ECE 574 – Cluster Computing
Lecture 2

Vince Weaver
http://web.eece.maine.edu/~vweaver
vincent.weaver@maine.edu

24 January 2019

Announcements

- Put your name on HW#1 before turning in!

Top500 List – November 2018

#	Name	Country	Arch /Proc	Cores	Max/Peak PFLOPS	Accel	Power kW
1	Summit (IBM)	US/ORNL	Power9	2,397,824	143/200	NVD Volta	9,783
2	Sierra (IBM)	US/LLNL	Power9	1,572,480	94/125	NVD Volta	7,438
3	TaihuLight	China	Sunway	10,649,600	93/125	?	15,371
4	Tianhe-2A	China	x86/IVB	4,981,760	61/101	MatrixDSP	18,482
5	Piz Daint (Cray)	Swiss	x86/SNB	387,872	21/27	NVD Tesla	2,384
6	Trinity (Cray)	US/LANL	x86/HSW	979,072	20/158	XeonPhi	7,578
7	ABCI (Fujitsu)	Japan	x86/SKL	391,680	20/33	NVD Tesla	1,649
8	SuperMUC-NG (Lenovo)	Germany	x86/SKL	305,856	19/26	?	?
9	Titan (Cray)	USA/ORNL	x86/Opteron	560,640	17/27	NVD K20	8,209
10	Sequoia (IBM)	USA/LLNL	Power BGQ	1,572,864	17/20	?	7,890
11	Lassen (IBM)	USA/LLNL	Power9	248,976	15/19	NVD Tesla	?
12	Cori (Cray)	USA/LBNL	x86/HSW	622,336	14/27	Xeon Phi	3,939
13	Nurion (Cray)	Korea	x86/??	570,020	14/25	Xeon Phi	?
14	Oakforest (Fujitsu)	Japan	x86/??	556,104	13/24	Xeon Phi	2,719
15	HPC4 (HPE)	Italy	x86/SNB	253,600	12/18	NVD Tesla	1,320
16	Tera-1000-2 (Bull)	France	x86/???	561,408	12/23	Xeon Phi	3,178
17	Stampede2 (Dell)	US	x86/SNB	367,024	12/28	Xeon Phi	18,309
18	K computer (Fujitsu)	Japan	SPARC VIIIfx	705,024	10/11	?	12,660
19	Marconi (Lenovo)	Italy	x86/SNB	348,000	10/18	Xeon Phi	18,816
20	Taiwania-2 (Quanta)	Taiwan	x86/SKL	170,352	9/15	NVD Tesla	798
21	Mira (IBM)	US/ANL	Power/BGQ	786,432	8/10	??	3,945
22	Tsubame3.0 (HPE)	Japan	x86/SNB	135,828	8/12	NVD Tesla	792
23	UK Meteor (Cray)	UK	x86/IVB	241,920	7/8	???	8,128
24	Theta (Cray)	US/ANL	x86/???	280,320	7/11	Xeon Phi	11,661
25	MareNostrum (Lenovo)	Spain	x86/SKL	153,216	6/10	Xeon Phi	1,632

Top500 List Notes

- Can watch video presentation on it here?
- Left off my summary: RAM? (#1 is 3PB) Interconnect?
- Power: does this include cooling or not?
  Cost of power over lifetime of use is often higher than the cost to build it.
- Power comparison: small town? 1MW around 1000 homes? (this varies)
- How long does it take to run LINPACK? How much money does it cost to run LINPACK?

- Lots of turnover since last time I taught the class?
- Operating system. Cost to run computer more than cost to build it?
- Tiahne-2 was Xeon Phi, but US banned Intel from exporting anymore, so upgraded and using own custom DSP boards now.
- Need to be 10 PFlops to be near top these days? 100k cores at least?
- First ARM system, Cavium ThunderX in Astra (US/LANL) at 204

What goes into a top supercomputer?

- Commodity or custom
- Architecture: x86? SPARC? Power? ARM
  embedded vs high-speed?
- Memory
- Storage
  How much?
  Large hadron collider one petabyte of data every day
  Shared? If each node wants same data, do you need to replicate it, have a network filesystem, copy it around

with jobs, etc? Cluster filesystems?

