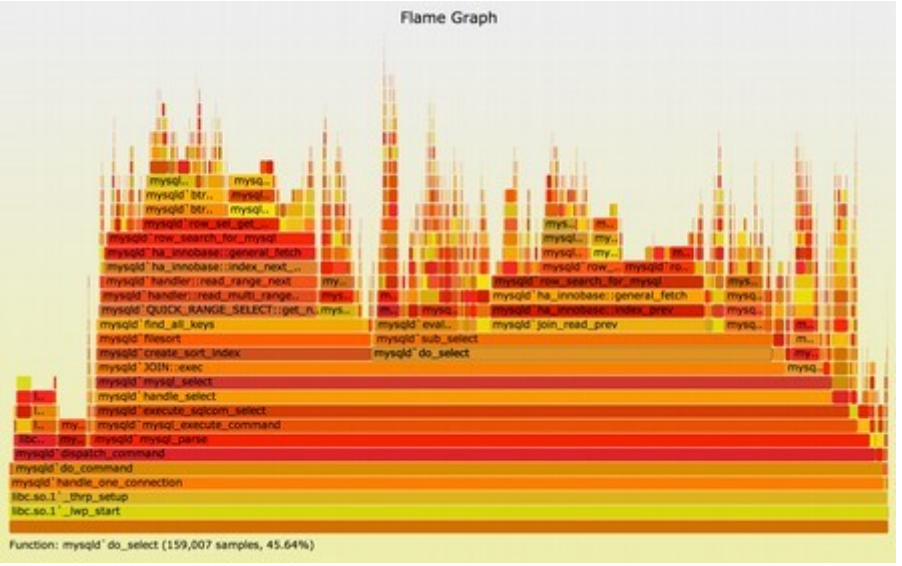
CS 470
Spring 2019

Mike Lam, Professor



Flame graph from brendangregg.com

Performance Analysis

Performance analysis

- Why do we parallelize our programs?
  - So that they run faster!

Performance analysis

- How do we evaluate whether we've done a good job in parallelizing a program?
  - Asymptotic analysis (e.g., for distributed sum)
  - Empirical analysis

Empirical analysis issues

- How do you measure time-to-solution accurately?
  - CPU cycles, OS clock "ticks", wall time, etc.
- How do you compare across systems?
  - Differing CPUs, memories, OSes, etc.
- How do you compare against the original?
  - 1-core parallel version will likely be slower
- How do you assess scalability?
  - Does performance improve as you add cores?
  - How do you quantify the improvement?
  - Is there a limit to how far we can improve performance?

Best practices

- Measure wall time for specific code regions of interest
  - Ignore startup and I/O time if not relevant
  - Make sure you have a high-resolution timer!
    - `/usr/bin/time -v` for whole programs
    - `gettimeofday()` from `sys/time.h` for Pthreads
    - `omp_get_wtime()` for OpenMP
    - `MPI_Wtime()` for MPI
  - Use barriers if necessary to make sure all threads/processes have finished before you stop a timer

Best practices

- Control for variance
  - Do all experiments on the same machine or cluster
  - Maximum of one thread per core and one job per node
    - Our cluster can support 8 threads per node (or 16 if hyper-threading, but this is not always recommended)
  - Run multiple trials and use minimum time
    - Avoids OS interference or noise
    - Use `/shared/bin/hyperfine` on cluster
  - Track variance across trials to measure system noise
    - If your variance is high or if your slowest and fastest time are relatively far apart, it's probably noise!

