Computational Engineering, Modelling and Simulation - Recent advances through High Performance Computing and Communication (HPCC)

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Abstract New ways of conducting non-destructive testing of vehicles, of analysing the processes and flows inside furnaces, of visualising the polluting processes above cities, and many other practical uses for HPCC, are changing not only the face of engineering, but of business and public policy-making. Modelling, simulation and visualisation are emerging as the regular tools which should/could be exploited by those charged with the responsibility of making decisions at national level. The challenge emerging now is to widen the field of application, and even more importantly, to ensure that practitioners in small and medium enterprises are given the opportunity to exploit the techniques in their drive for international competitiveness. This paper outlines what The Warren Centre at The University of Sydney is doing to bring the benefits of Computational Engineering - modelling, simulation and visualisation - to the wider arena of users and potential users of HPCC. A video of the project on HPCC and discussion of the methodology for assessing user needs and the way in which linkages with appropriate centres of excellence are established, will demonstrate The Warren Centre's pragmatic approach to helping industry to make use of the new tools.

1. THE NEED FOR COMPUTATIONAL ENGINEERING

This paper is about the application of high performance computational processes to the solution of engineering problems. Computational Engineering (CE) is a convenient shorthand for computational science and engineering, the technology of using computing and communication for analysing, visualising and solving the many complex problems encountered in modern industry.

CE is used for:

- Solving problems via simulation, modelling and other computational methods.
- Optimising and speeding product design .
- Optimising processes.
- Simulating complex phenomena, eg pollution.
- Testing public policy options.
- Communicating complexities, solutions and options through visualisation.

1.1. History of Computing in Engineering

Since Babbage, who last century devised the ancestor of modern computers, to calculate mathematical tables - which had been notoriously full of errors - automatic computation has been increasingly applied to solve engineering problems with speed and accuracy.

1.1.1. Earliest Problem Solving

In Australia early work using a differential analyser solved the engineering design problems of water flow surges in the then proposed Snowy Mountains Scheme, by simulating flows, given the rainfall records and the design parameters of the Scheme's storage ponds and conduits.

On SILLIAC in 1956, an early engineering problem of pinpointing leaks in gas distribution networks was solved by applying Hardy-Cross analysis.

1.1.2. Applied Science

The first commercial computers were not only used for business data processing, but for tackling major engineering works design and analysis. The IBM650 first installed in the MLC building in North Sydney, was used by many to do work not feasible by hand, such as multi-plate fractional distillation column design.

1.1.3. Challenges

Now, nearly forty years later, meeting the real challenges, of computing and presenting the results of massive simulations, of producing understandable images which model a process or a planned situation, are achievable by virtue of the advances in technology and in computation.

1.2. Key Steps: Modelling and Simulation

Most technical people from all disciplines like to 'see how things work' or 'find out what will happen' in various circumstances they may postulate. In the past that required them to build physical models or find satisfactory analogues to simulate the processes or things in question.

1.2.1. Mathematics and Movement

With modern mathematical tools it is possible to describe the processes and entities with high precision and to recalculate successive states with such speed as to effectively describe the transitions over time. As a result mathematical modelling permits researchers to follow the changes and movements of their subject-matter in 'real time' or even at a faster pace which permits extrapolation to an extent not otherwise possible.

1.3. Pragmatic Engineering Spawns Visualisation

'Learning by one's mistakes' can be an expensive exercise if dealing with modern complex capital goods. New designs of vehicles and weapons can be tried out in the field to an extent, but when it comes to testing for safety, and training new operators, the danger and expense, let alone the infrastructure necessary to control and measure physical tests, have made non-destructive mathematical modelling, simulation and visualisation attractive.

1.3.1. Human-Machine Synergy

The bonus benefit of using computer visualisation has been the synergistic way in which people interacting with the machine learn to excel and, even though it may only be a training experience, to make the most of the features of the system with which they are engaged.

1.4. High Performance Computing, a Strategic Tool

Use of very powerful, fast machines ('supercomputers') over the past decade to conduct such seemingly impossible tasks as to simulate the formation of smog over a city, or to explore the formation of silt beds and channels in rivers, has enabled administrators to make better informed decisions and to test the likely effects of alternative policies. HPCC has become a strategic support tool for many.

