



Century-of-Information Research – a Strategy for Research and Innovation in the Century of Information

[Link to publication record in Manchester Research Explorer](#)

Citation for published version (APA):

Atkinson, M. P., Britton, D., De, R. DE., Garnett, N., Geddes, N., Gurney, R., Haines, K., Hughes, L., Jeffreys, P., Perrott, R., Procter, RN., & Trefethen, A. E. (2008). *Century-of-Information Research – a Strategy for Research and Innovation in the Century of Information*. No publisher name.

Citing this paper

Please note that where the full-text provided on Manchester Research Explorer is the Author Accepted Manuscript or Proof version this may differ from the final Published version. If citing, it is advised that you check and use the publisher's definitive version.

General rights

Copyright and moral rights for the publications made accessible in the Research Explorer are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Takedown policy

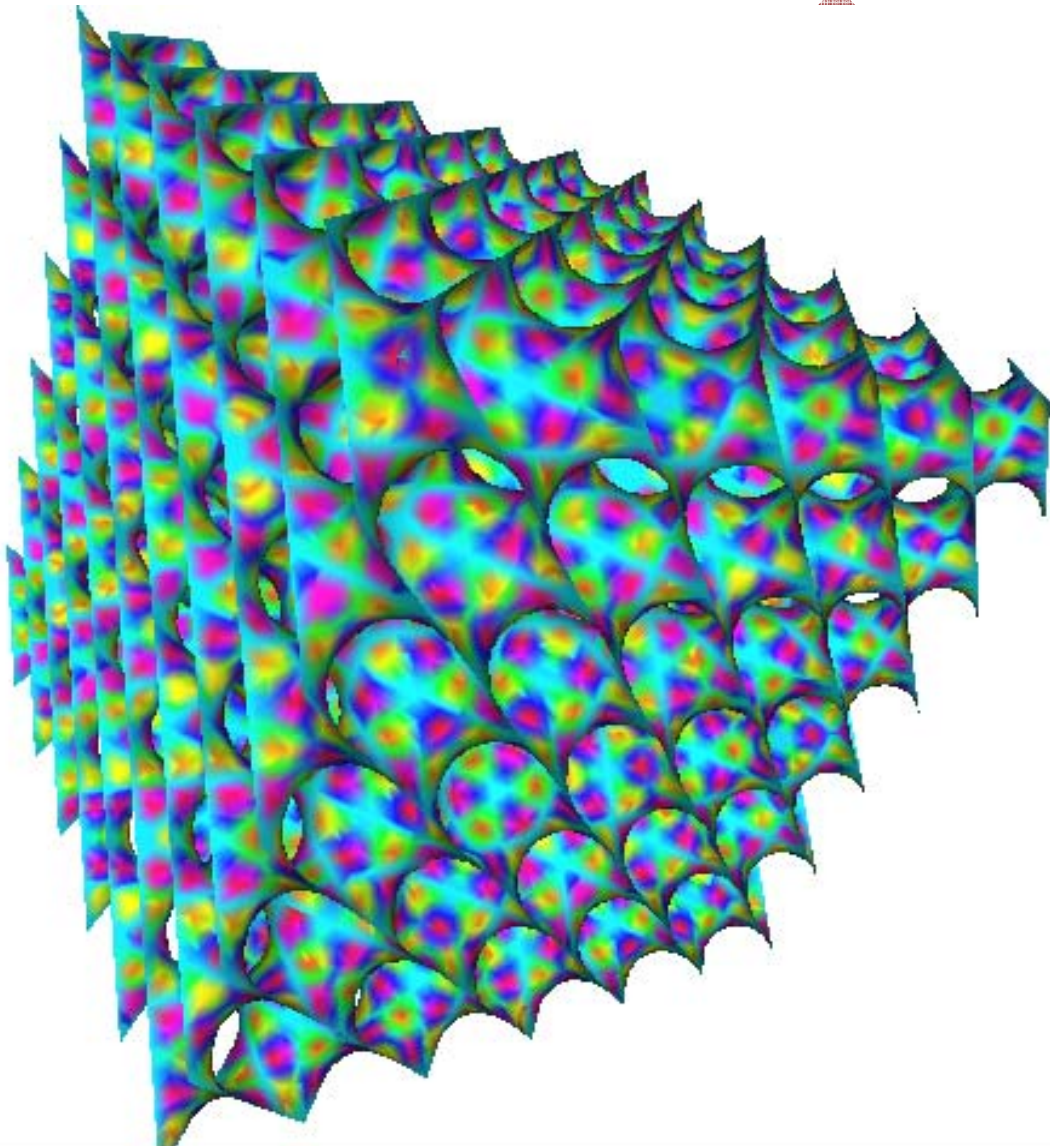
If you believe that this document breaches copyright please refer to the University of Manchester's Takedown Procedures [<http://man.ac.uk/04Y6Bo>] or contact uml.scholarlycommunications@manchester.ac.uk providing relevant details, so we can investigate your claim.



Century-of-Information Research (CIR)

A Strategy for Research and Innovation in the Century of Information¹

11th March 2008



¹ Please cite this *draft* document as: Atkinson *et al.*, “Century-of-Information Research – a Strategy for Research and Innovation in the Century of Information (CIR3), March 2008, http://wikis.nesc.ac.uk/escienvoy/Century_of_Information_Research_Strategy_%28CIR%29:_a_strategy_to_meet_the_research_challenges_and_opportunities_in_the_century_of_information

Executive Summary

It is estimated that 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 scientists throughout the UK research communities, a coherent strategy has been developed and presented here, which would nurture Century of Information Research (CIR).

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 judgement from the undergraduate level onwards that will equip research communities, businesses, government and society as 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 and industry. The Strategy is designed to enable these communities to meet challenges, to create knowledge and skills, and to exploit new opportunities. This proposal is a call to action for those engaged in research, those providing digital and computational facilities, those governing research and those shaping education policies. The aim is to strengthen the international competitiveness of the UK science base and increase its contribution to the economy.

The objectives of the proposed Strategy are to enable the UK to contribute world-leading fundamental research; to accelerate the translation of research into applications; and to develop improved capabilities, facilities and context for research and innovation. It envisages a culture that is better able to grasp the opportunities provided by the growing wealth of digital information. Computing has become a fundamental tool in all research disciplines, often preceded by assembling and managing large data collections and by exploiting computer models and simulations (a topic called e-Science). The e Science initiative enabled experts to invent and use new research methods and to demonstrate what is possible. The Strategy argues that the UK must now harness and leverage its own, plus the global, investment in digital technology in order to spread the benefits as widely as possible in research, education, industry and government.

The outcome of the Strategy would be to deliver the computational infrastructure and its benefits as envisaged in “*Science & innovation investment framework 2004–2014, July 2004*”, [HMG04] and the reports that have developed those proposals (see Chapter 2).

To achieve this, the Strategy proposes the following actions (see Chapter 3):

1. *Establish an Office of Strategic Coordination of Century-of-Information Research,*
2. *Support the continuous innovation of ICT-enabled research methods,*
3. *Provide easily used, pervasive and sustained e-Infrastructure for all research,*
4. *Enlarge the productive research community who exploit the new methods efficiently,*
5. *Generate capacity, propagate knowledge and develop skills via new curricula.*

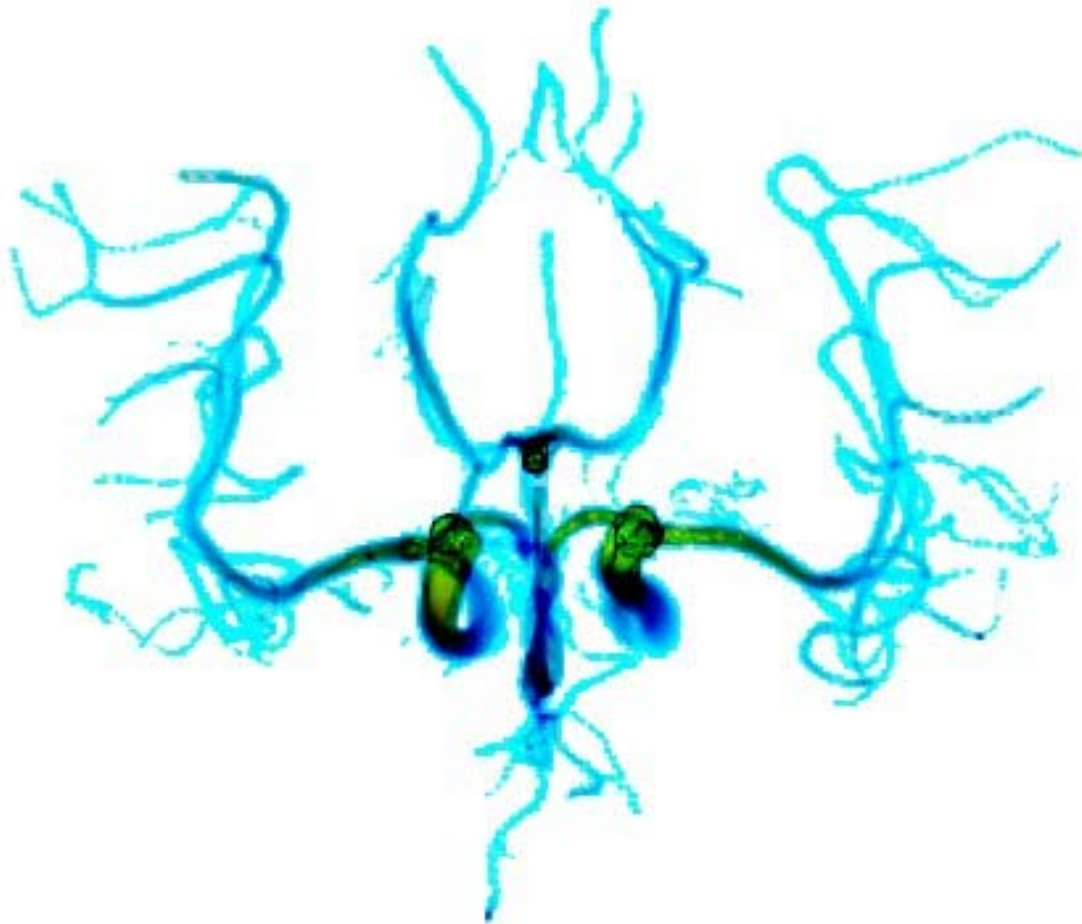
The intended benefits to research, education, society and government (see Chapter 4) align with the goals of the DIUS research priorities and announced research council plans (see Chapter 5).

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 expertly used to shape policy, support decisions and empower research. 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, maintenance, 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 in industry, or to extract knowledge in support of government decision making. This foundation plus the developed skills will launch many significant advances in research, in business and in the lives of UK citizens. The Strategy presented here, developed on behalf of the UK researchers, tries to address these complex and interlocking requirements.

Contents

Executive Summary	2
Contents.....	3
1. Introduction.....	5
1.1. Purpose of the CIR Strategy.....	5
1.2. Potential of Research in the Century of Information	6
1.3. Risk from Inaction	7
1.4. Required Actions	7
1.5. The Future with Century-of-Information Research.....	9
1.5.1. The ESFRI Roadmap – a portent of the changing context	11
2. Context for the CIR Strategy.....	17
2.1. Existing Strategic Coordination	18
2.2. Existing Support for Research Method Innovation	19
2.3. e-Infrastructure Provision and Support	20
2.3.1. Existing Elements of e-Infrastructure.....	20
2.4. Existing Outreach Strategy	21
2.5. Existing Educational Strategy	22
3. Action Now	24
3.1. Office for Strategic Coordination of CIR.....	24
3.1.1. OSCCIR Composition.....	25
3.1.2. OSCCIR Mission	25
3.1.3. OSCCIR Goals.....	25
3.1.4. OSCCIR Scope	26
3.1.5. OSCCIR Staff and Resources.....	27
3.2. Continuous Research-Method Innovation.....	28
3.3. Provision of Sustained e-Infrastructure.....	29
3.4. Enlarging the Community	32
3.5. Education for Century of Information Research.....	33
3.6. Example Target Attainments.....	35
4. Empowering UK Researchers.....	36
4.1. Research Benefits.....	36
4.2. Education and Skills Benefits	37
4.3. Societal Benefits	38
5. Empowering UK Research.....	41
5.1. Facilitating Cross-Council Programmes	41
5.1.1. Energy	41
5.1.2. Living With Environmental Change (LWEC).....	42
5.1.3. Global Threats to Security.....	43
5.1.4. Ageing: Lifelong Health and Wellbeing	43
5.2. Facilitating Research Council Delivery Plans.....	44
5.2.1. Digital Economy	44
5.2.2. NanoScience through Engineering to Application	44
5.2.3. Arts and Humanities Research Council.....	45
5.2.4. Biotechnology and Biological Sciences Research Council	45
5.2.5. Economic and Social Research Council.....	45
5.2.6. Engineering and Physical Sciences Research Council	45
5.2.7. Medical Research Council	46
5.2.8. Natural Environment Research Council	47
5.2.9. Science and Technologies Facilities Council	47
5.3. Requirement for Incremental Contributions	48
References	50

CIR Strategy working group members..... 52



Representation of the velocity magnitude flow field pertaining to a cerebral patient specific vascular tree and simulated with HemeLB. An example of urgent computing for diagnosis and treatment planning [Manos *et al.* 08].

1. Introduction

The CIR Strategy was developed by considering the requirements for research; the priorities defined by the government and its research councils (see Chapter 5) and an understanding of the power of computational and data intensive methods to transform research and deliver invaluable benefits to the UK economy and citizens.

The CIR Strategy and this document are being developed by a strategy working group set up by the UK e-Science Directors' Forum. It is open for comment and consultation – either contact Malcolm Atkinson (mpa@nesc.ac.uk) or add comments on the wiki, which also contains information about the working group membership, its consultations and other documents (http://wikis.nesc.ac.uk/escienvoy/Century_of_Information_Research_Strategy).

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 ICT-enabled methods into productive use and to encourage increasing numbers of researchers and innovators who are adopting and exploiting those methods. It proposes a sustained programme of education to prepare the community both technically and culturally. It addresses the need for investment in supporting emergent community effects as well as in new technology. It 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, 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, those who lead and undertake research and the educators that develop the UK's capabilities for research and the culture within which that research is conducted.

1.1. 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. Today's research challenges demand adroit exploitation of these new possibilities.

The Prime Minister, Gordon Brown, recently observed, "This is the Century of Information." [Brown07]. 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 *Research in the Century of Information* will address these requirements and improve understanding of how digital technology may be exploited to the greatest advantage.

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.

The Strategy will enable innovation in digital 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;*
2. *The rapid translation of successful methods into supported tools and productive services ready for extensive use;* and

3. *The attraction and induction of 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.*

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 ICT 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 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 the healthy ambient research achievements across all Research Councils (see box). However, the international competition is positioning itself to overtake the UK rapidly as they copy and invest in *coordinated* programmes to accelerate and transform their research — an eminent example is the USA’s NSF Cyberinfrastructure programme [NSF07].

e-Science is the invention and application of computer-enabled methods to achieve new, better, faster or more efficient research in any discipline. It draws on advances in computing science, computation and digital communications. As such it has been 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 Strategy for Century-of-Information Research will build.

In all disciplines, increasing amounts of data are being created with the use of public funds. These 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*. [DIUS07]

Following the Strategy will make it increasingly easy for researchers to use new digital resources and methods routinely. It will lead those who provide resources for research — including Research Councils, Technology Strategy Board, Charities, Joint Information Systems Committee and universities — to establish a *coordinated* framework supporting an environment where UK research and innovation will continue to 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.

1.2. Potential of Research in the Century of Information

The delivery plans for each of the UK Research Councils for the period 2008 to 2011 identify challenges that demand advances in the exploitation of complex data, the development of interconnected computational models and multidisciplinary collaboration. Advances in the ways the UK exploits the power of the new digital technologies are key elements for addressing the Government’s crosscutting priorities (see Chapter 5).

The e-Science programme has provided a valuable crucible for method innovation drawing on the expertise of both researchers within a given application domain and within computer science. As common requirements are established, the provision of an emerging

e-Infrastructure delivers a stronger platform for future innovation. This 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 found 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.

The architecture of e-Infrastructure provision must first and foremost allow easy and rapid uptake and thus engender community effects — the benefits achieved as a consequence of the scale of user engagement, especially in terms of developing self-sustaining activity. It must establish the correct balance between research-led diversity and provider-led interoperability.

The term “Cyberinfrastructure”, a parallel activity in the United States, possibly understates the importance of supporting collaborative and community behaviour; however, the definition of cyberinfrastructure used by the NSF makes the breadth of requirements and expected impact clear [NSF07].

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 organizations, and observatories, along with an interoperable suite of software services and tools. This technology is complemented by the interdisciplinary teams of professionals that are responsible for its development, deployment and its use in transformative approaches to scientific and 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.

1.3. 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 planned provision, interdisciplinary cross-fertilisation and community effects.
2. *Poor return on investment* as opportunities for sharing are lost and as duplication and excessive fragmentation in communities, processes, provision and outcomes favours independent initiatives — whose outputs are hard to aggregate — compared with those from a coordinated research environment.
3. *Lack of dissemination about the approaches used by researchers* in the Century of Information.
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.

