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Century-of-Information Research (CIR): A Strategy for Research and Innovation in the Century of Information[1]

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Abstract *More data will be produced in the next five years than in the entire history of human kind, a digital deluge that marks the beginning of the Century of Information. Through a year-long consultation with UK researchers, a coherent strategy has been developed, which will nurture Century-of-Information Research (CIR); it crystallises the ideas developed by the e-Science Directors' Forum Strategy Working Group. This paper is an abridged version of their latest report which can be found at: http://wikis.nesc.ac.uk/escienvoy/Century_of_Information_Research_Strategy which also records the consultation process and the affiliations of the authors. This document is derived from a paper presented at the Oxford e-Research Conference 2008 and takes into account suggestions made in the ensuing panel discussion.*

The goals of the CIR Strategy are to facilitate the growth of UK research and innovation that is data and computationally intensive and to develop a new culture of 'digital-systems judgement' that will equip research communities, businesses, government and society as a whole, with the skills essential to compete and prosper in the Century of Information. The CIR Strategy identifies a national requirement for a balanced programme of coordination, research, infrastructure, translational investment and education to empower UK researchers, industry, government and society. The Strategy is designed to deliver an environment which meets the needs of UK researchers so that they can respond agilely to challenges, can create knowledge and skills, and can lead new kinds of research. It is a call to action for those engaged in research, those providing data and computational facilities, those governing research and those shaping education policies. The ultimate aim is to help researchers strengthen the international competitiveness of the UK research base and increase its contribution to the economy.

The objectives of the Strategy are to better enable UK researchers across all disciplines to contribute world-leading fundamental research; to accelerate the translation of research into practice; and to develop improved capabilities, facilities and context for research and innovation. It

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envisages a culture that is better able to grasp the opportunities provided by the growing wealth of digital information. Computing has, of course, already become a fundamental tool in all research disciplines. The UK e-Science programme (2001–06)—since emulated internationally—pioneered the invention and use of new research methods, and a new wave of innovations in digital-information technologies which have enabled them. The Strategy argues that the UK must now harness and leverage its own, plus the now global, investment in digital-information technology in order to spread the benefits as widely as possible in research, education, industry and government.

Implementing the Strategy would deliver the computational infrastructure and its benefits as envisaged in the Science & Innovation Investment Framework 2004–2014 *(July 2004), and in the reports developing those proposals.*

To achieve this, the Strategy proposes the following actions:

1. *support the continuous innovation of digital-information research methods;*
2. *provide easily used, pervasive and sustained e-Infrastructure for all research;*
3. *enlarge the productive research community which exploits the new methods efficiently;*
4. *generate capacity, propagate knowledge and develop skills via new curricula; and*
5. *develop coordination mechanisms to improve the opportunities for interdisciplinary research and to make digital-infrastructure provision more cost effective.*

To gain the best value for money strategic coordination is required across a broad spectrum of stakeholders. A coherent strategy is essential in order to establish and sustain the UK as an international leader of well-curated national data assets and computational infrastructure, which is expertly used to shape policy, support decisions, empower researchers and to roll out the results to the wider benefit of society. The value of data as a foundation for wellbeing and a sustainable society must be appreciated; national resources must be more wisely directed to the collection, curation, discovery, widening access, analysis and exploitation of these data. Every researcher must be able to draw on skills, tools and computational resources to develop insights, test hypotheses and translate inventions into productive use, or to extract knowledge in support of governmental decision making. This foundation plus the skills developed will launch significant advances in research, in business, in professional practice and in government with many consequent benefits for UK citizens. The Strategy presented here addresses these complex and interlocking requirements.

Keywords: Century-of-Information Research (CIR); e-Infrastructure; e-Research; e-Science; digital economy

Introduction

The CIR Strategy has been developed by a working group set up by the UK e-Science Directors' Forum. The Strategy is shaped by requirements for research, priorities defined by the government and its Research Councils, and the power of computational and data intensive methods to transform research and deliver invaluable benefits to the UK economy and citizens. Its provisions will enable the pursuit of new avenues of research and will make it possible for many more researchers in the public and private sectors, government policy-makers and citizens to reap the benefits of the expanding wealth of digital information in a way which is cost effective.

The Strategy is intended to influence UK policy as it develops its research programmes in order to increase capacity to undertake and exploit research. It identifies the urgent need for coordination to develop synergies between and across disciplines, to accelerate the transfer of new digital-information research methods into productive use and to encourage increasing numbers of researchers and innovators to adopt and exploit those methods when they would benefit their research. It proposes a sustained programme of education to prepare the UK research community both technically and culturally. It addresses the need for investment in supporting emergent community effects as well as in new technology, and recognises the requirement for effective two-way exchange of ideas, methods, technologies and expertise between academia and industry in order to realise the benefits for the UK economy and the wellbeing of its citizens.