- Reliability. How long can it stay up without crashing?
  Can you checkpoint/restart jobs?
  Sequoia MTBF 1 day.
  Blue Waters 2 nodes failure per day.
  Titan MTBF less than 1 day
- Power / Cooling
  Big river nearby?
- Accelerator cards / Heterogeneous Systems
- Network
  How fast? Latency? Interconnect? (torus, cube,

hypercube, etc)
Ethernet? Infiniband? Custom?

- Operating System
  Linux? Custom? If just doing FP, do you need overhead of an OS? Job submission software, Authentication
- Software – how to program?
  Too hard to program can doom you. A lot of interest in the Cell processor. Great performance if programmed well, but hard to do.
- Tools – software that can help you find performance problems

Other stuff

- Rmax vs Rpeak – Rmax is max measured, Rpeak is theoretical best
- HPL Linpack
  - Embarrassingly parallel linear algebra
  - Solves a (random) dense linear system in double precision (64 bits) arithmetic
- HP Conjugate gradient benchmark
  - More realistic? Does more memory access, more I/O bound.

- #1 on list is Summit. 3PFLOPS CG wheras 143PFLOPS HPL
- Some things can move around, K-computer 18th in HPL but 3rd with CG

- Green 500

Historical Note

- From the November 2002 list, entry #332
- Location: Orono, ME
- Proc Arch: x86
- Proc Type: Pentium III, 1GHz
- Total cores: 416
- RMax/RPeak: 225/416 GFLOPS
- Power: ???
- Accelerators: None

Introduction to Performance Analysis

What is Performance?

- Getting results as quickly as possible?
- Getting *correct* results as quickly as possible?
- What about Budget?
- What about Development Time?
- What about Hardware Usage?
- What about Power Consumption?

Motivation for HPC Optimization

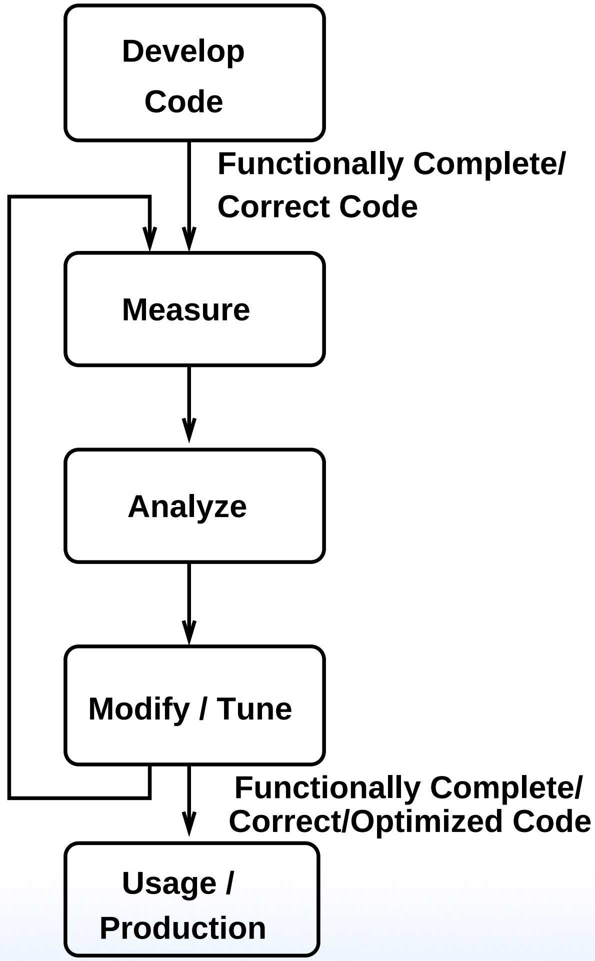
HPC environments are expensive:

- Procurement costs: ~\$40 million
- Operational costs: ~\$5 million/year
- Electricity costs: 1 MW / year ~\$1 million
- Air Conditioning costs: ??