1.4. Required Actions

The CIR Strategy requires the following actions (elaborated further in Chapter 3):

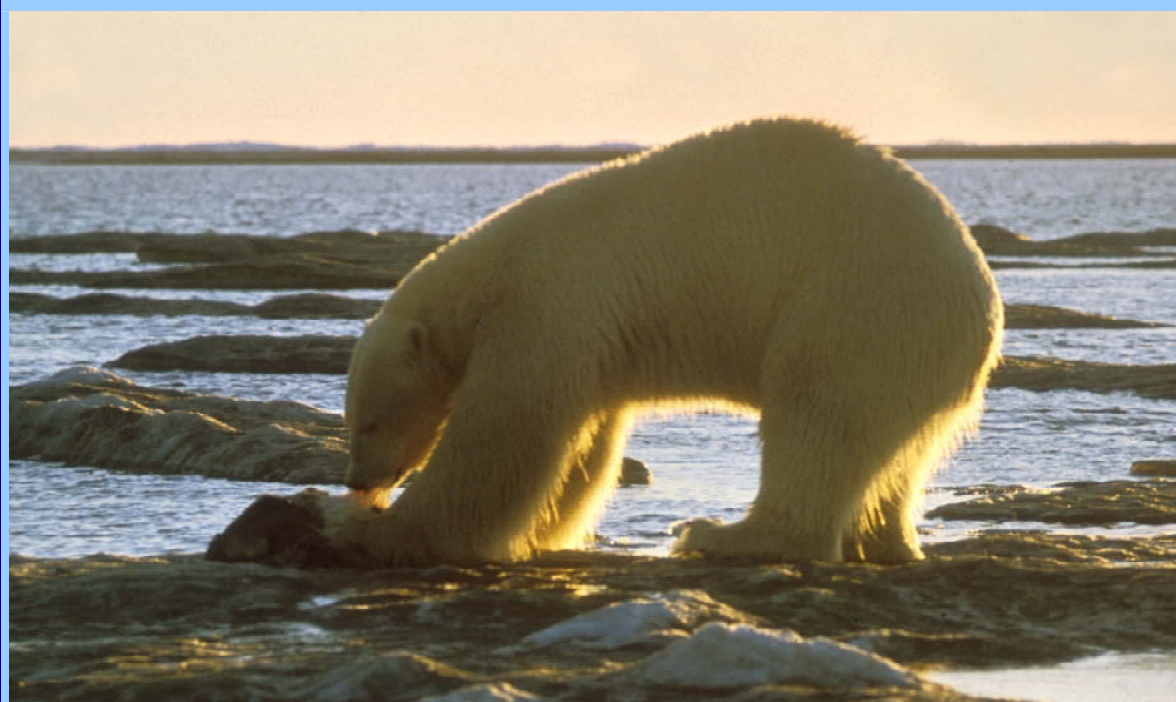
1. *Establish an Office of Strategic Coordination of Century-of-Information Research* that is responsible for the long-term guidance and coordination of the provisions for Century-of-Information Research. It will encourage and coordinate federations to

consolidate existing digital resources, to extend the digital infrastructure and to stimulate the use of these facilities and the new methods they enable. It will encourage the uptake of standards and represent the UK internationally to facilitate collaboration and innovation across boundaries.

2. *Support the continuous innovation of research methods* by encouraging and supporting the required interdisciplinary research, by supporting the retention and integration of the new methods and by ensuring that skills needed for this research are developed and properly valued.
3. *Provide an easily used, pervasive and sustainable e-Infrastructure for all research* that includes the required data, computational, software and communication facilities with adequate support for those using the facilities and to support the evolution of the e-Infrastructure to incorporate successful innovations in research methods.
4. *Enlarge the productive research community* in both industry and academia by a programme of outreach and training that ensures those whose research would benefit from the new methods and advances in e-Infrastructure are quickly informed of their potential and are assisted in adopting them when they choose to do so.
5. *Generate capacity, propagate knowledge and develop a culture* for Century-of-Information life, including research via updated curricula in the majority of university disciplines.

Chapter 4 presents the benefits that these actions will deliver and Chapter 5 indicates how they align with and support the announced UK research priorities and programmes.

Understanding climate change and planning to mitigate its impacts? (NERC & DEFRA)



Accurate prediction of the future environment depends on the development of computer-based models to simulate how the environment will respond to certain scenarios. That requires:

- an understanding of the dynamics of environmental processes;
- high quality data sets to validate the models;
- computational infrastructure to run the models and to manage large volumes of data;
- the resources to run the models many times in 'ensembles' to quantify their uncertainty associated;
- and the ability to visualise and analyse the result.

1.5. The Future with Century-of-Information Research

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 the 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 have developed 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. The CIR Strategy is committed to driving the innovations that make this possible, stimulating the education that will develop wide capabilities in exploiting these innovations and to ensuring the translation of innovation from breakthrough to widespread use.

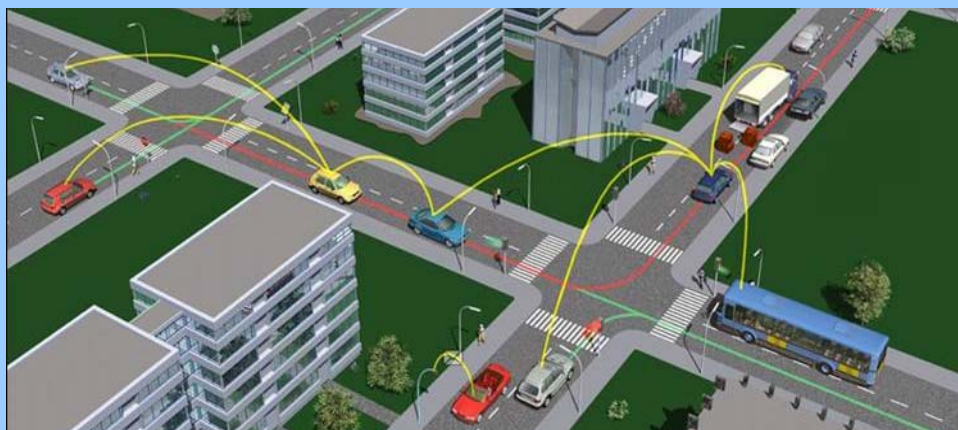
The CIR Strategy will evolve in the context of powerful changes in the global digital economy and the ways in which research is undertaken. The Strategy is designed to take best advantage of these changes and to secure the UK's role as they occur. Many of the forces for change are already visible while others are at present unanticipated. The nature and pace of change are illustrated below.

- *By 2020 there will be community support for advanced work.* When a broad spectrum of tasks is well supported there will still be significant challenges in making advances, dealing with more complex data, combining more precise models and supporting hard decisions. Many of these tasks are intrinsically difficult and depend on a rare combination of deep insight about the field of study and adept manipulation of the available components. Those who develop such insights need to be able to build their explorations drawing on previous experience with their familiar tools, components and data. This will be one of the engines of innovation that power the evolution of the technology and methods in research, business and government.
- *Research will be increasingly a collaborative undertaking.* Whilst leadership and insights will still depend on gifted individual researchers, the scale of challenges and the resources that are needed will demand coordinated research effort. To reach critical mass and to assemble all of the required skills and knowledge many teams will be international. Many of these teams will draw on the whole European Research Area. This is illustrated in the ESFRI road map examples in the Table below.
- *By 2020 research will depend 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. By 2010 the world will store a collection of a zetta byte (1,000,000,000,000,000,000 bytes) of digital data [Gantz07]. See the expected data outputs of the ESFRI road map projects below.
- *By 2020 research will depend on pervasive access to computational, communication and data storage services* that will be accessed when needed as the user triggers actions that require their power. By 2015 we envisage one million users in the UK, using between them 10 petaflops of computing power, which will have to be provided using a minimum carbon emission strategy.
- *By 2020 professional decision makers and researchers will share a rich ecosystem of evolving tools and services* that compete and cooperate to provide the analyses, modelling power, information and advice that users seek. Users will have their favourites. The specialist consumer columns and *Which?* magazine will compare them.
- *By 2020 every student will develop skills and judgement in using these systems* with universities producing graduates who have well-developed strategies for exploiting them,

and with a significant proportion well equipped to innovate to produce further advances in information and computation exploitation.

- *By 2020 all popular information manipulating tools*, such as browsers, spreadsheets, image processors, bioinformatics systems, statistical packages, design tools and mathematics packages, will draw on these computation and information services in ways that are virtually invisible to the user for routine daily tasks.
- *New community behaviours will emerge* across both public and private sector groups, people will collaborate and compete 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.
- *Investment in translational research will enable transformative effects*. Research into how to transfer newly invented ICT methods into a variety of production contexts will address engineering challenges, the interaction with existing systems and community behaviour.
- *Real-time control of experiments*. Experiments planned for 2015 will reach femtosecond (10^{-15} seconds) observational and control cycles that can only be managed by direct coupling with computational models — ITER is a prime example².
- *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*. 64-core chips are nearing production and 1024-core chips will be marketed by 2012 [ZZZ]. Low-power technology and flexible displays based on nanotechnology will lead to devices with a wide range of sensors that will be worn routinely and distributed throughout the built environment by 2015 [XXX]. An integration of communication networks will enable continuous mobile connection to very high performance network backbones. The plethora of applications that this will open up in wellbeing, healthcare, environmental monitoring and many other domains is almost unbounded.
- *By 2020 the ICT platform that makes it all possible* will “come in the box” that the users buy. The large resources to meet the most challenging problems will still be needed, but they will be used in just the same way as the pervasive and nationally available facilities.

Exploiting mobile sensors and wireless communication to monitor pollution and manage traffic to limit the health risk? (EPSRC & DfT MESSAGE project)



Sensors on vehicles provide streams of data that are combined with meteorological information. Statistical analysis and computational models will then support agile and reliable decisions.

² www.iter.org

1.5.1. The ESFRI Roadmap – a portent of the changing context

The ESFRI roadmap is a strategic assessment of the European research infrastructure opportunities and requirements over the next 20 years that have broad endorsement as priorities from the Member States [ESFRI06]³. It is therefore indicative of the context in which the CIR Strategy must develop.

Summary of Planned ESFRI research infrastructure				
Name	Description	Data	Cost M€ ⁴	Start
Social Sciences and Humanities				
CESSDA ⁵ Council of European Social Science Data Archives	Access for researchers to high quality social science data 21 EU countries 15,000 data collections >20,000 researchers		30 / 6	2008
CLARIN ⁶ Common Language RI	Progressing towards an integrated and interoperable research infrastructure of language resources and technology enabling eHumanities		108 / 10	2008
DARIAH ⁷ Digital RI for the Arts and Humanities	Network of Data Centres and Services: Germany (Max Planck Society), France (CNRS), the Netherlands (DANS) and the United Kingdom (AHDS). Cultural heritage online		10 / 4	2008
EROHS European Resource Observatory for the Humanities and Social Sciences	A coherent, comprehensive and integrated observatory – 'the dream machine' of the humanities and social sciences –to guarantee the existence, accessibility and comparability of data at a European level.		43 / 12	2008
ESS ⁸ European Social Survey	Europe's changing institutions and the attitudes, beliefs and behaviour patterns of its diverse populations covering 30 nations		9 / 9	2007
SHARE ⁹ Survey of Health, Ageing and Retirement in Europe	Economic and social science analyses of the changes in Europe due to population ageing. All 27 member states will join		50 / <1	2007

³ The ESFRI initiated an update process in July 2007 and there are working parties looking at common e-Infrastructure requirements <http://cordis.europa.eu/esfri/roadmap.htm>.

⁴ Estimated construction / Estimated annual operational cost

⁵ www.gesis.org/en/cooperation/data_service/cessda.

⁶ www.mpi.nl/clarin.

⁷ www.dariah.eu.

⁸ www.europeansocialsurvey.org.

⁹ www.share-project.org.

Summary of Planned ESFRI research infrastructure (continued)				
Name	Description	Data	Cost M€	Start
Environmental Sciences				
EMSO ¹⁰	Deep sea-floor observatories deployed on five sites: west of Ireland, south of France, mid-Atlantic ridge (Azores), Arctic and west of Norway. Part of global, long-term monitoring of environmental processes: ecosystem, life and evolution, global changes and geo-hazards. Key component of GMES and GEOSS		150 / 20	2011
EUFAR ¹¹	European Fleet of instrument carrying aircraft for atmospheric observation		50 - 100 / 2 - 4	2007
EURO ARGO (Global) ¹²	European component of global ocean observing system, based on autonomous profiling floats throughout the deep ocean. Data are transmitted in real time by satellite to data centres for processing, management, and distribution.		76 / 6	2010
IAGOS-ERI ¹³ Integrated Global Atmospheric Chemistry Observations	Equip 20 long haul passenger aircraft with new instruments for O ₃ , CO, H ₂ O, NO _y , NO _x , CO ₂ , aerosol, and cloud particles. Operation for 20 years.		20 / 6	2008
ICOS ¹⁴ (Global) Integrated Carbon Observation System	Co-ordinated, integrated, long-term high quality observational data of the greenhouse balance of Europe and adjacent regions		255 / 13	2010
LIFEWATCH ¹⁵	Protection, management and sustainable use of biodiversity. Network of observatories, facilities for data integration and interoperability. Virtual laboratories offering a range of analytical and modelling tools. Service Centre providing special services for scientific and policy users, including training and research opportunities for young scientists.		370 / 70	2014

¹⁰ www.esonet-emso.org/emso.

¹¹ www.eufar.net.

¹² www.ifremer.fr/euro-argo.

¹³ www.igospartners.org/Atmosphere.htm.

¹⁴ icos-infrastructure.ipsl.jussieu.fr.

¹⁵ www.lifewatch.eu.

Summary of Planned ESFRI research infrastructure (continued)				
Name	Description	Data	Cost M€	Start
Energy				
HiPER ¹⁶ High Powered laser Energy Research	Large-scale laser system to demonstrate significant energy production from inertial fusion. Supporting a broad base of high power laser interaction science. Revolutionary approach to laser driven fusion known as "Fast Ignition"		850 / 80	2015
IFMIF (Global) ¹⁷ International Fusion Materials Irradiation Facility	Accelerator based very high flux neutron source to provide a suitable data based on irradiation effects on material needed for the construction of a fusion reactor		855 / 80	2017
JHR ¹⁸ Jules Horowitz Reactor	Material Testing Reactor to develop materials and nuclear fuel used in the nuclear industry		500 / 30	2014
Biomedical and Life Sciences				
EATRIS ¹⁹ European Advanced Translational Research Infrastructure in Medicine	<i>Pre-Clinical Development:</i> compound libraries; chemistry, modelling and systems biology; assay development; in vitro and in vivo models; biobanking and GMP production. <i>Clinical Validation:</i> platform for clinical trials (EORTC); molecular medicine; imaging, monitoring and biobanking		255 / 50	2010
European Bio-Banking and Biomolecular Resources ²⁰	Network of existing and de novo biobanks and biomolecular resources Samples from patients and healthy persons, molecular genomic resources and bioinformatics tools		170 / 15	2009
INFRA-FRONTIER ²¹	<i>Phenomefrontier:</i> in vivo imaging and data management tools, for phenotyping of medically relevant mouse models. <i>Archivefrontier:</i> state-of-the-art archiving and dissemination of mouse models (major upgrade of EMMA)		320 / 36	2007
Infrastructure for Clinical Trials and Biotherapy ²²	An initial core network (ECRIN) of six national partners already started identifying bottlenecks to multinational clinical studies across the EU. A major upgrade will provide a network of distributed infrastructures for clinical trials in the EU.		36 / 5	2007

¹⁶ www.hiper-laser.org.

¹⁷ www.frascati.enea.it/ifmif.

¹⁸ www.cadarache cea.fr/rjh.

¹⁹ www.eatris.eu.

²⁰ www.biobanks.eu.

²¹ www.infrafrontier.eu.

²² www.ecrin.org.

Summary of Planned ESFRI research infrastructure (continued)				
Name	Description	Data	Cost M€	Start
Biomedical and Life Sciences (continued)				
Integrated Structural Biology Infrastructure ²³	A framework consisting of distributed centres, each of which will maintain a set of core technologies such as protein production, NMR, crystallography and different forms of microscopy, including electron microscopy and combine this with a specific biological focus that will drive the development of technological and methodological expertise, notably for the analysis of functional complexes.		300 / 25	2007
Upgrade of European Bioinformatics Infrastructure ²⁴	The infrastructure will be a secure but rapidly evolving platform for data collection, storage, annotation, validation, dissemination and utilisation, for the life sciences. It will be a substantial upgrade to the existing European Bioinformatics Institute (EBI). It will integrate secondary data resources that are distributed across Europe.		550 / 7	2007
Material Sciences				
ELI			150 / 6	2013
European Synchrotron Radiation Facility Upgrade ²⁵	Shared by 17 European countries and Israel. Disciplines served include: physics, chemistry, materials science, biology, medicine, geophysics and archaeology. Industrial applications include: pharmaceuticals, cosmetics, petrochemicals and microelectronics.		230	2007-2014
ESS: European Spallation Source ²⁶	World's most powerful source of neutrons; built-in upgradeability; initial 20 instruments; with 4,000 users / year; 40-year life		1050 / 80	2009 First neutrons 2016
European X-ray Free Electron Laser ²⁷	Generates ~30,00 intense, short (<100femtosecond) pulses of coherent X-rays, peak power >10GW, wavelength 0.1nm to 1.nm later to 0.01nm, 10 experimental stations – see atoms move	13PBytes/year initially	986 / 84	2013
Institut Laue Langevin (ILL) 20/20 ²⁸	World's most productive and reliable source of slow neutrons for study of condensed matter.		160 / NA	2012 - 2017
IRUVX-FEL ²⁹	Intense light from infrared to soft X-rays to study electronic properties of matter.		760 / 70	2006 - 2015
The Pan-European RI for Nano-Structures (PRINS)	Federation of three sites to enable European research into the ultimate scaling of electronic components, digital signal processing and novel devices.		1110 / 256	2008 - 2013

²³ www.instruct-fp7.eu.

