COUNCIL FOR SCIENCE AND TECHNOLOGY

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Prime Minister
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THE AGE OF ALGORITHMS: Algorithms, analytics, modelling and data for growth and public sector efficiencies[1]

Algorithms and the emerging economy

Every time we pick up a mobile phone, buy groceries online, use a search engine or buy insurance, we are interacting with algorithms.

We use algorithms as keys to unlock meaning from data. Algorithms underpin the technology that powers much of our everyday life and economy. The UK should aspire to be at the forefront of the economic revolution driven by algorithms.

An algorithm is a set of instructions and calculations used to analyse, manage, and improve many different types of process. They have a very broad range of uses across the public services and the economy.

This report is about the skilled people who generate algorithms, without whom we will be unable to take advantage of the revolution in information technology. They are the scientists, mathematicians, engineers and technicians who apply insight and analytical skills to develop the algorithms that in turn provide utility and value from data.

The speed of growth in data is well known: it has been estimated that the total amount of data at our disposal will grow more than tenfold in the next five years. Most of this material is unstructured. It doesn't sit in neat rows in a database, but takes forms such as voice, text, tweets, email, and video. New forms of technology are needed to handle these complex data that come directly from humans, managing complex ideas expressed in complex forms. British computer scientists excel at these forms of analysis, and we have business world leaders in this territory including Autonomy plc (from start-up to FTSE 100 in only 14 years), WPP, and Tesco.

[1] In drawing up this report, CST has benefited from the advice of a number of external specialists. We are grateful in particular to the contributions of Professor Chris Bishop, Professor Peter Coveney, Professor Nick Jennings, and Professor Sir Alan Wilson.

Companies increasingly realise that capturing, curating and owning the digital information that we produce is key to business success. The technology challenge is to store this information securely, to manage it and to make it accessible on many types of device at all times.

The rapid development of the "Internet of Things" will transform the way we interact with everyday commodities. For example, cars have already been developed that can send information to the manufacturer regarding maintenance and usage, as well as to their owners about the actions that they should take. In time, their manufacturers could, like others, develop a relationship with the customer founded on extensive data that will be difficult to migrate to a new company. Similar messages from cars to insurance companies and to road providers will transform the way in which we use our cars and road systems. The possibilities are almost unimaginable.

Widespread adoption of these technologies is imminent and with it the potential for ancillary services to develop. First-mover advantage will be critical, and the UK is very well positioned to provide many of these businesses and services.

Why does the Prime Minister have a role here?

The "Information Economy" constitutes one of 11 key sectors identified as priorities for the Government's Industrial Strategy. It is absolutely right that it should be on this list, but it has distinctive characteristics which set it apart from the other sectors.

In particular, the technologies enabling the information economy will transform the whole economy from retail to public services. They are extraordinarily versatile; methods used to monitor the performance of Formula One cars can help monitor very sick children. The range of participants that need to be mobilised to catalyse the information economy go well beyond any individual government department or industrial sector. The Government as a whole also need to be prepared for the challenges that algorithms will present for policy and regulation; in areas like the privacy and rights of citizens, and the increasing complexity of the processes underpinning our economy. It is appropriate therefore that the Prime Minister should take a keen interest in an area with such exceptional transformative potential.

Skills development

First and foremost, we need to develop the workforce of the future and to equip the general population with the know-how to be critical consumers of the information economy. Education and skills training are paramount needs of this fast developing area of technology. It is the availability of skilled people that will determine the future capability of the UK to develop the information economy. These are the people that will deliver the ambitions of the Government's set out in the Information Economy Strategy. But it is also important to note that there is a global skills market for those with advanced ICT skills, and the UK should position itself to compete effectively in this market as both an importer and exporter of education and skilled people.

Algorithms know no geographical boundaries, but the economic benefits are most likely to accrue to those that develop them. Action is needed in schools, universities and the workplace.

Schools

We must prepare a generation of school leavers who are 'data-savvy', avid consumers of advanced technology and can provide a workforce that can understand, analyse and handle large datasets. The shortcomings of the previous GCSE ICT curriculum are well known.[2] The publication of a new national curriculum for computing to GCSE is welcome, with its emphasis on understanding of the basic principles of logic, algorithms, and analysis. A new curriculum will take statutory effect in 2014.

[2] Royal Society, Shut Down or Restart? The way forward for computing in UK schools, January 2012.

But the inadequacies of the previous curriculum means that we are starting from a low base in terms of teachers' own skills. The Council for Science and Technology has written elsewhere about the need to ensure that teachers are equipped with subject specific knowledge. The need is particularly urgent in a subject where the technologies are developing so fast.

Our first recommendation is directed to schools and the Department for Education:

1. Schools must recruit teachers who are trained in computer science and embrace continuing professional development (CPD) to ensure that their profession is equipped to educate and enthuse students in Computer Sciences. The Department for Education should engage with the providers of CPD in STEM education to ensure that there is high quality subject-specific CPD provision to teachers of ICT.

The curriculum in mathematics beyond age 16 is the next step. Looking ahead, it is likely that the whole range of data science will become one of the most critical applications of mathematics across research and the economy. Computer science departments are already looking to mathematics A-level to prepare potential undergraduates for university level study in the discipline. The provision of post-16 mathematics teaching for all students is currently under consideration. The key forms of rigorous analysis that are the building blocks of effective data science need to be consolidated at the heart of the mathematics curriculum.

2. The Department for Education should ensure that logic, algorithms and statistics are included at an appropriate level in post-16 mathematics courses.

