MICROWAVE COOKING

Biotechnology, food and health

The area of biotechnology, food and health is clearly of great importance both in economic terms and also in terms of quality of life for the citizens of Europe. The human genome project will have a major impact on this area. Bioinformatics is a new discipline that combines genetics, mathematics and computer science in order to understand and exploit the information obtained from decoding the human genome. Many of the mathematical technologies described in the previous sections are applicable to biotechnology, food and health. Indeed, the information presented here could have been included in those sections. However, in view of its importance and the special nature of its problems, biotechnology, food and health is presented as a separate mathematical technology. It is a technology that will become increasingly important in the future.

- In the food industry, the final texture of baked goods, e.g. bread, cake and muffins, depends upon how the original material (e.g. dough in the case of bread) evolves during baking. A better understanding of the baking process would enable the industry to be more efficient in the design of processes for new products and in responding to changes in raw ingredients.
  The design of food processing equipment requires an understanding of how the material moves through the equipment and how heat is transferred to the material. Simulation can help to provide the insight required by the designer.
  Microwave cooking of pre-packaged meals presents a number of challenges such as how to make sure all the food is properly heated without burning some of it, how to control the moisture content so that the meal has the correct consistency and how to produce "crisping" and "browning". Simulation is beginning to be employed by food manufacturers to help address these issues.
- Understanding and managing risk is particularly important in the food and agriculture industries, where human and animal health is of concern. A recent, high profile example of risks to animal health and food safety is BSE in Europe.
  Extreme weather conditions are an ever-present source of uncertainty in agriculture that result in risk to crops.
- Simulation is used in the pharmaceuticals sector, in the design of drug delivery systems. For example, asthma inhalers need to be mechanically reliable and, despite slight manufacturing variations, capable of delivering a dose within a specified tolerance. To achieve this, both the stresses in the inhaler and the flow of the drug must be modelled. Since drug delivery systems are often produced in very large quantities, the manufacturing process itself must be carefully designed to ensure very low failure rates.
  Simulation, in the form of computational molecular biology, is helping pharmaceutical companies to understand the action of drugs, and to design them for specific therapeutic purposes.
  Demonstrating the safety of new drugs through extensive trials can generate large amounts of data, which must be managed by companies in the pharmaceuticals sector. Data quality can vary from highly accurate to noisy, and may even be non-numerical. Making effective use of the data generated by the human genome project is both an opportunity and a challenge for companies in this sector, and the subject of genome bioinformatics is of both academic and commercial significance.
- In the medical sector, the design of sophisticated modern medical equipment often requires input from several disciplines. For example, robots are increasingly being used to carry out remote sur-

gery, and these are complicated to design, requiring input from a number of engineering disciplines as well as from physicians.

- Medical imaging is a very powerful diagnostic tool that enables physicians to detect tumorous growths, and visualize organs and vessels for a variety of medical purposes. In the design of imaging equipment, medical scientists and physicians must work with specialists in engineering, electronics and imagine processing to produce useful new instruments that have minimal effect on the patient. Magnetic Resonance Imaging (MRI) is a widely used medical imaging technique and simulation plays an import role in the design of MRI scanners. It is being used to reduce acoustic noise, to design open rather than closed machines and to avoid any negative effects on a patient's nervous and muscular systems.

  The application of image processing techniques is an exciting area where mathematics is being applied to the medical sector. These techniques are used in products that can distinguish between different types of cell: for example, the differential counting of white blood cells.

- Other examples of the use of simulation in the medical sector are the design of patient-specific, and longer lasting, joint implants, thereby reducing the need for additional surgery to fit replacements, and the study of the behaviour of the soft organs. For example, studies of the heart can be used to help design effective replacement valves. More generally, simulation is increasingly being used in the design of patient-specific treatments.

The challenges presented by biotechnology, food and health are considerable. A multidisciplinary approach must be employed and mathematics has a vital role to play.

Biological systems are extremely complex, involving huge molecules that interact in poorly understood ways. It is unlikely that they will be understood in terms of fundamental chemistry and physics in the near future. Therefore, some type of system theory approach must be employed leading to black- or grey-box models. An important area for the future is metabolic engineering in which the objective is to design cells that do carry out a specific task. The benefits of success in metabolic engineering are enormous.

The challenge is to develop black and grey box models that can be used to model the behaviour of cells sufficiently accurately so that they can be designed to function in specified ways.

Hospitals and physicians gather large amounts of data during the process of diagnosing and treating patients. This data represents an extremely valuable resource.

The challenge is manage the vast amount of data being collected and harness it to improve diagnostic procedures and treatments.

UNDERSTANDING HOW INFORMATION FLOWS WITHIN A COMPANY

Emerging and new technologies

During the course of this study a number a number of very important areas were identified where there is an industrial and commercial need, but where the mathematics is not sufficiently well developed to be regarded as a technology yet. The three main areas are parallel and grid computing, complex systems and information flow in companies. A few brief comments are made here about these emerging technologies.

Parallel computers have been available for many years now, though the idea of grid computing is much newer. Until relatively recently, however, the main users of large parallel computers have been government laboratories, academic institutions and large companies. The main problem with parallel computing is that in almost all cases the parallelization of programs has to be done on a case by case basis and by hand. There are no powerful optimizing compilers that will automatically produce code that runs efficiently on distributed memory parallel machines. With parallel machines, such as workstation clusters and even networks of PCs, becoming more cost effective, it can be expected that they will become much more widely available in industry in the future. There is a pressing need for tools that will facilitate the writing of programs to make best use of such machines, and it is the lack of such tools that means this is still an emerging technology.

A complex system is made up of a large number of components in such a way that its size and the number of interactions between its components mean that its overall behaviour cannot easily be understood in terms of the behaviour of the individual components. Sometimes the individual components are complicated or poorly understood themselves; this is especially in the case when a human element is involved. One of the characteristic features of complex systems is that the system as a whole can exhibit new types of behaviour, called emergent phenomena, that could not easily be predicted from the behaviour of the constituent parts. Complex systems arise in an increasing number of industry sectors but the fact that there are no general methods for treating them means that this is an emerging technology. Significant progress can be expected in this area and it is expected to become a powerful mathematical technology with wide application in the future.

