest commercial success of parallel computing (divide tuples)
    - exploits semantics of relational calculus

- **AI**
  - search problems (divide search space)
  - pattern recognition and image processing (divide image)
Metrics in Application Performance

- **Speedup (often call strong scaling)**
  - ratio of time on n nodes to time on a single node
  - hold problem size fixed
  - should really compare to best serial time
  - goal is linear speedup
  - super-linear speedup is possible due to:
    - adding more memory
    - search problems

- **Weak Scaling (also called Iso-Speedup)**
  - scale data size up with number of nodes
  - goal is a flat horizontal curve

- **Amdahl's Law**
  - max speedup is $1/(\text{serial fraction of time})$

- **Computation to Communication Ratio**
  - goal is to maximize this ratio
How to Write Parallel Programs

- **Use old serial code**
  - compiler converts it to parallel
  - called the dusty deck problem
- **Serial Language plus Communication Library**
  - no compiler changes required!
  - PVM and MPI use this approach
- **New language for parallel computing**
  - requires all code to be re-written
  - hard to create a language that provides performance on different platforms
- **Hybrid Approach**
  - HPF - add data distribution commands to code
  - add parallel loops and synchronization operations
Application Example - Weather

- **Typical of many scientific codes**
  - computes results for three dimensional space
  - compute results at multiple time steps
  - uses equations to describe physics/chemistry of the problem
  - grids are used to discretize continuous space
    - granularity of grids is important to speed/accuracy

- **Simplifications (for example, not in real code)**
  - earth is flat (no mountains)
  - earth is round (poles are really flat, earth buldges at equator)
  - second order properties
Grid Points

- **Divide Continuous space into discrete parts**
  - for this code, grid size is fixed and uniform
    - possible to change grid size or use multiple grids
  - use three grids
    - two for latitude and longitude
    - one for elevation
    - Total of $M \times N \times L$ points

- **Design Choice: where is the grid point?**
  - left, right, or center of the grid

  ![Diagram showing grid points: L, C, R]

  - in multiple dimensions this multiples:
    - for 3 dimensions have 27 possible points
Variables

- **One dimensional**
  - \( m \) - geo-potential (gravitational effects)

- **Two dimensional**
  - \( \pi \) - “shifted” surface pressure
  - \( \sigma \) - vertical component of the wind velocity

- **Three dimensional (primary variables)**
  - \( \langle u, v \rangle \) - wind velocity/direction vector
  - \( T \) - temperature
  - \( q \) - specific humidity
  - \( p \) - pressure

- **Not included**
  - clouds
  - precipitation
  - can be derived from others
Serial Computation

- Convert equations to discrete form
- Update from time t to t + delta t

```plaintext
foreach longitude, latitude, altitude
    ustar[i,j,k] = n * pi[i,j] * u[i,j,k]
    vstar[i,j,k] = m[j] * pi[i,j] * v[i,j,k]
    sdot[i,j,k] = pi[i,j] * sigmadot[i,j]
end

foreach longitude, latitude, altitude
    D = 4 * ((ustar[i,j,k] + ustar[i-1,j,k]) * (q[i,j,k] + q[i-1,j,k]) +
        terms in {i,j,k}{+,-}{1,2}
    piq[i,j,k] = piq[i,j,k] + D * delat
    similar terms for piu, piv, piT, and pi
end

foreach longitude, latitude, altitude
    q[i,j,k] = piq[i,j,k]/pi[i,j,k]
    u[i,j,k] = piu[i,j,k]/pi[i,j,k]
    v[i,j,k] = piv[i,j,k]/pi[i,j,k]
    T[i,j,k] = piT[i,j,k]/pi[i,j,k]
end
```
Shared Memory Version

- in each loop nest, iterations are independent
- use a parallel for-loop for each loop nest
- synchronize (barrier) after each loop nest
  - this is overly conservative, but works
  - could use a single sync variable per item, but would incur excessive overhead
- potential parallelism is $M \times N \times L$
- private variables: $D$, $i$, $j$, $k$

Advantages of shared memory
- easier to get something working (ignoring performance)

Hard to debug
- other processors can modify shared data
Distributed Memory Weather

- decompose data to specific processors
  - assign a cube to each processor
    - maximize volume to surface ratio
    - minimizes communication/computation ratio
  - called a <block,block,block> distribution

- need to communicate \{i,j,k\}\{+,-\}\{1,2\} terms at boundaries
  - use send/receive to move the data
  - no need for barriers, send/receive operations provide sync
    - sends earlier in computation too hide communication time

- Advantages
  - easier to debug?
  - consider data locality explicitly with data decomposition

- Problems
  - harder to get the code running
Seismic Code

- Given echo data, compute under sea map
- Computation model
  - designed for a collection of workstations
  - uses variation of RPC model
  - workers are given an independent trace to compute
    - requires little communication
    - supports load balancing (1,000 traces is typical)
- Performance
  - max mfops = \( O((F \times nz \times B^*)^{1/2}) \)
  - \( F \) - single processor MFLOPS
  - \( nz \) - linear dimension of input array
  - \( B^* \) - effective communication bandwidth
    - \( B^* = B/(1 + BL/w) \approx B/7 \) for Ethernet (10msec lat., \( w=1400 \))
  - real limit to performance was latency not bandwidth