DISTRIBUTED AND HIGH-PERFORMANCE COMPUTING

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Overview

Briefly present

- Course Objectives
- Course Timetable
- Course Prerequisites and Assessment
- Contents Overview

Then on to

Lecture 1: An Overview of High Performance Computing (HPC) from a practical applications perspective.

Note: Course Web page at

http://www.dhpc.adelaide.edu.au/education/dhpc/

- Course Overview
- Course Work for Assessment
- Practical Programming Lab
- Course Outline and Lecture Notes
- References and Recommended Reading
Course Objectives

Aimed at bridging the gap between undergraduate computer science and state-of-the-art research work in distributed and high-performance computing (DHPC).

The course will discuss the following questions:

- What is High-Performance Computing?
- What is (High-Performance) Distributed Computing?
- Why are they important and to whom?

We will present:

- Background material on parallel and high-performance computing (HPC).
- Background material on distributed computing and distributed HPC (grid computing, metacomputing, Internet computing).
- Past and present research in DHPC.
- A historical review of some important hardware and systems.
- But emphasis is on software – how to exploit high performance computer hardware on local or wide-area networks for maximising efficiency and performance.
- Case studies and examples from computational science – course has a strongly applied outlook.
Course Timetable

11 Lectures:

1. Wed March 4
2. Wed March 11
3. Wed March 18
4. Wed March 25
5. Wed April 3
6. Wed April 10
   - Mid-Semester Break
   - Mid-Semester Break
7. Wed May 1
8. Wed May 8
9. Wed May 15
10. Wed May 22
11. Wed May 29
12. Wed June 5
13. Wed June 12

All at 4.10 - 6pm in CS Dept Lecture Theatre.
Prerequisites and Assessment

The course is assessed as follows:

- Practical programming exercise (choice of several) : 40%
- Research a topic (choice of several) and write a report : 20%
- Final exam : 40%

Considerable choice is given in the topics and systems used for the programming exercise and report.

You must be able to program in at least one of C, Fortran or Java.

Helpful to be able to understand example code presented in each of these languages.
Course Contents

Definition of Terms Supercomputing, High-Performance Computing, Parallel Computing, Distributed Computing, Metacomputing, Grid Computing

Applications and Motivation An overview of key applications areas for DHPC

Understanding Architectures and Applications A historical look at some important architectural aspects of HPC systems

Profiling, Measurement and Code Porting Some examples of how to get code running on a new HPC system and how to analyse/model what is best

Case Studies Computational science; Example applications using HPC

The Research Problems Security and authentication; name spaces for control and storage; heterogeneous systems and integration; interoperability.

Where to Find More Information Recommended reading and Web sites.
Course Contents II

Focus in particular on the following DHPC technologies:

**Data Parallelism** Historical background; Uses; Current systems and work in progress (HPF, HPC, HPJava...)

**Message Passing** Historical background; Uses; Current systems and research. (PVM, MPI,...)

**Shared Memory Systems** Historical background; Architectures; Multi-threading; New standards (OpenMP).

**Distributed Environments** Historical background; Uses; Current systems and developments (DCE, CORBA, Java RMI...).

**Cluster Computing** Beowulf PC clusters, networks of workstations, network technologies, cluster management software.

**Metacomputing or Grid Computing Environments** Globus, Legion, DISCWorld, SETI@Home etc.
Lectures

Lectures organized as:

- **Introduction to DHPC** – What is DHPC; Milestones in DHPC History; Some DHPC applications.

- **HPC Architectures** – An overview of the major classes of HPC architectures and their evolution.

- **Programming Models and Performance Analysis** – Parameterisation, modelling, performance analysis, efficiency, and benchmarking of DHPC systems.

- **Programming Parallel Computers** – Overview of parallel programming, parallel languages, parallelizing compilers, message passing and data parallel programming models.

- **Message Passing Computing** – Uses; historical background; current implementations; programming using the Message Passing Interface (MPI).

- **Shared Memory and Data Parallel Computing** – Uses; historical background; programming using High Performance Fortran (HPF) and OpenMP; parallel Java.

- **Case Study** – Computational physics application; different approaches to parallelism; tricks and techniques for parallel implementation and optimisation in MPI and HPF.
• **Distributed Computing** – Issues; transparency and design goals; shared file systems; architecture models; software requirements; protection and capabilities; location of services; time and ordering; latency; interprocess communication; shared memory communication; message passing communication; remote procedure calls; distributed systems issues.

• **Research Problems in Distributed Computing**
  – Naming, timing, authentication, reliable connections and multicasts, scheduling.

• **DHPC Software Systems** – CORBA, DCE, Nexus, Java RMI, Jini.

• **Cluster Computing** – Cluster computing and cluster management systems; Beowulf PC clusters.

• **Grid Computing or Metacomputing** –
  Metacomputing (or Grid Computing) over local and wide-area networks; metacomputing environments (Nexus and Globus, Legion, DISCWorld..); Internet computing (SETIHome, etc).
HIGH PERFORMANCE COMPUTING
The Terminology

- **Supercomputing** - hard to define since computer performance is constantly improving. One definition is “a (new) computer that costs more than a million dollars” (or maybe 10 million?). Another is “any machine on the Top 500 list” which ranks performance using a matrix benchmark.