Understanding how information flows within a company is clearly very important. This problem is likely to become much more acute in the future as the European economy matures into a truly knowledge based economy. Although there is a significant human component to the process of information flow in companies, there is a need for mathematical and computational tools. The central problem here is that satisfactory mathematical concepts and tools for representing information flow do not yet exist. Fundamental work is required in this important area in order to develop a technology that can become a powerful influence on business and industry.

HOW MATHEMATICS IS USEFUL

In order for mathematics to be useful to industry, a connection has to be made between its abstract concepts and techniques and the real world. The process of making this connection is known as mathematical modelling and is at the very heart of every application. Mathematical models vary enormously in their scope, complexity and sophistication, but they all have in common the idea that the phenomenon or process to be studied can be represented by appropriate mathematics.

Once a mathematical model has been developed, the task of the mathematician is to understand its implications. This requires various forms of mathematical analysis, including, increasingly, the use of computational tools. In order to build confidence in the model, comparisons of its implications are made with observations of the phenomenon under investigation. This part of the modelling process is called model validation and is itself often an exercise in the field of mathematical statistics. In some cases, the model needs to be improved in the light of validation and the process can iterate between comparison with observation and further model development. When the model is considered to be adequate, it can be used to make predictions about the phenomenon of interest and its results used by designers, production engineers, managers and so on to develop and improve products and processes in industry.

In the rest of this section, six case studies are presented. These illustrate, with specific examples, how this process works in practice. The examples are drawn from disparate industrial sectors and give an indication of the range and power of mathematics in industry.

ELECTRONICS INDUSTRY

The electronics industry has always been a very fertile working environment for mathematicians. In the 80s, the simulation of semiconductor devices provided an extremely challenging problem from the numerical point of view, and a similar observation can be made for the area of electronic circuit simulation in the 80s and 90s. Owing to the advent of new numerical methods, these simulations are now carried out routinely.

A rapidly growing segment of the market for consumer electronics is provided by wireless applications, such as mobile phones and in-house wireless systems. New generations of these products are characterized by smaller dimensions and higher frequencies. Electromagnetic effects that were previously neglected must now be taken into account. The influence of the interconnect (the wires carrying the current) and the packaging on circuit behaviour is becoming increasingly important. Accurate and reliable computer simulations are needed to predict this influence at an early stage in the design cycle.

Figure 2 shows a typical example of the interconnect structure of an FM tuner circuit. The system of metal wires must be analysed for its electromagnetic behaviour, in order to assess what influence this may have on the transport of signals that are sent along the wires when the tuner circuit is in operation. At the Philips Research laboratories in Eindhoven, software has been developed which enables designers to carry out this analysis. The software tool solves the Maxwell equations for the system of metal wires, and translates the results into a small electronic circuit containing resistors, capacitors, and inductors.

Figure 2: Layout of the FM radio tuner PCB.

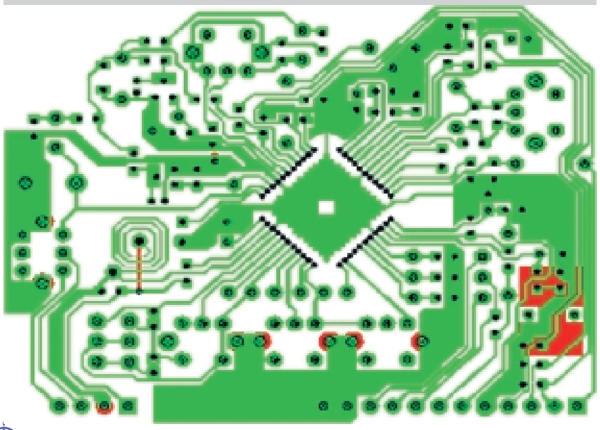
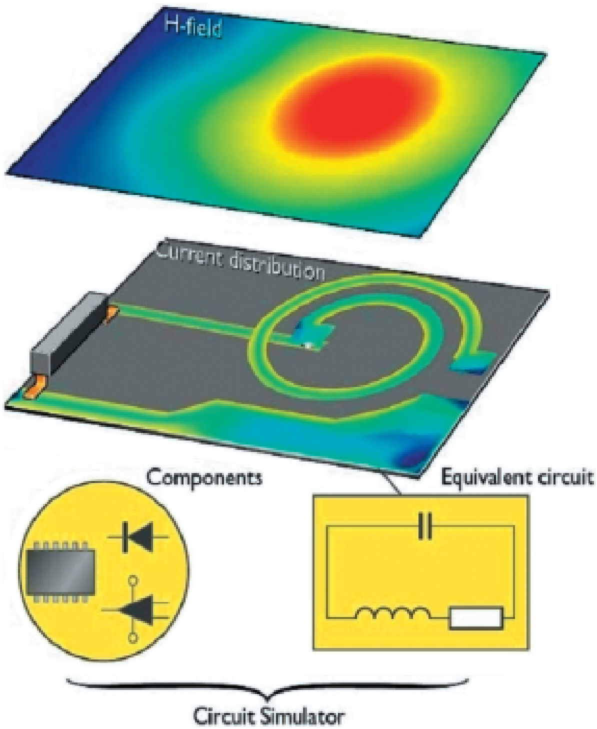


Figure 4: Composition of the circuit simulator input



Underlying the software tool is a multitude of advanced numerical techniques. In order to solve the Maxwell equations for an interconnect structure, boundary element methods are among the most reliable and efficient. The result is a large system of linear equations, for which state-of-the-art iterative solution methods are needed so as to obtain acceptable simulation times. Unfortunately, the resulting systems are too large to be coupled to the circuit equations. In order to be able to analyse the influence on circuit behaviour anyway, it is necessary to reduce the large system to a much smaller one. This reduction must be such that the dominant behaviour of solutions is similar for the small and large systems.

The principle of this step, which is often referred to as model order reduction, is shown in figure 3. The right-most picture is clearly recognized as being a rabbit, nevertheless it is represented by far less detail than the left-most picture.

