World Wide Research

Reshaping the Sciences and Humanities

edited by William H. Dutton and Paul W. Jeffreys

with a foreword by Ian Goldin

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World Wide Research: An Introduction

William H. Dutton and Paul W. Jeffreys

Researchers across all fields of study are being presented with exciting opportunities as well as significant threats by the use of advanced Internet capabilities, innovative computational networks, and related information and communication technologies (ICTs). Such technological resources and applications are enabling a growing spectrum of researchers to join collaborations that share a common network or large-scale sources of data and information.[1] The changes in research practices enabled by these innovations may have widespread and major implications for the quality and value of research.[2]

This book's aim is to assess the implications of these developments in computation and networking that are shaping the practice and outcomes of research—which we refer to generically and discuss more fully in this introduction as "e-research"—from a variety of interrelated social, institutional, and technical perspectives. The volume offers many tangible examples and case studies to help anchor readers in its exploration of the shaping and implications of e-research across different disciplines and institutions in many nations around the world.

The Significance of ICTs for Research and Society

Jacques Ellul (1964) warned his readers decades ago that technologies were a means to an end, but were being viewed as ends in themselves as society became increasingly focused on "technique." This book focuses on the ends and the means in e-research by examining the possible research outcomes and exploring both the potential and the limits of the supporting technologies. The wide significance of the ends being targeted—the improved quality of research and the informing of related theory, policy, and practice—also highlights the importance of the underpinning technologies in achieving that end.

The volume describes the promise of new approaches to research, but we also emphasize that a one-way relationship between technological potential and actual outcomes cannot be assumed. For example, despite the pace of ICT innovation, many still lack trust in the quality of information they are presented with. This refrain has been heard

so often that the questions it asks so vividly have become commonplace: "Where is the wisdom we have lost in knowledge? / Where is the knowledge we have lost in information?"

These lines, from the Choruses to T. S. Eliot's 1934 play *The Rock*, are at the heart of a modern conundrum.[3] In an age suffused with information enabled by innovation in ICTs, there is widespread uncertainty across many sectors of society over the quality of information. The global financial crisis that emerged in 2008 painfully illustrated this point, showing that decision makers cannot be complacent about the quality of information on which they make decisions.

Despite advances in ICTs, a critical challenge continues to be our ability to trust knowledge and information drawn from the growing deluge of data available at the fingertips of anyone with access to electronic technologies. Will the technologies be used to enable research to be pursued more effectively, or will they set up significant new barriers? Will innovations in the means result in higher-quality research or in a deterioration of what can be achieved? In examining answers to these kinds of questions, this book offers a critical perspective on the changes described in order to help those who seek to enhance associated policy and practice to chart a course that might avoid the emergence of a world "lost in information."

We show how uses of e-Research innovations can transform—for better or worse—the processes of discovery in ways that might either enhance or hinder our ability to grapple with many substantial problems facing the twenty-first century. In particular, we identify the nature and dynamics of the many factors that shape and constrain advances in e-research and its application.

World Wide Research: Seeking to Create a Virtuous Cycle of Innovation

The e-research developments illustrated in this book encompass activities that use a wide spectrum of sophisticated ICT capabilities, some of which have come under specific classifications such as "e-science" and "e–social science" (chapters 1 and 2). A vision of the enormous potential gains these innovations might bring has led to a broad range of initiatives in many countries. Many chapters discuss major pioneering e-research national initiatives, such as those related to "e-infrastructure" in the United Kingdom's e-Science Programme and to "cyberinfrastructure" in the United States (e.g., chapters 2 and 7). These initiatives typically involve large-scale data sets and are conducted via distributed collaborations that leverage access to powerful computing capabilities and collaborative environments for undertaking research.

A key example of an innovation in computation and networking that has been focused on supporting research is the Grid (see box I.1). The Grid, advanced Internet applications, and other research-centered computational networks (RCNs)[4] have become folded into broad definitions of e-infrastructures for research.

Box I.1
The Grid: A Powerful Distributed-Computing Service

Grid computing harnesses the capabilities of multiple computers to target a common purpose. It has become a well-used core element of e-infrastructures, using software that enables many computers in the same or distributed locations to work together as if they were a more powerful single system. This concept evolved from developments in the 1970s aimed at using "distributed-computing" techniques to make optimum use of available computing resources, such as by coordinating the deployment of processing and storage resources at places other than at the physical location of a researcher seeking an answer to a problem.