Learning outside the classroom

Hands-on programming and analytical skills are critical, and formal learning of the traditional sort can only go so far. The BBC Computer Literacy Campaign of the 1980s was a major UK success story of its day. It was a formative experience for many of the UK's leading technologists. It centred on a new computer, the BBC Micro, a tailored computer language, and a range of activities designed to make computing accessible.

There are many excellent initiatives geared at engaging young people in hands-on programming today. Events like 'hackathons' where programmers collaborate on intensive projects, have a strong impact on learning and career choices by young people. What might be done to derive still more advantage from these proliferating initiatives?

At the time of the Computer Literacy Campaign, few homes had a personal computer. Children increasingly have access to a computer at home or at school. The Raspberry Pi has been made available recently as a low cost platform for learning to programme computers. Widespread access to smartphones provides another avenue to developing skills in programming. New routes to formal learning are also developing. Massive Online Open Courses (MOOCs) are proliferating rapidly. These are structured courses delivered by universities and other providers online, usually free of charge, and often resulting in a certificate. By the very nature of the subject (involving the manipulation of data via a computer) MOOCs have huge potential to develop programming and data analysis skills.

Provision of schemes and courses is proliferating, but the need for an active campaign (and here traditional routes broadcasting remain important) remains.[3] Strongly motivated individuals will be well aware of the opportunities, but we need to reach out wider given the extent of the skills challenge.

[3] This point was also made by an important study sponsored by NESTA (Tilly Blyth, The Legacy of the BBC Micro: effecting change in the UK's cultures of computing, May 2012), which was based on extensive interviews relating to the legacy of the Computer Literacy Campaign.

3. The Government should sponsor a new Computer Literacy Campaign highlighting learning opportunities for individuals, schools and businesses.

Higher education

There are important career opportunities for scientists, engineers and technologists with advanced skills in algorithms, and the higher education sector needs to respond by the creation of excellent courses to provide the necessary education and training.

The study of data science at Masters and PhD levels will develop graduates with relevant analytical degrees to enable them to enjoy fulfilling careers in developing algorithms and information technology for a large variety of industrial applications. Courses might draw to an extent on existing postgraduate modules in (e.g.) mathematics, machine learning and data visualisation; businesses, including SMEs, might be encouraged to take part in a variety of ways varying from contribution of data case studies to 'sandwich' employment offerings.

4. Computer science departments should work in partnership with other university departments and with the private sector to develop multidisciplinary courses with a suitable focus on building aptitude for the practical application of data science. Universities should be encouraged to develop new options including Data Science MSc and PhD programmes.

The demand for these skills is likely to increase, which should, in principle, drive greater provision. The value of data science skills is increasingly recognised, but market failures can happen. The government's recent decision to fund 500 MSc places in aeronautical engineering jointly with business is one model for what might be done should the gap not be filled.

5. The Government should assess the response of the higher education sector and business to the challenge set out in our fourth recommendation in about three years time and review the case for any further action.

Building a closer relationship between research and business

In addition to improving skills development, there is the need for further catalytic action to foster the relationships between academia and industry. These relationships are essential in order to generate economic returns from our strong academic base in computer sciences.

We have made five recommendations that will help to ensure that we have the essential workforce to deliver the growth opportunities. Our sixth recommendation is for the creation, by means of a public private partnership, of a national centre that will anchor our advanced research capabilities and global leadership in computer sciences.

University computer science and mathematics departments come high on the balance sheet of the UK's assets in the context of the data revolution. Some of these departments already have an exceptional track record in knowledge transfer leading to economic growth. We must build on this success to ensure that the best computer science departments, working in a financial partnership with industry and the public sector can help to create the next generation of businesses and services founded on the advanced use of algorithms.

We support the actions that have been taken in the UK to create the Open Data Institute and the Connected Digital Economy Catapult. These are focused on promoting start-ups working with open data, and in the digital economy. We also welcome the fact that the Hartree Centre is seeking to put the government's investment in high performance computing to good translational use in the development of large-scale models and simulations. However there remains an important gap in the partnership between industry, academia and the public sector. This is in the area of research and development of advanced computing science including algorithms.

6. The Government, working with the universities and industry, should create a National Centre to promote advanced research and translational work in algorithms and the application of data science. This could fittingly be named the "Alan Turing Centre".

A single centre would have a critical role in setting a visible lead. We foresee a number of functions specific to this centre:

- to undertake research, knowledge sharing and to develop networks between leaders in higher education institutions, public service and business;
- to provide technically informed advice to policy makers on the wider implications of algorithms;
- to enable researchers from industry and academia to work together to undertake outstanding research with practical application;
- to act as a magnet for world leaders in academia and industry to engage with the UK as a global leader in information technology;
- to attract senior business and public service leaders to engage with and be trained in the business of data and analytics;
- to promote the transfer of skills and insight as well as of technologies.

The centre would be expected to make close links with other centres representing specialist areas of excellence, and to collaborate and work closely with the Open Data Institute, the Connected Digital Economy Catapult, and the Hartree Centre.

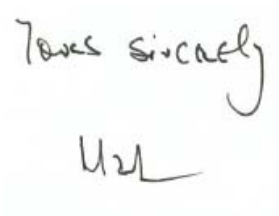
Conclusion

The Government is currently preparing a strategy for the Information Economy, which provides a useful framework for talking many of these actions forward.

Any strategy is only as good as the people that implement it. We have focused in this letter on the skills, partnerships and facilities that are essential to keep the UK in the forefront of the development of advanced algorithms. They are an essential component of any plan for the growth of the information economy.

We would of course be happy to discuss these recommendations with you or your ministerial colleagues in more depth.

We are copying this letter to the DPM, the Chancellor of the Exchequer, Vince Cable, Michael Gove, Francis Maude, Oliver Letwin, David Willetts and Sir Jeremy Heywood.



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