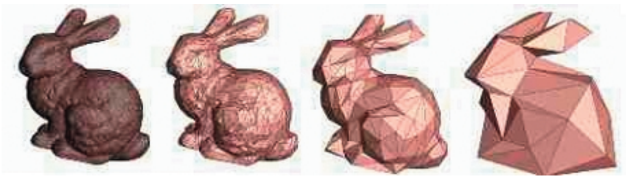


Figure 3: Principle of model order reduction

This model reduction step requires the use of sophisticated numerical linear algebra techniques, and is the subject of intensive research. It is one of the most important ingredients of the current trend towards the simulation of coupled problems, which is observed not only in the electronics industry, but also in many other application areas. Mathematics is an indispensable tool for these important simulations.

Returning to the example of the tuner circuit, figure 4 gives an overview of the data flow for the final circuit simulation. The simple circuit in the bottom-right part of this figure is the reduced order model describing the behaviour of the metal wire interconnect structure, whereas the bottom-left part of the picture is a simplified graphical representation of the electronic components in the tuner circuit. The two parts can be simulated together in a circuit simulator, thus achieving a coupled simulation including the electromagnetic effects caused by the metallization. The middle part of figure 4 shows the current distribution, whereas the top part shows the electromagnetic field.

Figure 5: Corex reduction plant
© VOEST-ALPINE Industrieanlagenbau GmbH & Co

IRON AND STEEL INDUSTRY

The iron and steel industry comprises all the stages in the production of finished steel products from raw materials. In the EU, 57% of crude steel is produced from iron ore and other raw materials; the rest is produced by recycling steel scrap. The EU is the world's largest steel producer and the largest steel exporter. In 2001, 158 million tonnes of crude steel were produced. Clearly, the iron and steel industry is an important component of the European economy.

Process engineers have to deal with a variety of problems that occur in the production of crude steel, and its processing into finished products, such as steel rod, wire and plate. Issues such as the efficiency of the production process, the life of production plant and operational strategies for ensuring the quality of the steel can have a significant economic impact.

In order to address these issues, the underlying processes have to be understood in detail. Very often, measuring devices cannot withstand the high temperatures and huge forces that occur in iron and steel plants. Numerical simulation, based on solving models describing the underlying physical and chemical processes using computers, provides a way for the process engineer to obtain important information about the conditions inside the plant. This information can then be used to improve the production process.

The use of mathematical modelling and numerical simulation can be illustrated with reference to the processes occurring in the COREX reduction shaft. The COREX process is a new technology that is used to produce metallic iron from iron ore. The metallurgical work is done in two phases. The first phase takes place in the reduction shaft and the second in the melter gasifier.

The iron-bearing raw material is fed into the reduction shaft via a locked hopper system at the top. The material is forced slowly down the shaft by specially designed screw conveyors, which remove the material at the bottom of the shaft. On its way through the shaft, the iron-bearing raw material is chemically reduced to approximately 93% metallized iron by a gas moving in the opposite direction to the raw material.

The mathematical model to describe this process has to reflect the motion of the granular material (the iron ore or pellets), the flow of the reduction gas, several chemical reactions (such as the reduction of the ore, the decomposition of limestone, the Boudouard and water gas reactions), the temperature distribution, and dust deposition in the shaft. All these phenomena are coupled together and so influence each other. Although the model is extremely complex, it is based on sound physical principles such as the conservation of mass, momentum and energy. This resulting mathematical model can be solved on today's powerful computers to simulate what actually takes place in the COREX reduction shaft.

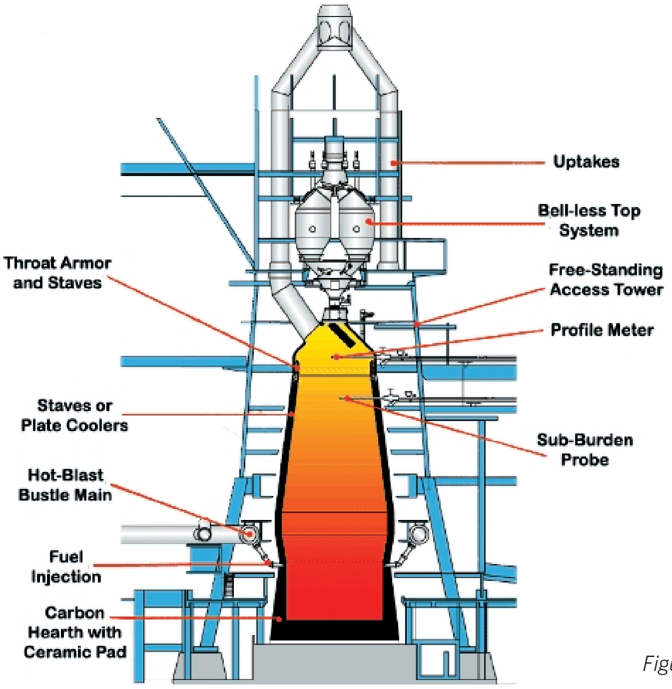
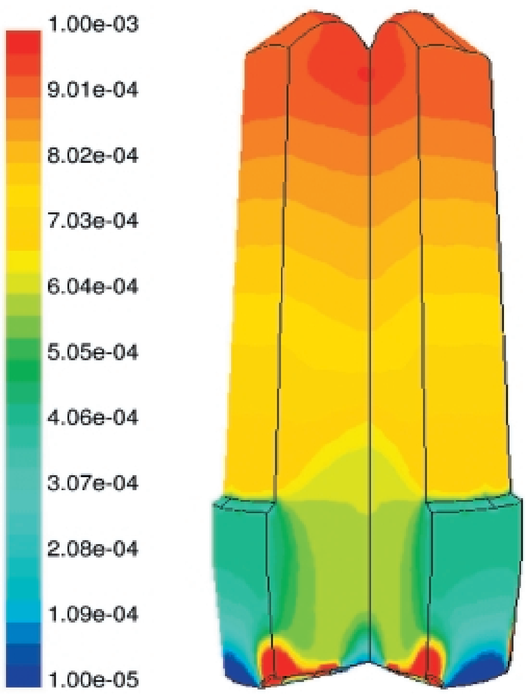


Figure 6: Schematic of the shaft

The formation of dead zones in the motion of the granular material is of major interest in the operation of the reduction shaft. A special material law, which takes account of the slowly deforming granular material that is neither fluid or solid, had to be developed in order to describe this behaviour in a realistic manner. Figure 7 shows a schematic representation of the shaft with a sector of 60° missing so that its interior can be seen. The colours indicate the magnitude of the computed velocity of the iron ore. The blue regions indicate the dead zones.

