Parallel Computing with GPUs

Introduction Part 1 – Course Context

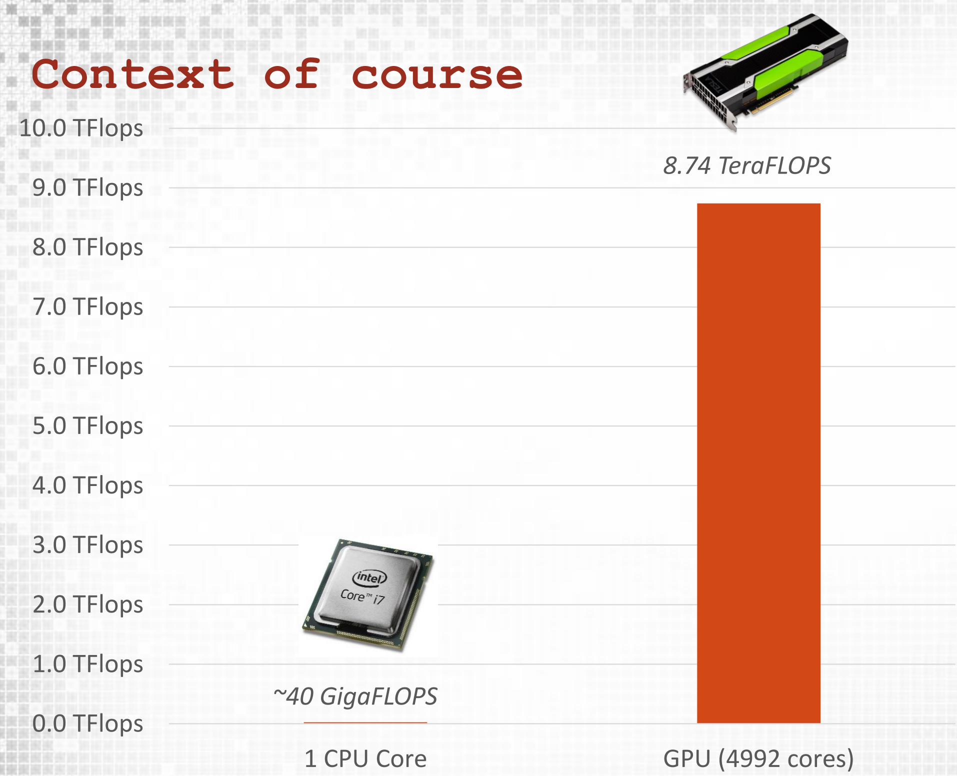
The University Of Sheffield.

Dr Paul Richmond
http://paulrichmond.shef.ac.uk/teaching/COM4521/

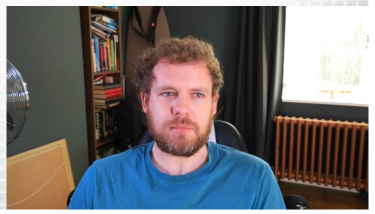
This Lecture (learning objectives)

- Introduce the course context
  - Identify the significance of GPU performance
  - Analyse the emergence of multi and many core architectures
  - Present accelerators as a co-processor