²⁴ www.ebi.ac.uk.

²⁵ www.esrf.eu.

²⁶ http://neutron.neutron-eu.net/n_ess.

²⁷ <http://xfel.desy.de>.

²⁸ www.ill.fr/Perspectives.

²⁹ www.iruvx.eu.

Summary of Planned ESFRI research infrastructure (continued)				
Name	Description	Data	Cost M€	Start
Astronomy, Astrophysics, Nuclear and Particle Physics				
The European Extremely Large Telescope (ELT) ³⁰	Enabling studies of planets around other stars, first objects in the Universe, super-massive black holes, and the distribution of the dark matter and dark energy.		850 / 40	2018
Facility for Antiproton and Ion Research (FAIR) ³¹	Enabling research in nuclear structure physics and nuclear astrophysics with radioactive ion beams, QCD studies with cooled beams of anti-protons, physics of hadronic matter at highest baryon density, plasma physics at very high pressure, density and temperature and atomic physics and applied sciences.		1168 / 120	2014
KM3NET ³²	A deep sea, cubic-kilometre sized neutrino telescope for astronomy based on the detection of high-energy cosmic neutrinos.		220-250 / NYD	2015
Square Kilometre Array (SKA) ³³	European share in a global project to build a 1km by 1km array of radio telescopes. With a frequency range of 0.1 – 25 GHz and a collecting area of about 1,000,000 m ² , it will be 50 times more sensitive than current facilities. With its huge field-of-view it will be able to survey the sky >10,000 times faster than any existing radio telescope.		1150 / 100	2014 - 2020
SPIRAL2 ³⁴	The project aims will deliver rare (radioactive) isotope beams with intensities not yet available with present machines. It will reinforce the European leadership in nuclear physics based on exotic nuclei.		137 / 7	2011
Computer and Data Treatment				
EU High-Performance Computing (HPC) ³⁵	A European strategic approach to HPC, concentrating resources in a limited number of top-tier centres in an overall infrastructure connected with associated national, regional and local centres, forming a scientific computing network. It will deliver both capability (high-performance) and capacity (high-throughput) computing.		200-400 / 100-200	2008

The ESFRI roadmap illustrates the extensive requirement for access to shared facilities. Virtually every one of these facilities will involve very large volumes of data, and their users will require ways of finding, accessing, analysing and annotating the data – in many cases the data is too large to copy and replicate in many places, and even the interactions concerning data increments or derivatives will require high bandwidth. The majority require significant computation to run simulations that are coupled with or compared with the instrument data.

³⁰ www.eso.org/projects/e-elt.

³¹ www.gsi.de/fair/index_e.html.

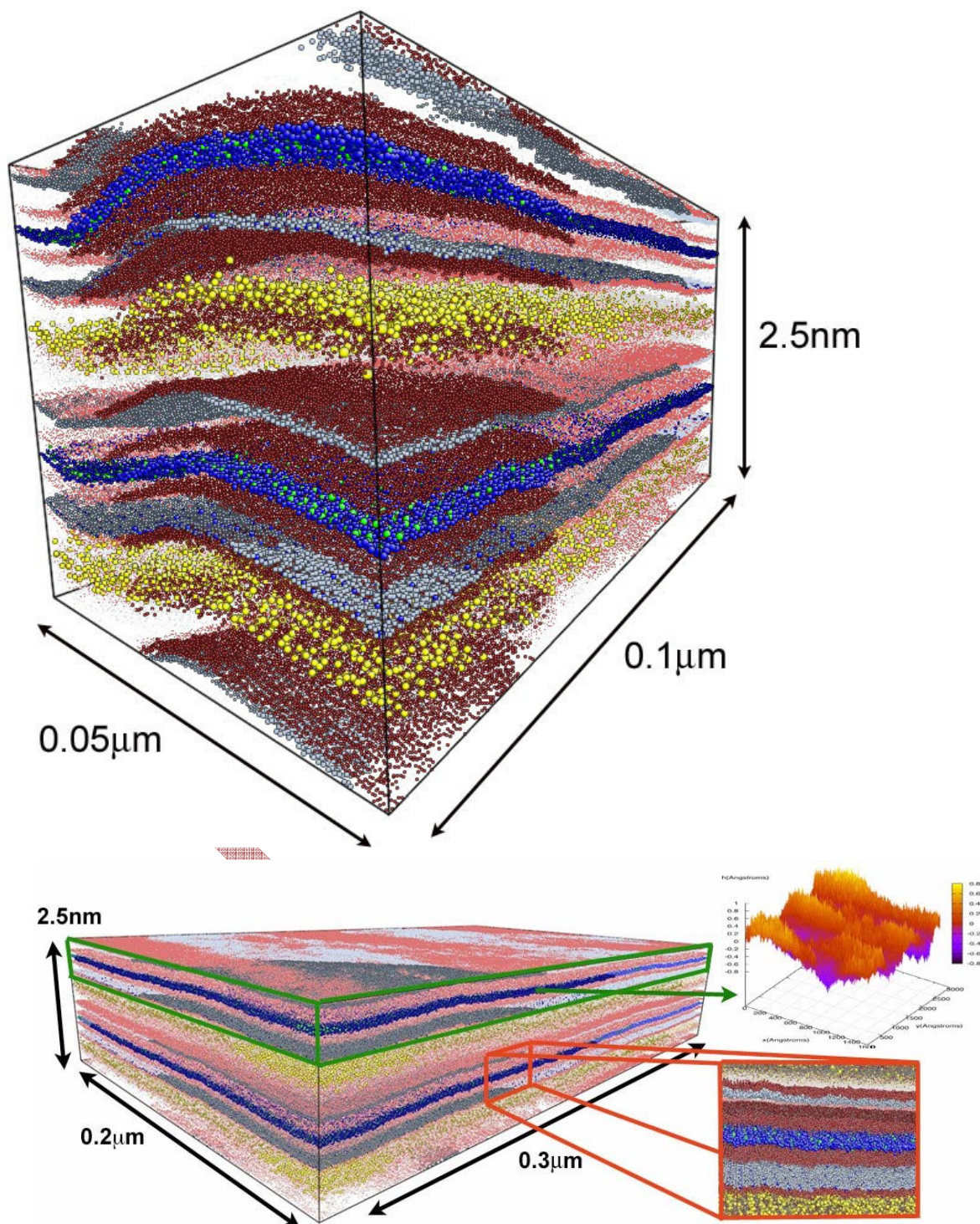
³² www.km3net.org.

³³ www.skatelescope.org.

³⁴ www.ganil.fr/research/developments/spiral2.

³⁵ www.hpcineuropetaskforce.eu.

They therefore have a recurrent requirement for software development and maintenance. Benefits should be obtainable from any consistency of access mechanisms and policies that can be established across all of the planned research infrastructure facilities.



AtomEye visualisation of sodium montmorillonite system (V), containing approximately 10 million atoms, after 0.5ns of simulation. The z direction has been expanded twenty times to allow visualisation of thermal sheet fluctuations. Simulations give information regarding the mechanical properties of these nanomaterials, allowing prediction of materials properties.

2. 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) initiative³⁶. The Joint Information Systems Committee (JISC) also supports the provision of shared research resources and encourages community effects³⁷. Therefore most of the responsibility for the future that should be shaped by the CIR Strategy falls within the remit of the Department for Innovation, Universities and Skills (DIUS).

The UK Cabinet Office has recently published a consultative paper, *Realising Britain's Potential: Future Strategic Challenges for Britain*, [CO08] 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." The first three examples of this that it gives identify advances in ICT as the driver of innovation.

This confirms 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* [NSF03] 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* [NSF06] of the Blue Ribbon Panel on Simulation-Based Engineering Science, chaired by Professor J. Tinsley Oden of University of Texas at Austin concluded:

SBES constitutes a new paradigm that will be indispensable in meeting the scientific and engineering challenges of the twenty-first century.

If an industry is to replace testing with simulation, the simulation tools must undergo robust verification and validation procedures for effectiveness.

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.

Within NSF, SBES should represent a new and fundamental thread of the Cyberinfrastructure theme, one that could well call for a parallel program that interfaces every division with the Directorate of Engineering, if not across the entire Foundation.

The CIR Strategy proposes coordinated actions, outlined in Chapter 3, 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 and challenging goal that will require national investment and strong community support.

³⁶ <http://www.rcuk.ac.uk/research/resinfra/srif.htm>

³⁷ <http://www.jisc.ac.uk/>

2.1. Existing Strategic Coordination

The RCUK provides a venue for strategic discussions but its remit does not include the educational agenda and it may not be able to find time and expertise to deliver the coordination of *ICT-enabled* research.

The research councils, led by the EPSRC, already use a quinquennial planning cycle for HPC provision and JISC in conjunction with the HEIs and research councils conduct a similar five-year programme for network provision, through Ja.net³⁸. 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 section 3.1.

In an earlier report, *Transformational Government*, [CO05] 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. Information sharing, management of identity and of geographical information, and information assurance are therefore crucial.

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. The scale and complexity of government business means its deployment of technology is often pushing the boundaries of what has been achieved in public or private sectors globally.

Behind the scenes virtually every public service depends upon large scale processes and technology, particularly the large and complex transactional systems that support individual front-line public services. Most public services would simply not function at all without their reliable operation. ...

A new Shared Services approach is needed to release efficiencies across the system and support delivery more focussed on customer needs. Technology now makes this far easier than ever before. Shared services provide public service organisations with the opportunity to reduce waste and inefficiency by re-using assets and sharing investments with others. Tackling this will be a major challenge as government prepares for the 2007 Comprehensive Spending Review. Particular attention should be paid to the following areas: ...

(3) **Common Infrastructure**, where as government services converge around the citizen and organisations adopt commercial off-the-shelf technology solutions, the ability to share items of common infrastructure increases. Common technology will enable joined-up solutions, leverage investments and shorten the implementation timeframe of new reforms. To facilitate this a user-led Common Infrastructure Board will be established; it will be supported from the Cabinet Office and financed through user investment; and it will set out a roadmap and timetable for the delivery of common infrastructure.

(4) **Data Sharing**: data sharing is integral to transforming services and reducing administrative burdens on citizens and businesses. But privacy rights and public trust must be retained. There will be a new Ministerial focus on finding and communicating a balance between maintaining the privacy of the individual and delivering more efficient, higher quality services with minimal bureaucracy.

(5) **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, with an effective range of tools to allow the most efficient use and sharing of information to all those across government that have a legitimate need to see and use it.

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 the research user community. It is also

³⁸ www.ja.net

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. The Office of Strategic Coordination of Century of Information Research is tasked with rallying and steering the available resources to best effect – see Section 3.1.

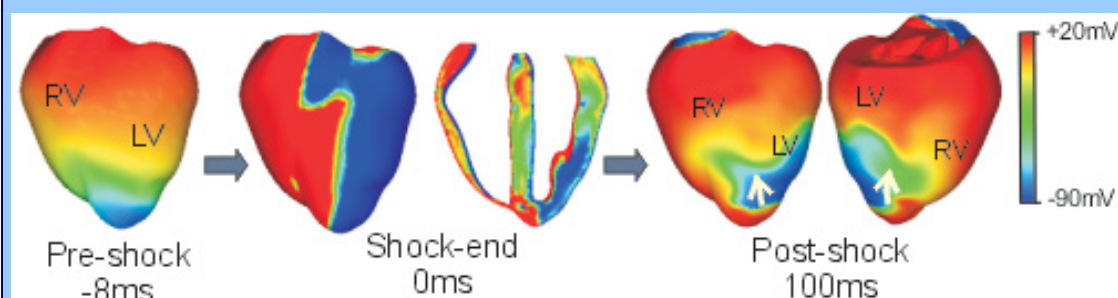
2.2. Existing Support for Research Method Innovation

The Digital Economy programme, led by the EPSRC (see 5.2.1) is providing cross-council leadership in the development of new digitally enabled methods.

The UK Computing Research Committee (UKCRC)³⁹ develops an agenda for computing research exemplified by its *Grand Challenges in Computing* [Hoare & Milner 04]. This agenda and these challenges are a major contribution to enabling the collaborative research engaging computer and computational scientists that is needed in the Century of Information. An even broader agenda is needed if the full benefits are to reach every discipline.

Fundamental research must be sustained and its interaction in interdisciplinary contexts encouraged. This requires stimuli, flagship actions and an increase in the recognition given to interdisciplinary, collaborative and translational research – see Section 3.2.

Modelling complete organs to understand disease and devise treatments? (MRC, EPSRC, BBSRC); developing the virtual human physiology (EU FP7)



Developing and testing understanding depends on a composition of models from bio-molecules to whole organs – computationally challenging task. These have to be calibrated with increasingly sophisticated medical imaging observations. Visualisation and analysis methods are used to compare models with observations, to steer computations and to engage human interpretation and judgement.

Detecting the Higgs boson from amongst trillions of background particles. (STFC)



Experiments at the Large Hadron Collider in Geneva will be searching for the Higgs Boson, widely believed to be the particle responsible for giving mass to everything around us. Detecting the Higgs will require identifying very rare signals in huge volumes of digital data, equivalent to over 1000 Library's of Congress. The collaborative computing infrastructure being developed by the worldwide LHC Computing Grid project will be essential to analysis of this data for the next 10 years.

³⁹ www.ukcrc.org.uk.

2.3. e-Infrastructure Provision and Support

The report, *Science & innovation investment framework 2004–2014, July 2004*, [HMG04] set out the requirement for an effective e-Infrastructure to enable the UKRC to conduct highly productive research and innovation and highlighted the central role of interdisciplinary and collaborative research.

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 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.

In response, 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* [OSIwg07]. It 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:

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
- A location-independent physical infrastructure for combining computation and information from multiple data sources
- Advanced technologies to support collaborative research
- The training and skills needed to exploit the services and resources available to them
- Exploit the power of advanced information technologies and applications to continuously enhance the process of research itself
- Collaborate and communicate securely with others, across disciplines, institutions and sectors
- Maximise the potential of advanced technologies to support innovation and experimentation
- Share their research outputs with others and re-use them in the future
- Engage with industry in support of wider economic goals

The CIR Strategy supports and complements the report from the OSI working groups.

2.3.1. Existing Elements of e-Infrastructure

The policy must build on the existing infrastructure in order to support and engage existing 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.net⁴⁰ and used almost subliminally by the majority of UK researchers in academia.
- Data collections, such as those that are managed at the European Bioinformatics Institute⁴¹, the British Atmospheric Data Centre⁴², MIMAS⁴³ and EDINA⁴⁴.
- Computational provisions, including large clusters in many universities, HPCx⁴⁵ and the HECToR capability HPC provision⁴⁶.
- The National Grid Service (NGS)⁴⁷, which provides several clusters and interconnects other facilities, including university campus grids.
- Community specific e-Infrastructures, such as GridPP⁴⁸ and the NERC Data Grid⁴⁹.
- HEFCE is funding a study into the provision of shared data services, UK Research Data Service, for universities that should have a lower carbon footprint [Sykes *et al.*08].
- Digital libraries with content supporting research, such as ePrints⁵⁰, **REPRESENTATIVE LIST HERE**. These are supported by advisory centres: UKOLN⁵¹ and the Digital Curation Centre⁵².
- Organisations developing the software needed for research, including the National HPC programmes, the Collaborative Computational Projects⁵³ and OMII-UK⁵⁴.
- Organisations supporting the development of user communities, such as, NCESS, NERC e-Science Centre at Reading, NeSC and regional e-Science Centres.

These varied and independent elements of UK e-Infrastructure 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 – see Section 3.3.

2.4. Existing Outreach Strategy

The Technology Strategy Board funds outreach programmes to UK business, the most relevant for the CIR Strategy being Grid Computing Now!⁵⁵

There are a number of programmes providing some outreach to academia supported by JISC, most notably, the e-Uptake project⁵⁶. However, the current investment and outreach and training will not generate a sufficient increase in uptake nor be sufficiently transformative – actions are required, which are set out in Section 3.4.

⁴⁰ www.ja.net

⁴¹ www.ebi.ac.uk

⁴² badc.nerc.ac.uk

⁴³ www.mimas.ac.uk

⁴⁴ edina.ac.uk

⁴⁵ www.hpcx.ac.uk

⁴⁶ www.hector.ac.uk

⁴⁷ www.grid-support.ac.uk

⁴⁸ www.gridpp.ac.uk

⁴⁹ ndg.badc.rl.ac.uk

⁵⁰ www.eprints.org

⁵¹ www.ukoln.ac.uk

⁵² www.dcc.ac.uk

⁵³ www.cse.scitech.ac.uk/ccp/ and www.ccp.ac.uk.