Empirical analysis

T_s = serial time

T_P = parallel time

p = # of processes

S = speedup = $\frac{T_S}{T_P}$

should increase as p grows

E = efficiency = $\frac{S}{p} = \frac{T_S}{p\,T_P}$

usually decreases as p grows

r = serial % of original program

$$T_P = \frac{(1-r)T_S}{p} + r\,T_S$$

$$S = \text{speedup} = \frac{T_S}{\frac{(1-r)T_S}{p} + r\,T_S}$$

Amdahl's Law: $S \le \frac{1}{r}$ as p increases

Amdahl's Law

p = # of processors

r = serial % of program

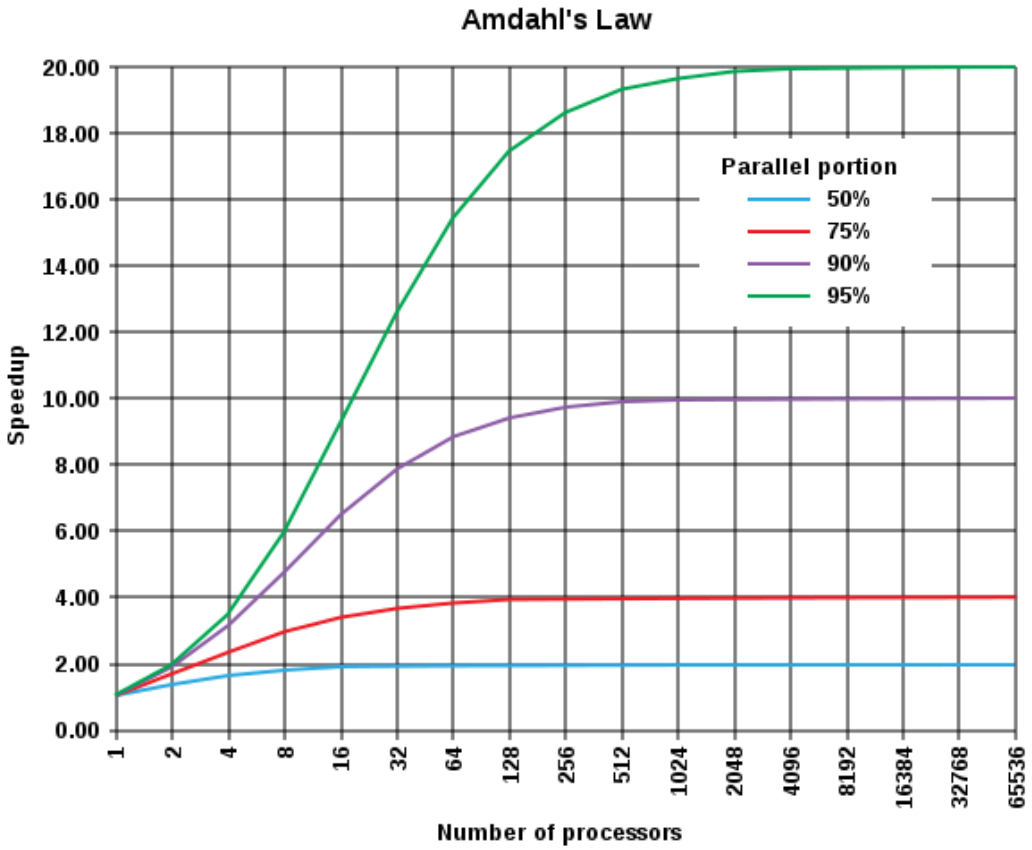
$$S = \text{speedup} = \frac{T_s}{\frac{(1-r)T_s}{p} + r\,T_s}$$

Amdahl's Law:

$$S \leq \frac{1}{r} \text{ as } p \text{ increases}$$

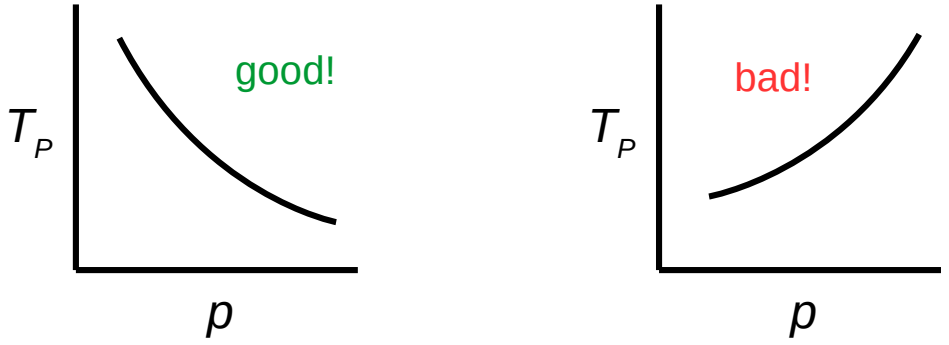
r = 50% → speedup limited to 2x
r = 25% → speedup limited to 4x
r = 10% → speedup limited to 10x
r = 5% → speedup limited to 20x

Speedup limited inversely proportionally by serial %



Scaling

- Generally, we don't care about any particular T_P
  - Or with how it compares to T_S (except as a sanity check)
- More important: how T_P , S, and E change as p increases
  - And/or as the problem size increases
  - Similar to asymptotic analysis in CS 240
  - In general, a program is scalable if E remains fixed as p and the problem size increase at fixed rates
  - Most common: graph T_P on y-axis vs. p on logarithmic x-axis



Scaling

- Strong scaling means we can keep the efficiency fixed without increasing the problem size
- Weak scaling means we can keep the efficiency fixed by increasing the problem size at the same rate as the process/thread count
  - Rate of work (e.g., Mop/s) per core remains roughly fixed