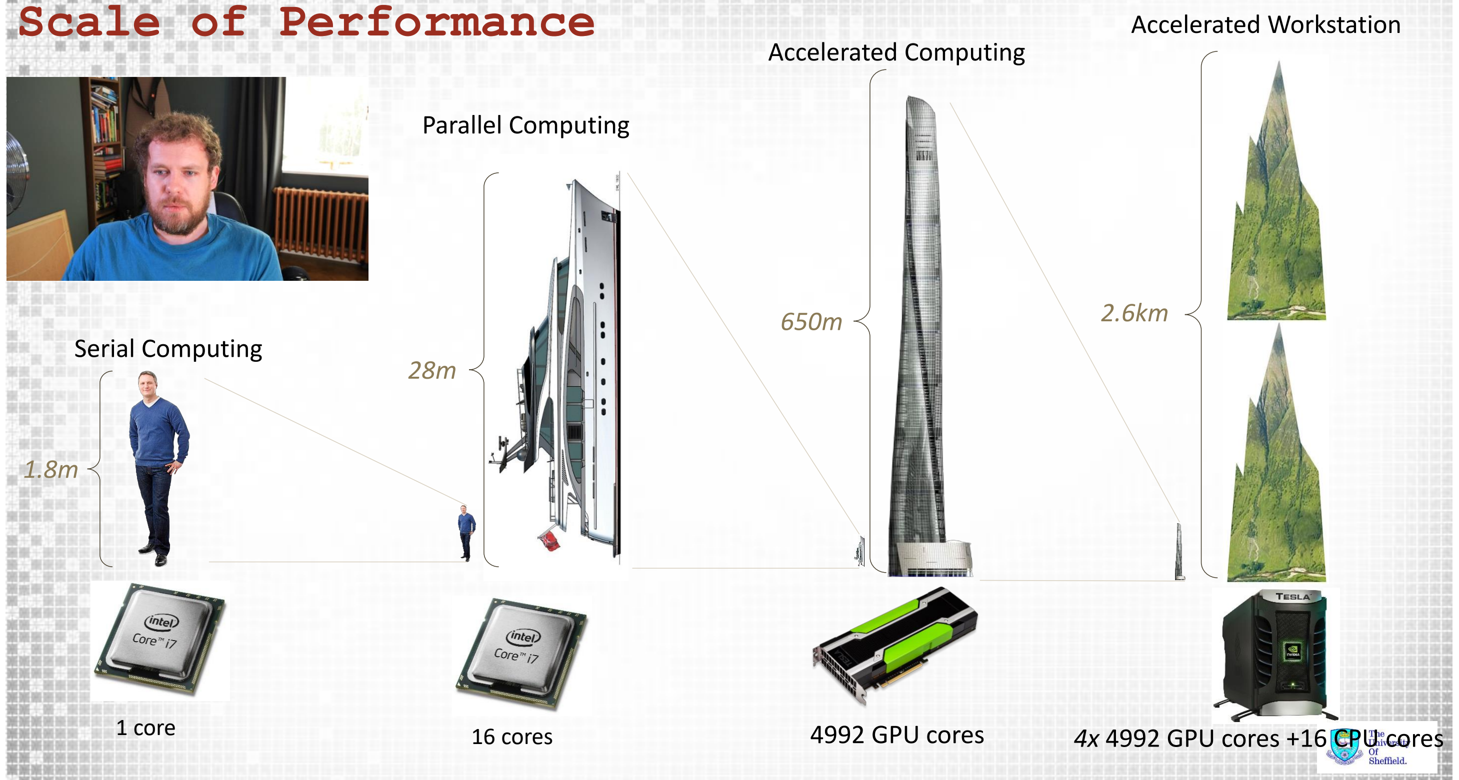
Context of course



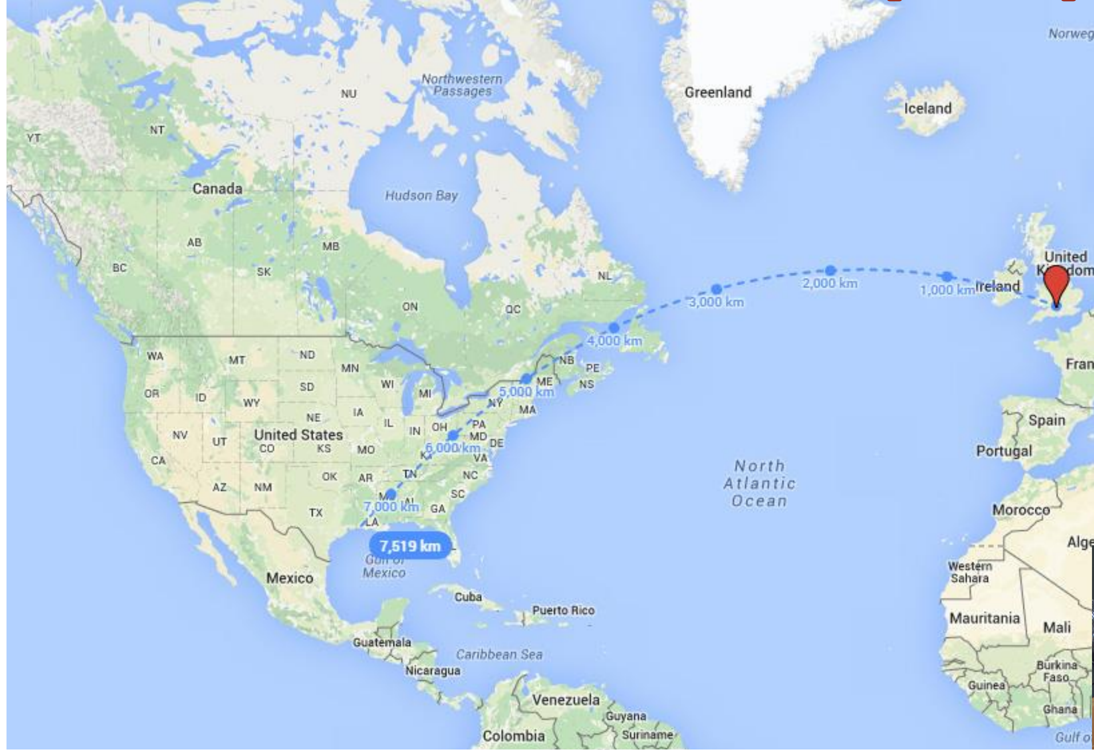
6 hours *CPU* time
vs.
1 minute *GPU* time

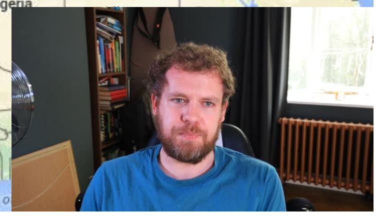


Scale of Performance



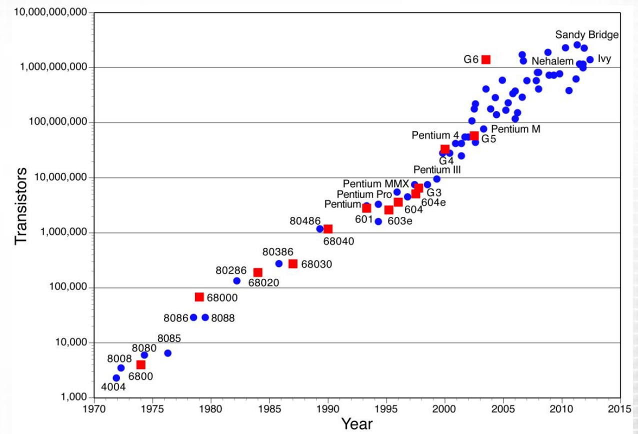
Scale of Performance: Titan Supercomputer





