Performance Definitions
Measurements
Software Tools

Reading
- Basic definitions: texts from CIS 314, CIS 629 (Hennessy, Patterson)
- Wilkinson & Allen, 2.3 - 2.4
- PDFs on-line:
  - paper on developing an efficient parallel application
- MPICH Manual
  - has brief section on performance tools
- TAU User’s Guide
  - UO research project; portable software for performance analysis

Wall Clock Time
- The simplest performance measurement: “wall clock time”
- Elapsed time from beginning to end of program execution
- Not the best metric for performance analysis: includes several components beyond the control of the application developer
  - O/S overheads (starting job, reading files, …)
  - Multi-process environment
    - daemons (web server, NFS server, …)
    - other users’ jobs
- If you use this metric:
  - gather data on a “lightly loaded” system
  - take mean of several measurements

CPU Time
- A common Unix utility: time
- Usage:
  ```
  % time X
  ```
- Runs X, then prints elapsed time, CPU time in user process, CPU time in O/S routines on behalf of user process
  ```
  % time ls -l
  ...
  ```
  ...output from “ls”...
  ```
  real  0m0.117s
  user  0m0.000s
  sys   0m0.010s
  ```
- Same command, from tcsh (where time is a shell command):
  ```
  0.000u 0.020s 0:00.11 18.1%
  ```
Bandwidth

- A different way to describe performance is bandwidth
  - also known as “throughput”
- Useful for describing parallel systems or other situations where several tasks are executed
- Elapsed time (aka “latency”) describes the amount of time required for a single job
  - unit: $T$
- Bandwidth describes the number of jobs that can be completed per unit of time
  - unit: $1 / T$

Example

- Suppose we have an N-Body application, and we need to simulate a system with 10,000 bodies
- We know it runs fine for 10 bodies, but are concerned it won’t scale to 10K bodies
- Methods to improve execution time (latency):
  - better algorithm
    - PP: 50,000,000 force calculations per time step
    - B-H: 130,000 * 3 = 390,000 forces per time step
  - more efficient data structures
    - reduce constant, but not asymptotic efficiency
    - vectors provide better instruction level parallelism
    - also better locality (caching)

Example (cont’d)

- Parallelism allows another possibility: improved bandwidth
- A parallel algorithm breaks job into smaller pieces, works on the pieces in parallel
- Our overall goal is still to have our program finish sooner, but now we have another way to approach the problem: optimize number of pieces completed per unit of time
- Performance can be improved through better throughput
  - more processors
  - smaller messages
  - faster delivery of messages
  - fewer messages

Parallel Performance

- Wall clock time for the parallel program is a function of
  - partitioning (can program be split into $N$ even parts?)
  - parallel programming overhead (making, sending messages)
  - system overhead (time waiting for work)
- $T_p = T_i + \text{overhead}$
- $T_s = \sum T_i$
### Speedup

- Speedup is a measure of how much faster the parallel version runs.

\[ S = \frac{T_s}{T_p} \]

**Example:**
- \( T_s = 9.5 \text{ sec} \)
- \( T_p = 3.6 \)
- \( S = \frac{9.5}{3.6} = 2.63 \)

### Amdahl’s Law

- Speedup is limited by the portion of the application that is inherently sequential.

\[ S = \frac{T_s}{T_p} = \frac{T_s}{pT_s + (1 - p)T_s/N} \]

**Example:**
- If \( p = 0.1 \)
- \( S = \frac{1}{0.1} = 10 \)

### Amdahl’s Law (cont’d)

- The limit to \( S \), as the number of processors \( N \) increases to infinity:

\[ S = \frac{T_s}{T_p} = \frac{T_s}{pT_s + (1 - p)T_s/N} = \frac{T_s}{pT_s} = \frac{1}{p} \]
Massive Parallelism

- The term “massive parallelism” means the use of a very large number of processors
  - coined by groups working on SIMD machines
  - \( N > 1000 \)
  - origin of the name “MasPar”

- Is “massive parallelism” feasible, or cost-effective, given Amdahl’s law?
  - are there problems where \( p < .001 \)?
  - does overhead mean speedup of 1000 is impossible?

Massive Parallelism (cont’d)

- Major speedups are possible if one increases the problem size along with the number of processors
  - Gustafson: “you wouldn’t hire 1000 painters to paint a kitchen”

  - contains parts of Gustafson’s CACM paper “Reevaluating Amdahl’s Law”

  - Describes simulation of 2D acoustic wave
  - Speedups over 1000x on 1024-node NCUBE system
    - NCUBE: competitor to Intel’s iPSC hypercube

Measuring Performance

- `time` shell command
  - returns user time and system time for the process

- Unix library calls
  - O/S specific
  - call once to reset timer
  - call again to measure CPU time since previous call

- Example: `clock()`
  (code on next slide)

Measuring Performance (cont’d)

```c
#include <time.h>
clock_t start = clock();
    // ... code to measure ...
clock_t end = clock();
float elapsed =
    (float(end) - float(start))/CLOCKS_PER_SEC;
cout << "time: " << elapsed << endl;
```
**clock() Measurements**
- `clock()`, `getrusage()`, and similar functions measure application time plus time spent in parallel libraries (e.g. MPI)
- Does not measure time a process is blocked, e.g. while it is waiting for an MPI message

**Fine-Grain Measurements**
- To improve single-processor performance, it's necessary to know where the application is spending most of its time
- An execution profile is a table showing the amount of CPU time in each function
  - reported as time and percent of total
  - table shows time in the function plus cumulative time in called functions
- Many scientific applications follow the 90/10 rule:
  - 90% of time spent in 10% of code
    - as measured by locality of reference for i-cache
  - especially true of applications that are candidates for SPMD

**Profiles**
- Software that generates an execution profile typically uses PC sampling
  - interrupt the program periodically
  - every 100 instructions? 1000?
  - record location of program counter (CPU's PC register)
  - write locations to a file
- Table produced by application that reads trace file
  - maps PC values back to source code function
- Slight overhead for sampling may skew results
- New software has lower overhead, doesn’t require linking with sampling library

**Performance Profiles for Parallel Programs**
- For parallel programs, we want to know how time is spent within a process (one node of an SPMD program)
- We also need to know about interprocess communication
  - time spent composing messages
  - waiting for messages
  - synchronization (e.g. at barriers, or in collective operations)
- One method: software library records events, as in execution profile, and graphic utility displays time line of processes and their interaction
Viewing Message Patterns

- A very early MPI-based tool: upshot
- Newer version, called jumpshot, uses Java

[Image of a jumpshot window (from presentation by R. Lusk, ANL)]

TAU

- TAU is a UO research project headed by Allen Malony
  - TAU = Tuning and Analysis Utilities
    - aka "tools are us"
- Platform-independent software to measure, analyze performance
- Supports sequential, MPI, and OpenMP applications
- Tools are installed on p690
- Read on-line documentation to learn more

Summary

- For CIS 455/555 projects this term:
  - for Mandelbrot, N-Body, and Laplace projects (first three projects this term) use simple methods -- wall clock time or getrusage()
  - if you have time explore jumpshot, Tau, or other tools
  - for term project try the simpler methods first, be prepared to delve deeper if code is not performing the way you expect it to