The pioneers of this technique (Foster and Kesselman 2004) coined the name "Grid" to indicate their vision of providing a computing utility equivalent to an electricity grid, into which users can "plug" their own systems. This utility offers enormous potential for giving many people access to virtually unbounded computational capacity (Foster 2003). Its emergence was one of the driving forces behind early e-research initiatives (Berman, Fox, and Hey 2003; see also chapter 2 in this volume). A related form of providing distributed-computing power of much value to support research has emerged through what is called the "Cloud" (essay 2.1).

The use of a growing range of RCNs might break the technical, geographical, institutional, and disciplinary boundaries that constrain research creativity and productivity. If implemented effectively, RCNs might offer flexible and sustained support for increased participation, improved access, and new ways to combine resources and skills. These results would have an impact on shrinking or expanding psychological as well as physical distances among colleagues around the world (Friedman 2005), but not necessarily spelling the "death of distance" (Cairncross 1997). In fact, the opposite might well be the case. New technologies can also create new centers of worldwide expertise. These centers might lead to a concentration of related resources and know-how, where geography would matter even more and inequalities in access to the tools of research would maintain and enhance local and global economic divides. This two-edged potential is typical of the possibilities tied to advances in technology in general.

Our edited collection focuses on how e-research is reshaping and will continue to reshape not only how research is done but, more important, its outcomes. These results emerge as a consequence of the way the tools are used to "reconfigure access" to research-related people, information, services, and technologies (chapter 1). Our aim is to create an understanding of this process in a way that enables researchers and an array of other relevant actors to generate a "virtuous cycle." This cycle would facilitate major advances in RCN innovations across the sciences and humanities, fostering

advances in research that would then feed back to support further innovation in computational networks.

By anchoring our discussion in specific research settings, the book identifies and analyzes a promising set of practical developments and outcomes tied to e-research innovations. All actors involved in research should consider these outcomes carefully to identify how the latter can enable new approaches to the conduct of work in the actors' own fields.

The Social and Technical Underpinnings of Change in Research

The themes of this book's critical examination of e-research innovations are interwoven around the two interrelated but inseparable forces and constraints affecting the developments it highlights: the technical and social shapers of change. The expectations raised by new technological capabilities underpinning e-research are not based simply on a blind faith in technology, but on a developing consensus that advances in ICTs enable many new choices for researchers regarding how they can conduct their work as well as on the observation that parallel changes are occurring in other sectors of society. The social dimension includes the institutional infrastructures as well as the legal and ethical issues that shape, facilitate, and constrain the development and application of ICTs (e.g., see part III and chapter 12).

The ways these and other factors shape emerging opportunities and challenges are illustrated throughout the book—for example, to highlight the way that some data are shared, but some need to be kept private and secure. Technology can similarly enable more open access to research, but privacy, confidentiality, or other ethical considerations will sometimes preclude that access. Although new collaborative software and systems promise to support virtual teams, cooperation can be hampered by disciplinary demarcations or institutional concerns about issues such as intellectual property rights and liability.

RCNs can be used to transform both how researchers do their work and the quality and scope of the outcomes produced. Investigations across the disciplines rely increasingly on powerful computational and networking tools through nearly all stages: observation; distributed collaboration and data sharing; modeling and simulation; and dissemination and publishing. These tools also open a window on the possible future of communication more generally, just as the development of the Internet and Web helped to generate new tools for research collaboration (see box I.2).

Types of Research-Centered Computational Networks

The pattern of innovations in computation and networking that support research defy any simple trajectory. They have sometimes moved from initial specialized areas

Box I.2
Inventing the Internet and the World Wide Web

The Internet was itself a product of efforts to support research, in that it was triggered by the ARPANET network developed by the U.S. Department of Defense's Advanced Research Projects Agency, beginning in about 1969. The aim was to support the sharing of computing facilities among computer scientists and engineers. From the 1970s, a variety of academic network initiatives began to evolve, including the National Science Foundation's (NSF) NSFNET[a] in the United States (c. 1984) and GÉANT[b] across Europe (c. 2000). ARPANET was moved beyond academia in 1974 under the Internet name, but has continued to support all phases of research.

The Internet's success was limited until a team at the European Organization for Nuclear Research (CERN)—including a computer scientist trained in physics, Tim Berners-Lee, and colleagues in particle physics—invented the World Wide Web (c. 1989) as a means of sharing documents within a collaborative science project. In this way, the Web was invented by domain researchers, users, working with computer scientists, within a "big science" project, requiring large-scale, computationally demanding ICT resources (e.g., CERN's high-energy physics research).