Transistors != performance

- Moore's Law: A doubling of transistors every couple of years
  - Not a law actually an observation
  - Doesn't actually say anything about performance
- Future of Moore's Law
  - Moore's law is dead!
  - A bright future for Moore's Law



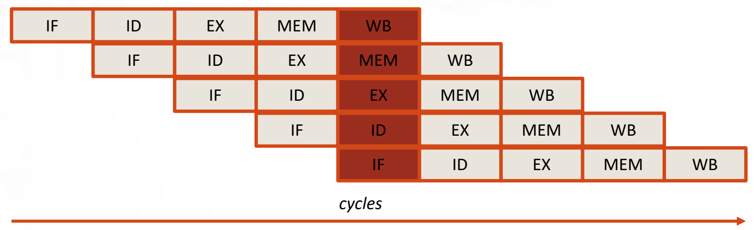
Dennard Scaling

"As transistors get smaller their power density stays constant"

Power = Frequency x Voltage²

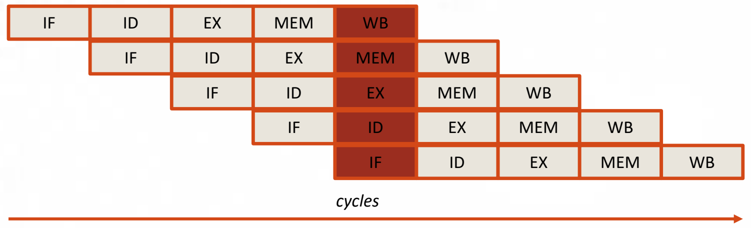
- Performance improvements for CPUs traditionally realised by increasing frequency
- Decrease voltage to maintain a steady power
  - Only works so far
- Increase Power
  - Disastrous implications for cooling

Instruction Level Parallelism



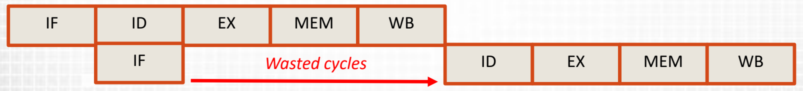
- Transistors used to build more complex architectures
- Use pipelining to overlap instruction execution

Instruction Level Parallelism



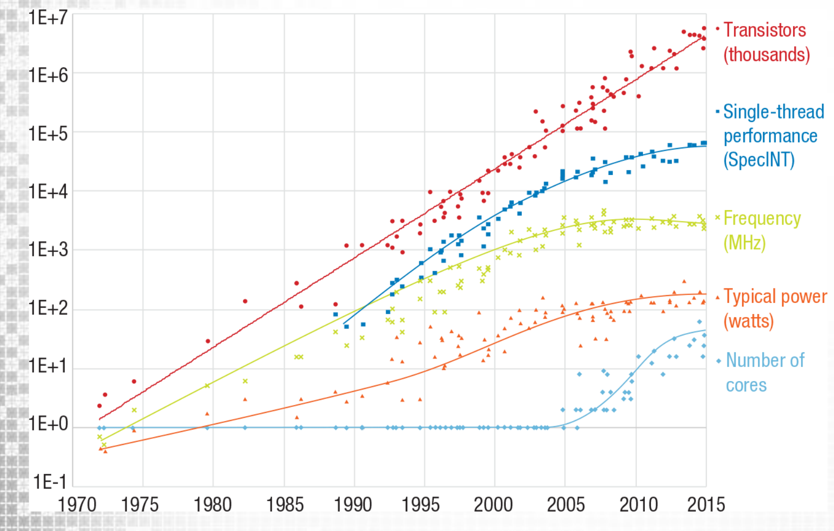
- Transistors used to build more complex architectures
- Use pipelining to overlap instruction execution

```
add 1 to R1
copy R1 to R2
```

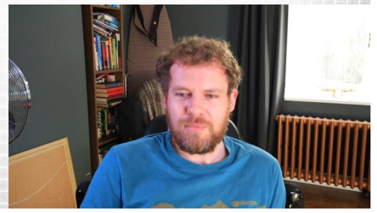


Golden Era of Performance

- 90s saw great improvements to single CPU performance
  - 1980s to 2002: 100% performance increase every 2 years
  - 2002 to now: ~40% every 2 years

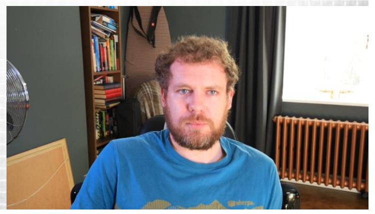


Adapting to Thrive in a New Economy of Memory Abundance, K Bresniker et al.