The parameters that are required for the model are often very difficult to determine. One example is the heat transfer coefficient of reduction shaft walls, which determines the rate at which heat is transferred to and from the shaft. Its value depends on the thickness of the wall, which is unknown, and varies throughout the lifetime of the plant. Using temperature measurements inside the wall it is possible, in theory, to determine the thickness. However, very small errors in the temperature measurements, which are always present, can produce very large errors in the resulting value for the heat transfer coefficient. Mathematicians call such problems "ill posed" and using standard numerical techniques will lead to unreliable results. Special techniques have been developed to address this type of problem and they allow realistic and reliable estimates of the heat transfer coefficient to be made.

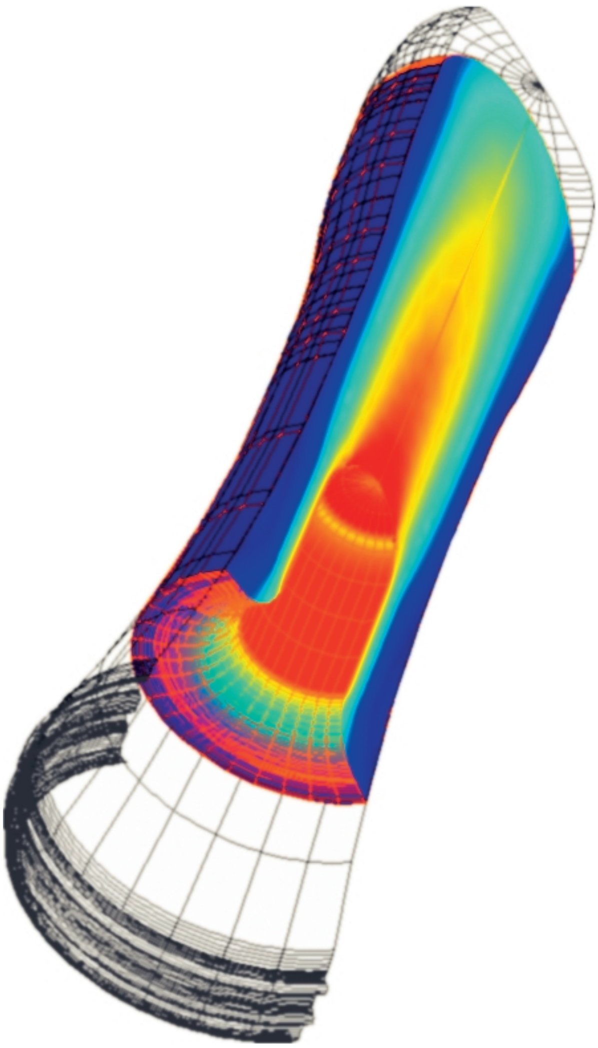


GLASS

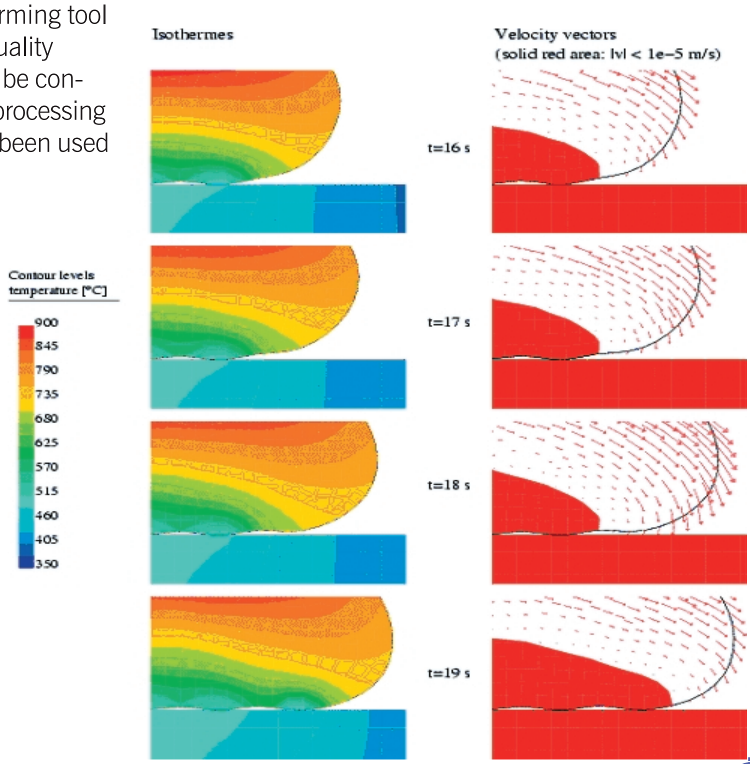
Glass is important to many aspects of modern life. It is used for windows in houses and offices, for drinking glasses, for storing food and drinks, for TV screens and car windshields to name but a few. The glass industry is an important component in the European economy. The European Union produces about a million tonnes of glass each year with a value of over 25 billion Euro. The glass industry employs over 200,000 people across Europe. Two thirds of the glass produced is used for packaging in the form of jars and bottles, one quarter of the production is in the form of float glass used for panes and the rest is for specialist products such as CRTs (Cathode Ray Tubes) and fibres.

For many years, glass technology based on the expertise of craftsmen and empirical knowledge was sufficient to ensure competitiveness. However, over the last twenty years mathematical modelling of various aspects of glass production has become increasingly important. There are several reasons for this change. In the food packaging industry, there is fierce competition from other materials, most notably polymers. Environmental concerns have also become important. This is not because of glass waste, since it is 100% recyclable (a significant advantage over most competing materials), but due to the large energy requirements of the production process. Production costs are dominated by the cost of melting sand to form liquid glass. Consequently, governments all over the world are imposing more stringent rules regarding the weight and thickness of glass products, particularly for packaging, subject, of course to the safety constraints.