Many other innovations in graphical user interfaces and browsers, such as Mosaic, contributed to the eventual success of the Internet and the Web through a series of top-down processes, but also more bottom-up processes of invention and diffusion.

Notes:
a. See http://www.nsf.gov/about/history/nsf0050/internet/launch.htm.
b. See http://www.geant.net/.
Sources: Adapted from Abbate 1999, Reid 2000, and Leiner, Cerf, Clark, et al. 2003.

requiring enormous computational power to other hard sciences before moving into the social sciences, law, and the humanities. However, there are many pathways to innovation, including user-led innovations. As David de Roure explains in essay 2.2, social networking and other Web applications that support a growing range of collaborations and interactions are increasingly moving from the world of everyday Internet use to the research arena, not just vice versa.

Despite many pathways to diffusion, similar advanced computing and data center capabilities are forming critical aspects of the infrastructure that enables e-research, the Internet, and the Web to offer what have become routine online uses in everyday life, such as Web searches, email, and other utility computing services (Carr 2008). In such ways, the boundaries between the RCNs that support research and the ICTs of everyday life increasingly intersect. This book explores this trend, while focusing primarily on RCNs, such as research applications of Grid computing. For simplicity, we generally use

the term *e-research* to refer to the wide array of research activities encompassed because it is not tied to a particular disciplinary area and is therefore suited to encompassing the broader potential of the application of ICTs to research. However, we occasionally refer to related terms, many of which are equally general, but which have become tied to particular areas of application, such as:

- *e-science* Used by the United Kingdom's e-Science Programme to denote "the systematic development of research methods that exploit advanced computational thinking."[5] Associated with worldwide collaboration in key areas of science, e-science moves to build "e-infrastructures" that can sustain the long-term growth of e-research (chapters 11 and 12 focus specifically on e-science).
- *Cyberinfrastructure* Used in the United States to refer to RCNs in an equivalent way to e-infrastructure in the U.K. e-Science Programme (U.S. NSF 2007; essay 1.1).
- *e–social science* Application and adaptation within the social sciences of many of the technologies and tools developed in e-Science (see chapter 6).
- *e-humanities* Adapts technical innovation based on e-Infrastructures to the humanities, such as in libraries and rare collections (U.S. NSF 2003; chapter 3).

Despite the similarity of these broad conceptions, each has become tied to particular communities of researchers and periods of time in the development of this emerging field. This is one reason why the terminology chosen in this book, such as *research-centered computational networks*, is not tied to a particular community—however, a particular terminology is used when it is significant to the contributor or to the disciplinary or historical context.

The Multidisciplinary Range of e-Research: Changing How Researchers Work

Examples of e-Research Benefits

This volume aims is to capture the potential significance of e-research in changing the nature of research processes and practices, such as in increasing collaborative opportunities. It does so by offering a concrete sense of how these capabilities are being applied across the disciplines, with illustrations of the many interrelated facets of the subject. Table I.1 gives a flavor of the new opportunities opened by applying human intelligence creatively to emerging RCNs.

Cross-cutting Themes

The examples in table I.1 illustrate some key themes in the book that apply across disciplines, such as:

- RCNs applied to outer space and microscopic observation demonstrate that researchers can change how they visualize objects of study and what they can see, thereby shap-

ing the quality and impact of their own work and that of their colleagues involved in collaborations.

• E-research applied to environmental and biological sciences points to the potential transformation of the way information is collected, analyzed, and viewed.

• The use of embedded submarine sensor networks illustrates that e-research does not necessarily substitute for direct observation of events or other phenomena, but can be used to assist researchers to be where they need to be in order to observe rare or critical events or processes.

• The Hubble telescope project is based on "softer" social and institutional infrastructures of international and interinstitutional collaboration, financed by many government agencies, indicating the centrality of such institutional arrangements as joint-funding models in the support of worldwide research.

• New forms of data visualization can help researchers better communicate their theories and research to a broader public—for example, in the social sciences, humanities, and biology.

• The biological stream of e-science work highlights major ethical issues, such as questions about patients' privacy and confidentiality (essay 8.2) or other research subjects (chapter 8). These issues might constrain some e-research activities despite the activities' potentially beneficial outcomes (e.g., in gene research to enable physicians to identify and select out embryos carrying the genes associated with breast or prostate cancer).

