Parallel Programming Introduction

* Parallel programming is using multiple cpus concurrently.
* Reasons for parallel execution:

1. shorten execution time
2. to permit a larger problem (memory resources)

* The days of waiting for the next-generation chip to improve your serial-code throughput are gone.

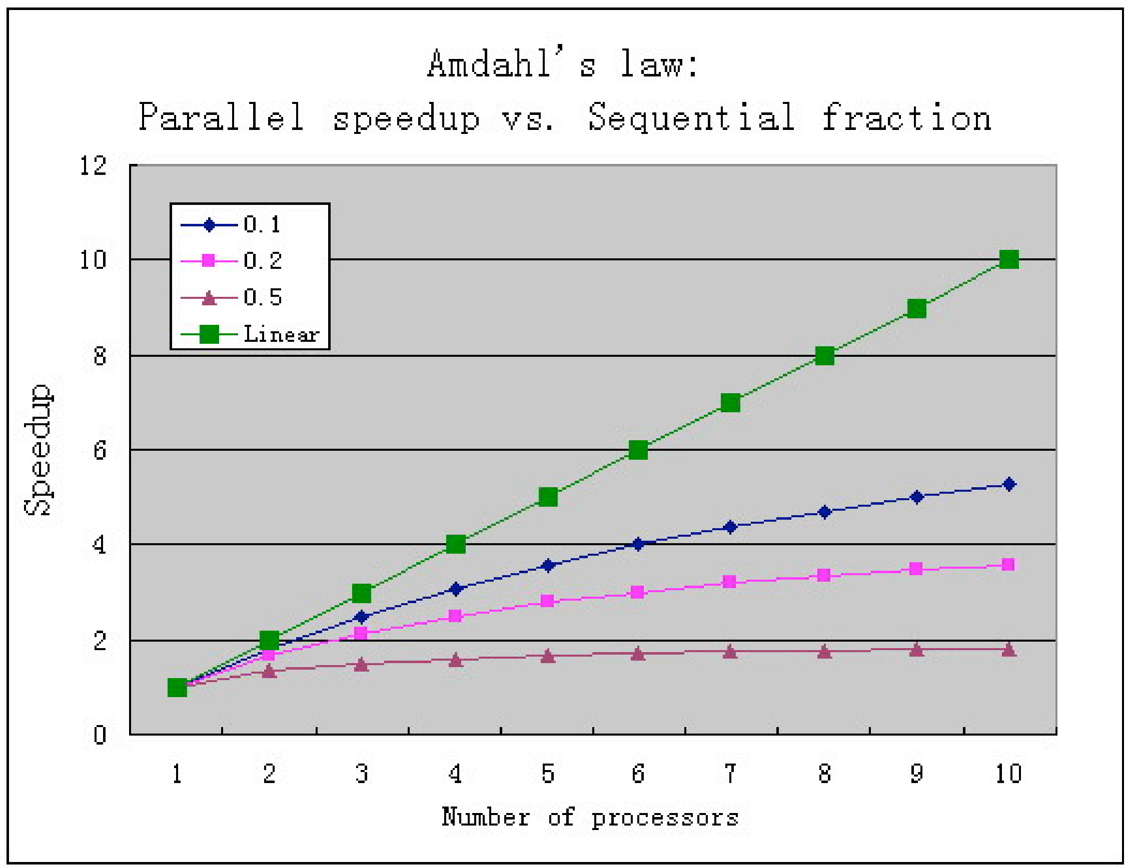
Amdahl's Law

* Describes the time speedup one can expect as a function of the number of processors used and the fraction of parallel code:

speedup = 1/(1-p+p/N)