In the glass production process, sand grains and additives, such as soda, are heated in a tank, which can be several tens of metres long and a few metres high and wide. Gas burners or electric heaters as used to raise the temperature of the material to about 1200°C. The liquid glass emerges at one end of the tank and is fed to pressing or blowing machines, or onto a bed of liquid tin, where it spreads out to become float glass. Many mathematical modelling issues are associated with glass production. Good mixing in the tank is very important. However, the two-phase material cannot be stirred using standard means and bubbling techniques are used, in which gas is forced through the mixture from pumps located in the bottom of the tank. There are many mathematical difficulties associated with modelling this process: the geometry is complicated, there are material inhomogeneities, heat exchange takes place by convection and radiation, and chemical reactions are taking place. Successful techniques require powerful computers and sophisticated numerical methods. Also on a smaller scale much remains to be done, like pressing (see fig. 8) or blowing of glass products. The interesting aspects are the slip of the wall and the precise filling of the glass moulds. From a customer's point of view the actual question is often an inverse problem: given a specification of the shape geometry and suitable strength parameters, design a mould that produces the proper form.



Chill ripples, which are also known as press or flow ripples, may occur on the surface of glass under certain production conditions. For example, it is often possible to see several concentric waves on the surface of the foot of a cheap wineglass. The name "chill ripples" reflects the fact that the waves usually appear if the tool temperature is too low. The obvious countermeasure of using higher tool temperatures is of limited value, since the glass tends to stick to the forming tool if its temperature is too high. To make high quality products, either the process conditions must be controlled very carefully, or expensive additional processing must be carried out. Numeral modelling has been used to study this problem and has led to an understanding of the origin of the chill ripples. The model confirms that the ripples develop on the glass surface if the mold temperature is too low. Close examination of the numerical results shows they are a consequence of the strong temperature dependence of glass viscosity. The glass in contact with the tool is much cooler than the rest of the glass and so, because of its much higher viscosity, moves very slowly. The less viscous glass flows over these cold regions in an arching flow pattern that causes the ripples (see figure 10). This understanding is of great value to glass manufacturers.



SEA DYKES

Two-thirds of The Netherlands is below sea level. For many centuries the Netherlands has been protected against the sea and rivers by dunes and man-made dykes. In 1953, a rare coincidence of a high tide and a heavy storm from a specific direction caused extremely high water levels in the North Sea. The resulting floods destroyed many dykes in the South-Western part of the Netherlands, called Zeeland. As a consequence, almost 2000 people and a large number of cattle were killed.

In order to prevent such a disaster from happening again, the Dutch government carried out a thorough investigation that finally led to the so-called Delta works: a huge system of dykes and other devices to control the water level. A major issue for this programme was to decide how high to build the dykes. To address this problem, research was carried out by mathematicians leading to a statistical model capable of indicating the heights of the sea dykes necessary to prevent another disaster. The research was led by the eminent Dutch statistician, Professor Hemelrijk, who reported his results in an address to the Dutch parliament. This was a significant event, indicating that mathematics can make a substantial contribution to decision making at the highest level. A slightly unfortunate footnote to the event is that the final decision was to build dykes 50 cm lower than Professor Hemelrijk's recommendations, presumably to reduce construction costs.

This study was based on an area of mathematics called extreme-value theory, which was in its infancy in the 1950s. It is now an established field in statistics and probability theory, with many applications outside the context of sea dykes. For example, it is used in the (re-)insurance industry, to manage the risks associate with large claims. Traditionally, statistical analyses are concerned with predictions of the average values of quantities. The well-known Central Limit Theorem says that the average of a large number

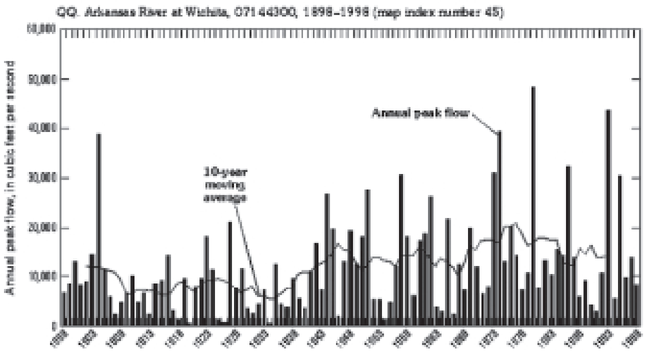


Figure 5QQ. Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of station shown in figure 3.

Figure 12: Eample of peak flow data

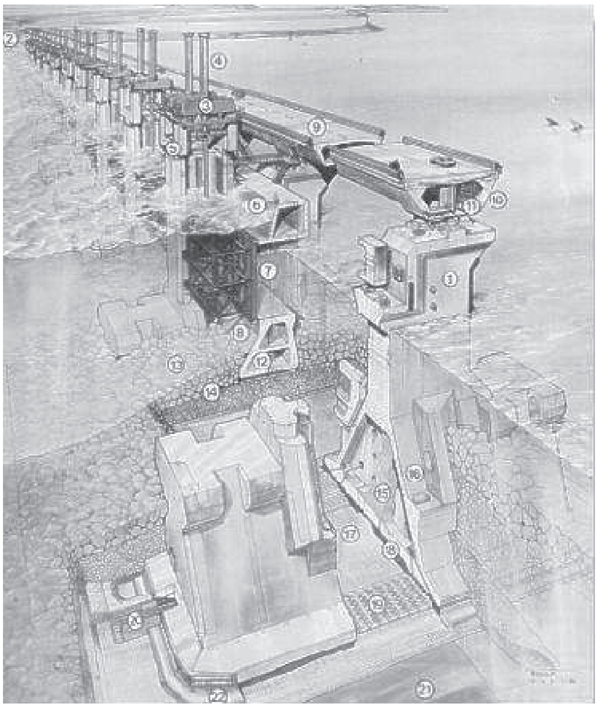


Figure 13: Design of "open" dam

of identical random quantities behaves like a normal distribution with its associated famous bell curve. A familiar example of the normal distribution is the distribution of individual's heights. However, for protection against high water levels it is not the average values that are important, but the extreme values. Extreme value theory is built on the counterpart of the Central Limit Theorem for maxima of random quantities, rather than the average of random quantities, and leads to very a different theory to that based on the normal distribution. One of the major remaining problems in extreme value theory is that, by their nature, extreme events are rare so that it is difficult to estimate the parameters required by the theory from the available data. Advanced techniques for addressing this problem have been developed, but extreme value theory is still an active and important area of research.