⁵⁴ www.omii.ac.uk

⁵⁵ grid.globalwatchonline.com/epicentric_portal/site/GRID/

⁵⁶ www.e-researchcommunity.org/projects/e-uptake/

2.5. Existing Educational Strategy

In 2006, Jeanette Wing stimulated discussion and engagement in education to develop “computational thinking” [Wing06]. This is a part of the agenda needed in education; called “digital-systems judgement” in Section 3.5.

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

- OECD and World Bank country studies have confirmed an obvious correlation between investment in education and quality of life and GDP [OECD06, WorldBank02].
- 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 [Barroso08]. E-Infrastructure is a technology, which can provide the tools that enable countries to “become better at producing knowledge through research, diffusing it through education and applying it through innovation”⁵⁷.
- 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?” [CEC07]

Several bodies are considering the educational strategies required, including:

- The e-Infrastructure Reflection Group (e-IRG)⁵⁸ Education and Training Task Force (ETTF)⁵⁹ is developing a view of the requirements and strategies for education and training to develop skills in the use and provision of e-Infrastructure for Europe.
- The Open Grid Forum (OGF)⁶⁰ Education and Training Community Group (ET-CG)⁶¹ is taking a more global look at the same issues as ETTF and is discussing possible curricula and certification schemes.
- The series of six International Summer Schools in Grid Computing (ISSGC) has developed curricula that develop a framework of principles and a range of practical skills in the use of e-Infrastructure⁶².
- The EU project, International Collaboration to Extend and Advance Grid Education (ICEAGE)⁶³ has run forum to shape the above activities and has supported their development. It is also collecting and collating a list of relevant courses.

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 – see Section 3.5.

⁵⁷ http://ec.europa.eu/information_society/edutra/skills/index_en.htm

⁵⁸ www.e-irg.org

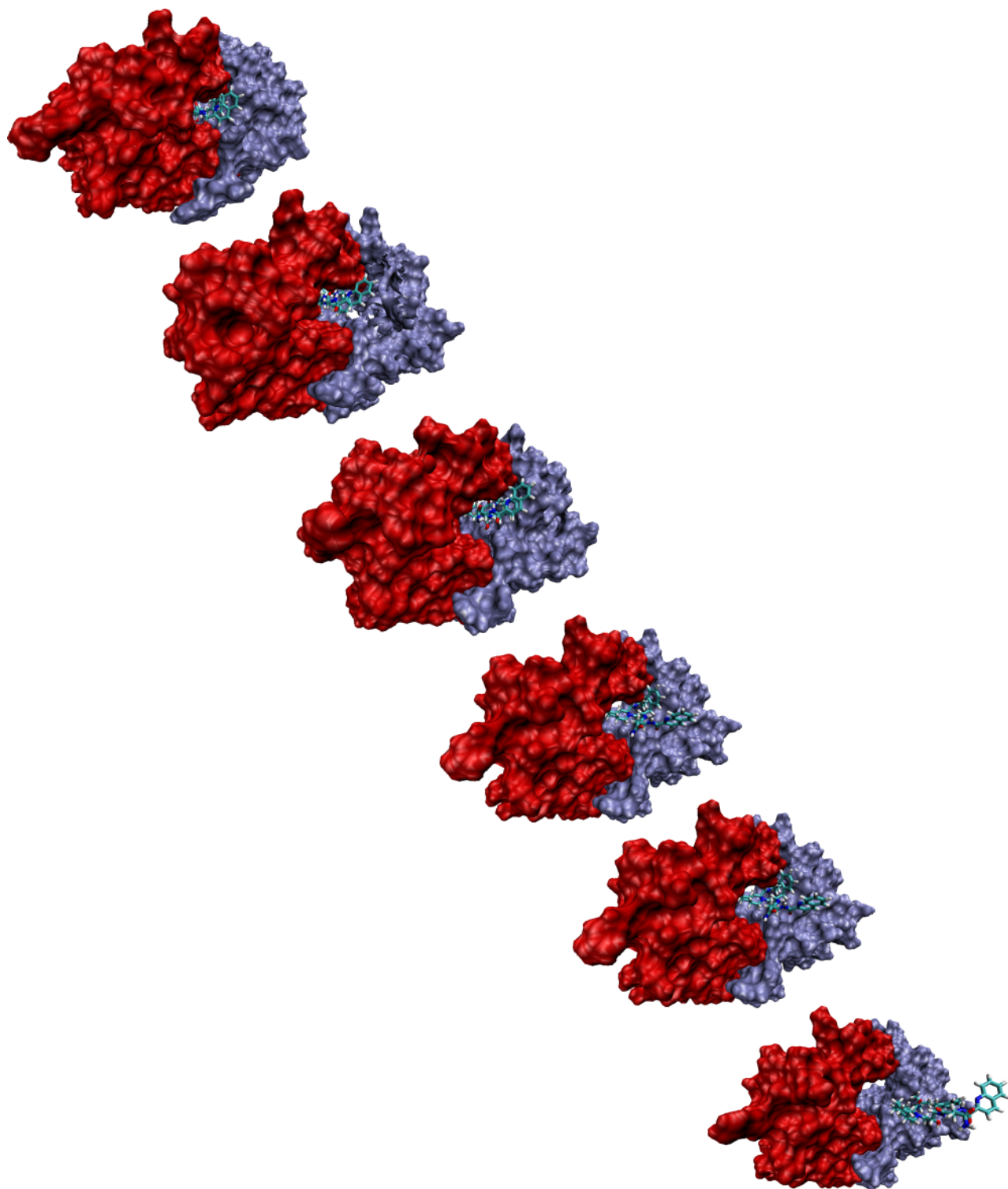
⁵⁹ <https://eirgsp-wiki.grnet.gr/bin/view/Main/TrainingAndEducation>

⁶⁰ www.ogf.org

⁶¹ <https://forge.gridforum.org/sf/projects/et-cg>

⁶² www.iceage-eu.org/issgc08/index.cfm

⁶³ www.iceage-eu.org



Lateral drug expulsion from the HIV-1 protease active site.

3. Action Now

The actions arising from the CIR Strategy must deliver a programme of:

1. Coordination across key areas of e-Infrastructure development and provision that plans and balances the provision and gains the confidence of researchers and other stakeholders.
2. Support and catalysis of innovation that generates and enables new research methods and the technology necessary to support them.
3. Provision and recurrent upgrade of an easily used, pervasive and sustained e-Infrastructure that supports the fluent use of the successful emerging research methods and the innovation of further methods.
4. Enlargement of the productive research community across academia and industry who fluently use the new research methods to make significant advances in their field.
5. An educational programme that increases the skill base so that the UK is better able to create and exploit new research methods.

3.1. Office for Strategic Coordination of CIR

Many stakeholders are involved with and will have their work transformed by the CIR Strategy — they include:

1. *The general public*, who expect safe and trustworthy results from the use of digital information and e-Science methods and effective use of their tax and charitable contributions.
2. *The researchers*, who expect to excel in their field, to be recognised for their achievements and who require the rapid and effective translation of their discoveries into beneficial applications.
3. *The educators*, who expect to develop knowledge and skills that equip their graduates well and who require the knowledge and facilities with which to accomplish this.
4. *The institutions, primarily universities and research centres*, who employ the researchers and educators and who must develop strategies and make provisions so that they compete successfully in the digital economy.
5. *The users: government, business, healthcare and organisations*, who require results and advice that can be trusted, employees with relevant skills and judgement and a flow of insights and innovation that enables them to compete in the global digital economy, to satisfy their customers and citizens and to avoid embarrassing failures.
6. *The funding bodies: DIUS, the research councils, the funding councils, the research charitable trusts and the Technology Strategy Board*, who require effective mechanisms for reaching their goals as quickly and as cost effectively as possible.

As the CIR Strategy is intentionally transformative and as there is such a range of interests concerned, a strategic coordinating body is required — the Office for Strategic Coordination of Century-of-Information Research (OSCCIR). It would be responsible for developing and achieving the CIR Strategy by balancing the interests of all of the stakeholders, by persuading the stakeholders to adopt harmonious contributions to the CIR Strategy within their careers, plans and programmes, and by negotiating national and international collaborative agreements. The OSCCIR is a much needed restructuring of the ‘social infrastructure’ for research (which guides and supports the technical infrastructure) so that it is more able to steer and direct future directions and resources, ensuring that the maximum benefits are achieved from technical and methods innovations.

The OSCCIR should be established within 12 months and will then take responsibility for driving the CIR Strategy. The pervasive nature of information-intensive and ICT-powered research requires that it have a wide remit and extensive influence. The high-rate of change in the capabilities of the digital systems and methods means that it has to capitalise on highly disruptive effects — therefore it will have to act with great sensitivity.

The success of the CIR Strategy depends 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.

A challenge for OSCCIR is to be effective for all three strands and to ensure that they all thrive and continuously provide each other with the necessary support. The pervasive effects of innovation in advanced information systems and in the ways we use digital systems mean that OSCCIR must itself draw on a very broad range of discipline-specific expertise and digital-systems judgment.

Initial ideas on the composition and responsibilities of OSCCIR follow — they will require careful revision by representatives of the stakeholders as OSCCIR is formed.

3.1.1. OSCCIR Composition

The OSCCIR will have a small office to sustain its activities and influence. Its staff will need a mixture of digital-systems judgement, political judgement and public communication skills. An initial suggestion is given below of its structure with estimated costs.

The OSCCIR staff will have goals set and be given authority by an Advisory Council that represented the stakeholders listed above. There will be several subsidiary technical and specialist committees, some of which are suggested below.

3.1.2. OSCCIR Mission

The OSCCIR will 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.

3.1.3. OSCCIR Goals

1. Work with researchers to develop requirements and the business case for meeting those requirements — a quinquennial planning cycle is needed to enable researchers to plan research which depends on it.
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. 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.

5. Work with the research communities using e-Science methods to balance the goals of supporting their diversity, agility and creativity with the goals of offering them an increasingly powerful, stable and shared platform for research.
6. Negotiate with other providers of research facilities and e-Infrastructure, in the UK *and internationally*, to harmonise provision and increase interoperability. Most computational tools used by researchers are developed internationally. The OSSCIR will have an important role in persuading these communities to integrate the access to CIR facilities seamlessly into tools — perhaps the single most important step in facilitating use. It will ensure that delegates are briefed according to the agreed plans and represent the full breadth of research requirements. (Representation of parts of the UK research community, currently the prevailing *modus operandi*, often increases divergence.)
7. 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.
8. 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.
9. Work with business, government and academia to improve the quality, sustainability and ease of use of the ICT-powered tools, e-Infrastructure and data resources that are needed for research and innovation.
10. Work with business to establish better pathways for the exploitation of CIR-enabled discoveries.
11. Work with the media, schools and society to promote a better understanding of the CIR-enabled research and of the products and consequences it produces.
12. Establish consultative processes on the ethics of information-intensive research methods.

3.1.4. OSSCIR Scope

The OSSCIR should respond to the needs of all researchers funded by UK Research Councils, UK charities, TSB and those funded from industry or international projects, who are employed in UK HEIs, research institutes or industry.

The OSSCIR should be the authoritative representative of the UK in international negotiations regarding e-Infrastructure and Cyberinfrastructure. It should promote standards that will engender increased international collaboration and be involved in decisions regarding the UK's participation in multi-national shared e-Infrastructure.

The OSSCIR would not be responsible for all e-Infrastructure provision and community support. However, it should have sufficient resources to influence the UK-wide provisions, e.g. by commissioning crucial services, by sustaining data repositories that are crucial to research and by encouraging the development of improved tools. It should base its direction and coordination on experience and well-researched plans. It should use contracts to enable independent provisions to interoperate or to use common standards. It will need to commission architectural design studies to identify synergies and technical evaluations to inform its recommendations. In some cases the contracts and studies would be co-funded with relevant agencies.

Such capacity for directly or jointly initiating contracts is required to:

1. Make commitments and cause them to be implemented quickly and influentially, when acting on behalf of the UK research community in international inter-operation and standards negotiations.

2. To prime an activity, which would not deliver sufficiently *immediate* benefits for one of the individual research councils, funding councils or some other agency — many provision actions only produce benefits (e.g. researcher mobility or delivery/cost gains) when a critical mass or network effect has been reached.
3. To investigate technical options and community response in adequate time to shape the provision planning cycle and to gain authoritative data with which to influence larger research community.

The OSCCIR will establish close collaborations with other providers of national-scale resources, such as UKERNA for digital communications, and the national networks of facilities for digital-data curation, data storage, service hosting, high-throughput computation, computational model development, e-Infrastructure provision and innovator support.

3.1.5. OSCCIR Staff and Resources

The following table provides an indication of the minimum resources needed to have adequate skills, knowledge, authority and influence. These are approximate per annum costs at 2007 levels.

Annual costs for OSCCIR		
Staff	Role	Cost
Director (1 FT + PA)	Directs OSCCIR to achieve goals set by funders	£240K
Chief Scientific Officer (0.5 FTE)	Ensures the understanding of opportunities and researchers' requirements informs OSCCIR actions	£80K
Chief Technology Officer (0.5 FTE)	Ensures understanding of technology trends, current provision and feasibility evaluations inform OSCCIR actions	£80K
Technical and Research staff (2 FTE)	Executive arm for the three staff above, manage planning, studies, report writing, tests and quality evaluations.	£200K
	Staff Total	£600K
Non-Staff	Purpose	
Serviced offices	To accommodate staff	£100K
Expenses	Conduct of meetings, staff travel expenses and subsistence	£60K
Studies	Studies commission as technology watch, requirements gathering, business case development and impact evaluation	£300K
Contracts	Commissioning work for service provision, interoperability and accessibility transformations, measurement of provision and use	£2,000K
	Non-Staff Total	£2,460K
	Total	£3,060K

Can we predict floods hours to weeks ahead and mitigate their effects? (NERC)



Integrating the hydrological, meteorological, terrestrial and coastal oceanography research communities to understand what causes and propagates floods and to forecast and quantify risk. The e-Science challenges include developing and coupling models of all the processes involved, collecting and organising the data necessary to validate those models and then composing the composite models with the real-time data to make reliable short-term predictions.

Continuous Research-Method Innovation

New methods can either make feasible research that which was previously unobtainable or accelerate and automate research processes to increase productivity and fidelity, which in turn may make new research goals feasible. Six ingredients are needed to achieve this innovation.

1. Applications researchers with a novel requirement, the willingness to invest time and the data with which to test putative solutions.
2. Computer or computational science researchers with the relevant knowledge and the will to invest time and work in close collaboration with applications researchers in developing the new methods. In some cases mathematicians, statisticians, engineers and others are also needed. Frequently progress will depend on and stimulate advances in fundamental research in these disciplines.
3. Dependable research platforms on which to build, e.g. established e-Infrastructure, so that the focus can be on the *extra* advances needed (see Section 3.3 below).
4. Support for agile developments in close collaboration with the application domain and sufficient resources and time to develop understanding, refine methods and deliver results. This support may include tool kits, available services, software engineers and technicians who help in the construction and testing of required technology. A rich and reliable ecosystem of components, supported as e-Infrastructure will stimulate their creativity.
5. Coordinated efforts in community capacity building to reduce wasteful duplication and to maximise the retention and re-use of lessons learnt.
6. Investment in follow through that translates the proven new methods and technologies into products and services that can be commercially exploited.

To deliver these requirements, several actions are required.

1. Those who propose, evaluate and fund research should improve procedures for encouraging and sustaining interdisciplinary teams.
2. Education to prepare participants for this work (see Section 3.5 below).
3. Conditions in which interdisciplinary research and innovation flourishes. They should include:
 - a. An increase in the value placed on research achievements in an interdisciplinary context. This will include development of understanding and capacity for interdisciplinary peer review.
 - b. Improve the context for collaborative and interdisciplinary research. In many universities there are accounting divisions that match traditional subject boundaries. The universities should consider how best to enable work across boundaries. For example, some universities have established a pro-vice chancellor position to encourage interdisciplinarity, others have done this with a broad swathe of research, such as life sciences and healthcare delivery, while Oxford University has established an Oxford e-Research Centre. As a result of the e-Science initiative there is energy for this at the grass-roots level that can be brought rapidly into play through higher-level leadership.
 - c. Inject energy into collaborative and interdisciplinary research to overcome the present counter forces. For example, the research councils should stimulate inter-disciplinary research through national challenges aligned with their delivery plans and with further funding of Interdisciplinary Research Collaborations (IRCs). The EPSRC-led Digital Economy programme is well aligned with this requirement.

- d. Engage with industry in a two-way dialogue on the facilitation of research-method invention and about the knowledge and opportunities that will enable and exploit new digital-technology powered research methods.
4. Develop and maintain a support network that can help initiate such work, bring together relevant skills, and which ensures broad uptake of new methods.
5. Identify where there are skill shortages and take measures to address them. This should become a recurrent process. It will include:
 - a. Analysis of the availability of computing science researchers (and researchers in other disciplines) for collaborating in the e-Science research in comparison with demand; this may be conducted by groups such as the UKCRC.
 - b. Identification of training and education requirements to repair any deficits.
 - c. Identification of impediments to engagement and suggestions of strategies to mitigate them.