Fostering e-Research and Innovation

New Environments for Researchers

Separate e-research developments have been brought together to create environments offering easy access to a wide range of relevant hardware and software digital resources. Such environments have generally become known as a "collaboratories" in the United States and as "virtual research laboratories" or "virtual research environments" (VRE) in Europe (chapter 10). These environments are designed to support the effective operation of collaborations and as much of the research process as appropriate for any given activity or role by providing a framework into which selected existing and new tools, services, data sets, and other resources can be plugged.

A feature of this kind of environment is the ability to underpin the workflow requirements of a particular research community (box I.3). However, the importing of engineering approaches into other disciplines has raised some concerns about the possibly unwelcome "industrialization" of the "art" of research as a creative process (see chapter 6).

There is a further sense in which e-Research is opening out. Many ICT innovations developed initially for scientific research have also been opened to broader user bases, as shown by the way in which the Internet evolved and grew from the U.S. Defense

Table I.1
Examples of the Multidisciplinary Range of e-Research Applications

Research Area	Examples
Observation of outer space	The U.S. National Aeronautics and Space Administration's orbiting Hubble telescope[a] integrates advances in satellites, optics, and computational science to enable scientists to see planets, stars, and galaxies that would otherwise be invisible. The images obtained can be accessed from anywhere in the world through the Internet.
Exploration of microscopic worlds	"Telescience" centers use advanced electron microscopes to view matter so small it could not be seen previously.[b] A Web portal offers remote control of such microscopes to scientists without access to similar local capabilities.[c]
Physics experiments	The European Organization for Nuclear Research (CERN) Grid is shared by particle physics researchers around the world, including thousands of scientists involved in high-energy physics experiments (Tuertscher 2008). Core aspects of collaboration across the world are managed using email, listservs,[d] and Web-based documents.
Social sciences	Research models to visualize social processes, computer modeling, and simulation of social and political networking (essay 2.1) are used in studying large-scale urban environments (Borning, Friedman, Davis, et al. 2005), such as in showing how rising water levels linked to climate change might affect London.[e]
Data visualization	New ways of visualizing information help to transform researchers' ability to model and display objects of research (e.g., to improve analysis of underlying patterns critical to reaching and explaining findings in many fields, from biological and environmental systems to social and economic trends).
Environmental and marine sciences	Embedded networked sensors (essay 4.1) enable the study of movements related to earthquakes in order to create powerful models to assist with early warnings. Placed under water, such sensors mean that marine biologists can respond to detections of actual events rather than having to plan expeditions in the hope of seeing such events occur.
Biological sciences	Complex, realistic, ICT-enabled models aid understanding of the working of the body, such as the heart (Noble 2002). E-research capabilities are also central to progress in genomics (e.g., the freely available International HapMap Project).[f]
Humanities and the arts	The arts and humanities can benefit from e-research, as in the virtual "haptic museum" (which enables visitors to manipulate three-dimensional models of objects)[g] or online access to high-quality digital facsimiles of valued historical documents and the tools to interpret and analyze them (essay 3.2) or in the rendering of a two-dimensional painting in three dimensions.[h]

Notes:

a. For information about the Hubble telescope, see http://hubble.nasa.gov/.

b. For example, the United States has supported the National Center for Microscopy and Imaging Research (NCMIR, http://www.ncrr.nih.gov/), and Japan has created a similar program in Osaka.

c. For a description of major telescience projects, including the NCMIR, see http://www.supercomputingonline.com/nl.php?sid=5183. More details of the U.K. Research Councils' e-Science Programme are at http://www.rcuk.ac.uk/escience/default.htm.

Table I.1
(continued)

d. A listserv facilitates the distribution of messages to members through an electronic mailing list, which can support discussion groups based on common interests.
e. This illustration is drawn from the work of the Geographic Virtual Urban Environments project at the University College London's Centre for Advanced Spatial Analysis (see http://www.casa.ucl.ac.uk/projects/projectDetail.asp?ID=57).
f. HapMap supports research into genetics associated with human disease (see http://www.hapmap.org/).
g. This project, conducted by the Integrated Media Systems Center of the University of Southern California, generated links with a wide variety of projects that were experimenting with touch in virtual environments in many fields (McLaughlin, Hespanha, and Sukhatme 2002).
h. Martin Kemp (2006) is a pioneer in new ways to apply computation to the visualization of art.

Department's Advanced Research Projects Agency Network (ARPANET). The global positioning system (GPS), which uses Earth-orbiting satellites to transmit signals, is a widely used development that followed a similar trajectory. It was initially developed for military applications (e.g., tracking movements of soldiers and equipment) but has become generally available as navigation guides for motorists. GPS can also be used in e–social science applications, such as in research that tracks the travel patterns of members of households enrolled in transportation studies, illustrating the diffusion of e-research innovations across disciplines.