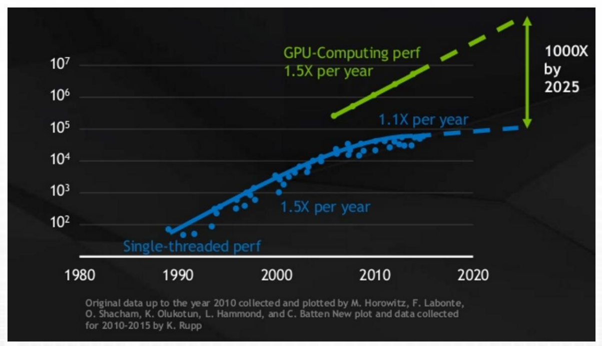
Why More Cores?

- Use extra transistors for multi/many core parallelism
  - More operations per clock cycle
  - Power can be kept low
  - Processor designs can be simple – shorter pipelines (RISC)



GPUs and Many Core Designs

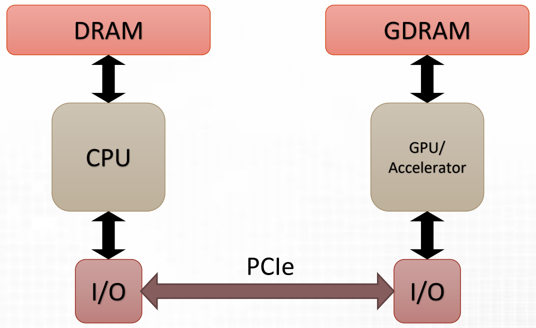
- Take the idea of multiple cores to the extreme (many cores)
- Dedicate more die space to compute
  - At the expense of branch prediction, out of order execution, etc.
- Simple, Lower Power and Highly Parallel
  - Very effective for HPC applications

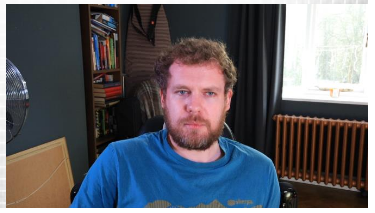


From GTC 2017 Keynote Talk, NVIDIA CEO Jensen Huang

Accelerators

- ❑Problem: Still require OS, IO and scheduling
- ❑Solution: “Hybrid System”,
  - ❑CPU provides management and
  - ❑“Accelerators” (or co-processors) such as GPUs provide compute power

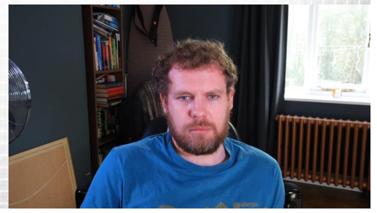




Types of Accelerator

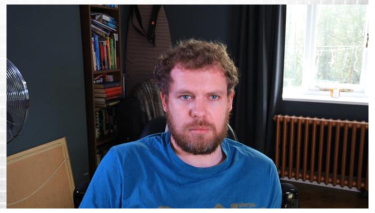
- ❑GPUs
  - ❑Emerged from 3D graphics but now specialised for HPC
  - ❑Readily available in workstations

- ❑Xeon Phis
  - ❑Many Integrated Cores (MIC) architecture
  - ❑Based on Pentium 4 design (x86) with wide vector units
  - ❑Closer to traditional multicore
  - ❑Simpler programming and compilation



Summary

- ❑Introduce the course context
  - ❑Identify the significance of GPU performance
  - ❑Analyse the emergence of multi and many core architectures
  - ❑Present accelerators as a co-processor
- ❑Next Lecture: Supercomputers and Software



Parallel Computing with GPUs

Introduction Part 2 – Supercomputing and Software

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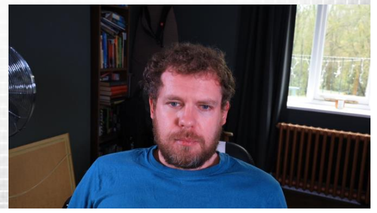
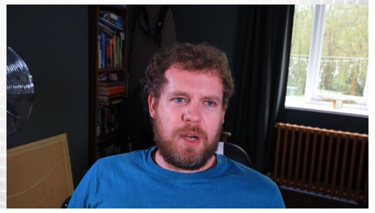
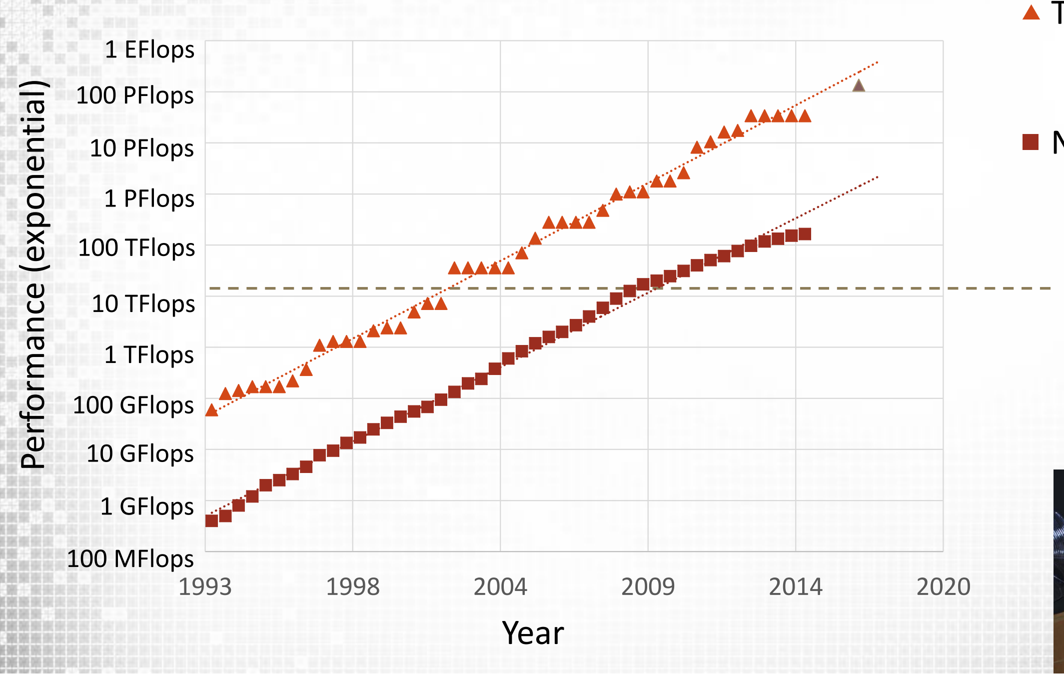