3.2. Provision of Sustained e-Infrastructure

The required e-Infrastructure includes the digital equipment, software, services, tools, portals, deployments, operational teams, support services and training that provide data, communication and computational services to researchers. The SUPER report [Newhouse06] highlighted the need for community-focused support which provides strategic and practical advice to researchers. The OSI working group reports [OSIwg07] 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 (see section 2.3). A primary requirement is to provide a pervasive, sustained, easily used and sufficiently capable e-Infrastructure for UK researchers. The e-Infrastructure challenges that must be addressed by the CIR Strategy via the OSSCIR are:

1. *Ease of use* is 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 will 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, Flickr and FaceBook, many of their expectations for ease of use and interfaces will rise. The collaborative practices negotiated by OSSCIR have to continuously balance improvements in consistency and ease of use against established user community requirements. Alongside more fundamental paradigm shifts, incremental change will be needed to give adequate time before old practices can be dropped. OSSCIR will need to drive the agenda of integrating access to CIR resources and facilities into the tools used by researchers.
2. *Sustainability* is crucial to adoption and effective use — researchers will not depend on facilities that may vanish before they can complete a programme of research. 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. This sustainability must depend on well-developed business plans that are agreed with the stakeholders and on assessments of utility that are agreed with the research communities. These plans will include international agreements to collaborate on building components and accessing resources, and expect contributions from the research community itself.
3. *Capacity* balanced across the infrastructure is essential for fluent use by a growing community of researchers. The CIR Strategy sets out to enlarge the community and to encourage expert use. At the same time, the rapid growth in the digital data resources make many methods much more computationally demanding, for example,

oceanographers that used to examine their data sets with a particular tool find that it can no longer perform adequately no that their data sets have increased in size. The OSCCIR will have to encourage balanced investment so that, as far as possible, the shared facilities meet the emerging essential requirements.

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. The gains from multi-disciplinary use, from collaborative behaviour and from international alliances must deliver overall improvement while attracting the researchers through better services.
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. This requires access to low-level components and high-powered resources in a closely collaborating relationship. It is essential to seeding the next rounds of innovation.

The steps that the CIR Strategy must take include:

1. Progressively drawing in and integrating existing providers, such as the national data services, the National Grid Service (acting as an integrating connector of many resources provided internationally and by UK universities), the data providers, the digital libraries and the legacy services, such as GridPP, developed by the e-Science core programme.
2. Organising a long-term planning cycle in agreement with the stakeholders that fund e-Infrastructure.
3. Conducting the planning cycle in close consultation with the research community and tracking delivery against goals.
4. Steering the delivery of the revised planning cycle to minimise disruption of ongoing research and to gain the maximum benefits from negotiated international collaboration.
5. Establishing operating standards and common policies that provide harmonised services to facilitate interoperability, skill transfer and staff mobility.

The majority of major advances are achieved by forming new combinations of well-developed components⁶⁴. The challenge for the e-Infrastructure providers is to make a well-chosen compendium of components available at all times, so that creative geniuses can generate new combinations with major transformative effect.

The components that the e-Infrastructure will need to provide and harmonise will include:

- *Digital communication networks*. They are needed for collaborative working, data transport and interaction with remote facilities, such as those proposed in the ESFRI roadmap (see Section 1.5). This is currently undertaken by JISC through Ja.net to provide SuperJanet for UK *academic* research and education and by Tarena to provide GÉANT for European interconnection. To achieve the full benefits of the CIR Strategy, especially rapid translation of new techniques and technology to business, they must be extended to make use by commercial organisations straightforward, at least during a translational

⁶⁴ For example, the internal combustion engine used existing components (including the carburettor, which derived from Venturi scent dispensers) at the time of its invention. Similarly, the invention of the transistor was built on familiar solid-state physics of semiconductors developed for diodes.

research and innovation period. The current separation reduces collaboration, information flow and speed of translation of research results into production.

- *Computational resources.* These are needed for a wide range of simulations, data analyses and instrument / experiment control purposes. They are currently provided via a large number of mechanisms that have already been illustrated. The diversity can have the advantage of matching architectures and configurations to particular research requirements. However, it militates against the savings in operational costs that have been demonstrated in commercial data centres, may slow the rate at which carbon footprint is reduced and places impediments in the way of those researchers who combine multiple computational resources. The CIR Strategy should migrate the provision to use appropriately consistent policies and standards, and to pool provision where this will reduce total ownership costs for equivalent or improved services. Inter-working with industrial research is often limited by licensing, IPR and discount constraints. The OSCCIR should address this complex boundary with both care and determination.
- *Data Storage.* As with computational resources the storage provision is diverse and independently managed, though there are pilot studies commissioned by HEFCE. The CIR Strategy will need to take account of current commercial experience in economically providing storage services⁶⁵ and developing trust through service-level agreements and address the issues identified for computational resources.
- *Data Services.* The provision of data services includes the full lifecycle of data curation, from instruments, models and digital libraries, and operations using these collections of data. They may draw on the data storage and computational resources considered above or use their own integrated provision. An example of the former, is the >20 data services, including the British Atmospheric Data Centre, hosted on the ATLAS storage service⁶⁶. An example of the integrated approach is EBI. Which is appropriate depends on scale and on the nature of the services required. Again, the OSCCIR will need to encourage economies from use of pooled infrastructure and harmonisation of access policies and mechanisms while respecting the need for diversity and flexibility. In some cases, the data services already make provision for joint use by academia and industry, in others only one of these communities is supported. For best outcomes in the CIR, such boundaries should be lowered or removed.
- *Interconnection and interoperability services.* Provision must include: (i) continued use of legacy systems, (ii) diversity to cover multiple needs, (iii) independent management to meet the concerns of investors, and (iv) the requirement to locate primary data close to the high-volume data generators. The requirements of researchers cross these boundaries. Therefore, services are needed that develop and support the interconnections, such as between national services and the international e-Infrastructures, and those between communities that have retained different legacy services. The emergence of a large number of shared facilities, e.g. the ESFRI facilities listed in Section 1.5, will increase the imperative for interoperation. Services, such as the NGS and GridPP, which provide interoperability today, will need to be developed or replaced with larger-capacity interoperation across a much wider range of resources under the guidance of the OSCCIR planning cycle.
- *Virtual Research Environments.* The breadth of resources and facilities available to researchers will be unmanageable without the help of research environments that compose and package *selected* collections of resources, facilities, data and tools appropriately for particular research communities. The JISC VRE programme has

⁶⁵ Google claims to provide storage at one tenth of the industry average.

⁶⁶ www.e-science.stfc.ac.uk/organisation/groups/data_services/

illustrated the power of this approach⁶⁷. Good quality research environments depend on significant community engagement and on sustained development effort. There is a strategic requirement to decide how this effort can be gathered, how its costs should be apportioned and how to promulgate the methodology across all the communities that should be able to benefit. Here again, there is potential for profitable interchange of ideas, pooling of resources and accelerated uptake if the divide between academic and commercial approaches can be crossed. The OSSCIR should engage in these issues and steer the e-Infrastructure towards productive and cost-effective provision of research environments.

- *Software Development and Maintenance.* Every component of e-Infrastructure listed above depends on software, often software that has to deal with demanding loads in distributed and persistent contexts. Every tool and research environment grows in complexity as the user community diversifies and as the computational platforms evolve. The software interacts with a changing ecosystem of users, providers and technological platforms; in consequence it needs maintenance to sustain existing functionality. In addition, there is usually research-driven demand for additional functions, improved performance, extended scale and increased dependability. These effects are cumulative and generate a significant and sustained requirement for software development and maintenance, over and above the initial effort involved in creating new methods and technologies. It is generally difficult to get this requirement fully recognised, to resource it with appropriate equipment, funds and skills, and to quantify the value of this investment. The CIR Strategy will need to address this, both directly by determining the proportion of investment that will yield the most research results and indirectly by developing skills and methods in the OSCCIR that improve the quality of and confidence in this investment decision. This is a prime example of an issue that faces virtually every research community, which may therefore benefit from a multidisciplinary approach. It is also an example where engagement with industry should yield significant advances.

This extensive range of e-Infrastructure components that will be used in a wide variety of combinations by researchers illustrates the advantage of a coordinating function to help make individual provisions compatible, to increase value for money through pooling and scale effects and thereby make the whole system more productive.

3.3. Enlarging the Community

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. Research councils may also decide that existing researchers will benefit from in-service training and awareness raising programmes for new research techniques that are important for their research community. The SUPER report identified many cases where researchers were not aware of the facilities, methods and training already available [Newhouse06]. 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. If it does not reach those already engaged in their research careers they will be unable to contribute to the new research and are liable to feel disenfranchised and undervalued. The action will include the following elements.

1. Establish several levels and forms of training and agree the curricula.
2. Develop and share the training material, and deploy suitable delivery methods, including access to self-paced learning, as many researchers wish to acquire a skill when their research generates the requirement.

⁶⁷ The succession of GridPP projects could be viewed as building a research environment for physicists using LHC and similar instruments.

3. Liaise with professional bodies and skills accreditation bodies to embed the training in standard practice to raise quality and recognition.
4. Work with research leaders to ensure that researchers are given the opportunities to develop their skills through training. The research councils and the Committee of Vice Chancellors and Principals should establish expectations that encourage relevant training.
5. The research councils, the Higher Education Funding Councils and JISC should organise a programme of communication and awareness raising that will alert researchers to the new methods and facilities, and encourage the uptake of training. This should include a requirement in all research grants to contribute effectively to outreach about the value of the research and its dependence on the nationally supported e-Infrastructure.
6. Work with industry and the Technology Strategy Board to agree training attainment targets and to establish a two-way flow of knowledge on the development, deployment and use of new research methods and technology.
7. Establish flagship examples through funder-university-industry consortia to showcase the opportunities and benefits and work with media organisations, museums and schools to disseminate their value.
8. Persuade high-profile research leaders to expound the achievements that have been made possible through computationally enabled research — e.g. as a British Association for Science Christmas Lectures presentation.

3.4. Education for Century of Information Research

In the long-term the school education system should prepare school leavers for an information society and help extend to a wide public the understanding of e-Science enabled 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.

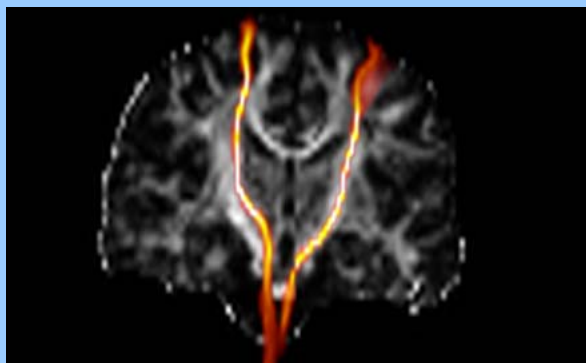
The CIR Strategy focuses on higher education. Here the goal should be that every graduate will have the opportunity to appreciate the emerging digital information age, including the opportunities provided by ICT-enabled collaboration, data collection, computational modelling and analysis. It is envisaged that HEIs will provide foundation courses for all students and more advanced courses for many disciplines, such as medicine, life sciences, earth sciences, physical sciences and engineering. The majority of doctoral and masters programmes should have relevant elements developing the ability to exploit e-Science. A substantial proportion should prepare their graduates to engage in the creation of new e-Science-enabled methods. The following activities will contribute to this, with initial action for doctoral and masters degrees to both prepare the academic community and to ensure that those already in the HEI system emerge properly equipped.

1. The EPSRC should, within 18 months, establish at least two Doctoral Training Colleges whose focus is generating experts in the invention of methods enabled by advances in ICT.
2. All research councils should, within 18 months, review their Doctoral Training Programmes to ensure that they contain a sufficient element of e-Science and its applications.
3. The Higher Education Funding Councils and the research councils should combine to develop incentives for the establishment of e-Science foundation and advanced material in a wide range of degree programmes. This should include encouraging

networks developing the curricula, material and teaching infrastructure in those disciplines. Demonstrable interdisciplinary collaboration and experience should be expected. Graduates should continue to emerge as experts in their own fields but should have additional transferable skills to equip them for work and research in the information age. The first of these new programmes should be running within two years. The Committee of Vice Chancellors and Principals should be asked to encourage the promulgation of these programmes, and bodies such as the UK Computing Research Committee⁶⁸ and the Council of Professors and Heads of Computing⁶⁹ should help shape them. They should be accredited by professional bodies, such as the Engineering Council, the British Computer Society and the Institute of Engineering and Technology.

4. The funding bodies should make the award of grants and the evaluation of their outputs include a significant element of contribution to education in the domain of the research.
5. Within two years the Royal Society and the Engineering Council should convene a workshop to identify the educational goals and criteria that must be attained to equip UK citizens for the Century of Information. This should lead to working groups run by the relevant professional bodies developing or revising curricula in their discipline and a combined working group developing a core curriculum. A follow up workshop after a further two years would integrate the results of these working groups and stimulate the adoption of their recommendations.
6. Within five years a concerted effort to bring this into schools would be appropriate. To prepare for this, alliances between universities and local education authorities can pioneer material and explore the resource requirements.

Can we make better use of increasing performance of medical imaging systems to improve knowledge of physiology, diagnosis and treatments? (MRC and DoH)



Collection, calibration, registration and analysis of large numbers of images reveals variations – both normal and pathological. In the case above, researchers are integrating over many MRI scans to observe how damaged tissue develops in the brain and to discover whether the onset of Schizophrenia can be predicted. The computation is necessary to warp each image so that it is aligned with a standard before the images are combined.

⁶⁸ www.ukcrc.org.uk

⁶⁹ www.cphc.ac.uk

3.5. Example Target Attainments

The following table of anticipated attainments assumes that a commitment to the CIR Strategy is made by mid 2008. As a result of consultations while developing this strategy some actions are already underway.

Examples of CIR Strategy Target Attainments					
Date	Coordination	Innovation	e-Infrastructure	Uptake & training	Education
2008					
mid	Commitment to CIR Strategy & OSCCIR	Recognised as required by research council delivery plans	Integration of HPC, computational and e-Science planning	Select priority targets	
late	Director of OSCCIR appointed	Calls for interdisciplinary research	Key components of national e-Infrastructure (e-I) selected	Coordinated outreach and training initiated	>10 universities offering MSc programmes
2009	OSCCIR represents integrated UK interests in international negotiations, e.g. EGI	>4 Doctoral training centres (DTC) and ecosystem of components and tools supported	Start harmonisation of e-I systems: HPC, NGS, GridPP, major data centres, campus resources		>8 DTC providing researchers adept in the new methods in their discipline
mid	Quinquennial e-I planning cycle started – requirements and technical options	>10 universities strongly supporting interdisciplinary research and careers	Standards for interconnection and use widely established and all major legacy services engaged	Accreditation of training in e-I delivery	
late	International & national alliances established to develop key tools and services	Skill shortages for CIR innovation identified & targets set	International and national consortia develop, maintain and support e-I services	Accreditation of training in CIR methods	>5 universities provide CofI-related undergraduate programmes
2010	Planning cycle e-I business case	All research universities strongly support interdisciplinary work & careers	Model for delivery of e-I established, e.g. for procurement via tender		RS launch study of curricula for CIR
late	Planning cycle procurement				>5 universities develop digital-systems judgement in all undergraduates
2011	Formal agreement between EGI and UK e-I planning & provision	National agreement on interdisciplinary work & careers	Initial operation of <i>planned and coordinated</i> e-I	European-wide accreditation of training	RS publish report on Education for CIR
2012					
2013				Launch Schools Curriculum	
2014	Second quinquennial cycle starts				
2015					
2016					

4. Empowering UK 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.

In the Century of Information, there is rapid change in both the research and digital-economy worlds. 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 search for and find specific datasets, to combine the datasets, to undertake new types of computationally intensive analysis, to visualise the output, and thereby to extract information and knowledge in innovative ways. 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 processes increasing amounts of disparate data. To meet this challenge researchers, and society at large, need to be equipped with new methods and provided with e-Infrastructure that will support their investigations at the required scale. Without these, UK researchers will not compete effectively.

The e-Science Programme demonstrated how this could be done, 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 use of these techniques is fluent for all that need them*. Researchers should use these new tools when they need them, as fluently as an engineer uses a differential equation or an artist uses a brush.

Gifted researchers will often make great leaps attaining intellectual breakthroughs at the same time as they demonstrate more powerful ways of using the latest computational tools. Rapid promulgation of the newly advanced tools and newly invented methods amplifies the benefits, enabling others to solve many similar classes of problem and raising the ambient level of expertise on which the next major achievements will build.

The Century-of-Information Research Strategy recognises that empowering researchers requires support for a continuous mode of method and technology innovation. 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. It must support a diversity of these as they emerge independently and yet it must sustain interoperability by recognising commonalities and exploiting opportunities for synergy. Frequently this will require adoption of international standards, which the UK must continue to influence for the benefit of its research, industry and citizenry.