The latest trend is to combine statistical analyses of heights, based on observed water levels, with mathematical models for the motion of the water in the North Sea, or with economic models, since dykes are extremely expensive to build. Aesthetic and environmental considerations have also to be taken into account: 10 m high dikes may be safe but they are not very attractive.

The Delta works programme has been completed, but the dyke issue remains. In the 1990s, the Netherlands (and other European countries) suffered from flooding caused by rivers. The threat posed by rivers is now receiving particular attention in the Netherlands. Mathematics will continue to play a major role in assessing and managing these risks and in the associated decision making at the highest level.

Figure 14: Oosterschelde dam

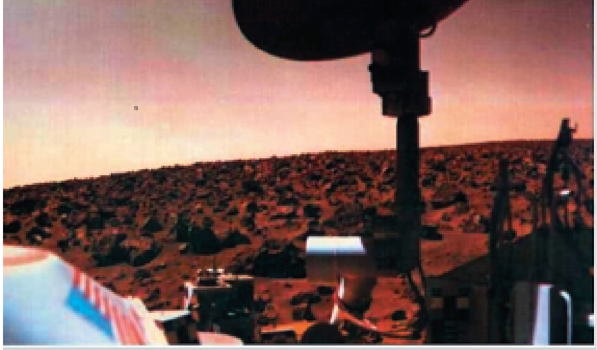


Figure 15: A picture of Mars transmitted to Earth

ERROR-CORRECTING CODES

Anyone who has ever played a word game like Lingo knows that an unknown word can often be guessed by knowing only a few of its letters. Try, for instance, to fill the gaps in c - - m - - i - - t - - n. Experiments show that on the average about a third of the letters in a word define that word. The other letters are there to protect the word against background noise or misspellings. Whenever digital data are recorded (e.g. CD, DVD, magnetic tape or hard disc) or transmitted (e.g. satellite, modem, mobile), similar techniques are used to guarantee correct read-out or reception. Figure 15 shows a picture of Mars transmitted to Earth. Errors, that inevitably creep into the data as it is transmitted over millions of kilometres, are detected and corrected to produce the high quality image shown in figure 15.

An obvious technique for protecting the data would be to repeat each symbol a few times, but this is a highly inefficient way to achieve that goal, as was demonstrated by Claude Shannon of Bell Labs in 1948. He showed that for a channel that confuses 0s and 1s with a certain fixed probability, it is better to wait for a larger group of *information* bits and protect these by adding a group of *redundant* bits. He proved that this could be done in an arbitrarily reliable way. Unfortunately, Shannon did not say how to determine the redundant symbols to make error-correction possible.

Richard Hamming, in 1950, described a general technique to correct a single error. His method is illustrated in figure 16 for four information bits protected by three redundant bits. The four bits in the intersection regions (see figure 16a) carry the information. They are protected by the bits in the three outer regions by the rule

Every circle contains an even number of ones.

Figure 16b shows how to set the redundant bits for the message 1011, shown in figure 16a. It is easy to detect and correct a single error. This is illustrated in figures 16c and 16d, where circle A satisfies the rule, but circles B and C do not, so the error is in bit 4, which should be 1 and not 0. In general, when two or three circles do not satisfy the rule, the error lies in one of the information bits 1 to 4. When only one circle does not satisfy the rule, the error is actually in one of the redundant bits 5 to 7.

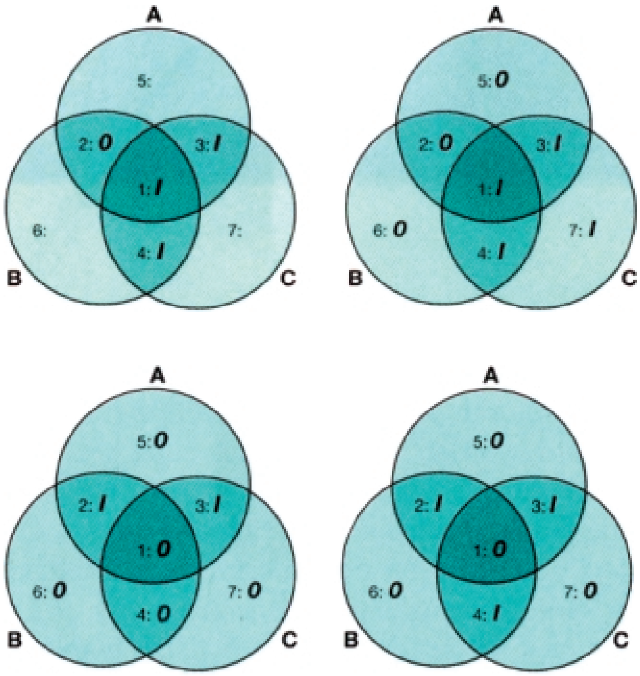


Figure 16: The Hamming code of length 7
top: 16a, 16b
bottom: 16c, 16d

Figure 17: Compact Discs

For a CD (see a close-up in figure 18) much more powerful methods are needed to ensure the integrity of the data. These methods are based on fundamental mathematical ideas proposed by Reed and Solomon in 1960. Here, to every group of twenty information bytes, each of 8 bits, four extra bytes are added in such a way that any two erroneous bytes of the resulting twenty-eight bytes, can always be corrected. To achieve this, arithmetic is needed, like multiplication and division, but instead of working with real numbers, these Reed-Solomon codes work with deep mathematical concepts called *finite fields* (here of size $2^8=256$). These codes are so efficient that the correction of the errors can be done in real time!