The Strategy has been designed to influence those who fund research and education, including the DIUS, the Higher-Education Funding Councils and their Joint Information Systems Committee (JISC), the Research Councils, the Technology Strategy Board and charitable trusts that fund research. It should influence those who provide a research environment in universities and laboratories, and those who lead and undertake research. It should encourage educators to evolve curricula to develop the UK's capabilities for research, innovation and translation into practice and to shape the culture within which those activities are conducted. In addition it should influence those who plan and stimulate the take up of new digital-information research methods, research results and innovations enabled by advances in digital-information systems in business, government and all aspects of UK society.

Purpose of the CIR Strategy

Globally, we are witnessing fundamental changes in the way research and innovation are undertaken, which are being brought about by dramatic increases in the volume and pervasive nature of the data being collected and the availability of increasingly powerful computational facilities for its analysis. Today's research challenges demand adroit exploitation of these new possibilities.

The Prime Minister, Gordon Brown, recently observed, 'This is the Century of Information'.[2] The UK needs new skills and new technologies to ensure it gains the maximum benefits from that wealth of information. The adoption of the Strategy for Century of Information Research will address these requirements and improve understanding of how digital technology may be exploited to the greatest advantage for the UK's citizens and economy.

Over several decades UK researchers have demonstrated great skill in exploiting the latest advances in computation to deliver major contributions to research. As the pace of innovation in digital technologies intensifies, the UK must increase its efforts to nurture the creation, deployment and widespread use of new research methods enabled by innovation in digital technology.

Today, successfully exploiting the diverse sources of data that researchers need often takes an inordinate amount of coordination and effort, creating obstacles to discovery and innovation whose impact can only increase as more and more sensors are deployed in the environment, as records of human activities grow, as more sensitive instruments are commissioned, as more laboratory tasks are automated and as researchers are called on to address more complex and global challenges. The CIR Strategy directly addresses researchers' needs by tackling these

obstacles. By stimulating the relevant digital-information technology research, by developing the relevant skills among researchers and by providing more powerful, pervasive e-Infrastructure it will facilitate their use of information systems and judgement in pursuit of their research.

The Strategy will enable innovation in and exploitation of digital-information technology through three sustained effects, which must be well coordinated to maximise their synergy and impact:

1. increase in the rate of invention of new computationally powered methods of exploiting digital information—the rapidly advancing context requires continuous innovation;
2. rapid translation of successful methods into supported tools and production services matching the needs of researchers and ready for extensive use; and
3. attraction of and engagement with a growing cohort of researchers who can exploit these methods fluently to advance their research and spawn user-led developments that in turn drive further technological developments.

These three effects are ineluctably interconnected. They will occur in repeated cycles throughout the research community, with the user-led developments driving the whole process. Research communities themselves are not only the motivators of this cycle of innovation, they are also the inventors and implementers, pioneering new methods as they need them.

The three effects will build on the existing platform of community strengths, and be achieved through progressive improvements in the culture and capabilities that drive invention, by the steady rise in the power and convenience of the services and tools on which they build, and through outreach that helps develop user communities. Because of the generic power of digital-information systems to transform research, business, government and society, the benefits will be enormously amplified by coordination that crosses discipline boundaries, delivers multi-disciplinary benefits and facilitates interdisciplinary research. The *Digital Economy* cross-council programme already targets the immediate gains in translating research to business and healthcare practice. The Strategy builds on that programme and considers a broader as well as longer-term set of goals and opportunities.

The UK has developed notable leadership in the domain, particularly as a result of the impetus brought by the e-Science programme (2001–06) building on healthy ambient research achievements across all Research Councils (see Figure 1).

However, the international competition is positioning itself to overtake the UK rapidly as they copy and invest in *coordinated* programmes to accelerate and transform

e-Science is the invention and application of digital-information methods to achieve new, better, faster or more efficient research in *any* discipline. It draws on advances in computing science, computation and digital communications. It has been a conceptual foundation and an important tool for researchers for many decades. The data deluge and the scale and complexity of today's research challenges have greatly increased its importance for researchers. As a consequence, in 2001 the UK led the world by initiating a *coordinated* e-Science research programme to stimulate the development of e-Science across all fields of research. That investment, £250 million, has developed assets on which the Century-of-Information Research Strategy will build.

Figure 1. The e-Science foundation for the CIR.