In other words, the UK should *enable the continuous improvement of the methods used in Century of Information Research as well as supporting fluent use of existing methods*.

4.1. Research 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. The power of e-Science is the ability to construct re-usable ICT components that encapsulate new methods. The CIR Strategy must organise the ecosystem in which these emerge so that they are rapidly taken up across multi-disciplinary communities and deliver the benefits of sharing.

The CIR Strategy will benefit the diversity of research within UKRC as is illustrated in Chapter 5. These benefits will be delivered by improving the facilities, such as information and computational resources for researchers in all disciplines. Innovation and optimisation in the use of these facilities and in the methods they enable will enhance the effectiveness of the researchers. The benefits must reach researchers in a wide range of contexts and conditions:

1. Research in teams led by gifted researchers, where it must help both leaders and the many team members to work together. Many such teams are multi-institutional, some are spread across multi-national consortia and many are interdisciplinary.
2. Research by individuals and small groups. In some cases these engage as part of their employment, in others they may be contributing as volunteer experts.
3. Research in or with industry and governmental bodies.
4. Research addressing established challenges, such as understanding and preventing or mitigating mental diseases, to research driven by curiosity about a detailed topic, such as the origin of mass.
5. Researchers who are pioneering the development of innovative computational and data-intensive methods to meet new challenges.
6. Researchers who, persuaded by the efforts of pioneers, wish to use a specific leading-edge e-Science method and tools through a supporting system.
7. The majority of researchers who are likely to gain the maximum advantage from innovative methods and tools only when these become embedded seamlessly and, perhaps invisibly, within their familiar environments.

4.2. Education and Skills Benefits

The UK must equip its population with the skills and judgement to benefit from Century-of-Information Research. We refer to this category of understanding and skills as “*digital-systems judgement*” — that is, we have 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, including those appropriate to playing significant roles in:

- Recognising when to enhance or (less often) create digital systems.
- Designing, commissioning, evaluating and managing digital systems.
- Choosing which systems to use and how to use them.
- Recognising and exploiting the creative arts and business opportunities enabled by digital systems.
- Recognising and addressing the ethical, social and security issues raised by digital systems.
- Using digital systems in research, industry, government and healthcare.

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. 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.

Currently there is a severe shortage of the required skills. Therefore, a transformative programme must be undertaken to generate widespread digital-systems judgement. It should engineer a cascade of positive and inter-linked actions.

1. Create the knowledge and skills in a growing number of researchers across as many disciplines as possible, both through direct engagement in research enabled by advanced digital systems and through doctoral training programmes.
2. Amplify and propagate this knowledge through broad educational programmes in UK universities. The researchers developed in the first step will need to be engaged in shaping and pioneering that education. This should eventually pervade all disciplines and universities, thereby, changing the UK culture to include digital-systems judgement at all levels. The requirement to transfer discoveries from research to education benefits both — it demands clarity of thought, deeper understanding and better exposition of discoveries, and it enriches the learning process and the capabilities of its graduates.
3. Transfer the knowledge and skills to industry, government, healthcare and society through vigorous campaigns including: the flow of graduates, the interchange of skilled staff, joint projects between research and industry, university-schools programmes, outreach and training.

The whole educational and skills development programme has to be continuously innovative and constantly evolving. Each generation will be seeded with ideas that enable them to envisage what is technically possible and potentially valuable. They will then realise those visions and enrich the digital technology, the compendium of intellectual tools, the methods and the resources deployed as e-Infrastructure. The following generation has to be equipped to use these and to carry on the creative cycle.

The prevalent benefits from advances in research methods described above should rapidly infect the broader academic community with an enthusiasm for developing *digital-systems judgement* in their disciplines. Almost every activity can benefit from drawing on the abstractions and metaphors that have been developed by engineers and computer scientists to describe, design and understand systems that involve computers, communication, data, human interaction and digital sensors. Bringing these concepts, such as process interaction models and simulation of stochastic models to estimate risk, into the broad educational agenda will deliver significant benefits. Again, these educational effects have already been demonstrated in specific projects in schools, in universities and with general public. *The challenge for the CIR Strategy is to make these effects pervasive.*

4.3. Societal Benefits

The UK government's priorities described in Section 5.1 are all motivated by the urgent need to address a series of unprecedented challenges which face the UK's citizens and economy. As we outline above, the CIR Strategy is designed to empower the UK research community to

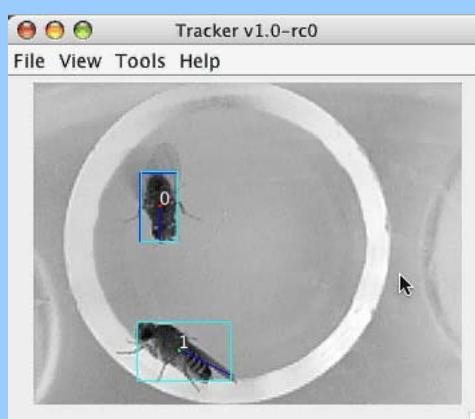
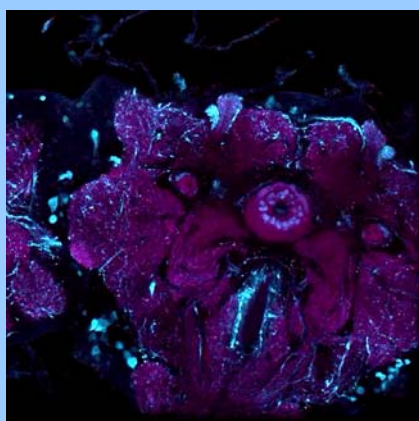
meet these challenges. By doing so, the CIR Strategy will inevitably contribute to broader societal benefits. The wider and long-term impacts of innovations, however, have been notoriously hard to predict with any certainty. Instead, we prefer to emphasise the importance to society of being able to respond to, promote and shape processes of innovation more effectively, including empowering its citizens to make more informed choices about both public and private investments. This leads us to identify a number of areas where we expect the CIR Strategy to have a significant beneficial societal impact.

- Meeting the challenges facing the UK's citizens and economy is likely to require broad swathes of communities and industries to explore, shape and adapt to new ways of working and to new mechanisms for delivering the services on which a modern and rapidly changing society depends. The general public can cope well with such changes if it understands them, if proper ethical consideration has been developed through consultation, appropriate governance mechanisms are identified and implemented, and if delivery is well accomplished. This requires that there are sufficient opportunities for wider public engagement through well-informed debate and sufficient participants with adequate digital-systems judgement. The educational programmes outlined in the previous section will eventually supply a proportion of this requirement, but the current pace of change demands more immediate action which the CIR Strategy will be designed to deliver through, for example, joint initiatives combining research, universities, schools, interest groups and the media. The collaboration between ClimatePrediction.Net and the BBC is an example of what can be done [CPDN07].
- 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 getting involved in interdisciplinary projects [COSEPUP04]. Working beyond established disciplinary frameworks and boundaries may place impediments in the promotion paths or career transitions of researchers and hence dissuade them from taking part because they will fear that it will damage their careers. For example, and despite a lack of evidence, the UK RAE is widely believed by researchers to discriminate against interdisciplinary research [Rogers00]. The CIR Strategy will engage in changing attitudes to eliminate such impediments and, by working at various levels, ranging from the professional societies to the disciplinary grass roots, will help promote the changes which will be vital to the long-term flourishing of an innovation-driven research culture.
- Trying new methods is inherently risky — there is a chance they will not work, there is a chance researchers will not cope with the new concepts or tasks, and there is a worry about whether results they produce can be trusted. Yet new methods are necessary and these will depend on new technologies. How can the barriers to uptake be lowered? Clearly making the new tools work well, with familiar interfaces, and embedded in familiar environments is an essential step. But there still remains a “fear of the unknown”. Leaders and well-publicised examples of successful research may prime community effects. But every new method and technology has to “cross the chasm” from the land of innovators and enthusiasts to the much larger cautious communities. The CIR Strategy will draw on multi-disciplinary and international communal effects to provide the bridges.
- Driving forward research increasingly depends on collective action by 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. Advances in computer-supported collaborative working, video-conferencing and remote computational steering provide *technical* support. However, major socio-economic hurdles to successful collaboration often remain. For example, when researchers contribute to a model, a data collection or incremental data analysis how is responsibility and credit properly assigned?

Different communities and different project scales have significantly different mores. Teasing out the best ways of gaining collaborative intellectual power remains a major challenge. The CIR Strategy will ensure it receives attention and that steps towards its solution are suitably propagated.

- As we approach a million users of e-Infrastructure in the UK (still fewer than the number of students) then the dynamics of user behaviour become a major concern for e-Infrastructure providers. It is highly desirable to develop group dynamics that positively encourage the uptake of e-Science methods. But there is a severe risk of being overtaken by a success-disaster that swamps the available resources. The CIR Strategy will, by investing in observing, modelling and understanding the community dynamics, help ensure that such events can be anticipated and disasters averted.
- The previous example provides a compelling case for investing in observation, data collection and analysis to understand how the community responds to the opportunities, facilities and challenges of the Century-of-Information Research and, thereby, to develop an enhanced capacity to measure and evaluate its impacts. The ESRC, through the National Centre for e-Social Science, has committed to this in its delivery plan (see Section 5.2.5) – in effect, using Century-of-Information Research-enabled methods to track and analyse the trajectory of Century-of-Information Research. The CIR Strategy will ensure that the derived understanding is fed into the decisions and actions that guide planning and delivery for the benefit of all disciplines.
- While their precise form cannot be predicted with any certainty, major changes in behaviour and expectations can be expected, many driven by outside forces, such as global patterns of community intelligence, the impact of all communication media converging on digital technologies, the growth of personal digital sensors to promote wellbeing, the market place of web-enabled services and the prospects for the ‘virtualisation of the scientific market’ as research becomes progressively open to globalisation trends now firmly established in other sectors [RAND06]. It is therefore crucial that the CIR Strategy is supported by a strong intelligence arm that gathers information about these effects and helps the CIR leaders interpret them. Studies of comparable international programmes will help to identify differences in strategy and outcomes, explicate how these differences relate to differences in national, cultural, economic and policy contexts, and provide lessons for future CIR Strategy development.

Can we understand how the brain works from the genes that form it to the behaviour it generates by building a complete model of a drosophila brain?



An image of a slice of the brain (left) shows a step in building a map of all the neurones and synaptic connections. The tracker (right) is used to obtain statistical observations of behaviour. Genetic knock-out studies and optical sensitised neurones explore the function of each neurone. The research has to assemble the data from a worldwide consortium and test hypotheses of brain function described as mathematical models with these data.

5. Empowering UK Research

A primary goal of the Strategy is to enhance the UK research community's ability to achieve and excel within the nationally agreed research priorities. The recent (11/11/07) publication by the DIUS of *The Allocations of the Science Budget 2008/9 to 2010/11* [DIUS07] presents a major portion of those priorities. The CIR Strategy will be invaluable in meeting those priorities as is illustrated below.

Each UK Research Council published its delivery plan on the same date. Some examples given below from those delivery plans reinforce the potential value of the CIR Strategy. A complete analysis of those plans will be undertaken to show the full extent of the CIR Strategy's benefits. 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. That further study should identify specific cases where collaboration and standards are potentially beneficial. Individual researchers will choose when to use provided facilities and the Office for Strategic Coordination of CIR (OSCCIR) will monitor take up and impact in order to steer investment and incentives towards a set of clearly advantageous facilities that are actively used by researchers. Pressure or compulsion to use facilities would be counterproductive and an incremental, evolutionary, adaptive and multi-element approach is needed.

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

An overarching goal of research policy is to foster world-leading research. For a great many research topics in the majority of disciplines world leadership will depend on adequate access to the data-intensive methods and computational facilities that the CIR Strategy will make routinely available. 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.

5.1. Facilitating Cross-Council Programmes

These responses to HM Treasury's priorities are introduced with "As a country, we are facing unprecedented challenges to our quality of life, environment and security. Meeting these challenges requires new, innovative ways of thinking." The CIR Strategy will develop a crucial, innovative way of thinking that will contribute to each cross-council programme.

5.1.1. Energy

This programme is introduced with the following paragraph.

Energy is at the top of our national and international policy agenda. We need secure and sustainable energy supplies to facilitate our economy and way of life. However, energy provision is the major contributor to greenhouse gas emissions. The Stern Review emphasises the need for an urgent global response to climate change including energy demand reduction and new technology in power generation, transport, and energy use.

Every form of energy generation benefits from computational modelling to improve the efficiency of materials, devices, installations and operating procedures. In many cases, computational modelling is also required to assess safety, environmental impact and sustainability of energy output. These in turn may depend on other models, e.g.:

- of the sequestration of CO₂,

- of the containment and deep storage of radioactive waste,
- of the distribution of wind speed as climate changes,
- of the perturbation of water flow, channel depths and estuary margins from a tidal barrage.

Many of these model runs depend on access to large collections of digital data. Engineering and policy depend on the quality, use and interpretation of these models and data resources. A consequent requirement is to deal economically with the growing scale and complexity of these models, developing methods that improve their accuracy and ensuring they are easily used and trusted by all of the disciplines. The CIR Strategy will provide significant help in addressing these challenges.

Energy demand reduction will also be advanced through better modelling of the deployed systems, alternative devices, storage systems to use (micro) renewable energy more efficiently, community heat and power schemes, and so on. It would include models of the built environment, urban behaviour, transport, and the domestic and commercial response to the introduction of energy saving options. A set of model and data compositions is again needed. The data required is more sensitive as it will include: census data, property data and sampling of personal and commercial energy use and responses to initiatives and new technologies. Again, the CIR Strategy offers the potential of preparing the acceptable and trusted practices and the technology to support them.

Energy transmission is again the subject of much data collection, and modelling to improve materials, devices, installations, operating practices, environmental impact, safety and reliability. The three sub-domains (generation, transmission and use) form a coupled system that may show complex resonances and similar pathologies. To explore this requires coupling the models and data of the sub-domains — a complex technical challenge that we will see emerging repeatedly — hence the value of the Strategy's pooled effort to devise methods and e-Infrastructure to meet these challenges.

To address the Energy challenge widespread and enhanced digital-systems judgement will be needed — a key contribution of the CIR Strategy.

5.1.2. Living With Environmental Change (LWEC)

In [DIUS07], this is introduced with the following paragraphs.

Human activities, most notably worldwide fossil-fuel demand and rapid population and economic growth in the developing world, are accelerating environmental change and are increasing pressure on ecosystems and services, challenging our social and economic wellbeing. HM Treasury has identified this issue as a key challenge that the UK must address in the next decade, a concern supported by the Intergovernmental Panel on Climate Change Fourth Assessment, the Millennium Ecosystem Assessment, and the Stern Review.

Living With Environmental Change (LWEC) is a major interdisciplinary research and policy partnership to tackle environmental change and the societal challenges it poses, ... LWEC aims to provide the knowledge, tools, predictions, solutions and business opportunities needed to increase resilience to, and reduce the economic costs of, environmental changes such as more severe weather and reduced biodiversity; and the best information to enable sustainable management and protection of vital ecosystem services — such as clean air, fresh water, healthy soils, and flood and disease protection — on the time and space scales on which the economy is managed.

To meet this challenge needs many disciplines, researchers and agencies working effectively together. It requires the collection and curation of many forms of data, and tools, which will facilitate their discovery, access and linkage. It requires the construction and validation of many complex models well in advance of those achieved today. It requires many compositions of models and data. These often have to be assembled and used quickly if they are to address rapidly developing events. They have to be trusted and used by all those involved.

These are technical and socio-economic challenges *similar* to those already seen in the energy challenge — there may be more sensitive personal data — e.g. to support emergence response or to plan adaptation of agriculture or coastal communities. There is a new dimension — the tools that support response to exceptional environmental events have to be able to make predictions with sufficient speed as well as accuracy.

As these technical challenges are immense and as they have significant overlap with those for energy the CIR Strategy is invaluable. It pools and focuses effort on the common technical challenges — effort that will inevitably be in short supply and it establishes a programme through education, training and outreach to significantly improve the UK's capability. It also improves international research interoperation, which is vital for climate and environmental research.

5.1.3. Global Threats to Security

Its introduction states:

Trans-national global crime such as drugs, people smuggling, money laundering and cyber crime, is increasing in sophistication and scale as criminals exploit today's open and globalised world. Terrorism in pursuit of particular aims is increasing across the globe as many disparate groups see violence as a means to achieve their aims. Environmental stresses will continue to interact with human vulnerabilities to provide a powerful basis for insecurity in many parts of the world. Systematic research is needed to capture the direct and indirect contributions to global [in]security arising from the continuing experience of extreme poverty — the world's poorest people are often those most vulnerable to harm from security threats.

A similar pattern of complex information and modelling requirements emerges here but with heightened requirements for security and privacy of the computational systems, data resources and models. Models will include human behaviour in the context of terrorist incidents, the distribution of toxins, etc., in order to assist in planning and conducting responses. These models can interact with those used in building and transport design. If models and data are used to support emergency response then they have to be well protected against attacks. If they are dependent on high throughput computations then it may be appropriate to commandeer other research-computing resources during the emergency. This requires common standards and agreed policies. The common elements and the capabilities to use these and address the special requirements will be best delivered with the contributions from the CIR Strategy.