The reliable storage, retrieval and transmission of data are absolutely vital in the current Information-Age. This case study illustrates the importance of mathematics in underpinning the technology that is so important to a dynamic knowledge-based economy.

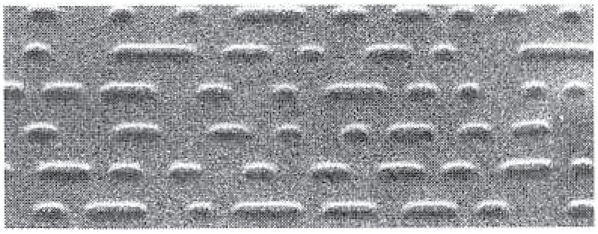


Figure 18: Tracks on a cd

Figure 19: Thermogram measurement device Regutherm 952, gbo-AG / Germany

DATA MINING IN THE MEDICAL SCIENCES

Regulation Thermography (RTG) is a medical diagnostic technique that is based on the idea that diseases or their precursors cause characteristic changes in the human body's ability to react to changes in the ambient temperature. The body's nervous system is such that it allows medical conclusions about specific internal organs to be drawn from abnormalities in the skin's response to changes in external temperature.

The diagnostic procedure consists of measuring the temperature at 110 specific locations on the body both before and after a cold stimulus is applied. This set of 220 temperature values is called the regulation thermogram (RT). A typical RT is shown as a bar plot in Figure 20. The temperatures before the stimulus is applied are shown as black bars and those after as red bars. The RT of the subject is evaluated by comparing it against a normal RT that corresponds to a healthy subject. Deviations from the normal pattern are indicative of certain diseases. For example, a set of rules exists for female breast cancer that enables the physician to estimate the likelihood of the disease being present on a scale of 1 to 6.

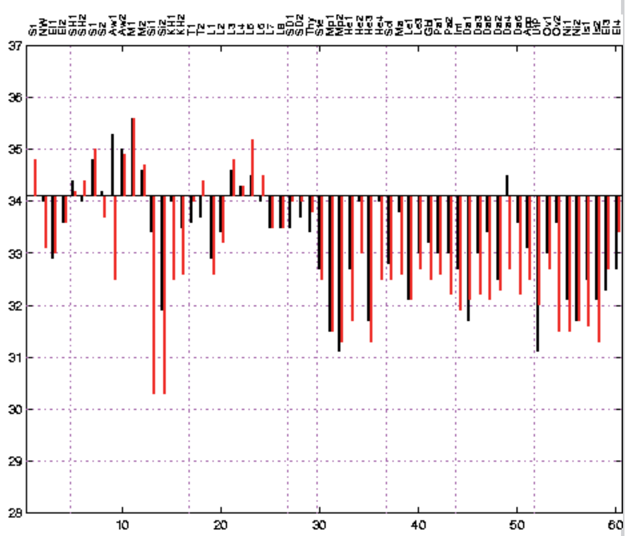


Figure 20: Thermogram of a breast cancer patient

A typical rule is:

Expert rule

The thermoregulation at area X is considered to be pathological if the temperature difference between the values measured at X before and after the cold stimulus indicates a warming up. The severity of the pathology depends on the amount of warming-up.

Regulation Thermography is still being actively developed and is not yet widely accepted. Mathematics, in the form of pattern-recognition and data-mining techniques, is playing an important role in this development. Some of the areas where mathematics is having an impact on Regulation Thermography will now be described.

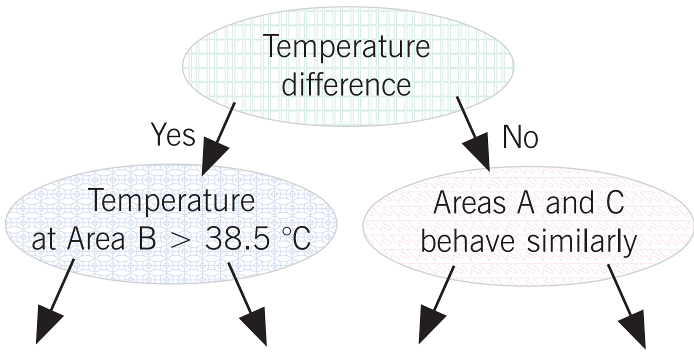
The accumulated expertise of the physicians is captured in an "expert system", which is an algorithm, based on expert rules, that takes the RT as input and arrives at the same conclusion as an experienced physician. Typically, the expert rules are not sharply defined and vary slightly among the physicians applying RTG. A special mathematical technique, called fuzzy logic, is used to account for this variability. The expert system is used to help develop and check widely accepted RT-evaluation procedures.

Although the experts' RT-evaluation rules are based on long-term experience, their power to discriminate medically defined groups of RTs is often not optimal. A great deal of information is available in the form of RTs from patients with a known degree of pathology. This information can be used to improve the expert rules so as to optimize the RT-evaluation process. Suitably designed neural nets are used to tune the parameters in the expert system based on the data in the medical test set.

Since Regulation Thermography is still under development, thermographers need to examine new RT-evaluation hypotheses and investigate the contribution of specific measurement areas or rules to the RT-classification process. A mathematical technique called discriminant analysis provides various methods for finding and evaluating criteria to separate groups in a given set of classified data. These methods also allow the significance of including a particular measurement area in the process, for a given disease, to be evaluated quantitatively.

RT-evaluation is at least partially based on heuristics. While automatic knowledge retrieval can support the process of discovering new classification rules for RTs, these methods frequently yield classification rules that an average physician would find very hard to understand. An alternative approach is for the physician to prescribe the logical structure of the rules in a tree-like template – see figure 20. Using methods from multivariate statistics, the free parameters are then estimated from data that have previously been classified. Classification trees produced in this way have led to evaluation rules quite similar to the ones experts are already using, thus providing a valuable crosscheck and increasing confidence in the procedure.

In conclusion, the combination of medical knowledge with pattern matching and data mining techniques is providing an effective method for the critical evaluation of Regulation Thermography and may help to establish this complementary diagnostic technique as a valuable additional resource for the medical profession.