This Lecture (learning objectives)

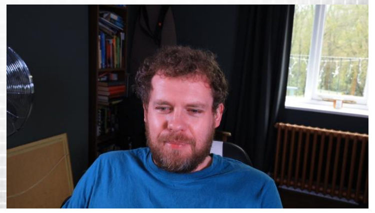
- ❑Supercomputing
  - ❑Analyse High Performance Computing (HPC) observations
  - ❑Predict future hardware trends in HPC
  - ❑Contrast types of super computing system
- ❑Software
  - ❑Explain the limitations of parallelism with respect to speedup
  - ❑Classify programming models and types of parallelism



Top Supercomputers

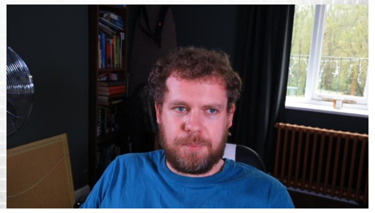


Volta V100 (15TFLOPS SP)



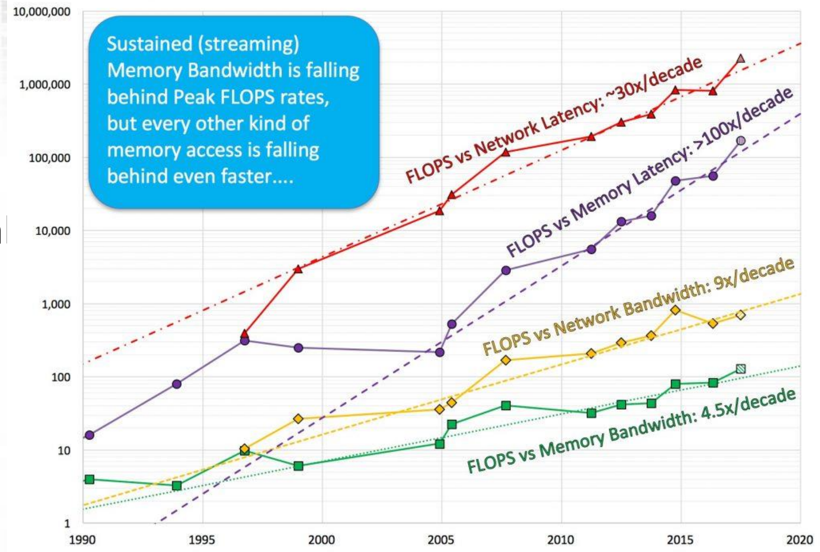
Supercomputing Observations

- ❑Exascale computing
  - ❑1 Exaflop = 1M Gigaflops
  - ❑Estimated for mid 2020s
- ❑Pace of change
  - ❑Desktop GPU top supercomputer in 2002
  - ❑A desktop with a GPU would be in Top 500 in 2008
  - ❑A Teraflop of performance took 1MW in 2000
- ❑Extrapolating the trend
  - ❑Current gen top500 on every desktop in < 10 years

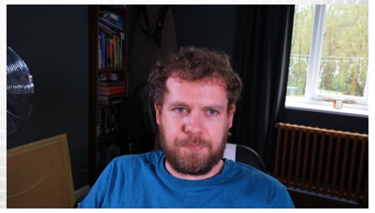


HPC Observations

- ❑Improvements at individual computer node level are greatest
  - ❑Better parallelism
  - ❑Hybrid processing
  - ❑3D fabrication
- ❑Communication costs are increasing
  - ❑Memory per core is reducing
- ❑Throughput > Latency