NSF's ***Cyberinfrastructure*** Vision for 21st Century Discovery is presented in a set of interrelated chapters that describe the various challenges and opportunities in the complementary areas that make up Cyberinfrastructure: computing systems, data, information resources, networking, digitally enabled-sensors, instruments, virtual organization, and observatories, along with an interoperable suite of software services and tools. This technology is complemented by the interdisciplinary teams of professionals responsible for its development, deployment and of its use in transformative approaches to scientific engineering discovery and learning. The vision also includes attention to the educational and workforce initiatives necessary for both the creation and effective use of Cyberinfrastructure.

Figure 2. The NSF's definition of cyberinfrastructure.

their research—an eminent example is the USA's National Science Foundation (NSF) Cyberinfrastructure programme[3] (see Figure 2).

In all disciplines, increasing amounts of data are being created, often with the use of public funds, and the expectation is that these will be curated and shared to increase their value to society. These data must be analysed in innovative ways to provide better answers to society's pressing questions, for example, those identified as Cross-Council themes: 'Energy, Living with Environmental Change, Global Threats to Security and Ageing: Lifelong Health and Wellbeing'.[4]

Implementing the Strategy will make it increasingly easy for researchers to use new digital-information resources and methods routinely. It will lead those who provide resources for research to establish a *coordinated* framework supporting a diverse digital-information environment, shaped by the researchers themselves, where UK research and innovation will flourish. It will transform aspects of each graduate's education to equip them with the insights and skills to exploit the new opportunities and transfer knowledge to industry and government so that they can be adept leaders in the digital economy. The consequent impact on international competitiveness and productivity motivates the Strategy.

Research Potential in the Century of Information

The delivery plans for each of the UK Research Councils for the period 2008–11 identify challenges that demand advances in the exploitation of complex data, the development of interconnected computational models and interdisciplinary collaboration. Advances in the ways the UK exploits the power of the new digital-information technologies are key elements for addressing the Government's cross-cutting priorities.

The e-Science programme has provided a valuable crucible for digital-information research method innovation by facilitating close collaboration between researchers in an application domain with researchers in computer science. As common requirements are established, the provision of an emerging e-Infrastructure delivers a progressively stronger platform for them to build on. The success of such collaboration and supported platforms has been well illustrated in an exciting development where NERC scientists conducted research across a range of areas from earth systems to nuclear-waste disposal and demonstrated the advantage of shared methods, tools, data storage and high-throughput computing. In that case it led to advances in understanding of the processes and materials, and 13 papers in *Nature* in a period of three years.

Risk from Inaction

Failure by the UK to act strategically would mean that each researcher or research community has to act independently to find the resources and develop the methods they need to access and interpret the growing wealth of digital-data resources. This in turn increases the barriers to collaborative cross-disciplinary endeavour, itself widely recognised as key to future innovation. In the medium and longer term this would expose UK research and innovation to major risks.

1. *Loss of competitive position* as complexity inhibits agile innovation and as fewer collaborating communities form to reap benefits from shared digital resources, interdisciplinary cross-fertilisation and community effects.
2. *Poor return on investment* as opportunities for sharing are lost and as there is duplication and excessive fragmentation in communities, processes, and provision.
3. *Lack of dissemination about the approaches used by researchers* as user communities would not reach a critical mass.
4. *Loss of international influence,* of opportunities to engage effectively in international consortia and to host international research facilities.

If we do not empower researchers to thrive in the Century of Information we will not seed the growth of relevant knowledge and skills in education, industry and the community.

Research Future in the Century of Information

The CIR Strategy will launch the UK on a path to a future where the culture, skill base and national facilities will support the agile and adroit use of rich digital-data resources and pervasive computational access. Today a growing majority use web resources, both public and private, to support their work, their personal lives and their social interactions. By 2020, implementation of the CIR Strategy will develop the culture, skills and easily accessed pervasive facilities to enable individuals, businesses, education, governmental organisations, healthcare and many groups in society to benefit from information and computational wealth, as fluently as they use the Web today. To achieve this, the digital environment for research not only has to be shaped by researchers' ideas and requirements, it also has to exploit all the advances in the ambient digital infrastructure—pervasive sensors, mobile phones/devices, web-enabled community activity, globally and commercially resourced computational services, and data by-products from citizens' interactions with thousands of transactional systems.

