5612 — HPC systems and hardware

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September 2016

What? When? Where? Who? Huh?

- 5611 — High Performance Computing Software
- 1 lecture per week
- Mondays 3pm (Michaelmas term)
- Room 212 Lloyd Institute (here)
- 50% Exam, 50% Assignments
- Slides will be posted on ~~Blackboard~~ the MSc website

What about systems and hardware?

- 5612 — High Performance Computing Systems and Hardware
- 1 lecture per week
- Wednesdays 5pm (Michaelmas term)
- Room 212 Lloyd Institute (here)
- 80% Exam, 20% Assignments
- Slides will be posted on ~~Blackboard~~ the MSc website

Course outline

- 5611A
  - MPI basics
  - Point to point comms
  - Collective comms
  - Non-blocking comms
  - Problem decomposition
- 5612A
  - Processors
  - Caches
  - Memory
  - System Architecture
- 5611B
  - Advanced MPI
  - One sided comms
  - Topologies
  - OpenMP
  - Threaded programming
  - Hybrid programming
- 5612B
  - Process Management
  - VM and IO sub-systems
  - Execution Tracing
  - Batch systems
  - Networks

Computer Basics

- What is a computer?
  - A device that turns electricity into Age of Empires
  - Programmable electronic machine that performs high-speed mathematical or logical operations
- Key Features
  - Programmable — multi-purpose
  - Digital
  - Electronic
  - Deterministic

Essential Features

- Input
  - Punch Card
  - Keyboard
  - Retinal Scanner
  - Network
- Output
  - Monitor
  - Printer
  - Robot
  - Network

- Short Term Storage
  - Registers
  - RAM
  - Swap space
- Long Term Storage
  - Disk
  - DVD
  - Tape
- Processing Units
  - ALU
  - FPU
  - MMU

A brief history of computing

- 3000BC Invention of the abacus (1 FLOP)
- 1642 Pascal's adding machine
- 1832 Babbage's difference engine
- 1904 Diodes
- 1943 Colossus (code breaking)
- 1945 ENIAC
- 1947 Transistors
- 1957 Fortran
- 1969 Arpanet
- 1970 Unix and C
- 1976 Cray I (100 MFLOPS)
- 1983 SX-1 (570 MFLOPS)
- 2001 Earth Simulator (40 TFLOPS)
- 2005 BGL (150 TFLOPS)
- 2008 Roadrunner (1 PFLOP)
- 2016 TaihuLight (93 PFLOP)
- 2020 Who knows! (1 EFLOP ??)

What is HPC?

- High Performance Computing is the art of getting bigger things done faster
- Faster — squeeze every last drop out of the hardware
  Use specialised hardware for specific tasks
- Bigger — use many machines together to tackle problems that are not feasable on a single computer
- Memory limited — jobs that need more memory than can fit in a single system
- CPU time limited — jobs that take forever to run

Limits on Serial Code

- Memory limited — jobs that need more memory than can fit in a single system
- Moving to a parallel system allows you to tackle problems than you could before
- CPU time limited — jobs that take forever to run
- Moving to a parallel system reduces time to solution
- Often a combination of both

Parallelism in Computer Systems

- Parallelism can occur in two different places in a parallel computer system
- Processor — low level instruction parallelism
  - Your compiler will try to take advantage of this
- Algorithmic — higher level parallelism
  - You, the programmer, need to manage this

HPC at TCD

- Founded in 1997. Joint IBM SP system with QUB
- Several generations of clusters (PIII, Xeon, Opteron)
- Lonsdale (2009)
  - 11.5 TFLOP, AMD cluster with IB
- Kelvin (2011)
  - 12.8 TFLOP, Intel cluster with IB
- Over 100TB of shared GPFS filesystem
- For MSc course, initially use lab computers but will be running on the large systems

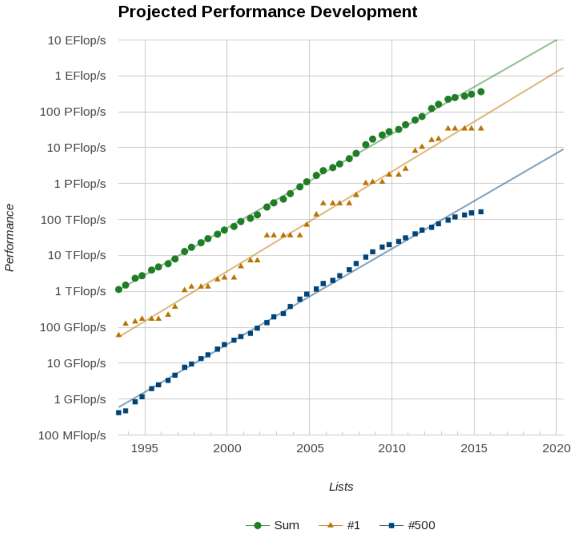
HPC in Ireland

- ICHEC — Irish Centre for High End Computing
- Fionn system (2013)
- 140 TFLOP, Intel cluster with IB
- Also has Tesla and Phi accelerators
- IBM research lab in Mulhuddart working on HPC
- Tullow Oil, Paddy Power
- Many traders in the IFSC use HPC daily