5.1.4. Ageing: Lifelong Health and Wellbeing

Its introduction states:

There is an unprecedented demographic change underway in the UK with the proportion of young people declining whilst that of older people is increasing. By 2051, 40 percent of the UK's population will be over 50 and one in four over 65. There are considerable benefits to the UK of having an active and healthy older population with potential economic, social and health gains associated with health ageing and reducing dependency in later life.

The proposed interdisciplinary centres will target themes such as healthy ageing and the factors over the whole life course that may be major determinants of health and wellbeing in later life. Here again are requirements for extensive and varied repositories of digital information supporting discovery, access and linkage — this time with extensive privacy and ethical constraints — against which to test understanding and to verify hypotheses. Once again many models, from developmental biology and virtual human physiology, epidemiology, social geography, landscape genomics, proteomics and human responses to opportunities will be needed to develop and test understanding and then provide predictive tools essential, for example, for planning future services provision. New technology in health care to assist people with independent living, post-episode recovery and maintaining healthy lifestyles, will draw on distributed and mobile digital systems advances and will generate new requirements for decision support and deliver increased sources of evidential data. Several

existing e-Science projects are exploring the socio-economic, ethical and technical issues that will arise in this field. The demands for the relevant underlying methodologies, facilities and skills will be best met by taking advantage of the CIR Strategy.

In summary, the four cross-council priorities have common requirements for computational and digital information resources. Many of the techniques that will be needed for dealing with scale, complexity, decision-support quality, ease of use, discovery and access, security and privacy have commonalities. They will all require an increasingly large community of researchers and other staff equipped with improved digital-systems skills. By treating these recurrent aspects in a coordinated manner the CIR Strategy will greatly facilitate their programmes of research.

5.2. Facilitating Research Council Delivery Plans

A single example is taken from each of two other EPSRC-led multi-disciplinary programmes and from each Research Council's delivery plan to illustrate the breadth of the CIR Strategies benefits. If each delivery plan is examined in detail many more compelling demonstrations of its value emerge.

5.2.1. Digital Economy

The description of the Digital Economy programme given in [DIUS07] is congruent with the CIR Strategy — this should be no surprise as they both address the same aspirations for research, innovation, commerce and the economy. To quote:

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. In an ever changing world, being able to respond rapidly to new opportunities and challenges is key to the future economic and social prosperity of the UK.

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 focused 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, MRC and STFC) will concentrate on areas where the management and presentation of information can have maximum transformational impact: healthcare, transport and the creative industries.

The synergy between the Digital Economy programme and the CIR Strategy is patently obvious — the CIR Strategy adds a coordinating and effort-pooling dimension that will benefit the Digital Economy programme. It also seeks to have more pervasive impact on education and thereby achieve a broader impact on the skills base required by the Digital Economy.

5.2.2. NanoScience through Engineering to Application

The opening paragraph of this programme reads:

Nanotechnologies can transform society, they offer the potential of disruptive step changes in electronic materials, optics, computing, and in the application of physical and chemical understanding (in combination with biology) to generate novel and innovative self-assembled systems.

Again, this demands computational resources, information repositories and dependable ICT services to support the researchers, designers and engineers working in this field. The CIR

Strategy would therefore help with the provision of those systems and the skills necessary to accomplish this programme.

5.2.3. Arts and Humanities Research Council

The AHRC's priorities and key deliverables include: "Develop novel models of support for the creative industries (CIs) and digital services", "Apply new learning generated from creative user-centred approaches in the arts and humanities and the CIs to key economic and societal challenges", "Shape public policy through the research insights of the humanities which help to understand causes and manifestations of current threats to global security", "Support policy makers to develop more appropriate strategies for enhancing public understanding of the implications of environmental uncertainties", and "Shape public policy around diverse aging needs." [AHRC 07] As these are all related to the cross-council programmes above their requirements have already been discussed. The AHRC will also lead a programme of research "Science and Heritage" in partnership with the EPSRC, STFC and TSB. This will continue to build valuable collections of digital information recording our heritage and provide easily accessed services to enable a wide range of researchers and UK citizens to draw on these resources. The CIR Strategy will help in the development of repositories, policy, services and skills needed by these programmes.

5.2.4. Biotechnology and Biological Sciences Research Council

In their executive summary, the BBSRC state, "Particularly, we will continue support for 'systems approaches' that harness the power of mathematics, physics and engineering to generate new understanding of biological processes and enable effective and responsible intervention and utilisation of knowledge." [BBSRC07] These systems approaches make intensive use of digital data resources and computational models. As in the examples described above they are raising challenges of scale, complexity, fidelity and security — challenges which the CIR Strategy will pool resources and focus effort to solve. Similarly, the systems approaches make great demands for researchers with enhanced digital judgement.

5.2.5. Economic and Social Research Council

In its summary in [DIUS07] the ESRC explicitly mentions its continued commitment to e-Social Science: "improved access to and use of a variety of data (international, administrative, business and biomedical)" and "building on the National Centre for Research Methods and National Centre for e-Social Science." Their priority of understanding migration and population change cites an example of recent simulations: "Recent ESRC research at the LSE, the London School of Hygiene and Tropical Medicine and Southampton has simulated the structure of the UK population over the coming few decades. It highlights the seismic changes that will take place in terms of household structure and composition, diversity and the availability (or not) of extended family networks." [ESRC07] This exemplifies the requirement for "sustained investment in a world class data infrastructure ... based on the most advanced skills, tools and techniques" facilitating discovery, access to and linkage to extensive collections of often sensitive data — including transactional and administrative data — for improving access to international datasets and for increasing the secondary use of research data more generally, as well as the need for a continuing commitment to the development of advanced quantitative methods — activities facilitated by the CIR Strategy.

5.2.6. Engineering and Physical Sciences Research Council

The relationship of the CIR Strategy with the EPSRC is special for two reasons:

1. The EPSRC is the Research Council most concerned with ICT and computational research and therefore is key in generating the inspiration, insights, methods and technologies on which the CIR Strategy will build, and
2. The EPSRC has had a leading and coordinating role in providing e-Infrastructure for research, which is a crucial input into the CIR Strategy, namely the HPC provision, the CCPs and the e-Science core programme.

The first three priorities identified by the EPSRC delivery plan [EPSRC07] are:

- Energy,
- Digital Economy and
- Nanoscience through Engineering to Application,

which have been discussed in the preceding sections.

Under the “Energy” initiative, which is led by the EPSRC, is included the use of the Joint European Torus (JET) and the International Tokamak Experimental Reactor (ITER). The use of large facilities is one of the drivers for establishing international standards for scientific data management, access and analysis, particularly in the case of ITER where the predominant activity at present is simulations, which will evolve into computationally assisted steering of reactor experiments.

The “Digital Economy” programme includes a commitment to DTCs and IRCs that are ICT oriented — this will be a valuable element of the CIR Strategy. The “Digital Economy” programme already includes many valuable alliances, with other research councils, with the TSB and with healthcare organisations. It is hoped that this network of alliances can extend deeply into education via the CIR Strategy.

The next EPSRC delivery plan priority, “Towards Next-Generation Healthcare” includes “Excellent research to support the development of novel medical technologies, sensors and information systems.” and “The delivery of better health and well-being through dynamic information and intervention.” These are areas where the CIR Strategy’s emphasis on raising the quality of pervasive e-Infrastructure and the ambient levels of relevant skills will have direct benefits to the research and to society.

The “Sustainability” priority of the EPSRC delivery plan states an overall goal of

Support for the core of engineering and physical sciences research activity ensures a vibrant and healthy research capacity, delivering outputs for all of science and the knowledge-driven economy. Our aspirations for a sustainable research base are to:

- Deliver a vibrant, creative and healthy science and engineering base
- Ensure the long-term health of disciplines
- Encourage a move to more transformative and multidisciplinary research
- Supply trained people for the economy and provide the next generation of world-leading researchers
- Enhance capacity in areas of national importance.

The CIR Strategy has the goal of assisting EPSRC (and all other research councils) with achieving these fundamental goals by delivering e-Infrastructure that is routinely used to enable innovative research and by developing the skills needed. This aligns with EPSRC’s commitments to “A Healthy Science and Engineering Base” and “Securing the Future Supply of People”.

5.2.7. Medical Research Council

The MRC is leading the “Ageing: Lifelong Health and Wellbeing” cross-council programme discussed above. In its summary in [DIUS07] the MRC states:

It has partnered with other Research Councils in developing the e-science programme, and funds methodological and behavioural research that will underpin new opportunities in health data transfer, data integration, data mining, novel use of ICT in behaviour change and patient self-management.

The MRC delivery plan [MRC07] explains the complex new context in which the MRC research agenda must operate. In such a complex context flexibility and interoperability of

ICT systems based on standards is likely to prove beneficial — an example arises in the “E-Health — ‘Connecting for Research’ described in the delivery plan as follows:

The MRC’s current investment is underpinning, for example, supporting a wide range of cohort studies, methodologies, e-science and networks such as the General Practice Research Database. Examples of MRC-funded studies providing underpinning developments include piloting of strategies for recruitment of patients to trials and development of epidemiological data collection and management systems by UK Biobank. As part of its ongoing contributions to developing e-health, the MRC will invest in two joint initiatives on maximising the use of electronic datasets with the Wellcome Trust, EPSRC and ESRC and on Information Driven Healthcare with the EPSRC. MRC will facilitate linkages and alignments between existing activities, new plans developed with NIHR and OSCHR and activities such as the cross-council programme on Digital Economy.

The recurrence of requirements to link data sets, build up systems that cross organisational boundaries and the engagement in the programme on Digital Economy all suggest that MRC research might benefit from alignment of different e-Infrastructure provisions. The work on patient recruitment for clinical trials already draws on foundations developed in the e-Science programme to establish acceptable security and privacy mechanisms.

5.2.8. Natural Environment Research Council

The NERC is leading the cross-council programme “Living with Environmental Change (LWEC)” described above. Stimulated by the many international efforts to collaborate on predicting and mitigating the effects of climate change there are many international efforts to share data and jointly develop models, which in the UK are often sponsored by NERC or one of the many partners in LWEC. This suggests that NERC probably already has within its plans strategies that are similar to the CIR Strategy. The NERC delivery plan [NERC07b] was preceded by the very readable “*Next Generation science for planet Earth 2007–2012*” [NERC07a]. An excerpt from the delivery plan describing NERC’s contribution to LWEC

Climate and environmental change prediction on local-regional and seasonal-decadal scales, through creating the next generation of high-resolution climate models supported by more strategic observing systems and identification of key feedback processes.

makes it clear that coupling more complex models together with more observational data is a key requirement. This requirement is reiterated in the description of NERC’s Technologies theme.

Technology will play an essential role in enabling solutions to this century’s most pressing environmental challenges. Technologies are used to observe and monitor the environment, provide sophisticated models of environmental processes to predict the future state of the environment and develop mitigation solutions such as carbon capture and storage.

Identified critical UK infrastructure includes:

The key tools of environmental science are observations and simulations of the Earth, which place a heavy demand on facilities and equipment. NERC funded scientists use a range of infrastructure including: cutting edge facilities such as specialist laboratories, Antarctic bases and the Diamond synchrotron; Earth observation satellites, ships and aircraft to access remote parts of the Earth; and high performance computing to simulate models of how the Earth behaves.

As the NERC community made very substantial progress using e-Science methods during the e-Science initiative and as their priorities it is probable that they would be major contributors to the CIR Strategy.

5.2.9. Science and Technologies Facilities Council

The work of PPARC in preparing for the LHC and in supporting high-volume digital data processing for astronomy was one of the major foundations on which the e-Science initiative built. The CCLRC has played a central role in e-Science projects in many disciplines,

including the PPARC GridPP and AstroGrid projects, the NERC Data Grid and eMinerals projects and the EPSRC Integrative Biology projects. The STFC Delivery Plan [STFC07b] builds on this legacy. The delivery plan's commitment to particle physics includes:

Our highest priority will be to exploit the Large Hadron Collider (LHC) at CERN, which starts operation in 2008; this is because discoveries are guaranteed. This accelerator is the first with sufficient energy to access the regime where our existing knowledge breaks down: at the very least, we hope to find the Higgs Boson, which is postulated to give particles their mass; theoretical models suggest we will likely observe new symmetries of nature, new particles and forces beyond those known.

With the commissioning of the LHC, CERN will be for at least the next decade the world's most advanced particle physics laboratory. Our membership of CERN gives us a strong and central role in this transformative project: one of the two major experiments at LHC is UK-led. If CERN Council agrees the proposed uplift in the CERN subscription to enable the LHC to be operated optimally. This uplift will be funded from the particle physics grants line.

The UK research community has been a major player in constructing the LHC and the highly advanced computing infrastructure to handle the data. The community is now prepared and ready to exploit the results from the machine and we will support the community to do so, within our financial constraints.

There are similar commitments to astronomy:

In ground-based astronomy, our highest science priority is to focus on galaxies — exploring how they form and are arrayed in large-scale structures. Through our membership of ESO, UK astronomers now have access to the world's most productive 8m class telescopes and when commissioned in 2008 the UK-built VISTA telescope, giving world-leading capability in surveying the sky. Without membership, the UK, indeed Europe, would not have been able to afford joint participation with the USA in the ALMA project. ALMA is a giant, international observatory currently under construction on a high-altitude site in Chile. It will be the world's most powerful sub-millimetre telescope in the next decade and will begin operation in 2009.

We will continue to invest, in collaboration with European and other global partners, in design studies for two future instruments with transformative potential: an Extremely Large Telescope ten to a hundred times more sensitive than present instruments and the Square Kilometre Array, the next generation radio telescope, fifty times more sensitive than current facilities. Such increases in sensitivity will transform our view of the Universe by allowing us to see planets around distant stars, the formation and evolution of galaxies, and the nature and distribution of the dark matter and dark energy which dominate the evolution of the Universe, with unprecedented clarity and precision. Decisions on investment in construction of these facilities will not be needed before 2010.

These priorities will continue to have very demanding requirements for e-Infrastructure and suitably skilled researchers; they may therefore be expected to continue to be an innovative force in the CIR Strategy. They also illustrate the requirement to recognise crucial differences; whereas in all other fields protecting the data against inappropriate access is mandatory, and in many fields there are sensitive ethical and privacy issues, here they are almost absent.

5.3. Requirement for Incremental Contributions

All of the examples above illustrate the common requirement for capabilities in computational and information systems skills to facilitate research and many cases where there is a *potential* for synergy to be discovered and hence for the CIR Strategy to deliver benefits. Without the Strategy there will not be a pooling of effort to stimulate growth in capabilities and skills and without the Strategy very few of the potential synergies will be discovered.

With the Strategy in operation, these positive effects from collaboration will take time to develop and must be developed and delivered incrementally. It is both infeasible and undesirable to attempt to design a complete and pervasive infrastructure that meets all the

needs of researchers, even in one research council's domain. As research progresses rapidly it is impossible to collect and collate all requirements as fast as they develop. As understanding at the boundaries of research is inevitably uncertain, researcher-led innovations in technologies and methods must be supported while ensuring that further investment to encourage wider adoption is grounded in clear evidence of the benefits. Many researchers have deep experience of particular technologies and this depth enables them to exploit the technology to the full. Many facilities, instruments and research programmes have a large installed base of particular technological choices. For all of these reasons, diversity must be accepted as necessary and accommodated in the Strategy delivery plans.

Given such a complex context, information system architects and technological experts must work with communities to spot potential synergies. They should then conduct pilot studies and finally commission or recommend the provision of a common solution. Researchers will then incrementally adopt that solution if it benefits their research. Often they will postpone such adoption until others have made the commitment, the facilities are clearly robust and easy to use and they need to make a technological change for some other reason.

The Office for Strategic Coordination of CIR will have the responsibility for resourcing and organising such investigations, taking account of international trends and decisions and with an alert technology watch. It will need to develop analyses that lead to long term plans and then adapt these plans as the research usage develops. There will always be a number of such incremental changes underway. The OSCCIR will try to see that they converge towards consistent and complementary, sustainable and easily used elements of the e-Infrastructure provision. As the level of provision rises, new opportunities and new requirements will emerge to be considered by OSSCHIR.

This coordinated and integrated approach that still retains flexibility and dynamism, will lead to more cost-effective investment in research, will address emerging issues and will give the UK research communities the platform that they require to address their priorities and to achieve world-leading advances. The investment in translational R&D will promulgate these benefits widely and increase the impact on the UK's economy. The new methods and technologies will have a wide impact on the wellbeing of UK citizens.

Can we increase researchers' productivity – rate of acquiring new methods and using them successfully – by sharing know how as workflows?



Workflows express methods of working, e.g., strategies for exploring data systematically. Will the community effects, as seen in the Web 2.0 world, e.g., wikipedia, work in research? Will researchers share and improve each other's workflows? What do we need to establish this as a way of developing and publishing important research methods?