The nature and pace of change in digital information and systems that the CIR Strategy will need to respond to, exploit and influence are illustrated via a selection of examples of the anticipated needs by 2020:

- community support for advanced work dealing with more complex data and combining higher precision models, with increased collaboration;
- research dependent on sustained, easily used and well-curated digital-data resources that have common access policies, providing a balance between open access to encourage scrutiny and wide investigations, and constraints that protect emerging results, privacy and ethical standards (The European Bioinformatics Institute demonstrates that this balance can be achieved, enabling more

than a million users to benefit from its bioinformatics data and computational services);
- one million users in the UK, using between them 10 petaflops of distributed computing power, which will have to be provided *using a minimum carbon emission strategy*;
- professional decision makers and researchers building and sharing a rich ecosystem of evolving tools and services that compete and cooperate to provide the analyses, modelling power, information and advice that users seek;
- each student developing skills and judgement in using these systems with universities producing graduates who have well-developed strategies for exploiting them;
- all popular information manipulating tools, such as browsers, spreadsheets, image processors, bioinformatics systems, statistical packages, design tools and mathematics packages drawing on the computation and information services in ways that are virtually invisible to the user;
- new community behaviours emerging across both public and private sector groups, people collaborating and competing using the new skills, capabilities, tools, data and computing power to build the information collections, models and services that address their group's vision and needs;
- real-time control of experiments; reaching femtosecond (10^{-15} seconds) precision, observational and control cycles that can only be managed by direct coupling with computational models—ITER[5] is a prime example; and
- multi-core computers, wearable computers and disposable computers will be prevalent, pervasive and interconnected by a rich hierarchy of wireless, electrical and optical digital-communication networks.

Context for the CIR Strategy

The *UK Research Community* is predominantly funded by the Research Councils, the Technology Strategy Board (TSB) and research-funding charities. Many researchers have resources provided by their own institutions, for example, many universities have recently invested in campus grids and HPC clusters through the Science Research Investment Fund (SRIF) initiative.[6] The JISC also supports the provision of shared research resources and encourages community effects.[7]

The UK Cabinet Office has recently published a consultative paper, *Realising Britain's Potential: Future Strategic Challenges for Britain*,[8] that states 'The increasing pace of technological innovation will open up a host of new economic opportunities, and will drive further increases in interconnectedness and further improvements in quality of life'. This confirms results from similar analyses on the requirement for computational infrastructure and innovation to support research, conducted in the USA. The *Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure*[9] states:

> The Panel's overarching finding is that a new age has dawned in scientific and engineering research, pushed by continuing progress in computing, information, and communication technology; and pulled by the expanding complexity, scope, and scale of today's research challenges. The capacity of this technology has crossed thresholds that now make possible a comprehensive 'Cyberinfrastructure' on which to build new types of scientific and engineering knowledge environments and organizations and to pursue research in new

ways and with increased efficacy. The cost of not doing this is high, both in opportunities lost and through increasing fragmentation and balkanization of the research communities.

A more recent NSF report *Simulation-Based Engineering Science—Revolutionizing Engineering through Simulation*[10] concluded:

- SBES constitutes a new paradigm that will be indispensable in meeting the scientific and engineering challenges of the twenty-first century.
- The development of effective multiscale modeling techniques will require major breakthroughs in computational mathematics and new thinking on how to model natural events occurring at multiple scales.
- The era in which data-intensive computing and large-scale scientific computing were essentially disjoint camps is over.

The CIR Strategy proposes coordinated actions to achieve a synergistic and integrated development of the UK research and innovation, educational programmes and translational outreach for the full range of subject disciplines. This is an ambitious challenge that will require national investment and strong community support.

Existing Strategic Coordination

The Research Councils, led by the EPSRC, use a quinquennial planning cycle for HPC provision, and JISC in conjunction with the HEIs and their Funding Councils conducts a similar five-year programme for network provision, through Ja.net (Ja.net, 2008). Such a pattern of strategic and business-case development, technological and business option evaluation, and procurement is recommended for the full breadth of the CIR Strategy.

In an earlier report, *Transformational Government—Enabled by Technology*,[11] the Cabinet Office identified the crucial role of information and the requirement for shared services.

- Modern government—both in policy making and in service delivery—relies on accurate and timely information about citizens, businesses, animals and assets.
- Across the whole public sector, government spends about £14 billion a year on new and existing information technology and related services, directly employs about 50,000 professionals in this field, and is one of the largest customers of the technology industry.
- Behind the scenes virtually every public service depends upon large-scale ICT processes and technology, particularly the large and complex transactional systems that support individual front-line public services.
- A new Shared Services approach is needed to release efficiencies across the system and support delivery more focussed on customer needs. Particular attention should be paid to the following areas:
    - Common Infrastructure;
    - Data Sharing: data sharing is integral to transforming services and reducing administrative burdens on citizens and businesses;
    - Information Management: to facilitate the move towards more collaborative working on issues that involve a range of government organisations, common standards and practices for information management will be developed.

The term ***e-Infrastructure*** is used to denote the digital equipment, software, services, tools, portals, deployments, operational teams, support services and training that provide data, communication and computational services to researchers. An e-Infrastructure is usually multi-purpose and has to be a sustained and dependable facility so that researchers can plan to use it for the duration of their work. Growing researcher expectations and continuous digital-technology and information-system innovation generate requirements for incremental enhancement.