Top 500 List

- Twice yearly list of the most powerful systems in the world
- Announced at ISC in June and SC in November
- Rankings based on the Linpack benchmark results
    - Solves a set of dense equations
    - Good test of processor performance
    - Not so good at testing memory and interconnect
- See `http://www.top500.org` for more details

Top 500 List


Projected Performance Development
10 EFlop/s
1 EFlop/s
100 PFlop/s
10 PFlop/s
1 PFlop/s
100 TFlop/s
10 TFlop/s
1 TFlop/s
100 GFlop/s
10 GFlop/s
1 GFlop/s
100 MFlop/s
Performance
1995
2000
2005
2010
2015
2020
Lists
Sum
#1
#500

Top 500 List

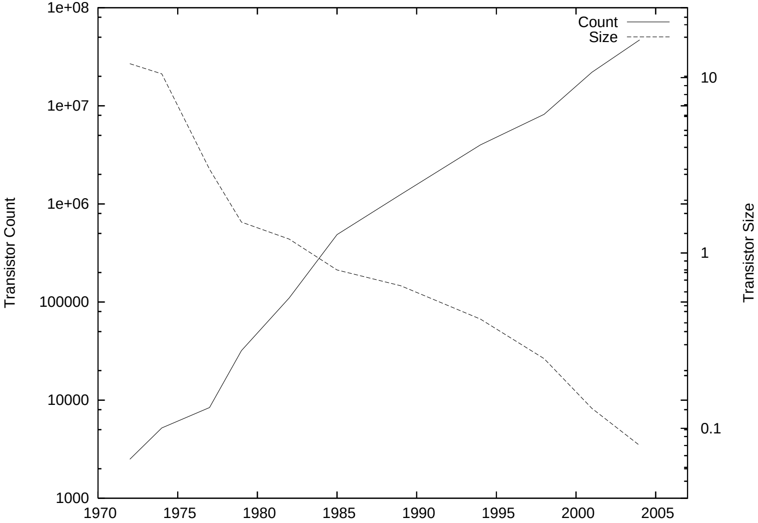
1. Wuxi, China "TaihuLight" — Sunway 93PF
2. Guangzhou, China "Tianhe 2" — Xeon Phi 33.8PF
3. Oak Ridge, "Titan" — Cray + Nvidia 17.6PF
4. Lawrence Livermore, "Sequoia" — IBM BlueGene/Q 17.2PF
5. Riken, "K computer" — SPARC64 10.5PF
6. Argonne, "Mira" — IBM BlueGene/Q 8.6PF
7. Los Alamos, "Trinity" — Cray XC40 8.1PF
8. Swiss National Centre, "Piz Daint" — Cray + Nvidia 6.3PF

Moore’s Law

- "the level of integration of ICs doubles every 18 months" — Gordon Moore, founder of Intel
- Stated in 1964, pretty much true ever since
- Starting to tail off
- Corollory: Gates’ Law — "the speed of software halves every 18 months"
- Over a billion transistors per chip
- Using 14nm technology (5nm projected for 2022)
- Clock speeds up towards 5GHz

CPU	Scale	Cores	Transistors	Size (mm^2)
Icelake	10nm			
Skylake	14nm	4+GPU	1.8B	122
Broadwell	14nm	22	7.2B	133
Haswell	22nm	8	2.6B	355
Ivy Bridge	22nm	4	1.4B	160
Sandy Bridge	32nm	6	2.34B	435
Westmere	32nm	6	2.27B	240
Nehalem	45nm	4	731M	296

Moore’s Law



Transistor Count
1e+08
1e+07
1e+06
100000
10000
1000
1970
1975
1980
1985
1990
1995
2000
2005
Count
Size
10
1
0.1
Transistor Size

Influencing Moore's Law

- Density of transistors
  — denser packing gives lower power consumption and higher switching speeds
- Size of wafer
  — Bigger wafer gives more compute units
- Density of defects
  — Fewer defects gives less waste
- Just avoid it by going parallel!!
  — Brings in lots of other problems though

The plan for this semester

- Next week - no classes but do some background reading
- Then to focus on 5612 until reading week
- Allow time to get back into programming in 5613
- Then only do 5611 until end of semester
- By the end of the semester you should be comfortably writing parallel applications and know all about processor design

Reading List

Don’t go out and buy all these!

- High Performance Computing — Severance and Dowd
- Introduction to Parallel Computing — Grama et al
- Parallel Scientific Computing — Karniadakis and Kirby
- Parallel Programming in OpenMP — Chandra
- Parallel Programming in C with MPI and OpenMP — Quinn
- Introduction to Parallel Programming — Pacheco
- The C programming Language — Kernighan and Ritchie

Reading List 2

Don’t go out and buy any these!

- Computer Systems — O’Hallaron
- Advanced Computer Architecture — Hwang
- Design of the Unix Operating System — Bach
- Advanced Computer Architecture and Parallel Processing — El-Rewini
- Computer Networks — Tanenbaum
- Computer Architecture and Organization — Murdocca and Heuring
- Computer Organization and Architecture — Stallings
- Digital Design and Computer Architecture — Harris and Harris