- **High-Performance Computing (HPC)** - even harder to define, now that the performance of PC’s matches that of high-end workstations (which was not true as little as 5 years ago).

- **HPC/HPCC** - the second C (for Communications) was added as we started the transition towards distributed high-performance computing, high-speed networks, and use of the Internet.

- **HPCN** - High Performance Computing and Networks (of course Europe had to be different).

- **Parallel Computing** - HPC using multi-processor machines. These days HPC almost implies parallel, but this was not always the case.

- **Distributed Computing** - utilizing distributed computers, more concerned with added functionality than performance.

- **DHPC, Grid Computing, Metacomputing** - Distributed, High Performance Computing.
Cornerstones of HPC

- **Compute** - data processing capabilities to carry out simulations, or to combine data sources. (FLOPS,IPS,LIPS,GFLOPS,MPIS...)

- **Storage** - hierarchical from cache memory, to local main memory, remote memory (in a parallel system), local disk, bulk RAID, tape silo, ... (Read/Write MBytes per second)

- **Communications** - internal to a box, or a network, local (LAN) or wide area (WAN). (Mbit/s bandwidth and millisees latency for Ethernet, Gbits and microsec for supercomputer comms, Gbits and millisec for high-speed WANs)

- **Visualisation** - important to visualise some large data sets, virtual reality, CAVEs, remote collaboration (FPS,PPS,TPS,...)

These groupings can apply to hardware, or systems software or applications.

Visualisation is perhaps a separate area, since not required for all applications.

DHPCCS may be an appropriate new acronym to recognise that Distributed Communications and Storage are equally important as Computation.
Historical Milestones

- Serial Computing Era (IBM Mainframes and competitors)
- Vector Computers (Cray and imitators)
- SIMD Parallelism (AMT DAP, Thinking Machines CM, Maspar)
- MIMD Parallelism (Transputers and other proprietary chip combinations)
- Workstations (Sun and competitors)
- Massively Parallel Processors (MPPs) of various fixed topologies (Hypercubes, Tori, meshes)
- Personal Computers (IBM, Intel, Microsoft, Apple)
- Emergence of commercial MPPs (mostly from small start-up companies)
- Commodity chips gradually take over in MPPs
- Networks of Workstations
- Large-scale shared memory machines fail
- Enterprise Servers use small scale (up to 64 procs) shared memory technology
- Parallel computing goes mainstream, start-ups usurped by the big computer companies
• SPMD/Data Parallelism (MPI and HPF) become accepted parallel models
• WANs become accessible to universities (ATM technology)
• Distributed memory machines move to switched communications networks rather than fixed topology
• Distributed Computing replaces Parallel Computing as the trendy area in HPC
• Client/Server Computing become a widespread software model
• Distributed Objects, Java and Agent/Servlet Model becomes popular
• Faster PCs, cheaper networks, and Linux lead to popularity of Beowulf commodity PC clusters
• Use of Internet and Web expands rapidly
• Return of large-scale shared memory systems (that actually use physically distributed memory)
• Grid computing and metacomputing combine distributed and high-performance computing for large-scale applications
• Internet computing becomes popular with GIMPS and SETI@Home
• Broadband Internet access starts to become available through faster Internet backbone, cable modems, ASDL, satellite, wireless, etc.
Applications Review

From Pasadena Workshop on the future of HPC.

Information Simulation - Compute-Dominated:

1. Computational Fluid Dynamics - all sorts of fluids
2. Structural Dynamics - civil and automotive
3. Electromagnetic Simulation - eg radar
4. Scheduling - eg airline
5. Environmental Modelling - atmosphere, land use, acid rain
6. Health and Biological Modelling - empirical models, MC
7. Basic Chemistry - ground state and transitions
8. Molecular Dynamics - and astrodynamics
9. Economic and Financial Modelling - option pricing, portfolio position
10. Network Simulations - Telecon and power grid, utilities
11. Particle Flux Transport Simulations - eg nuclear, stockpile safety
12. Graphics Rendering - marketing
13. Integrated Complex Simulations - eg weather, climate
Applications Review

Information Repository - Storage-Dominated:

14 Seismic Data Analysis - more done now in real time
15 Image Processing - growing databases of imagery
16 Statistical Analysis and Legal Data Inference - transcripts, text DB
17 Healthcare and Insurance Fraud - trend analysis, illegal patterns
18 Market Segmentation Analysis - eg data mining

Information Access - Communications-Dominated:

19 Online Transaction Processing (OLTP) - banks and insurance
20 Collaboratory Systems (eg WWW) - and proprietary
21 Text on-Demand - encyclopaedias
22 Video on-Demand - hotel consumer, homes, marketing
23 Imagery on-Demand - film archive
24 Simulation on-Demand - military, market planning, near real-time
Applications Review

Information Integration - Systems of Systems:

25 Command, Control and Intelligence (C2I) - wargames
26 Personal Decision Support - shopping and finance
27 Corporate Decision Support - JIT
28 Government Decision Support - macroeconomics and polls
29 Real Time Control Systems - military and civilian aircraft
30 Electronic Banking - security and encryption and trust
31 Electronic Shopping - reliable access to heterogeneous DB
32 Agile Manufacturing - multiple DB, coupled models
33 Education - training material, interactive, exams, delivery
Top 500 List

- Supercomputers are often rated by Top 500 list (www.top500.org) which comes out twice a year.