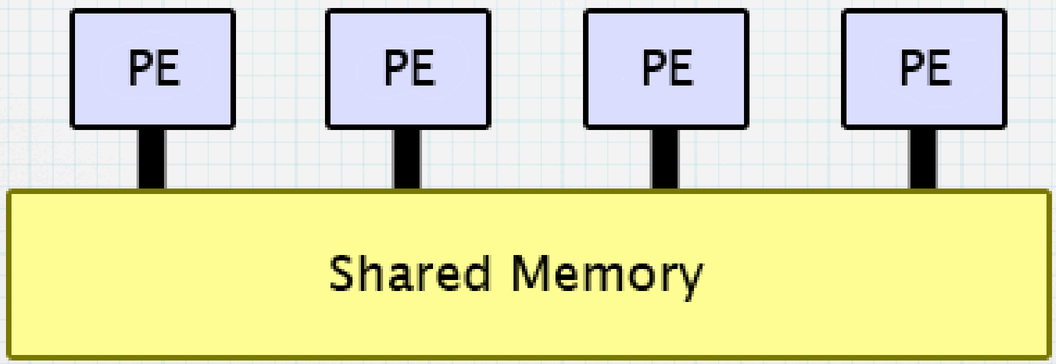
N - number of procs

p - fraction of parallel code



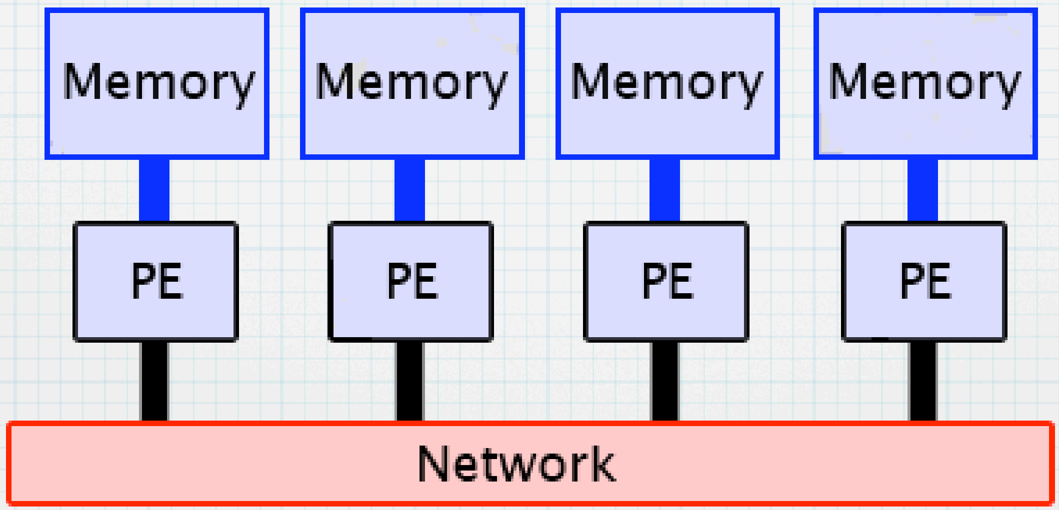
Types of Parallel Machines

* Symmetric Multiprocessors (SMP) - multiple cpus sharing memory resource, bus connection - kaibab, desktop Macs



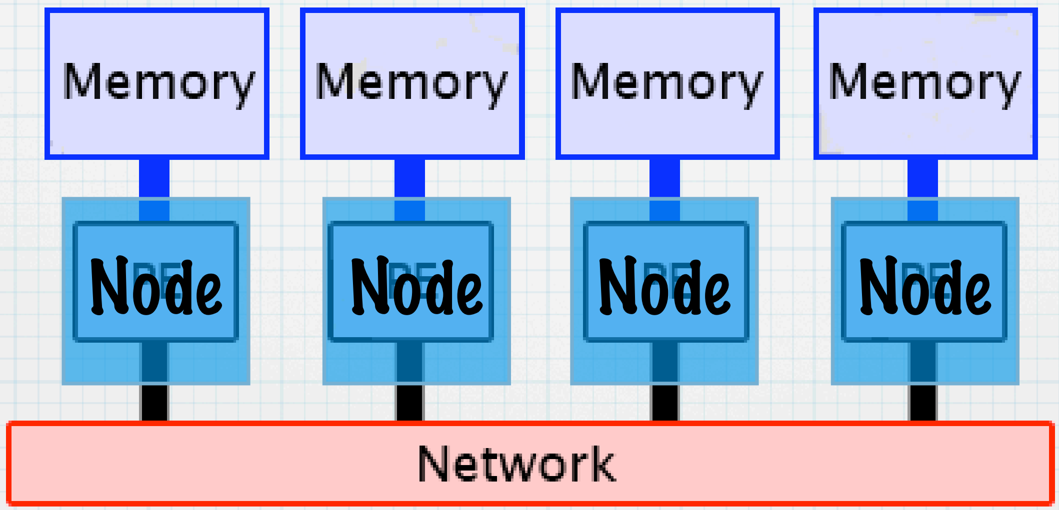
Types of Parallel Machines

* Distributed computing - individual computing elements each with their own memory, and network connection - Cray T3E



Types of Parallel Machines

* Clusters - combine the above two models. SMP nodes can be connected by network - **slikrock, saddleback**



Types of Parallelism

* Process Parallelism (MPMD) - a code may contain different segments that can be computed concurrently. Example: ocean, land, and ice parts of climate model, or convection and radiation parameterizations in an atmosphere.
* Low overhead, but often limits on how many procs can be used.