1.4.1. National Issues

In the USA the White House, Congress and The Pentagon are all said to have used HPCC simulation and modelling to support decisions on national issues.

1.4.2. Grand Challenges

Some proponents of truly massive HPCC development aver that the 'Grand Challenges' of Science, including the secrets of DNA, the origin of the universe and the boundaries of knowledge may now be explored effectively.

2. THE WARREN CENTRE FOR ADVANCED ENGINEERING

At a very pragmatic level, the need for engineers to make the most of burgeoning technology, and to be innovative, so as to assist Australia in its pursuit of wealth creation, has led the Warren Centre to investigate the new ways in which engineering, including computational engineering, can make effective contribution.

The Warren Centre was established in 1983 as a Foundation within The University of Sydney, to mark the first 100 years of Engineering there. With several million dollars, donated by Australia's largest and other well known companies, and some far-sighted individuals, it has established a reputation for nominating and exploring the key issues emerging for engineers, and for the country. Although it operates within the university, its board of management has a majority of members from industry. It thus bridges the gap between academia and the world.

2.1. Advanced Engineering Technologies and Techniques

From the outset, the Warren centre has played a catalytic role in bringing important, advanced engineering technologies and techniques to the attention of Australian industry and in helping industry apply those technologies.

2.2. Projects and related Activities

The principal vehicles for this work have been projects in which timely topics have been explored and the knowledge gained disseminated through the participants and by subsidiary activities such as Forums, Workshops, Seminars and Lectures. Further, each of these have given rise to substantial publications (eg The Chief Executive's Handbook) which form valuable references.

2.3. New Technologies Impact

The shift of emphasis in Australia from the traditional heavy engineering industries to those with electronics, communication and more recently to computing and information technology, has impacted the work of the Centre considerably. Computer Aided Design, Local Area Networks and Educating Australia for a Technological Future were early project topics.

Inevitably, in 1991, attention turned to 'Supercomputing' or 'High Performance Computing', and their likely interaction with advanced engineering. A project to explore these, which was to lead to the concept of Computational Engineering, was thus conceived and launched.

3. THE SUPERCOMPUTING/HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS PROJECT AND SEMINAR.

By 1992 it was clear that Australian industry needed guidance in how the new High Performance Computing and Communications (HPCC) using 'supercomputers' might best, profitably and quickly be employed by government and industry. Following the usual pattern of its public projects, The Warren Centre set up a steering structure and project manager to enable practitioners and experts to come together, to learn, to discuss and to explore the subject practically.

3.1. A National Focus Demanded an International Leader

The scope of the new project was such that it needed strong and effective leadership, by someone of significant stature, internationally and technically. The Visiting Fellow (Project Leader) who amply filled this role was Professor Greg McRae, an Australian chemical engineer, originally from Melbourne, but then at Carnegie-Mellon and deeply involved in the USA supercomputing centres program, and also an adviser to the US administration on policy matters arising. He later went on to MIT.

3.2. Real Cases on an Impressive Scale

It was agreed that the project was of such importance that a number of highly visible case studies, in a spread of application areas, should be simultaneously conducted and if possible major companies and national organisations should be involved. This was achieved with great effect. Some sixty project fellows (practitioner participants) from companies large and small, government enterprises, universities and private practice came together, formed teams and over several months pursued in depth the use of HPCC in nine widely differing substantial case studies, ranging from vehicle design to waterway behaviour and from steel making to fruit packing and delivery.

3.3. Complex Techniques, yet Simple to Use

The mathematical modelling necessary to describe the mechanisms and processes in these studies employed the full range of techniques (arrays of simultaneous differential and difference equations were a familiar sight) and the range of necessary software to effect solutions was equally impressive. Understandably, with a network of not necessarily compatible high performance machines, some compromises were necessary, but the project was most effective in achieving cooperation among the participants and in gaining strong support from the various vendors involved.

New ways of conducting non-destructive testing of vehicles, of analysing the processes and flows inside furnaces, of visualising the polluting processes above cities, and other practical uses for HPCC, were brought to bear on the case studies with great success. The outcome was not only a demonstration of what can be done but in a number of the cases laid the foundation for very practical application by the participants when back in their own organisations. What is more, under Greg McRae's guidance participants soon became aware that HPCC is capable of changing not only the face of engineering, but of business and public policy-making.