- Ranked according to performance on Linpack (linear algebra package) parallel matrix solver:
  - well suited to running on parallel and vector machines (i.e. gives good speedup)
  - many HPC applications use matrix solvers

- Doesn’t include all machines in the world (e.g. Google, Amazon, etc clusters, secret defence installations).

- Mainly rewards good compute performance, but requires reasonable memory size and communications performance to scale up to large numbers of processors.

- Criticized for not addressing other important areas like fast memory access, communications, I/O.

- Alternative benchmarks are being developed to try to cover these areas - vector machines rank higher here (mainly for fast memory access).

- But Linpack is still a useful benchmark that gives a single number for performance.
Changes in Top 500 List

Interesting to look at the Top 500 list and track changes in from June 1993 to November 2001.

- **Power Users** – top 10 is usually dominated by US National Labs with some European and Japanese labs or national supercomputing facilities.

- **Other Large Users** – Weather forecasting and climate research, industry and government research labs, large universities, military, ISPs, telcos, IT services.

- **Performance** – beating Moore’s Law, doubling in performance almost every year.

- **Architecture** – decline in vector and large shared memory, increase in clusters of SMPS (CLUMPS or constellations) and networks of workstations (NOWs).

- **Chip technology** – changed from 80% proprietary to 90% COTS.

- **Usage** – increase in industry use as powerful commercial multiprocessor shared memory servers have become popular, taking over from mainframes. Industry and military use is probably underreported.
Industry Use in Top 500 List

Increase in industry use, and expanding from traditional use base of science and engineering simulations:

- Aerospace – Boeing, NASA, Raytheon, ...
- Automobile – Ford, DaimlerChrysler, BMW ...
- Oil exploration – Shell, Mobil, Saudi ARAMCO ...
- Pharmaceutical companies and drug design – Bayer ...

...to e-commerce and general business use (online transaction processing, data mining, etc):

- Finance, banking, insurance – Prudential, Charles Schwab, Paine Webber, Lloyds, Barclays Bank, ...
- Telcos – Vodafone, AT&T, France Telecom, Optus ...
- e-Commerce – Amazon ...
- Government IT services – EDS, NYC HR ...
- General – Braun, Nokia, Cisco, BASF, Unilever, American Airlines ...

Most science and engineering applications use vector machines and large (128 - 1024 processor) clusters of workstations or SMPs.

Most general business use is on large (64 - 128 processor) shared memory machines.
Worldwide Initiatives in HPC

- US Domination? Most machines in Top 500 list are in the US, and 8 out of the top 10. National labs, supercomputing centers, military, ...

- US Accelerated Strategic Computing Initiative (ASCI) Program provides lots of money to build Teraflop machines from all the main vendors (Intel, IBM, SGI, Sun, Compaq), mainly for simulating nuclear weapons testing.

- Europe has ESPRIT, Alvey, Parallel Applications Programme, Europort, Fourth Framework etc.

- Japan has a lot of HPC projects, mainly produces and uses large parallel vector machines (NEC, Hitachi, Fujitsu).

- Australian Partnership for Advanced Computing (APAC) is recent Australian initiative to provide HPC equipment and training.

- Explosive growth of the Internet has led to renewed interest in IT, HPC and distributed computing worldwide.

- US Internet2 project provides very high-speed research network.

- GrangeNet is Australian (actually eastern states) project for high-speed research network.
Trends in DHPC R&D

- “Parallel” is no longer enough, and all aspects must be recognised for performance.

- DHPCCS may be an appropriate new acronym to recognise that Communications and Storage are equally important as Computation.

- Parallel programming is still quite difficult (especially porting existing codes) – need better code development tools; greater reliability of HPC systems; code migration tools; compilers; etc

- Different HPC architectures implies trade-off between portability and performance.

- The ongoing mission for DHPC is to make the system more usable - that is more flexible, so that performance can be obtained but also the software maintained.

- Integration software for inter-operability is a major challenge.

- Era of HPC for just science and engineering is over - too many people with more money out there... now used in Web serving, e-commerce, financial modeling, etc.

- Clusters of commodity workstations starting to replace expensive big iron supercomputers - better price/performance, more scalable.
• Cheap, fast networking technologies for cluster computers is the current bottleneck.

• Grid computing (metacomputing) is becoming very important – hyped as the future of the Internet.

• Many new large-scale grid projects underway in last 1-2 years, attracting support from IBM, Sun, Microsoft etc.

• Still considerable number of interesting (unsolved) research problems in DHPC.