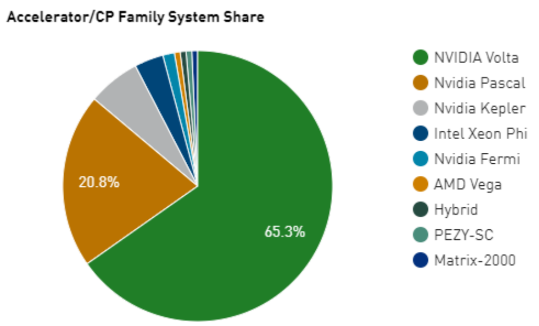


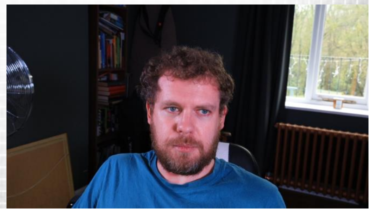
http://sc16.supercomputing.org/2016/10/07/sc16-invited-talk-spotlight-dr-john-d-mccalpin-presents-memory-bandwidth-system-balance-hpc-systems/



Supercomputing Observations

Rank	Site	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	DOE/SC/Oak Ridge National Laboratory United States	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband IBM	2,414,592	148,600.0	200,794.9	10,096
2	DOE/NNSA/LLNL United States	**Sierra** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband IBM / NVIDIA / Mellanox	1,572,480	94,640.0	125,712.0	7,438
3	National Supercomputing Center in Wuxi China	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway NRCPC	10,649,600	93,014.6	125,435.9	15,371
4	National Super Computer Center in Guangzhou China	**Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Matrix-2000 NUDT	4,981,760	61,444.5	100,678.7	18,482
5	Texas Advanced Computing Center/Univ. of Texas United States	**Frontera** - Dell C6420, Xeon Platinum 8280 28C 2.7GHz, Mellanox InfiniBand HDR Dell EMC	448,448	23,516.4	38,745.9	
6	Swiss National Supercomputing Centre (CSCS) Switzerland	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 Cray/HPE	387,872	21,230.0	27,154.3	2,384
7	DOE/NNSA/LANL/SNL United States	**Trinity** - Cray XC40, Xeon E5-2698v3 16C 2.3GHz, Intel Xeon Phi 7250 68C 1.4GHz, Aries interconnect Cray/HPE	979,072	20,158.7	41,461.2	7,578
8	National Institute of Advanced Industrial Science and Technology (AIST) Japan	**AI Bridging Cloud Infrastructure (ABCI)** - PRIMERGY CX2570 M4, Xeon Gold 6148 20C 2.4GHz, NVIDIA Tesla V100 SXM2, Infiniband EDR Fujitsu	391,680	19,880.0	32,576.6	1,649

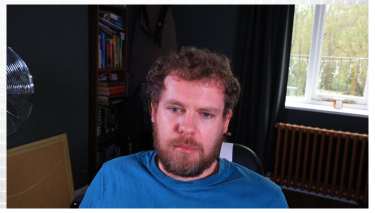




Green 500

Rank	TOP500 Rank	System	Cores	Rmax (TFlop/s)	Power (kW)	Power Efficiency (GFlops/watts)
1	159	**A64FX prototype** - Fujitsu A64FX, Fujitsu A64FX 48C 2GHz, Tofu interconnect D , Fujitsu Fujitsu Numazu Plant Japan	36,864	1,999.5	118	16.876
2	420	**NA-1** - ZettaScaler-2.2, Xeon D-1571 16C 1.3GHz, Infiniband EDR, PEZY-SC2 700Mhz , PEZY Computing / Exascaler Inc. PEZY Computing K.K. Japan	1,271,040	1,303.2	80	16.256
3	24	**AiMOS** - IBM Power System AC922, IBM POWER9 20C 3.45GHz, Dual-rail Mellanox EDR Infiniband, NVIDIA Volta GV100 , IBM Rensselaer Polytechnic Institute Center for Computational Innovations (CCI) United States	130,000	8,045.0	510	15.771
4	373	**Satori** - IBM Power System AC922, IBM POWER9 20C 2.4GHz, Infiniband EDR, NVIDIA Tesla V100 SXM2 , IBM MIT/MGHPCC Holyoke, MA United States	23,040	1,464.0	94	15.574
5	1	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM DOE/SC/Oak Ridge National Laboratory United States	2,414,592	148,600.0	10,096	14.719
6	8	**AI Bridging Cloud Infrastructure (ABCI)** - PRIMERGY CX2570 M4, Xeon Gold 6148 20C 2.4GHz, NVIDIA Tesla V100 SXM2, Infiniband EDR , Fujitsu National Institute of Advanced Industrial Science and Technology (AIST) Japan	391,680	19,880.0	1,649	14.423
7	494	**MareNostrum P9 CTE** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, Dual-rail Mellanox EDR Infiniband, NVIDIA Tesla V100 , IBM Barcelona Supercomputing Center Spain	18,360	1,145.0	81	14.131
8	23	**TSUBAME3.0** - SGI ICE XA, IP139-SXM2, Xeon E5-2680v4 14C 2.4GHz, Intel Omni-Path, NVIDIA Tesla P100 SXM2 , HPE GSIC Center, Tokyo Institute of Technology Japan	135,828	8,125.0	792	13.704