Types of Parallelism

* Data Parallelism (SPMD) - the same code works on different datastreams. For example, dividing a global domain into subdomains - each processor executes all the code for an individual subdomain.
* Data and process parallelism may be employed together.

Parallel Programming Paradigms: Shared Memory

* Shared memory techniques launch threads during execution.
* Automatic Parallelizers - just turn on the compiler switch - it finds the do loops that can be done in parallel.
* Compiler Directives - Open MP is the current standard. User inserts 'comments' in code that compiler recognizes as parallelization instructions. Modest changes to code.
* Only works with shared memory.

Parallel Programming Paradigms: Message Passing

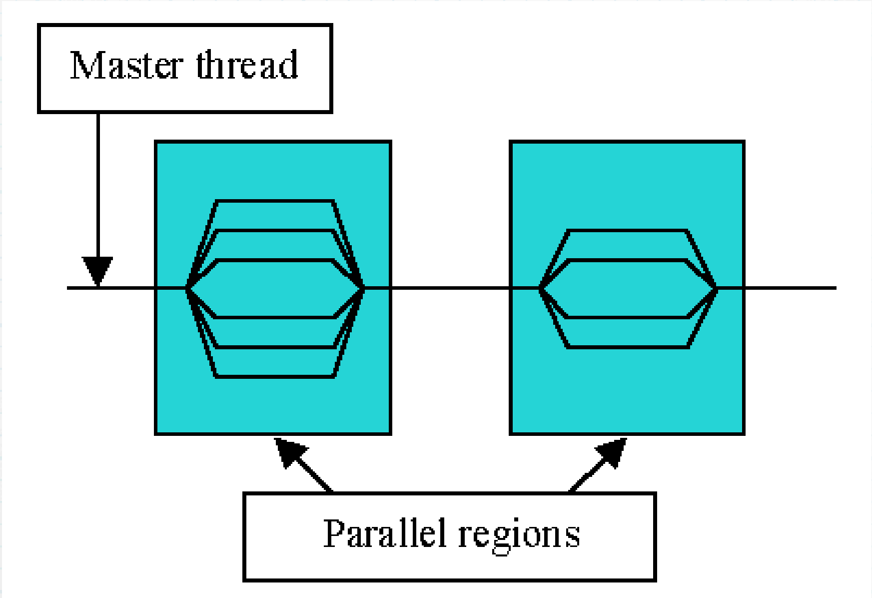
* Can work with both distributed and shared memory.
* MPI is the standard, several packages exist: MPICH2, lam-mpi, open-mpi.
* Library calls explicitly control the parallel behavior - extensive user rewrite of code. Code is explicitly instructed to send and receive messages from the other processes.
* Ross will discuss in much more detail next few weeks.
* Message passing and shared memory techniques can be used in a hybrid-mode.

Parallel Programming Concepts

* Synchronization - making sure all code gets to a certain point before proceeding.
* Load balancing - trying to keep processes from being idle while others are computing.
* Granularity - how much work is in each parallel section.

Open MP - a Brief Intro

- OpenMP is an API for writing multithreaded applications in a shared memory environment
- It consists of a set of compiler directives and library routines
- Relatively easy to create multi-threaded applications in Fortran, C and C++
- Standardizes the last 15 or so years of SMP development and practice