3.4. Far-Reaching Cooperation and Network

A notable achievement of the project was the rapid assembly and interconnection of a multi-million dollar network of powerful technology, spread over the Eastern Seaboard with supercomputing facilities in Brisbane, Sydney and Melbourne all cooperating, and made accessible for the project fellows from a single laboratory in Sydney. Here we had powerful units from Silicon Graphics, Cray, Digital, and IBM, networked to reach virtually world-wide through the AARNet connection.

A 12 minute video of the project on HPCC will demonstrate The Warren Centre's pragmatic approach to helping industry to make use of the new tools. Other outputs from the project have been a more detailed video, project and seminar reports, and other publications.

Since then The Warren Centre has extended the work on HPCC with proposals to government and discussion with others on methodologies for assessing user needs and the ways in which linkages with appropriate centres of excellence can be established. It is expected that an effective network of resources and expert guidance for HPCC users will result.

4. LESSONS FROM THE HPCC PROJECT

The experience gained during and since the HPCC project points to several valuable conclusions:

- HPCC is applicable to a wide range of industries and applications. The case studies spanned government enterprises, agriculture, mining, heavy process industries, engineering fabrication and federal, state and local government interests.
- There are substantial benefits possible through HPCC. Improved product design, and processes, products to market faster, support for public policy choices, and so on, were demonstrable outcomes. The benefits were there for enterprises, large and small.
- HPCC is not difficult to apply. The project started by providing participants with basic awareness, then offered access to the necessary advice, skills and facilities and gave the appropriate training so that tangible results were achieved in a very tolerable time. (Project fellows from widely differing backgrounds, some scarcely PC literate, were soon all doing useful work. Few would have credited that they would produce meaningful results in just a few hours.)
- Access to HPCC facilities, skills, networks and advice, really opens up new perspectives and opportunities for engineers. Whole new avenues for professional development emerged as the work progressed.

- It was particularly gratifying for those involved to see peoples' eyes opened to the new possibilities via visualisation tools which were a complete revelation to them.
- Modelling, simulation and visualisation are emerging as the regular tools which should/could be exploited by those charged with the responsibility of making decisions at national level.

The technology of course continues to evolve at breakneck pace, and what at the commencement of the project was stimulating and new, may to some have now become quite routine. Even so, the almost immediate acceptance of the new tools means that people are finding them useful and filling a real need. HPCC technology and its application is giving rise to new industries, and visualisation, for instance, is already supporting, even driving, multi-media and 'infotainment', as seen daily on TV, as well as extending the boundaries of engineering and science.

4.1. Wide Range of Industries/Applications

Engineering based industries are not the only ones to benefit from the techniques explored. Agriculture is a key industry for Australia and one of the case studies concerned the need to model the processes at work while transporting fruit in overseas containers. The outcome is likely to be delivery of produce to market in prime condition and within predictable economic constraints.

4.2. Improved Product Design and Processes

Designing products to satisfy the many constraints which must be met in the competitive international marketplace has never been easy. HPCC showed project participants that vehicle design, for instance, can be made safer, stronger, more flexible and more economic to build, using the tools made available.

4.3. Straight-Forward Application

The new graphics based computational and software tools enabled engineers to connect computational processes by 'pipes' which could be seen on the screen and manipulated as 'objects' with ease. Quite straightforward steps permitted them to show physical processes, modelled mathematically, as coloured moving pictures on their screens. As a consequence the stimulus to the participants' imaginations soon led to innovative modifications to their studies and enabled very real decisions capable of affecting design, fabrication or operation.

One of the most interesting was the Pacific Power team's modelling of combustion in steam-raising furnaces. Once the descriptive equations were set, their work showed visually how flame, temperature and gas-flow patterns would change inside a furnace, given different conditions and configurations. How much simpler, quicker, more economic and less dangerous it was to study changes and effects on a screen than trying to probe inside a high temperature furnace!

4.4. New Perspectives

Even more challenging was the study of the flows of molten metal in a continuous operation steel furnace. New ways of visual presentation were devised to show how different flow patterns might affect production and quality. In a similar way the flows of polluting gases in the atmosphere over Port Phillip and Melbourne under differing conditions were shown visually, using the new techniques, to give greater insights and understanding.

