Ubiquitous Mathematics

Shail Patel FIMA, Programme Director, Mathematical & Psychological Sciences, Unilever Corporate Research

This article plagiarises with pride the concept of Ubiquitous Computing, a term coined in 1991 by Mark Weiser of Xerox Parc to mean a third age of calm technology, where computing devices are everywhere but disappear into the background [1]. Ubiquitous Mathematics speaks to a similar concept: computations and algorithms that are everywhere, that shape our lives, but are invisible to the majority of people. The idea of mathematics being hidden but impacting every aspect of daily life has previously been described in the mathematics education community as a 'hidden but ubiquitous formatting power' or 'realised abstractions embedded in social practices' [2,3,4]. However, the existence and impact of these computations and algorithms are now surfacing in the business press. A recent article in the Economist describes the use of algorithms in transportation network optimisation, credit card fraud detection, and the placement of incoming calls in call centres or products on supermarket shelves [5]. Earlier articles in Business Week describe how quantitative analysts "turned finance upside down a generation ago, and are now mapping out ad campaigns and building new businesses from mountains of personal data" [6], and Forbes describe how "the next Coca-Cola or Unilever marketing campaign" may be optimised using game theory and agent based modeling [7].

The premise of this article is that the mathematical sciences, being ubiquitous, may add value to any function in a large company like Unilever. The main body of the text is devoted to a number of supporting examples. They are not necessarily comprehensive, nor the best examples, nor an unbiassed sample. However they are sufficient to support the claim. Some have gone all the way through to delivering business value, some are still in research phase, and some may be little more than a gleam in the eye. The relationship to ubiquitous computing is not entirely metaphorical. The rise in the wide spread use of mathematics is powered by the increase in computational muscle, and driven by partnerships between mathematicians and computer scientists. For this reason, I draw a wide definition of "the Mathematical Sciences" to include Discrete Maths, Statistics and some elements of Computer Science eg, Artificial Intelligence, Complexity and Algorithmics.

The core of Unilever's business rests on bringing new packaged goods to the supermarket shelves, with well-known brands such as Flora, Hellmans, Liptons, Dove, Sunsilk, and Persil. The longest tradition is the use of classical applied mathematics and statistics to support product innovation. Continuum methods of one kind or another are regularly applied in the modeling of soft solids, from margarine through mayonnaise, ice cream, skin cream, shampoo and soap to laundry detergents. For example, the hydrodynamics of the teabag brewing process has been modeled as three stages of solute release, washing, and convection / diffusion. The CFD (computational fluid dynamics) model showed that external agitation of a teabag (teabag dunking!) results in a forced fluid flow through the porous bed of tea leaf particles that is much greater than the buoyancy driven natural convection (not dunking). As a result, the solute concentration is more homogeneously distributed throughout the teabag and bulk fluid, and the rate of infusion is much greater [8]. This work has been used in the optimal design of PGTips's pyramidal teabag, and the mathematical insight into the swelling of tea leaf and porous flow has helped inspire a marketing campaign around "Room to Move" [9]. Equally the use of statistics for experimental design, results analysis and claim support is well established in Unilever, as it is in many industries. Other examples of classical industrial / applied maths & statistics are not discussed further here, instead we focus on methods and application areas that stretch away from the norm.