Know Your Limitation

- CPU Constrained
- Memory Constrained (Memory Wall)
- I/O Constrained
- Thermal Constrained
- Energy Constrained

Performance Optimization Cycle



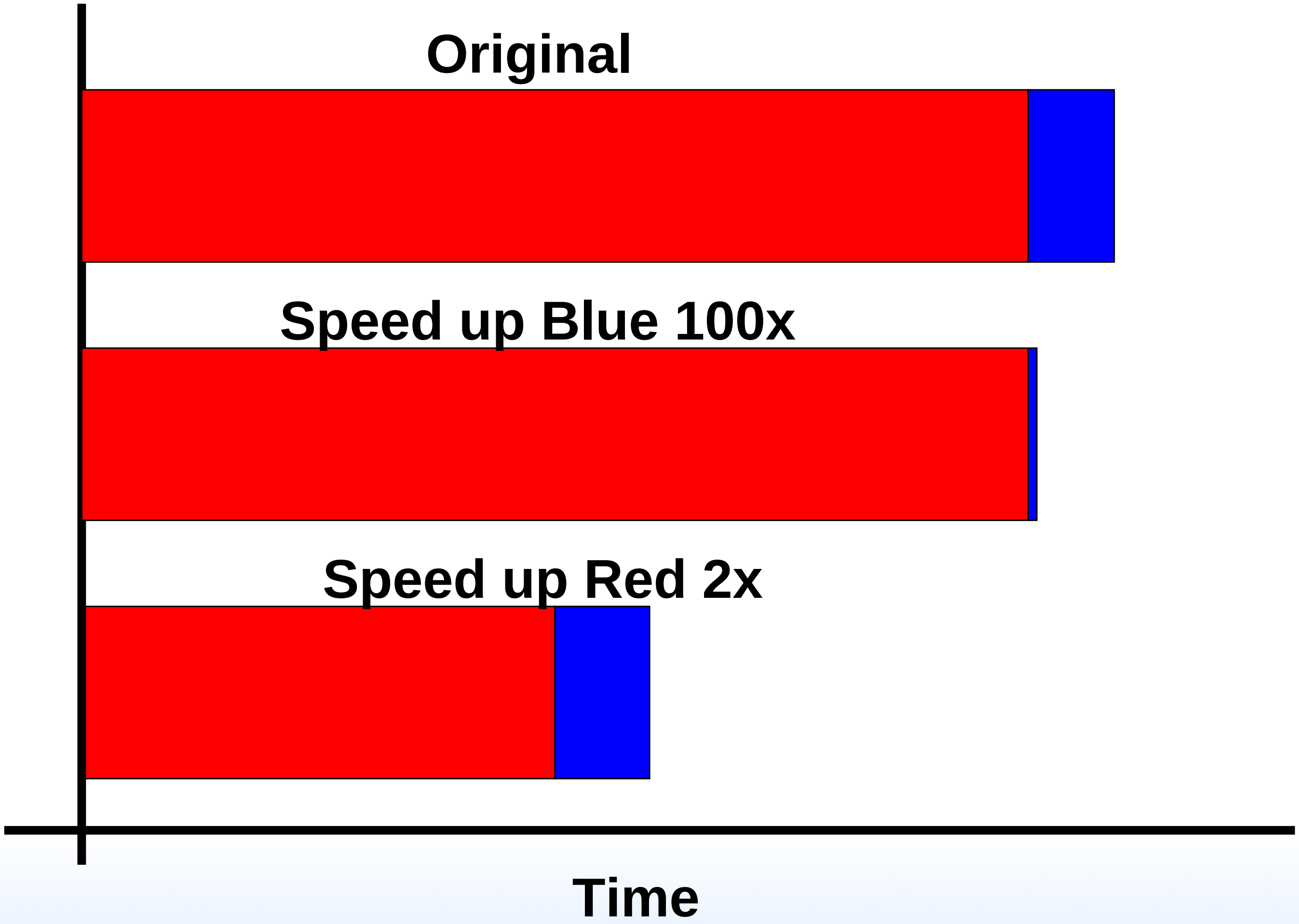
Wisdom from Knuth

"We should forget about small efficiencies, say about 97% of the time:

premature optimization is the root of all evil.