Figure 3. e-Infrastructure—a shared platform for research.

The CIR Strategy is congruent with these Cabinet Office goals, in particular it sets out to produce economies through sharing assets in the context of research and proposes that the shared provision should be strongly steered by researchers. It is also designed to pioneer the technologies and methods and to produce the skills and cultural change that will be needed by the shared services envisaged in that paper.

e-Infrastructure Provision and Support

The report, *Science & Innovation Investment Framework 2004–2014*,[12] set out the requirement for an effective e-Infrastructure (see Figure 3) to enable the UKRC to conduct highly productive research and innovation, and highlighted the central role of interdisciplinary and collaborative research.

In response to the report, working groups established by the Office of Science and Innovation (OSI) outlined the elements needed to provide adequate e-Infrastructure, *Developing the UK's e-Infrastructure for Science and Innovation, March 2007*[13] which states:

> The growth of the UK's knowledge-based economy depends significantly upon the continued support of the research community and in particular its activities to engage with industry and to apply its world-leading innovations to commercial use. A national e-Infrastructure for research provides a vital foundation for the UK's science base, supporting not only rapidly advancing technological developments, but also the increasing possibilities for knowledge transfer and the creation of wealth.

The report's key recommendations are that the UK's e-infrastructure should provide researchers with:

- access to the systems, services, networks and resources that they need at the point that they need them;
- facilities to discover resources easily and use them appropriately;
- confidence in the integrity, authenticity and quality of the services and resources they use;
- assurance that their outputs will be accessible now and in the future;
- location-independent physical infrastructure for combining computation and information from multiple data sources;
- advanced technologies to support collaborative research;
- training and skills needed to exploit the services and resources available to them;

- the power of advanced information technologies and applications to continuously enhance the process of research itself;
- secure collaboration and communication;
- shared research outputs; and
- engagement with industry in support of wider economic goals.

It is essential to appreciate that infrastructures, including the e-Infrastructure for research, are not built 'top-down' to the dictates of a master plan but grow from the 'bottom-up' through the efforts of a wide range of players and stakeholders.[14] The Strategy must nurture that growth by providing a context for recognising changes in requirements, by analysing options and by supporting exploration and diversity. The mechanisms employed have to be sensitive to researchers' goals, to economic pressures and to governmentally agreed priorities. They have to take full account of the international context and commercial activity, they need to be judicious in their progress towards agreed commonalities, policies, standards and shared resources, and be backed by sufficient resources to provide incentives for change to gain coherence and adoption.

Existing Elements of e-Infrastructure

The growth of the UK's future e-Infrastructure must start from existing infrastructure in order to support and engage research communities and to retain the value of major UK investments. The following examples illustrate the facilities and services that should be considered as foundation elements of e-Infrastructure.

- The national SuperJanet provision sustained by Ja.net.[15]
- Data collections, such as those that are managed at the European Bioinformatics Institute,[16] the British Atmospheric Data Centre,[17] Mimas[18] and EDINA.[19]
- Computational provisions, including large clusters in many universities, HPCx[20] and the HECToR capability HEC provision.[21]
- The National Grid Service,[22] which provides several clusters and interconnects other facilities, including university campus grids.
- Community specific e-Infrastructures, such as GridPP[23] and the NERC Data Grid.[24]
- Digital libraries with content supporting research, such as ePrints;[25] supported by advisory centres: UKOLN[26] and the Digital Curation Centre.[27]
- Organisations which develop and curate software that is needed for research, including the National HEC programmes, the Collaborative Computational Projects,[28] and OMII-UK.[29]
- Organisations which support the development of user communities, such as, NCeSS, NERC e-Science Centre at Reading, National e-Science Centre and regional e-Science Centres.

HEFCE is funding a study into the provision of shared data services, the UK Research Data Service, with the intention to establish a national data repository which complements local stores.[30] These varied and independent elements of UK e-Infrastructure, of which the above are just a small example, are used by their own communities and exhibit a wide variety of access policies, interfaces and standards. The CIR will benefit from mechanisms, which, by encouraging the adoption of standards, will ensure interoperability between these different elements.

Digital-systems judgement: is an understanding of how large and long-lived digital systems, such as shared data services and distributed computational modelling services work, and of how to use them wisely and productively. It should include practical appreciation of security, ethical and other socio-economic issues, and the strengths and weaknesses of statistical, logical, process, stochastic and numerical models. It should include an understanding of the strategies for data organisation, curation, interpretation and analysis. This is not about developing programmers; it is about developing people who can think about and work effectively in an environment rich in information and in computational systems. Digital-systems judgement will also equip people to interact effectively with the professional engineers who design, create and maintain information systems and will strengthen the pool of inventors who create new methods and technologies.