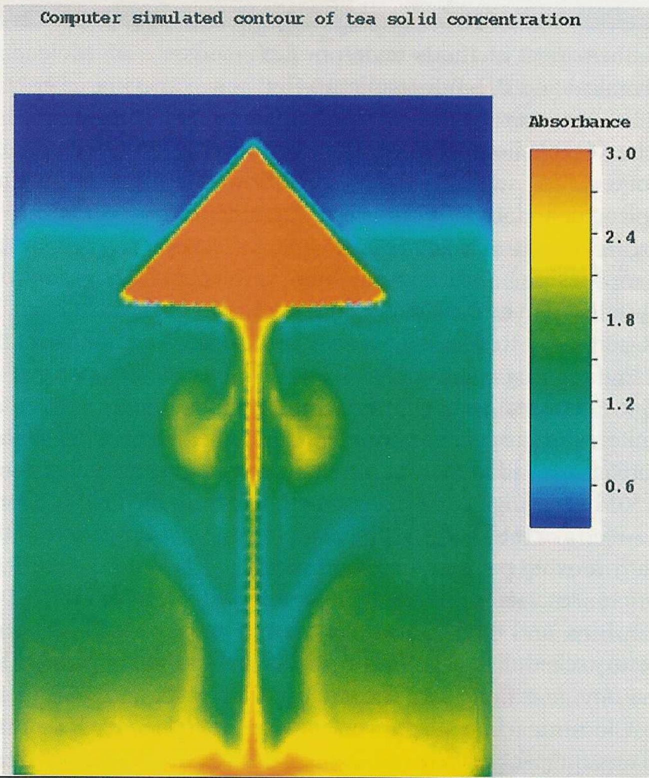

Fig 1: This figure shows the natural convection driven dispersion (no agitation or dunking!) of tea solids through a pyramidal tea bag.

Unilever's margarine business has gained advantage over the years from the use of linear programming and linear regression models to optimise the sourcing of oils for margarine products. This was systematised in a Fat Blend Formulation system in the early 1990's, and delivered an average 1-2% cost saving on raw material costs, on a global scale. During the 2000's new methods based on chained Bayesian Neural Networks were able to take the next step, capturing the non-linear sequence of relationships from raw materials, through intermediate tri-glyceride content, to different stages of solid fat content creation. These chained models made the empirical link from raw materials through synthesis to product characteristics – the idea being to maximise raw material flexibility, while making margarines that are hard in the tub, easy to spread, and soft on eating. Multi-objective genetic algorithms, developed for engineering optimisation, were used to leverage these empirical models to optimise simultaneously raw materials and characteristics against cost and performance profiles at different temperatures. This model and optimise method, elements of which are patented in the US [10,11], are essentially generic and have also been used in our Home Care business, with 'computer-generated' products on the supermarket shelves.

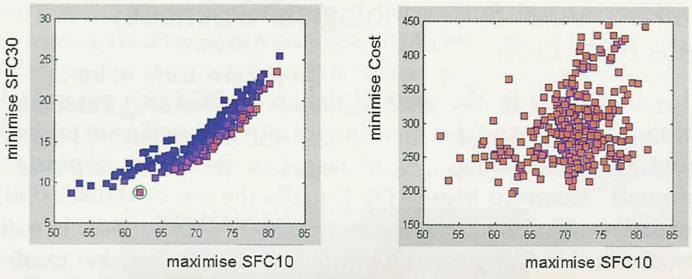

Figure 2: Models of different margerine blends based on 22 different raw materials, through tri-glycerides, and predicting the solid fat content at 10°C, 30°C, and the overal cost. The task is to minimise SFC30 and cost, and maximise SFC10.

Mathematical methods underpin the emergence of Molecular, Chemical and Bio-Informatics to find new active ingredients. A £13M Unilever Centre for Molecular Science Informatics has been established in Cambridge University to develop new methods for in-silico experimentation based on large-scale molecular databases [12]. Amongst other things the group is researching chemical mark-up languages, computer aided molecular design, and modelling molecular aggregation, crystallisation and protein-ligand interactions.

Operations Research leverages optimisation methods in the Manufacturing and Supply Chain functions. In the late 1990's a mixed integer linear programming based cost model of Unilever's European laundry factories, together with feasibility studies, resulted in factory rationalisation and generated around £150M in savings. More recent methods, from the field of Complexity, take into account the complex interactions between the many moving parts in a modern factory. A Scientific American article describes our collaborations with Vince Darley of EuroBios, and the use of an 'ant-based' method for optimising factory scheduling [13]. This approach uses software 'ants' to lay pheromone trails (hence the analogy with real ants), to find the best locations for and movements between the storage tanks, mixers and packing lines. In a similar vein, EuroBios helped build Agent-Based Models of the myhome.com home cleaning and laundry business. Business sensitivity to the complex interactions between cleaners, supervisors, self-driving cleaners, and transport vans was modeled [14]. A non-intuitive result was that optimal schedules could be found even if only half of the clients were willing to give myhome the key to their house, so that it could be cleaned when it suited the schedule. A US-based competitor, Procter & Gamble, is also active in this area. They have claimed $200M savings in their Supply Chain from the use of traditional OR methods [15], and a further $300M by using Agent-Based Methods [16].