4.5. New Industries

It became clear that the combination of these techniques, computational engineering, modelling and simulation, which together constitute the art of 'virtual reality', could be the basis of whole new industries. Entertainment, architecture, environmental science, and health and safety investigation, for instance, might all benefit from new products and services incorporating HPCC visualisation.

5. WHERE IS AUSTRALIA'S HPCC NOW?

One would think that with such demonstration of pragmatic utility, the use of HPCC for computational engineering, modelling and simulation might accelerate dramatically. It has certainly grown but there is much yet that can be done, given encouragement. It is an aim of The Warren Centre to act as a gateway and catalyst for the more widespread effective use of HPCC as an essential aid to Australia's international competitiveness and as a means for wealth creation for the benefit of all.

5.1. Real Competition for Australia

Our competitors in Asia are already conscious of the potential and some are already making good use of HPCC. This imposes urgency on our need to take advantage of what has been done, and to build on that lead. A coordinated effort to apply HPCC strategically in Australian industry would seem a priority imperative.

5.2. Warren Centre Seminar Highlighted Needs

In April 1994, the 'supercomputer' project was followed with a seminar to look at the prospects of high-performance computing and communication into the remaining nineties. The aim was to raise the profile of HPCC, to stimulate awareness outside the circle of those already involved and to enable diffusion of the technology to those who might most benefit.

5.3. National Policy, Recognition and Funding

Considerable effort in and through Canberra was successful in drawing attention of senior people to the potential and importance of HPCC, at a national policy level. In late 1994 there was a meeting of a task force in which The Warren Centre was involved with the Prime Minister's Science and Engineering Committee (PMSEC). This drew attention to the importance of the subject and to the need for tangible support. Both DEET and DIST have taken action, and it is hoped that some $30 million will be spent over three years. Industry keenly awaits the Minister's Innovation Statement in which it is hoped that emphasis will be placed on the wider use of HPCC.

5.4. Diffusion to Where it is Needed and Practicable

It has become clear that it is not only the very large organisations that should apply HPCC, but the small and medium enterprises, through which a great proportion of Australia's wealth is expected to be created. Further it is also clear that the rapid development of the technology has brought down the cost of accessing the facilities, so that for even very small groups of SMEs who have the need, it is very affordable.

The project and seminar showed that using network access and appropriate software, existing HPCC facilities centres can be used easily from any location. Thus, strengthening existing centres to cope with an increased SME usage would seem a prudent use of the available funds.

6. HOW DOES A LOCAL SME USE HPCC ?

One of the case studies illustrates quite dramatically what can be done to turn this new technology to real advantage. It involved a well regarded SME, here in the Hunter Region, long established as an innovative engineering enterprise.

6.1. "The A. Goninan & Co. Story"

A Goninan & Co. is best known as the largest Australian designer and manufacturer of railway rolling stock. They have other engineering design and manufacturing activities, and have for years been an innovative user of computers, including on-line networks, for their work.

6.2. PCs to Advanced Workstations

As shown in the video, A Goninan & Co. brought their PC models, using FEA (finite element analysis) in their bogie design to the Warren Centre project. Their PC models typically required computation for days to run different designs. Using the HPCC facilities accessed by the project these times were reduced from days to hours, an improvement which enabled them to think in much wider terms for exploring design alternatives.

Subsequently, A Goninan & Co. found that advanced workstations could enable them to progress the HPCC applications from within and also to integrate the FEA process with an advanced CAD/CAM application.

From there they have progressed to a purpose-built engineering design centre at Cardiff, bristling with advanced workstations, which together are able to approach, if not match the 'supercomputer' performance achieved at the Warren Centre project, at a fraction of the cost.

6.3. 3D Images, Models and FEA

The computational engineering at A Goninan & Co. proceeds in three streams:

- Conceptual design with 3-D images,
- 3D solid modelling, creating prototypes within the computer that can be thoroughly tested for manufacturability and assembly ('digital assembly'), and
- FEA to confirm strength and integrity of design in structures and to optimise their weight.

6.4. From Licensee to Exporter

A Goninan & Co. is now a design contractor to the US locomotive giant General Electric Co. So, in five years, the company has gone from a licensee of overseas technology to an exporter of designs in this field.