Yet we should not pass up our opportunities in that critical 3%. A good programmer will not be lulled into complacency by such reasoning, he will be wise to look carefully at the critical code; but only after that code has been identified" — Donald Knuth

Amdahl's Law



Speedup

- Speedup is the improvement in latency (time to run)

$$S = \frac{t_{old}}{t_{new}}$$

So if originally took 10s, new took 5s, then speedup=2.

Scalability

- How a workload behaves as more processors are added

- Parallel efficiency: $E_p = \frac{S_p}{p} = \frac{T_s}{pT_p}$
  p=number of processes (threads)
  T_s is execution time of serial code
  T_p is execution time with p processes

- Linear scaling, ideal: $S_p = p$

- Super-linear scaling – possible but unusual

Strong vs Weak Scaling

- Strong Scaling –for fixed program size, how does adding more processors help
- Weak Scaling – how does adding processors help with the same per-processor workload

Strong Scaling

- Have a problem of a certain size, want it to get done faster.
- Ideally with problem size N, with 2 cores it runs twice as fast as with 1 core (linear speedup)
- Often processor bound; adding more processing helps, as communication doesn't dominate
- Hard to achieve for large number of nodes, as many

algorithms communication costs get larger the more nodes involved

- Amdahl's Law limits things, as more cores don't help serial code

- Strong scaling efficiency: t1 / (N * tN) * 100%

- Improve by throwing CPUs at the problem.

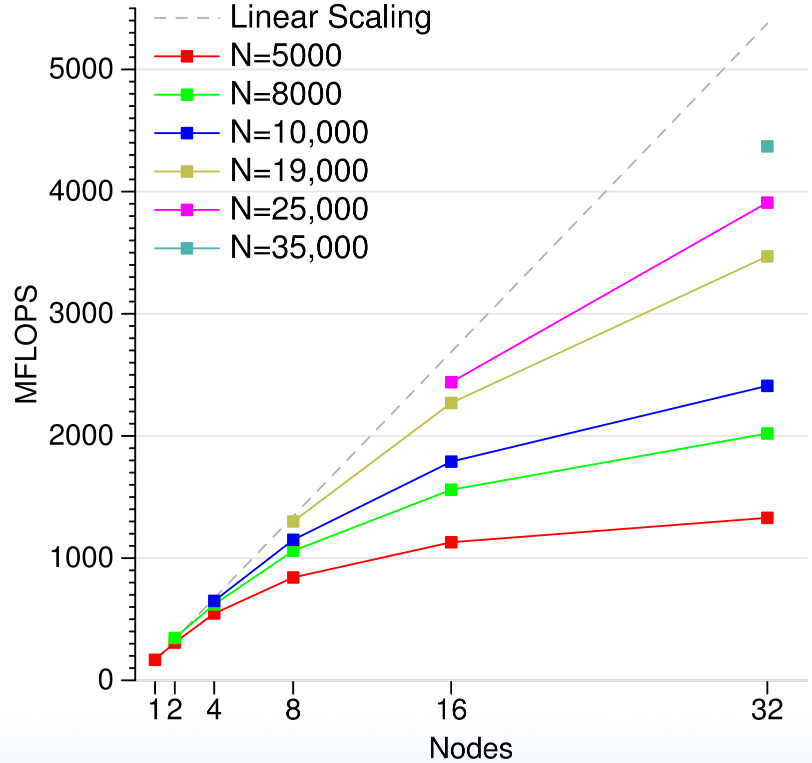
Weak Scaling

- Have a problem, want to increase problem size without slowing down.
- Ideally with problem size N with 1 core, a problem of size 2*n just as fast with 2 cores.
- Often memory or communication bound.
- Gustafson's Law (rough paraphrase)
  No matter how much you parallelize your code, there will be serial sections that just can't be made parallel

- Weak scaling efficiency: (t1 / tN) * 100%
- Improve by adding memory, or improving communication?

Scaling Example

LINPACK on Rasp-pi cluster. What kind of scaling is here?



Weak scaling. To get linear speedup need to increase problem size.
If it were strong scaling, the individual colored lines would increase rather than dropping off.