In recent years we have seen the emergence of a variety of new Service-based industries, exemplified by Amazon, ebay, last.fm, as well as on-line versions of mainstream retail such as tesco.com. These industries are data-rich, in that they are able to compile large amounts of information about their user base, and the most successful ones are highly competent at leveraging that data to improve and target their services. iShakti is an interactive Web application developed by Unilever and deployed in rural India. The system provides accessible information on health, agricultural, legal, beauty, and veterinary topics, and was short-listed for the Stockholm Challenge award [17]. In a Collaborative Filtering method similar to the Amazon.com 'people like you also bought', iShakti uses algorithms to personalise information content, market research and marketing promotions [18]. A little known Neural Net method, Adaptive Resonance Theory (ART), is used dynamically to cluster individuals based on demographic, attitudinal and behavioural profile – ART is similar to k-Nearest Neighbours, but allows for dynamic determination of the number of clusters and heterogeneous cluster sizes [19]. At present, iShakti is deployed across 1000 rural kiosks, covering 5000 villages and reaching 1 million people. We have also spun out a new start-up, MiLife, that specialises in on-line behaviour change programmes for weight management – we all know that we should exercise more, eat less and more healthily, and the MiLife system helps us achieve these goals through personalised advice. Personal Activity Monitors, incorporating accelerometers in a wrist-watch shaped device, provide real-time feedback on activity levels – going up and down the stairs or cleaning the house, not to mention other activities, burn up a surprising amount of energy [20]. In a collaboration with LeShop, the largest online retailer in Switzerland, we have developed algorithms based on Naïve Bayes and Bayesian Graphical Models to recommend product purchases to shoppers [21]. The challenge can be loosely described as: given that you have bought particular brands of frozen pizza, mayonnaise and tea, can we devise an algorithm to recommend the type of wine you'd prefer?

Many commercial enterprises leverage statistical analyses of aggregate market data to improve their marketing ability, with terms such as: market mix modeling or optimising return on

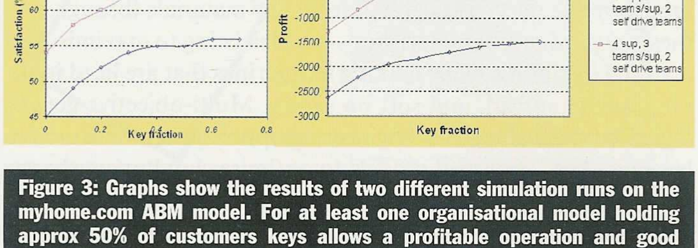

Figure 3: Graphs show the results of two different simulation runs on the myhome.com ABM model. For at least one organisational model holding approx 50% of customers keys allows a profitable operation and good standards of customer satisfaction.

Figure 4: Landing page for iShakti application. The highlighted boxes show the personalised information content and the targeted promotion – in this case no discount is offered.

marketing investment. In the early 2000's Unilever used classical statistical & time-series methods to model the relationship between advertising activity, such as television advertising campaigns, and sales and market share. The changes made as a result of this analysis, which showed under-advertising will lead to a substantial loss over time, resulted in a significant improvement in advertising efficiency [22]. There is a growing awareness of the challenges thrown up by an increase in 'consumer complexity', ie. an increased diversity of choice and growing consumer control over purchase and life-style decisions. We are researching game-theoretic approaches to modeling brand competition in these complex consumer markets [23]. A Unilever sponsored workshop at Surrey University on Agent-Based models of market dynamics and consumer behaviour, recently published in a special issue of the Journal of Business Research, identified key challenges for research in this area including: methods for verification & validation of agent-based models, the balance between theoretical & empirical approaches, and the appropriate level of granularity & detail needed to capture real-world properties [24]. There is strategic commitment to this area across the industry: Procter & Gamble has set up a 100-strong group, quaintly called "über-analytics", to underpin their strategy of 'Competing on Analytics' [25].