CONCLUSIONS

The computer revolution

One of the major drivers behind the dramatic changes taking place in the global economy is the advent of powerful and affordable digital computers. Indeed, a knowledge-based economy is only possible in the context of the current computer revolution. Not only are computers becoming more powerful, but they are also becoming less expensive and more widely available at the same time. The rate of progress appears to be following the suggested form put forward by Gordon Moore in 1965, subsequently known as Moore's Law. Moore suggested that the number of transistors that could be included in an Integrated Circuit would double approximately every couple of years. The implications of this are that computer power doubles every two years, and this trend is indeed born out in practice. For example, when Seymour Cray developed the world's first supercomputers in the late 1970s, they were capable of performing one hundred million arithmetic operations per second (100 Megaflops in computer jargon). The most powerful machine available at the time of writing is capable of 30 trillion[2] arithmetic operations per second (30 Teraflops in the jargon). This is an increase in speed of a factor of three hundred thousand, equivalent to approximately 18 doublings and actually ahead of Moore's prediction, due to the use of parallel computing technology.

Equally importantly, but not so widely appreciated, is the fact that there has been a similar improvement in the algorithms used to solve mathematical problems using computers. Over the past 50 years, many new algorithms have been developed and existing algorithms have been dramatically improved. The improvements in speed due to better algorithms have been as significant as the improvements in computer hardware.

2 1 trillion = 1,000,000,000,000

The impact of all this on science and engineering has been considerable. Computer simulation is now an accepted tool for scientific investigation, and has completely revolutionised many areas of science. As is evident from this work, industry is already feeling the benefit of these advances, resulting in an increase in efficiency and competitiveness. The trend in the computer industry for machines to perform better and become more reliable at the same time as getting cheaper is being passed on to manufactured goods such as cars. This is a direct result of the effect of simulation in reducing design time and improving quality and performance. This trend can be expected to continue and indeed accelerate in the future as more and more sectors of industry make use of simulation.

The knowledge-based economy

The computer revolution has been a great source of global wealth creation, and it is interesting to consider the form this wealth actually takes. The raw materials required to build computers are relatively abundant and inexpensive. The production of software, as opposed to its development, is even less resource intensive; indeed many vendors supply software from their web sites so the actual production and distribution costs are negligible. The value of computers and especially of software lies in the information and knowledge required to develop them. Interestingly, much of this knowledge is stored on computers in the form of designs, data, and software source code.

As the use of computers expands, so too does the information and knowledge content in the goods, products and services that they have been used to design. This observation captures the essence of the knowledge-based economy. Furthermore, there is the prospect of continued wealth generation and growth, in the form of increased information and knowledge, without placing an excessive burden on natural resources and the environment. Indeed, computationally based tools are being used to understand and mitigate potentially adverse impacts of industry on the environment.

It should be very clear from this document that harnessing the power of computers to enhance industry's competitiveness is a task in which mathematics plays a pivotal role. It follows that if Europe is to achieve its goal of becoming the most competitive and dynamic knowledge-based economy in the world, it will continue to need access to a vibrant, creative and enthusiastic mathematics community, prepared to engage actively with industry and the science base.

The universal applicability of mathematics

Further, it is very clear from this report that the scope of applicability of mathematics is very wide indeed. It is not overstating the case to say that mathematics is everywhere! Mathematical methods are being used or beginning to be used in virtually every area of industry and commerce. What is particularly interesting is that developments in one particular area can often be transferred to a completely different area with significant impact. One of many examples is the numerical solution of partial differential equations. For many years this has been at the heart of engineering simulation of problems such as heat transfer, fluid flow and structural mechanics. The same techniques for solving partial differential equations are now being deployed in the banking, insurance and finance sectors to model financial instruments.

The need for mathematicians

The fact that mathematics is so widely applicable and that the same piece of mathematics can often be used and reused in several different contexts leads to the conclusion that mathematicians are valuable members of the multidisciplinary teams that are required to carry out modern development projects within industry. Some of the most powerful new ideas in mathematics that are finding fruitful application are complex and sometimes difficult to use, which is why professional mathematicians are required. Further, mathematicians can often make a significant contribution to solving production problems faced by industry.

Mathematicians have played an essential role in the task of making the computer revolution work to the benefit of industry and commerce. Their role and importance in the future is likely to increase not decrease. It follows that there is an urgent need for a new generation of mathematicians to take up the challenges and opportunities presented by industry as Europe seeks to become the leading knowledge-based economy. Despite the wonderful mathematical tradition in Europe in all disciplines, the numbers of students studying mathematics is declining in many countries, in stark contrast to the needs of society.

RECOMMENDATIONS

The basic message of this report is that if Europe is to achieve its goal of becoming the leading knowledge-based economy in the world, mathematics has a vital role to play. In many industrial sectors the value of mathematics is already proven, in others its potential contribution to competitiveness is becoming apparent. The benefits resulting from a dynamic mathematics community interacting actively with industry and commerce on the one hand and the science base on the other are considerable and certainly far outweigh the rather modest costs required to support such a community. Nevertheless, such benefits will not be realized unless action is taken to develop mathematics within Europe. The following recommendations are aimed at strengthening mathematics, particularly the mathematics needed for the future success of the European economy.

Mathematics should be regarded as a technology in its own right. Its crucial role in many industrial problems requires the active participation of mathematicians. Truly multidisciplinary projects will benefit significantly from the involvement of mathematical modellers and this should be encouraged by future funding programmes.

Consideration should be given to making the participation of mathematicians in appropriate multidisciplinary projects a condition of project funding.

There is a need for positive action to promote the increased use of mathematics by European industry. The success of local initiatives where mathematicians are working on industrially relevant problems is clear evidence that they are already making a significant contribution to the development of the knowledge-based economy. However, more needs to be done to encourage companies, especially SMEs, to make use of mathematics and mathematicians.

Consideration should be given to creating a programme funding projects that will enable companies, especially SMEs, to explore areas where mathematics can make a contribution to their improved competitiveness.

There is an urgent need for more training in the area of industrial mathematics. It is essential to attract bright students to this area and to convey the challenge and the excitement of solving practical problems.

Consideration should be given to specific funding for training programmes in industrial mathematics across Europe.

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