Implications of Innovations in Research for Social and Economic Well-Being

The opening out of e-research means it increasingly intersects with general Web capabilities that offer parallel types of collaboration. Table I.2 highlights the key stages in the ongoing evolution of Internet and Web capabilities and applications toward these kinds of intersections.

A number of groups (e.g., OpenScience[6] and Science Commons[7]) have been set up to promote more open e-research technologies and applications (see essay 11.2). Neurocommons[8] is such an initiative, providing an open platform that offers free powerful tools to allow scientists to improve the efficiency and effectiveness of searching for particular information. De Roure (essay 2.2) highlights the prospects for further broadening of e-research through more open forms.

The consequences of enhancing the value of research can be immense in many fields affecting everyday life and health. For instance, the use of e-research in biomedical disciplines is bringing more insight into the human genome and related tools that may enhance individual and social well-being. Business and industry also depend heavily on ICTs, which are increasingly including e-research capabilities. For instance, commercial enterprises are employing the Grid for the search and mining of massive

Box I.3
Workflow Requirements: The Diffusion of Engineering Techniques

The processes through which work is expected to flow to produce a desired outcome can be described or modeled as a sequence of operations (i.e., as a process in a chart that depicts the flow of operations required to conduct a survey). Workflow tools can coordinate elements of calculation or analysis processes by enabling researchers to select, edit, or add components easily. This general process originated in operations research and engineering, where parts of the workflow and links between steps can be completed by the supporting ICT services. It can be more widely adapted through e-research—for example, to assist the organization, analysis, and graphical presentation of data.

Table I.2
Types of Collaborative Networking and the Evolving Web

Phase	Type	Description
Collaboration 1.0	Sharing	The Web's original design, aimed essentially at finding and sharing electronic documents and information.
Collaboration 2.0	Contributing	Moving to a greater focus on interactions between people and groups, and blurring the distinction between producers and users of information on the Web. Typified by social networking and user-generated content services such as YouTube, Second Life, and the wider "blogosphere" of individuals' comments and reporting.
Collaboration 3.0	Cocreating	Developing and applying collaborative software to support cooperative working between groups and individuals, including networked research collaborations and other activities involving the cocreation or coproduction of reports, software, and other outputs.

Source: Adapted from Dutton 2008.

amounts of data to identify shifting consumer preferences or borrowers' credit worthiness—with some well-recognized limitations. And pharmaceutical companies are increasingly developing new medicinal drugs by searching through research results as a complement to clinical trials of newly developed drugs.

These kinds of developments demonstrate that e-research infrastructures are not simply strategies for better research, but key to everyday life and to global competition and collaboration. It is for this reason that many governments are supporting e-research and e-infrastructure initiatives, seeing them as critical to national industrial strategies in a networked society. The social and technological infrastructures and capabilities of e-research are particularly significant elements because they can underpin or undermine the quality of research and therefore of any potential benefits arising from these innovations.

Risks Tied to e-Research

Although we identify the numerous and often astonishing possible benefits of e-research, we also take a critical perspective on these innovations. This balanced approach helps us to assess both the potential prizes and risks at stake, which determine whether investment in the promise of RCNs is realized or not. For instance, e-research might privilege some researchers over others, such as those with less funding or from less-prestigious centers.

A core area of concern is to understand where and how e-research might boost or undermine the nature, quality, and agenda of research. For example, choices made about the use of e-research might lead some researchers to substitute virtual observation for more grounded experience in the field (see chapter 6). Many social scientists use ethnographic methods to study work, social and cultural processes, and behavior through detailed observation, documenting and analyzing how people behave and feel in particular contexts (e.g., see Hine 2008, an insightful study of e-science based on observing discussions and forums among scientists). Such study has usually been carried out by researchers who participate in the environments they are observing. If online approaches to ethnographic research become more common, how should researchers balance virtual online research with real experience? Or is this distinction perhaps becoming too blurred to be useful anymore?

E-research also raises new legal, institutional, and ethical issues, such as over privacy and data protection. Digital trails left by the use of networked services challenge efforts to protect personal privacy and the confidentiality of personal information vis-à-vis not only governments, but also researchers. For example, concern would be raised if social scientists tracked individuals through GPS or video recordings of public spaces without their consent. Collaboration in open-science medical trials may be put at risk if sharing data openly across jurisdictions proves to be intractable for institutional rather than technical reasons, such as conflicts over the ownership or confidentiality of data (see essay 7.1).