The world of Finance is now highly dependent on mathematical modeling of one kind or another, whether in automated traders, hedging strategies, risk management or decision making under uncertainty. The City of London is a magnet for mathematicians, attracted by the large salaries and not daunted by the high level of secrecy! Within Unilever the Finance function is a key part of business strategy and there are many opportunities for added value from mathematical methods, for example in optimising foreign exchange transactions [26]. While much pre-competitive research activity exists in the literature, very few examples of real commercial benefit are reported in the open press.

A big challenge in Sales is 'knowing what we know'. With global operations and many thousands of different brand, product and pack sizes in many thousands of different retail outlets, it is not a trivial task simply to compile the relevant data for strategic decision making. The opportunities for the mathematical sciences lie in reducing the dimensionality and complexity of the data and presenting it in a way to facilitate short and long-term strategy. There is also a world of text-based information (news feeds, blogs, chat sites) waiting to be analysed to identify the causes of any major upsets or successes in the market place. As the industry moves to RFID (radio frequency identification) tags on all pallets and packs, we will know what products are selling where and at what rate, and be able to make much more accurate demand forecasts. Chaining and optimising this back through the supply network will then allow us to lower costs as well as carbon miles.

The last business function to consider is Human Resources and Organisational Design. Sometimes thought of as a maths-free culture nonetheless even here there are possibilities. Groups of people are complex systems, and methods such as Social Network Analysis may yet help in optimising overall corporate performance.

The examples above lend support to the idea of Ubiquitous Mathematics, and if one looks there are many others. That mathematics can be applied anywhere is both a strength and a weakness. The strength is clear, there is a potential high value add for any business function in a major industry such as Unilever. By extension one may claim the same for any Sector of Industry – there are equivalent examples in Telecomms, Health, Utilities, Transport, Biotech, Entertainment and even Politics to name just a few.

However this doesn't match our experience: we know that opportunities are typically untapped and the mathematical sciences are not typically perceived as a core engine for growth. Why should this be so? The answer may lie in the weaknesses. Most discipines have clear champions in an industrial Sector: Chemists have the Pharmaceutical & Chemicals Industry, Economists have Finance & Banking, Biologists have the Biotech industry and so on. These champions foster the link between scientific research and business application and provide a coherent voice for their areas. In the mathematical sciences both the business and academic communities are highly fragmented, isolated and therefore lacking in what is essentially political clout. In 1996 we conducted an internal review of Mathematics and came to the conclusion that there were "isolated islands of mathematical excellence" within Unilever. I suspect the same is true in other companies. Because it's an underpinning science, mathematics (and often mathematicians!) is (and are) invisible. There is typically no tangible output: no molecule, device, gadget or widget. Nothing to hold up in the group photograph and say "we made this". Furthermore, the output of an industrial mathematical activity is rarely seen as delivering value straight to the bottom line. More often than not mathematicians or statisticians will be delivering value through intermediating individuals or groups. This long "food chain" is a classic credit allocation problem - and with low allocation of credit comes low visibility and low funding.

It is not impossible to rectify this. It seems the US is better at funding and leveraging mathematics than we are in the UK [6,22]. We need to understand the reasons - this article just scratches the surface. We need to learn from the US experience, we need to organise better, and we need to claim our successes more vocally. The overtures between the IMA and the LMS are a good step in the right direction. But perhaps as a community we need to address this issue much more explicitly. The pages of Mathematics Today seem at least one good place to stimulate this debate!❑

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