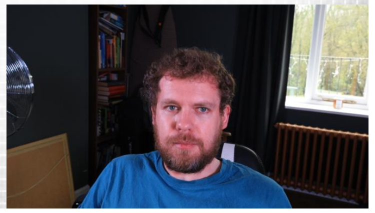
- Top energy efficient supercomputers



Software Challenge

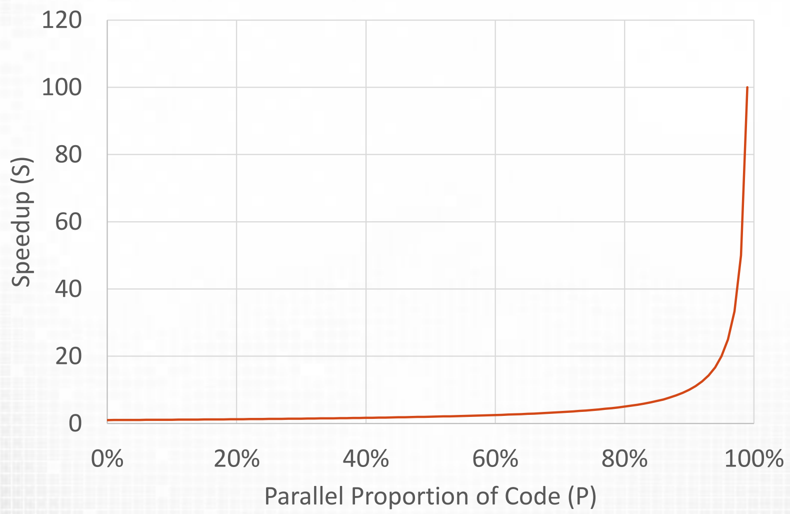
- How to use this hardware efficiently?

- Software approaches
  - Parallel languages: some limited impact but not as flexible as sequential programming
  - Automatic parallelisation of serial code: >30 years of research hasn't solved this yet
  - **Design software with many core parallelisation in mind**

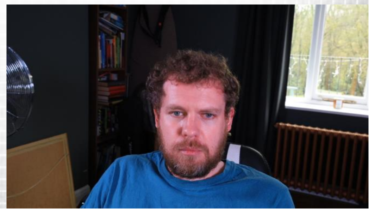


Amdahl's Law

- Speedup of a program is limited by the proportion than can be parallelised

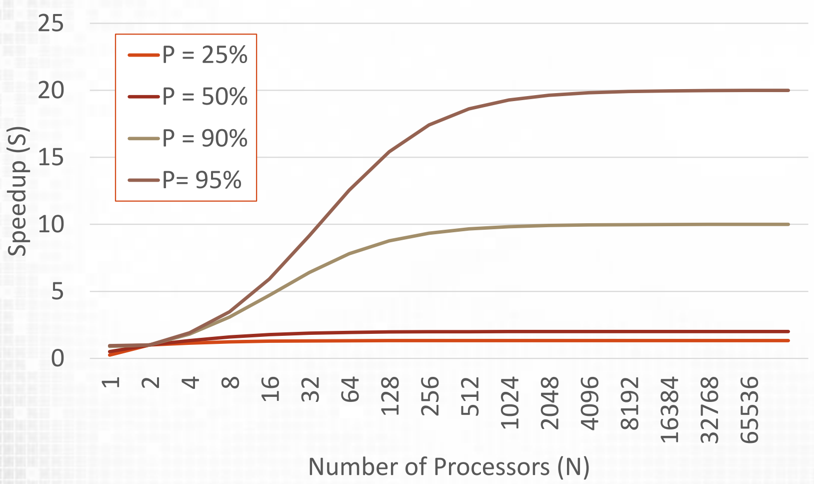


$$Speedup\ (S) = \frac{1}{1-P}$$

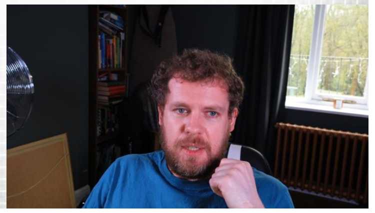


Amdahl's Law cont.

- Addition of processing cores gives diminishing returns

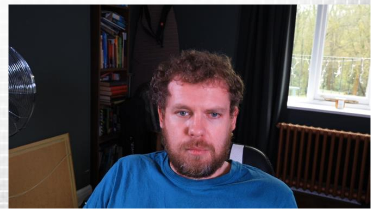


$$Speedup\ (S) = \frac{1}{\frac{P}{N} + (1 - P)}$$



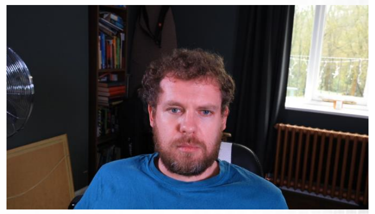
Parallel Programming Models

- Distributed Memory
  - Geographically distributed processors (clusters)
  - Information exchanged via messages
- Shared Memory
  - Independent tasks share memory space
  - Asynchronous memory access
  - Serialisation and synchronisation to ensure correctness
  - No clear ownership of data
  - Not necessarily performance oriented



Types of Parallelism

- Bit-level
  - Parallelism over size of word, 8, 16, 32, or 64 bit.
- Instruction Level (ILP)
  - Pipelining
- Task Parallel
  - Program consists of many independent tasks
  - Tasks execute on asynchronous cores
- Data Parallel
  - Program has many similar threads of execution
  - Each thread performs the same behaviour on different data