Tutorial: http://www.osc.edu/hpc/training/openmp/big/fsld.002.html

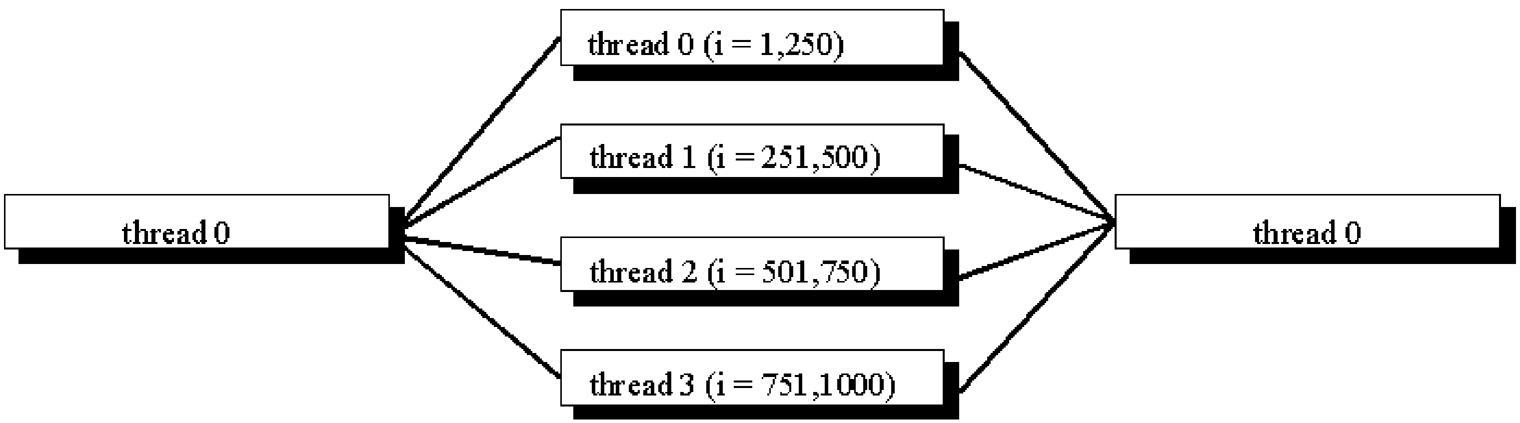
OpenMP: http://www.openmp.org/

Open MP - first steps

* Identify parallel do-loops. Each do loop carries overhead so it can be helpful to have a larger outer do-loop for parallelism.
* Identify functionally parallel regions (Think F90 case construct as an analog).
* Identify shared and private data
* Identify 'race conditions' where shared data can change program output unexpectedly.

Open MP - parallel do loop

```
c$omp  do shared(x) private(i)
c$omp& schedule(static)
          do i = 1, 1000
            x(i)=a
          enddo
```



Open MP - reduction

- Allows safe global calculation or comparison.
- A private copy of each listed variable is created and initialized depending on `operator` or `intrinsic` (e.g., 0 for +).
- Partial sums and local mins are determined by the threads in parallel.
- Partial sums are added together from one thread at a time to get gobal sum.
- Local `mins` are compared from one thread at a time to get `gmin`.

```
c$omp do shared(x) private(i)
c$omp&  reduction(+:sum)
      do i = 1, N
         sum = sum + x(i)
      enddo


c$omp do shared(x) private(i)
c$omp&  reduction(min:gmin)
      do i = 1,N
         gmin = min(gmin,x(i))
      end do
```

Open MP - sections

```
c$omp parallel
c$omp sections

c$omp section
      call computeXpart()
c$omp section
      call computeYpart()
c$omp section
      call computeZpart()

c$omp end sections
c$omp end parallel

      call sum()
```

- Each parallel `section` is run on a separate thread.
- Allows functional decomposition.

Open MP - data dependency

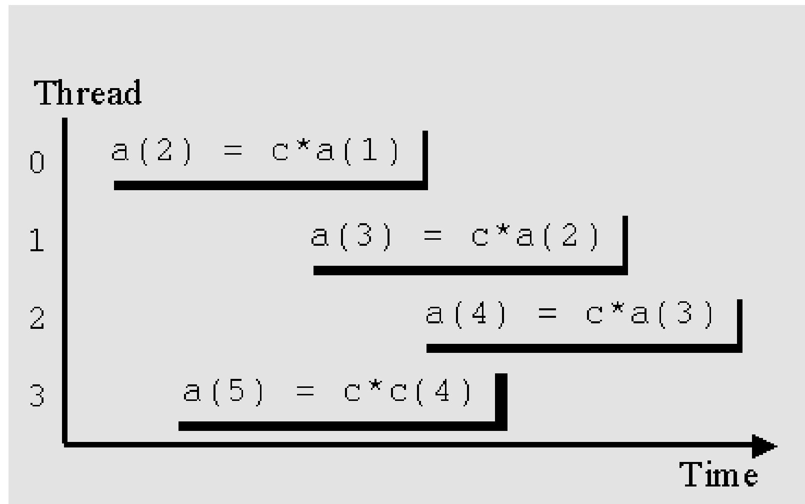
- Only variables that are **written** in one iteration and **read** in another iteration will create data dependencies.
- A variable cannot create a dependency unless it is **shared**.
- Often data dependencies are difficult to identify. **APO** can help by identifying the dependencies automatically.

Recurrence:

```
do i = 2,5
      a(i) = c*a(i-1)
enddo
```

Is there a dependency here?

```
  do i = 2,N,2
    a(i) = c*a(i-1)
enddo
```



Open MP - run time

OpenMP Environment Variables

- `OMP_NUM_THREADS`
  - Sets the number of threads requested for parallel regions.
- `OMP_SCHEDULE`
  - Set to a string value which controls parallel loop scheduling at runtime.
  - Only loops that have schedule type `RUNTIME` are affected.
- `OMP_DYNAMIC`
  - Enables or disables dynamic adjustment of the number of threads actually used in a parallel region (due to system load).
  - Default value is implementation dependent.