Figure 4. Digital-systems judgement—key understanding for CIR.

Educational Strategy

In 2006, Jeanette Wing stimulated discussion and engagement in education to develop 'computational thinking'.[31] This is a part of an agenda needed in education called 'digital-systems judgement' (see Figure 4), and relates directly to the CIR strategy.

There is widespread recognition that there is a shortage of required ICT skills, for example:

- OECD[32] and World Bank[33] country studies have confirmed an obvious correlation between investment in education and quality of life and GDP;
- the EC has recognised ICT as key to a knowledge-based economy and social cohesion, and so it must have a place in education and training;[34] and
- the recent EU review of progress towards realising the Lisbon vision identifies the need for education to equip the research community, 'How could the specific education and training needs of researchers be addressed at all stages of their careers, starting with post-graduate and doctoral curricula, building on the Bologna process for higher education?'.[35]

Several bodies are considering the educational strategies required for the Century of Information, including:

- the e-Infrastructure Reflection Group,[36] Education and Training Task Force;
- the Open Grid Forum,[37] Education and Training Community Group;[38] and
- the EU project, International Collaboration to Extend and Advance Grid Education.[39]

The educational requirements for the Century of Information span a much broader range of skills and disciplines and will benefit from an integrated approach that encourages synergy between educational initiatives and mobility of skills.

CIR Mission and Actions

The CIR Strategy prepares a path for the UK to develop the culture, skill base, infrastructure, facilities and resources to exploit opportunities which arise in the Century of Information.

CIR Strategy Mission

The CIR mission is to guide UK investment and effort in Century-of-Information Research to achieve the best effects in: research and innovation, education and business to the benefit of UK citizens and the economy.

The success of the CIR Strategy will be vitally dependent on keeping three strands of progress evolving together so that they are mutually supportive:

1. innovation in and provision for research methods and the technology that supports those methods;
2. translation into transformative, effective and fluent use—in research, education, business, government and social actions—through knowledge transfer, people movement and collaborative exploitation channels; and
3. capability development through education and training delivering more participants in research and innovation, who are better prepared to engage in the research or to exploit the results.

CIR Strategy Goals

The goals of the CIR strategy are as follows.

1. Work with researchers to develop requirements and the business case for meeting those requirements—a quinquennial planning cycle is needed.
2. Work with providers, technologists, Research Councils (and other research funders) and Higher Education Funding Councils to balance cost-effective provision of e-Infrastructure with the priority of enabling the best possible research.
3. Work with educators and education policy makers to encourage the development of the knowledge and skills to exploit new information-intensive research methods and develop the ability to invent new methods and the digital and computational systems that support them.
4. Ensure that an easily used, pervasive, and sustainable national e-Infrastructure is provided for all researchers, that includes the required data, computational, software and digital-communication facilities with adequate support for people using those facilities.
5. Negotiate with other providers of research facilities and e-Infrastructure, in the UK and internationally, to harmonise provision and increase interoperability.
6. Generate capacity, propagate knowledge and develop a culture for Century-of-Information life via updated curricula in the majority of university disciplines.
7. Work with professional bodies and the institutions that employ researchers to develop the recognition of and preparation for the new forms of research and to ensure that achievement in interdisciplinary and information-intensive research is valued well.
8. Support and catalyse innovation that generates and enables new research methods and the technology necessary to support them.
9. Enlarge the productive research community across academia and industry who fluently use the new research methods to make significant advances in their field.
10. Create an educational programme that increases the skill base so that the UK is better able to create and exploit new research methods.
11. Monitor the impact and provisions of the CIR Strategy and ensure that the Strategy is achieving its goals and that the provisions are cost effective.

12. Commission periodic strategic reviews to examine the position of the UK in global research and review whether the necessary investments are in place by the Research Councils and others to ensure that the UK's relative position is at least maintained and preferably enhanced in a cost-effective way.
13. Work with business to establish better pathways for the exploitation of CIR-enabled discoveries.
14. Establish consultative processes on the ethics of information-intensive research methods.

As the CIR Strategy is intentionally transformative, and as there is such a range of interests concerned, a strategic coordination is required to balance the interests of all of the stakeholders and to facilitate the growth of UK research and innovation.

Transforming the UK in the Century of Information

Researchers

Empirical science dates back thousands of years, theoretical and predictive science started a few hundred years ago, and in the last few decades there has been the advent of computational science, which enables the simulation and modelling of complex phenomena. Scientific research today unifies empirical science, theory and simulation. Often it is focused on data; data captured by instruments and researchers, data generated by simulations, models, sensor networks and as the side effects of people going about their daily lives. The same unification is happening across many areas of research outside science, and exciting new opportunities are emerging. The CIR Strategy has the potential to transform all research.