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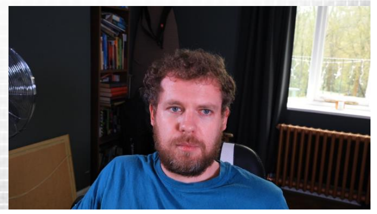
  - Contrast types of super computing system
- Software
  - Explain the limitations of parallelism with respect to speedup
  - Classify programming models and types of parallelism

- Next Lecture: Module Details



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Introduction Part 3 – Module Details

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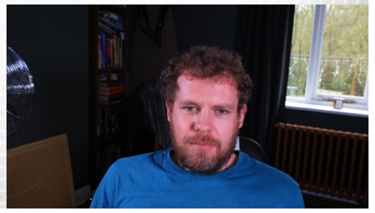
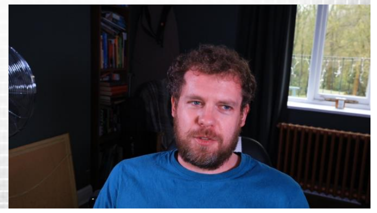


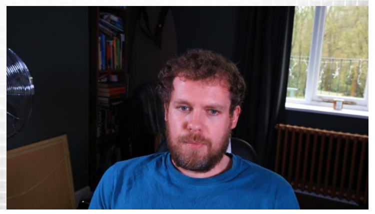
COM4521/6521 specifics

- Designed to give insight into parallel computing
  - Specifically with GPU accelerators
  - Knowledge transfers to all many core architectures
- What you will learn (Learning Objectives)
  - Compare and contrast parallel computing architectures
  - Implement programs for GPUs and multicore architectures
  - Apply benchmarking and profiling to GPU programs to understand performance
  - Identify and address limiting factors and apply optimisation to improve code performance



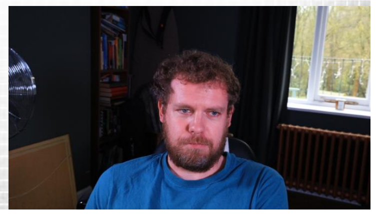
Course Mailing List

- A google group for the course has been set up
  - You have already been added if you were registered 04/02/2021
  - If you have not had an email then you need to manually join
- Mailing list uses;
  - Request help outside of lab classes
  - Find out if a lecture has changed
  - Want to participate in discussion on course content
- https://groups.google.com/a/sheffield.ac.uk/forum/#!forum/com4521-group



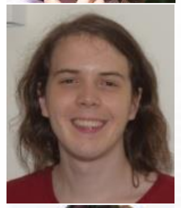
Module Delivery

- ~1.5 hours of Lectures available per week. Available in 10-15m recorded mini lectures.
  - Expected timetable for watching these on in the course website
- 2.0 hour online lab
  - Online Assessed MOLE quiz in Weeks 5 and 9 at 11:00-12:00 (10% each)
- Single assignment (80% of module mark)
  - Released week 4
  - Hand-in week 12
  - Use the lab classes to get feedback on your work!

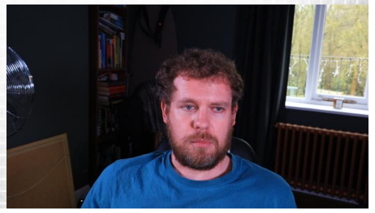


Lab Classes

- 2 hours every week
  - Essential in understanding the course content!
  - Do not expect to complete all exercises within the 2 hours
- Labs are run by Coding help from lab demonstrators;
  - Dr Rob Chisholm (RSE Group)
  - John Charlton
  - Luis Rene Montana Gonzalez

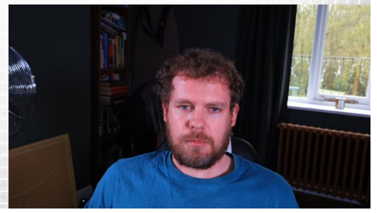


Assignment and lab class help questions should be directed to the google discussion group



Machines Available

- Diamond Virtual Computer Lab 1 (lab reservation)
  - Access via myTimetable
  - NVIDIA GTX1050 GPU
- Diamond High Spec Lab (lab reservation)
  - Access via myTimetable
  - NVIDIA Quadro P4000
- Diamond High Spec Lab - Computer Room 4(https://www.sheffield.ac.uk/findapc/rdp/room/4/pcs) - This room can not be reserved but machines can be requested. These machines have slightly higher capability GPUs (Quadro P4000) but are limited in availability.
- Diamond High Spec Lab (no reservations)
  - Access via findapc
  - NVIDIA Quadro P4000
- Any other Diamond Computer Lab
  - Access via findapc
  - NVIDIA GTX1050 GPU
- Your own Machine: See Module Website



Learning Resources

- Course website: http://paulrichmond.shef.ac.uk/teaching/COM4521/
- Blackboard: Links for the online lab sessions
- Recommended Reading:
  - Edward Kandrot, Jason Sanders, "CUDA by Example: An Introduction to General-Purpose GPU Programming", Addison Wesley 2010.
  - Brian Kernighan, Dennis Ritchie, “The C Programming Language (2nd Edition)”, Prentice Hall 1988.