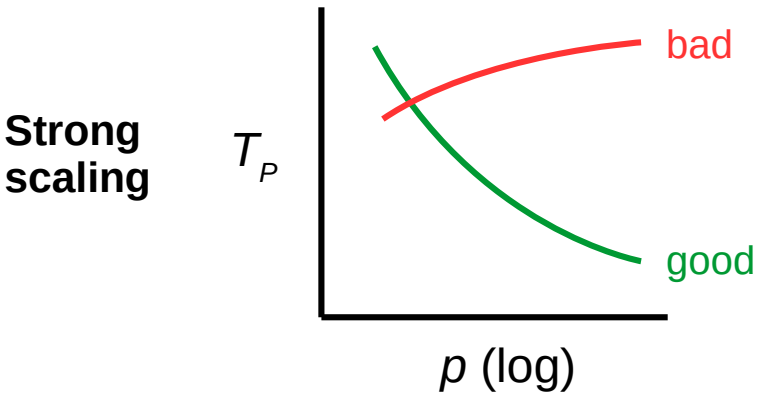
$$E = \text{efficiency} = \frac{S}{p} = \frac{T_S}{p\,T_P}$$

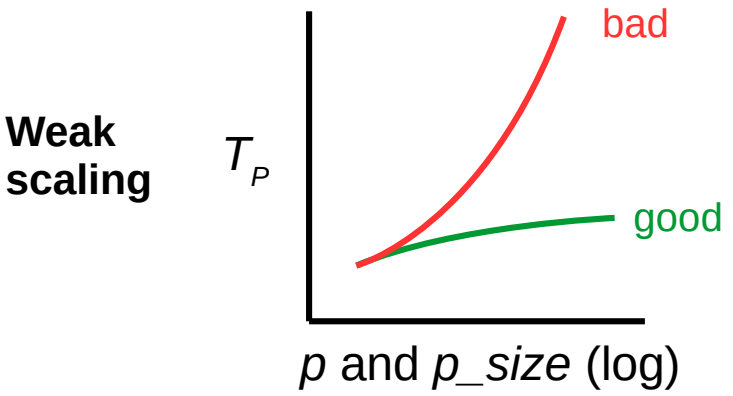
usually decreases as p grows

Scaling

- Strong scaling: as p increases, T_P decreases
  - Linear speedup: same rate of change (2x procs → half time)
  - Sublinear (most common) / superlinear (exceedingly rare) speedup
  - Be careful to interpret linear vs. logarithmic axes correctly

- Weak scaling: as p increases AND the problem size increases proportionally, T_P stays roughly the same





Cluster access

- Detailed instructions online:
  `w3.cs.jmu.edu/lam2mo/cs470/cluster.html`
- Connect to login node via SSH
  - Hostname: `login.cluster.cs.jmu.edu`
  - User/password: *(your e-ID and password)*
- Recommended conveniences
  - Set up public/private key access from `stu`
  - Set up `.ssh/config` entries
  - Install Spack for access to more software

Cluster access

- Things to play with:
  - "`squeue`" or "`watch squeue`" to see jobs
  - "`srun <command>`" to run an interactive job
    - Use "`-n <p>`" to launch *p* processes
    - Use "`-N <n>`" to request *n* nodes (defaults to *p*/8)
    - The given "`<command>`" will run in every process
  - "`salloc <command>`" to run an interactive MPI job
    - Must run "`module load mpi`" first
    - Use "`-n <p>`" to launch *p* MPI processes

```
srun hostname
srun -n 4 hostname
srun -n 16 hostname
srun -N 4 hostname
srun sleep 5
srun -N 2 sleep 5
```

```
module load mpi
salloc -n 1 mpirun /shared/mpi-pi/mpipi
salloc -n 2 mpirun /shared/mpi-pi/mpipi
salloc -n 4 mpirun /shared/mpi-pi/mpipi
salloc -n 8 mpirun /shared/mpi-pi/mpipi
salloc -n 16 mpirun /shared/mpi-pi/mpipi
(etc.)
```

What's the max *n*?

Job management

- SLURM (Simple Linux Utility for Resource Management) is a piece of system software outside the OS (a.k.a. middleware) that handles job submission and scheduling on our cluster
- An interactive job takes control of your terminal
  - Run with srun or salloc
  - You may interact with it (provide standard input, etc.)
  - You also have to wait for it to finish
  - Similar to a foreground shell job
- A batch job runs in the background without interaction
  - Create a shell script and run it with sbatch
  - Sends output to a file (named "`slurm-JOBID.out`" by default)
  - Use squeue to check to see if it has finished

Batch jobs

- To run a batch job on the cluster, create a shell script and run it with sbatch
- Bash example:

```
#!/bin/bash
#
#SBATCH --job-name=hostname
#SBATCH --nodes=1
#SBATCH --ntasks=1

<your commands go here>
```

Running experiments

- Common experimentation patterns in Bash:

```
# run 5 times
for i in $(seq 1 5); do
    <cmd>
done
```

```
# run common thread counts
for t in 1 2 4 8 16; do
    OMP_NUM_THREADS=$t <cmd>
done
```