References

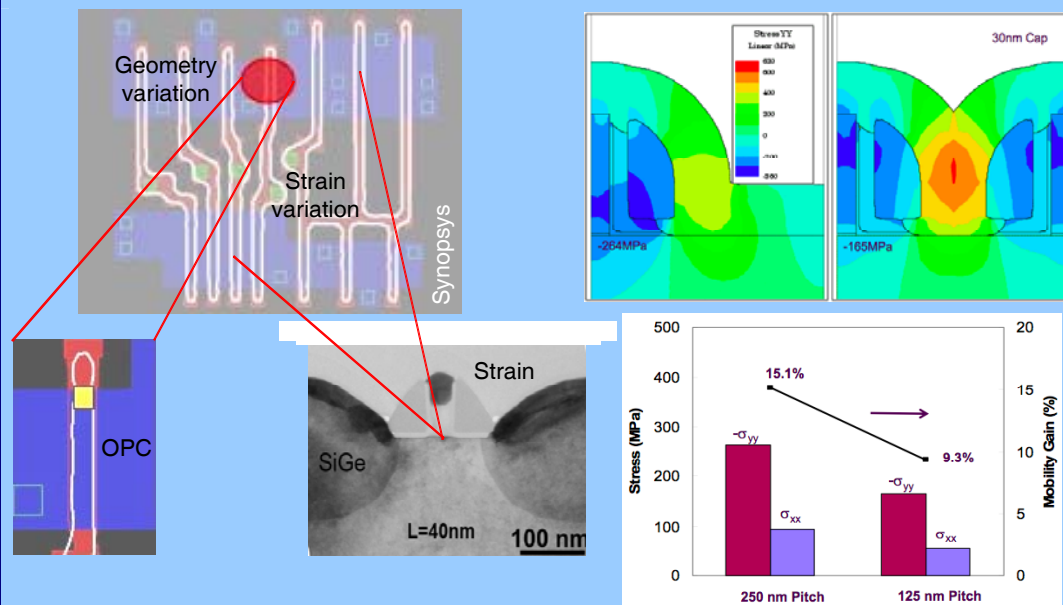
- AHRC07 Arts and Humanities Research Council, *Delivery Plan 2008-2011*, December 2007, URL www.ahrc.ac.uk/about/delivery_plan.asp.
- Atkinson et al. 07 Atkinson, MP, Britton, D., De Roure, DE., Garnett, N., Geddes, N., Gurney, R., Haines, K., Hughes, L., Jeffreys, P., Perrott, R., Procter, RN. and Trefethen, AE., Century of Information Research: research challenges and opportunities in the Century of Information, Dec. 2007.
- Atkinson et al. 08 Atkinson, MP, Britton, D., De Roure, DE., Garnett, N., Geddes, N., Gurney, R., Haines, K., Hughes, L., Jeffreys, P., Perrott, R., Procter, RN. and Trefethen, AE., "Beyond e-Science, ...", February 2008.
- Barroso08 Barroso, JMD., ICT Industry has a Major Role to Play in the European Economy of the 21st Century, CeBIT Trade Fair, Hannover, 3 March 2008 <http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/08/120&format=PDF&aged=0&language=EN&uiLanguage=fr>
- BBSRC04 Biotechnology and Biological Sciences Research Council, Bioscience for Society: A ten Year Vision, "Towards Predictive Biology", (URL www.bbsrc.ac.uk/about/pub/policy/vision.html).
- BBSRC07 Biotechnology and Biological Science Research Council, *Delivering Excellence with Impact – BBSRC Delivery Plan 2008-2011*, December 2007, URL www.bbsrc.ac.uk/publications/policy/bbsrc_delivery_plan.html.
- Brown07 Brown G., "Speech on Liberty", University of Westminster, 25 October 2007, (URL www.number10.gov.uk/output/Page13630.asp).
- CEC07 Commission of the European Communities, *Green Paper: The European Research Area: New Perspectives*, COM(2007) 161 final, Brussels, 4 April 2007 URL ec.europa.eu/research/era/pdf/era_gp_final_en.pdf.
- CO05 HMG Cabinet Office, *Transformational Government – enabled by Technology*, Cm 6683, HMSO, URL archive.cabinetoffice.gov.uk/e-government/strategy/.
- CO08 HMG Cabinet Office, Strategy Unit, *Realising Britain's Potential: Future Strategic Challenges for Britain*, Feb. 2008, URL www.cabinetoffice.gov.uk/strategy/.
- COSEPUP04 Committee on Science, Engineering, and Public Policy, *Facilitating Interdisciplinary Research*, The National Academies Press, Washington DC, 2004.
- CPDN07 BBC and Climate Prediction Team at Oxford University, *The BBC Climate Change Experiment*, 2007, URL <http://bbc.cpdn.org/>.
- Coveney06 Peter Coveney, Stewart Cant, Sam Falle, *et al.*, The High End Computing Strategic Framework Working Group, EPSRC, Dec. 2006 (URL www.epsrc.ac.uk/ResearchFunding/FacilitiesAndServices/HighPerformanceComputing/HPCStrategy/2006StrategicFramework.htm).
- DIUS07 Department for Innovation, Universities and Skills, *The Allocations of the Science Budget 2008/09 to 2010/11*, December 2007, DIUS/PUB8663/3K/12/07/NP, URN 07/114. URL <http://www.dius.gov.uk/publications/URN07114.pdf>
- e-IRG07 The e-Infrastructure Reflection Group, 2007 (URL www.e-irg.org).
- eSCP06 e-Science Core Programme, (URL <http://www.epsrc.ac.uk/ResearchFunding/Programmes/e-Science/default.htm>), Dec. 2006.
- ESRC05 ESRC strategic plan 2005-2010, (URL <http://www.esrcsocietytoday.ac.uk/ESRCInfoCentre/about/strategicplan/>)
- ESRC07 Economic and Social Research Council, *Delivery Plan 2008-2011*, December 2007, URL www.esrcsocietytoday.ac.uk/ESRCInfoCentre/about/delivery_plan/.
- EPSRC06 High-End Computing committee, Challenges in High-End Computing, EPSRC, Dec 2006 (URL www.epsrc.ac.uk/ResearchFunding/FacilitiesAndServices/HighPerformanceComputing/HPCStrategy/Challenges.htm).
- EPSRC07 Engineering and Physical Sciences Research Council, *Delivery Plan 2008-2011*, December 2007, URL www.epsrc.ac.uk/Publications/Corporate/DeliveryPlan2007.htm.
- ESFRI06 European Strategy Forum on Research Infrastructures, European Roadmap for Research Infrastructures, Cordis 2006. (URL cordis.europa.eu/esfri/roadmap.htm).
- Gantz07 Gantz, J.F., Reinsel, D., Chute, C., Schlichting, W., McArthur, J., Minton, S., Xheneti, I., Toncheva, A. and Manfrediz, A., *The Expanding Digital Universe: a forecast of worldwide information growth through 2010*, An IDC white paper, 34, March 2007, URL <http://www.emc.com/leadership/digital-universe/expanding-digital-universe.htm>.
- Grid5000 (URL <https://www.grid5000.fr/mediawiki/index.php/Grid5000:Home>), checked Sept. 2007
- Hoare&Milner04 Hoare, T and Milner, R., Grand Challenges in Computing Research, BCS, 2004 URL <http://www.ukcrc.org.uk/gcresearch.pdf>.
- HMG04 HM Treasury, DTI and DfES, Science & innovation investment framework 2004 – 2014, July 2004.

- HMG06 HM Treasury, DTI, DfES and DoH, Science and innovation investment framework 2004-2014: next steps, March 2006.
- Hud07 Andy Hudson-Smith, Richard Milton, Michael Batty, Maurizio Gibin, Paul Longley, and Alex Singleton, Public Domain GIS, Mapping & Imaging Using Web-Based Services, xxxxxxxx
- IPCC07 Intergovernmental Panel on Climate Change, IPCC Fourth Assessment, UNEP, 17 November 2007, (URL <http://www.ipcc.ch/ipccreports/ar4-syr.htm>).
- JISC07a JISC, JISC Response to OSI Report: "Developing the UK's e-Infrastructure for Science and Innovation", Aug. 2007.
- Manos *et al.* 08 Manos, S., Zasada, S. and Coveney, P.V., Life or death decision-making: The medical case for large-scale, on-demand grid computing, UCTwatch, Feb. 2008.
- MRC07 Medical Research Council, *Delivery Plan 2008/09 – 2010/11*, December 2007, URL <http://www.mrc.ac.uk/Utilities/Documentrecord/index.htm?d=MRC004269>.
- MEA05 The United Nations Millennium Ecosystem Assessment (URL <http://www.millenniumassessment.org/en/index.aspx>)
- NERC07a Natural Environment Research Council, *Next Generation Science for Planet Earth 2007-2012*, November 2007, URL <http://www.nerc.ac.uk/publications/strategicplan/nextgeneration.asp>.
- NERC07b Natural Environment Research Council, *Delivery Plan 2008-11*, December 2007, URL <http://www.nerc.ac.uk/about/perform/documents/deliveryplan200712.pdf>.
- Newhouse06 Newhouse, S., Schopf, J.M., Richards, A. and Atkinson, M.P., Study of User Priorities for e-Infrastructure for e-Research (SUPER), UK e-Science Technical Report Series, UKeS-2007-01, April 2007 (URL www.nesc.ac.uk/technical_papers/UKeS-2007-01.pdf).
- NSF07 National Science Foundation Cyberinfrastructure Council, *Cyberinfrastructure Vision for 21st Century Discovery*, NSF 07-28, March 2007 (URL <http://www.nsf.gov/pubs/2007/nsf0728/index.jsp>).
- NSF06 Blue Ribbon Panel on Simulation-Based Engineering Science, chaired by Professor J. Tinsley Oden of University of Texas at Austin, *Simulation-Based Engineering Science - Revolutionizing Engineering through Simulation*, 2006.
- NSF03 National Science Foundation, *Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure*, 2003.
- OECD06 OECD, *Education at a Glance, OECD Indicators 2006*, Annex 3, Sources, Methods and Technical Notes, Chapter A: The output of educational institutions and the impact of learning. http://www.oecd.org/document/52/0,3343,en_2649_39263238_37328564_1_1_1_1,00.html
- OSIwg07 The OSI e-Infrastructure Working Group, Developing the UK's e-Infrastructure for science and innovation, March 2007 (URL www.nesc.ac.uk/documents/OSI/).
- RAND06 Horlings, E., Ligtoet, A., Cave, J., Frinking, E., Mildt, C., Shergold, M. and Kahan, J.P., *Markets of Virtual Science*. Report for the German Ministry of Education and Research, RAND Europe, Cambridge, 2006.
- Rogers00 Rogers, J., The intellectual consequences of the research assessment exercise: a response, *History of the Human Sciences*, 13, 2000.
- Stern07 Stern, M. *et al.*, Stern Review on the economics of climate change – Final Report, Cambridge University Press, November 2007, (URL http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm)
- STFC07a (URL www.stfc.ac.uk/SciProg/CompSci/ESci/escience.aspx).
- STFC07b Science and Technology Facilities Council, *STFC Delivery Plan 2008/9 – 2011/12*, December 2007, URL http://www.scitech.ac.uk/resources/pdf/delplan_07.pdf.
- STSC98 Science and Technology Select Committee First Report, 1998. www.publications.parliament.uk/pa/cm199798/cmselect/cmsctech/303i/st0102.htm
- Wing06 Jeanette Wing, Computational Thinking, *CACM*, 49(3), p33-35, March 2006.
- WorldBank02 World Bank, Education Group, *Constructing Knowledge Societies: New Challenges for Tertiary Education*, A World Bank Report, April 16 2002. www1.worldbank.org/education/pdf/Tertiary%20Education%20Paper%204-10.pdf

CIR Strategy working group members

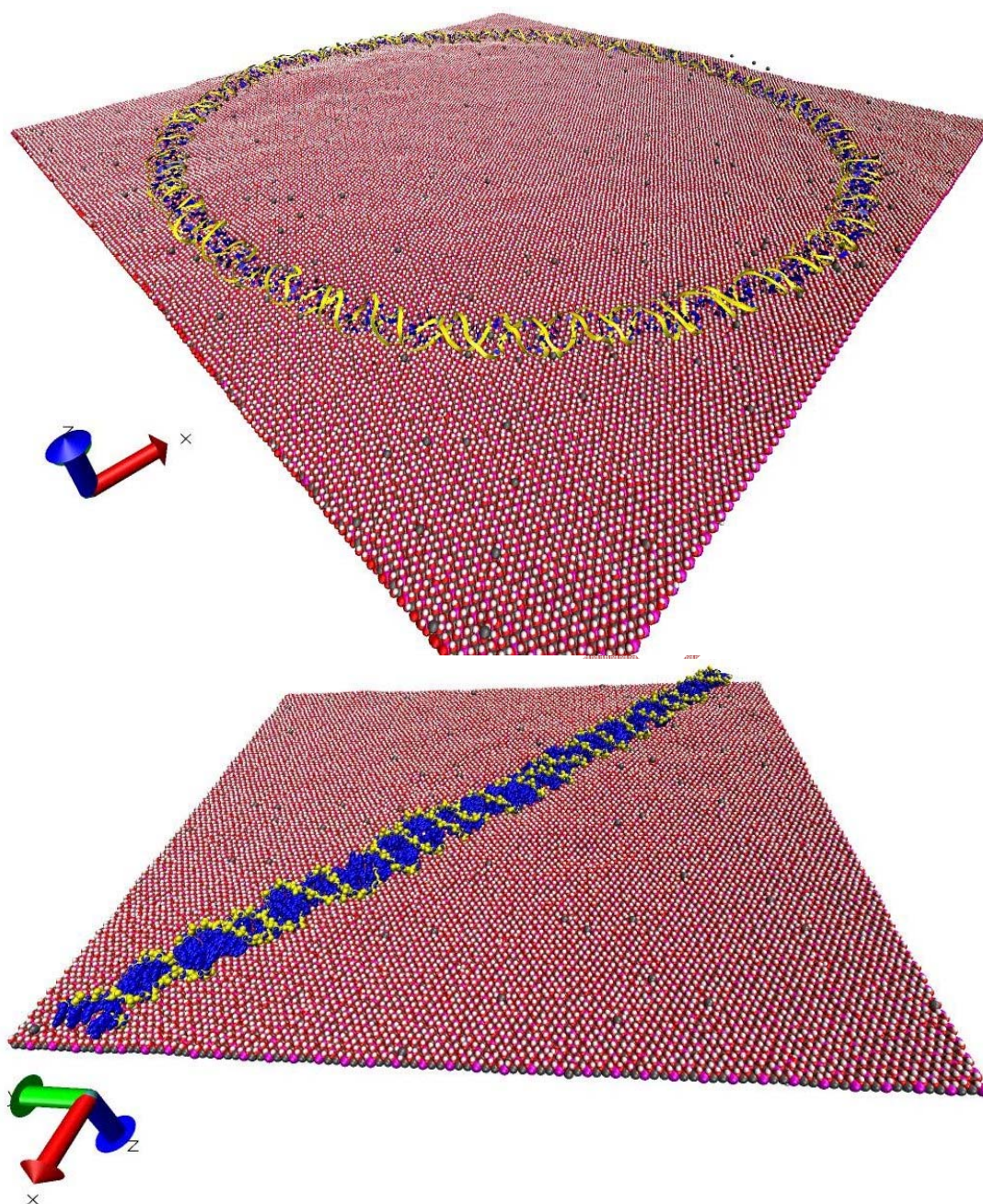
Name	Affiliation
Prof Malcolm Atkinson (chair)	Director, e-Science Institute, e-Science Envoy, University of Edinburgh
Prof David Britton	University of Glasgow (GridPP)
Prof Peter Coveney	University College London & chair of the CCP ⁷⁰ committee
Prof David De Roure	University of Southampton & OMII-UK chair
Dr Ned Garnett	NERC
Dr Neil Geddes	STFC e-Science Centre & NGS director
Prof Robert Gurney	Reading e-Science Centre & NERC
Prof David Ingram	Director of CHIME at UCL
Prof Keith Haines	Reading e-Science Centre & NERC
Dr Lorna Hughes	Director, Arts & Humanities e-Science Support Centre, King's College London
Prof Paul Jeffreys	IT Director, University of Oxford
Dr Liz Lyon	Director UKOLN, University of Bath
Mr Ian Osborne	INTELECT and director of Grid Computing Now!
Prof Ron Perrott	Queen's University Belfast, Belfast Regional e-Science Centre & HEC Technology Panel
Prof Rob Procter	National Centre for e-Social Science & ESRC, University of Manchester
Mr Chris Rusbridge	Director, Digital Curation Centre, University of Edinburgh
Prof Anne Trefethen	Oxford e-Research Centre

Can we characterise the atomic variations and device properties as chip features become smaller and devise circuits that are nevertheless reliable?



Exploration of the materials using computational models and stochastic samples has to be coupled with circuit models. This requires computational steering of demanding computations within a security shield that protects the IPR of the participating corporations. The NanoCMOS project uses the NGS to compose models run in Glasgow, Manchester and London.

⁷⁰ www.cse.scitech.ac.uk/ccp/ and www.ccp.ac.uk.



(Top) Visualisation from a 1 million atom molecular dynamics simulation of a DNA plasmid ring within a layered double hydroxide sheet after 1ns of molecular dynamics simulation and (bottom) represents a 108 base pair DNA strand inside layered double hydroxide. The simulations were performed using a molecular dynamics package called LAMMPS and visualised using the atomic visualiser VMD.