In the Century of Information, there is rapid change in both the research and digital economy worlds. It is estimated that more data will be created in the next five years than through human kind's entire history. The challenge for society is to be able to collect new datasets, to discover specific datasets, to combine the datasets, to undertake new types of computationally intensive analysis, to visualise the output, and thereby to extract significant information and knowledge. This is transforming not only how researchers from science, arts, humanities and social scientists do their work, but also what they will discover, with whom they will collaborate, how they will share work, how they will report their findings, and what know-how they will require. These changes are already reflected in business, with a growing awareness of the opportunities and risks associated with our ability, or lack thereof, to process increasing amounts of disparate data.

The e-Science Programme demonstrated how the challenge would be addressed, but it delivered in a bespoke mode for a small sample of pioneering researchers. To thrive in the Century of Information the UK must empower researchers such that the use of these techniques is fluent for all that need them.

The Century-of-Information Research Strategy recognises that empowering researchers requires support for a continuous mode of method and technology innovation. Researchers in all fields will drive this process. Researchers will constantly encounter new problems that demand new methods and technology. Computer scientists and engineers will continually deliver new *potential* elements of their solution. The research platform must therefore be dynamic and evolving. It must support the continuous invention, development, deployment and evaluation of new

methods. Frequently this will require adoption of international standards, which the UK must continue to influence for the benefit of its research, industry and citizenry.

Benefits

The CIR Strategy is directed at both supporting advanced research and providing translation mechanisms to ensure the resulting benefits are delivered to a much wider research community and society as a whole. It has to enable significant advances in world-leading research and support the broader communities that support these advances and exploit breakthroughs.

Education and Skills

The school education system should prepare school leavers for an information society and help extend to a wider public the understanding of e-Science initiated research methods so that well-informed debate can help in the development of public trust. A broad campaign is needed to develop a culture which makes as much of the digital data as possible available for research use and review—including data from publicly funded research and data that underpins governmental decisions and policy. A consensus has to be established as to the ethical, privacy and security issues that constrain access or use.

This category of understanding and skills is referred to as '*digital-systems judgement*'; it is important to equip UK citizens to be able to make decisions about the digital systems that will underpin almost every activity and process in the Century of Information; this will demand a wide range of skills.

Elements of Future e-Infrastructure

A future e-Infrastructure for researchers will include: digital equipment, software, services, tools, portals, deployments, operational teams, support services and training that provide data, communication and computational services. The SUPER report[40] highlighted the need for community-focussed support which provides strategic and practical advice to researchers. The OSI working group reports[41] provided a preliminary analysis of requirements and a recognition of the existing elements of e-Infrastructure on which the strategy should build and bring together into a coherent framework.

The e-Infrastructure challenges that must be addressed by the CIR Strategy are as follows.

1. *Ease of use*, a prerequisite for expanding and accelerating the take up of computational and data-intensive methods. As more researchers from more disciplines try to use diverse digital resources in combination they may be thwarted by apparently arbitrary policy and interface variations that may already be accepted by the original users. As researchers gain experience of well-supported Web services, such as Google, Wikipedia, YouTube, Flikr and FaceBook, their expectations for ease of use and interfaces will rise.
2. *Sustainability*, crucial to enable adoption and effective use—but not every service can be sustained indefinitely; hence a long-term plan is needed encompassing provision, funding and withdrawal of superseded services and those that are no longer cost effective.

3. *Capacity* balanced across the infrastructure is essential for fluent use by a growing community of researchers.
4. *Evolution* of the services, facilities, tools and knowledge of the support teams must keep pace with the advances in methods so that the majority of researchers can meet their needs with modest effort proportional to the complexity of their goals.
5. *Efficiency, cost-effectiveness and green computing* have to be demonstrably addressed without compelling researchers and institutions to use the pooled or common provision.
6. *Support for extreme e-Science* must empower those gifted researchers who choose to pioneer new ways of building and composing models, of exploring and analysing data, of working collaboratively, of pushing the scale and complexity boundaries. Supporting researchers who invent new methods, in all disciplines and in all scales and modes of research, is essential for seeding the next rounds of innovation.

The steps that the CIR Strategy must include to develop a future e-Infrastructure are as follows.