6.5. Virtual Reality?

Where will this all lead in the future? A recent statement by a senior A Goninan & Co. executive provides a glimpse into their thinking about the role of HPCC in their future:

> 'I can see in the future that we will be able to simulate manufacturing processes, such as welding and assembly, using virtual reality techniques, without physical prototyping.'

Such is the progress A Goninan & Co. have made with HPCC.

7. HOW WILL OTHER SMES ACCESS HPCC?

The A Goninan & Co. story is certainly a success. How can we assist others, particularly SMEs, to follow with their own successes? The Warren Centre has proposed a means and a way to do so. We believe that the practical approach of providing a gateway and guidance in using HPCC is now appropriate. The plan is to create a Resource Centre for Computational Engineering (RCCE).

7.1. The Warren Centre Proposal

The RCCE is to be a vehicle by which awareness of the potential and relevance of computational engineering can be fostered and the current shortage of skills in the field can be addressed, particularly among SMEs. There is abundant affordable technology to serve this important sector, but they need a facility to enable effective use of it.

The proposal, now before government, is to establish the Resource Centre at the Australian Technology Park in Redfern as a focus for users in NSW. There users can be trained, given advice and assistance to access the very capable centres of HPCC excellence at ANSTO, UTS, VisLab and engineering computing resources at The University of Sydney, CANCES at UNSW, and others, via the Broadband Network.

From this beginning it will be possible to extend the facility nationally, by use of other broadband networks which will connect to RCCEs in other states, and ultimately internationally, as a technology diffusion network for Computational Engineering.

7.2. The Role of the Resource Centre

The RCCE is not intended to duplicate or conflict with the existing HPCC facilities, but rather to act as an enabling bridge between industry, at present slow to adopt the technology, and the available skills and facilities of the universities, research institutions and 'supercomputer' bureaux. Through the RCCE users and potential users will be guided to make effective use of high performance computing, and to take the knowledge back to their organisations, fully able to access HPCC from their own workstations.

7.3. Keeping up with Progress

The Warren Centre at The University of Sydney is maintaining its thrust to bring the benefits of Computational Engineering - modelling, simulation and visualisation - to the wider arena of users and potential users of HPCC. It recently held a forum on 'The Internet and Industry' which further emphasised the benefits of connectivity for individual users in industry, via the computer networks, now made accessible through features like the WorldWideWeb. Other activities are planned.

8. TOWARDS 2000: DEVELOPMENTS AND EMERGING OPPORTUNITIES.

Development and proliferation of information technology continues relentlessly. It is useful to review the recent rate of development and to project forward, say to the end of the century, as to what we may expect.

8.1. Accessible and Usable Technology

The most important development for small and medium enterprises has been the ready availability of substantial computing power plus communications capability on the desktop. Now, for a few thousand dollars computational engineering can be set up and initiated right where the engineer works. Problems, designs and plans can be explored and tested there, and then when necessary the main computational load can be sent off to be carried out on the larger, higher speed machines elsewhere. Visualisation enables the user to literally watch 'what happens' and receive results visually.

8.2. The Pyramid of HPCC 1994-2000

This past year we have seen the speeds of computation and the necessary accompanying storage grow dramatically. This is not only true of the 'supercomputers' but of their smaller cousins, the medium-scale supercomputers, and the even smaller (desktop) workstations. The latter are now proliferating so that in terms of numbers, rather than capability, they can be represented by a pyramid, with supercomputers at the apex and workstations across the base. Measured in floating point operations per second (flops) the speeds are now heading towards a 'teraflop' (1,000,000,000,000)!

9. CONCLUSIONS

Undoubtedly the twenty-first century will see advances in technology well beyond our ability to imagine. Nevertheless we are assured that the ability we have now to formulate models, to simulate processes and to visualise them through the use of high performance computing and communications, is an excellent foundation for the ways we will be able to use the technology, its speeds and its capacity, beyond 2000.

What we must all strive for, however, is a better and wider understanding of the fundamental tools we now and will use. This means that organisations like the Warren Centre must emphasise, foster awareness of, and initiate effective education and training in the systematic analysis of the underlying problems, the mathematical models we employ and the techniques for presentation of results.

If we maintain our effort towards these objectives, these new tools of advanced engineering can indeed be put to profitable and sensible use, on a wide scale.

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