1. Progressively draw in and integrate existing providers, such as the national data services, the National Grid Service, the data providers, the digital libraries and the legacy services, such as the particle physics community's grid, GridPP.
2. Organise a long-term planning cycle in agreement with the stakeholders that fund e-Infrastructure; conduct in close consultation with the research community and track delivery against goals.
3. Steer the delivery of the revised planning cycle to minimise disruption of ongoing research and to gain the maximum benefits from negotiated international collaboration.
4. Establish operating standards and common policies that provide harmonised services to facilitate interoperability, skill transfer and staff mobility.

Societal Factors

The UK government's priorities described previously in 'Empowering UK Research', are motivated by the urgent need to address a series of unprecedented challenges which face the UK's citizens and economy. As outlined above, the CIR Strategy is designed to empower the UK research community to meet these challenges. By doing so, the CIR Strategy will inevitably contribute to broader societal benefits, and will help to address the following.

- Many of the obstacles to realising the full potential of the Century-of-Information Research will be primarily social rather than technical. An important example is the disincentives that researchers may sometimes perceive when contemplating participating in interdisciplinary projects.[42]
- Driving forward research increasingly depends on collective action by international research community members. For example, many of the major challenges require *sustained and collaborative* effort, often across disciplines and nations. This requires new modes of *social* research behaviour, well illustrated in projects such as the decoding of the Human Genome and the development of experiments for the Large Hadron Collider.
- The number of users of the UK e-Infrastructure will approach a million (still fewer than the number of students) and it is highly desirable to develop group

dynamics that positively encourage the uptake of e-Science methods, and to invest in observation of the process.

Increasing Engagement

In order to accelerate the uptake of new methods an effective communication and training programme is required. In part, this will be delivered through the universities supported by JISC. The SUPER report identified many cases where researchers were not aware of the facilities, methods and training already available.[43] Addressing this communication and training deficit is an urgent and essential part of the change management necessary to transform a significant proportion of UK research.

Empowering UK Research

A primary goal of the CIR Strategy is to enhance the UK research community's ability to achieve and excel. The publication by the DIUS of *The Allocations of the Science Budget 2008/9 to 2010/11* presents a major portion of the nationally agreed research priorities. Each UK Research Council has also published its delivery plan. A balance is needed between the agile, researcher-led processes that are essential for establishing the innovative potential of new technologies and the more slow moving provider-led processes that are important for nurturing the standards which help to guarantee interoperability and sustainability.

Other organisations, such as the research funding charitable trusts, the Technology Strategy Board, and other government departments also set research goals. International programmes, for example the European Union's Seventh Framework Programme, also affect the UK research context. Analysis of goals from these sources of research funds, and the need for coordination to meet these goals, provides further evidence for the value of the CIR Strategy.

In many cases, world leadership depends on research teams having the relevant skills—the CIR Strategy will develop this capability by creating the insights and skills that will enable teams to make the best use of the plethora of information resources and computational methods.

Facilitating Cross-Council Programmes

The CIR Strategy will develop a crucial, innovative, way of thinking that will contribute to each cross-council programme. One example of this is the Digital Economy programme.

Digital Economy

The description of the cross-cutting Digital Economy programme given in *The Digital Economy Programme*[44] is congruent with the CIR Strategy—they both address the same aspirations for research, innovation, commerce and the economy. Quoting from the report:

- Early adoption of Information and Communications Technology (ICT) tools supported by research capacity and skilled people, better positions the country to reap the economic and social advantage of technological change.

- ICT is everywhere. It is embedded in every aspect of our lives, Business, Government, the Health Service, and other users depend on how we capture, manipulate and share information. ICT has the power to transform the way business operates, the way that government can deliver, and the way science is undertaken to improve life.
- The Digital Economy programme will link the world-class ICT research base with the other disciplines needed to deliver its benefits and match those with a strong user pull to deliver multidisciplinary, user focussed research aimed at building a base of expertise to put the UK at the forefront of the digital technology. Through the Digital Economy programme we will make a step-change in the type of industrial engagement to pursue key research challenges so that the transformational possibilities of ICT are employed to support the innovation cycle. The initiative (involving the EPSRC, AHRC, ESRC and MRC) will concentrate on areas where the management and presentation of information can have maximum transformational impact: healthcare, transport and the creative industries.

The CIR Strategy adds a coordinating and effort-pooling dimension that will benefit the Digital Economy programme. It targets long-term effects, including improving the capability of the research community, and a pervasive impact on education. It will achieve a broad impact on the skills base required by the Digital Economy programme.

The Next Steps

More detailed plans are needed to set out the ways in which all of the stakeholders should develop the CIR Strategy and establish a commitment to its goals. The existing working group will complete its documentation shortly, and plans are in place to move to a new phase to take the strategy forward through a consensual approach with broad engagement. Details are available at: http://wikis.nesc.ac.uk/escienvoy/Century_of_Information_Research_Strategy.

Notes and References

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