Outline of the Book

We employed three complementary strategies to achieve the book's objectives, as outlined earlier in this introductory chapter:

- Reaching out to contributors from a wide range of relevant disciplines. This task was assisted by contacts established by the editors during their careers within different disciplinary backgrounds, spanning the social and natural sciences.
- Extending a core foundation of work developed from a related set of projects in e-research based at the University of Oxford through contributions from research associates across the university and the United Kingdom, as well as colleagues from North America, the rest of Europe, and Asia.

• Including a range of short essays from world-leading experts in specialized areas of e-research, wherever a specific need was identified to deepen the coverage of that chapter.

The Structure

The book's guiding framework aims to inform a critical understanding of the ways in which the new technologies and processes can reconfigure the processes and outcomes of research. To achieve this goal, the book offers many tangible examples and case studies of the social and institutional shaping and implications of e-research across different disciplines and institutions. It is organized into four main parts:

• Part I, "Foundations" (chapter 1 and 2), sets out the basic themes and issues addressed, including an historical perspective, an outline of the book's conceptual frame, identification of key technological landmarks, and an overview of developments and implications more widely, beyond research arenas.
• Part II, "State of the Practice" (chapters 3–5), looks at how the emphasis placed on the social and institutional shaping of e-research does not diminish the role played by the underlying pace of technological innovation in giving momentum to the rapid advance of the research potential explored. This section exemplifies key underpinning technologies and application exemplars, including how the technology can be made more usable.
• Part III, "Social Shaping of Infrastructures and Practices" (chapters 6–8), provides a more detailed examination of some of the broader research and of the institutional and ethical dimensions being affected by the take-up of new processes and practices made possible by e-infrastructures.
• Part IV, "Implications for Research" (chapters 9–12), focuses on what the innovations analyzed earlier mean for research policy and practices, including the nature and politics of moving toward a more open science environment and the global implications for developing counties and regions.

A short summary coda after part IV is followed by a glossary and a list of abbreviations and acronyms used in this book.

Chapter Outlines

Foundations of e-Research Chapter 1 (Dutton) explains why the concept of reconfiguring access to information, people, services, and technologies through e-research offers a coherent thematic structure within which contributions to this book can illuminate different aspects. Tied to this chapter are three essays: Geoffrey Bowker and his colleagues identify shared patterns, processes, and emergent lessons learned from examining the history of cyberinfrastructure developments; Mike Thelwall discusses

how e-research might reconfigure research "winners and losers"; and Robert Ackland examines possible impacts on the rise of research "superstars."

Chapter 2 (Jeffreys) gives an introductory perspective on the history and future of e-research and the technologies it encompasses, distinguishing between the applications and the technologies underpinning them. The associated essays cover the emergence of the "Cloud" to complement the Grid's distributed-computing capabilities (Hey, Barga, and Parastatidis) and the wide promises and threats of the opening out of RCNs to general publics (De Roure) and to business and nations (Taylor).

Illustrations of e-Research Practices Starting part II's exploration of the state of e-research practice, chapter 3 (Meyer, Madsen, and Fry) focuses on the future of libraries in an era where digital resources and collections rise in importance. Related essays move into the requirements for facilitating access to specific types of resources associated with libraries and digital collections: image repositories (Shotton) and ancient manuscripts (Bowman).

Chapter 4 (Wilks and den Besten) describes in depth some key technologies for selecting, gathering, analyzing, organizing, and displaying information to help researchers cope with the digital data flood being generated by e-research capabilities. The essays that follow this chapter provide further illustrations of related issues and solutions, such as embedded sensor networks (Borgman); methods of efficiently identifying digital objects (Fraser); and the emergence of the Semantic Web as a more effective way of sharing information than traditional document-based Web methods (O'Hara, Berners-Lee, Hall, and Shadbolt).

In chapter 5, Grace de la Flor, Marina Jirotka, Sharon Lloyd, and Andrew Warr examine, with examples and recommendations, how difficulties in using e-research systems can be overcome by adopting appropriate requirements analysis and usability design principles. Essays on this theme discuss examples of the ways in which designers and developers have addressed these issues (Martin on building trust in ICT systems and Thelwall on affordances provided by Web 2.0's social-networking innovations).

Social Shaping of e-Research Part III's attention to the social dimensions of e-research starts with William Dutton and Eric Meyer's review of how e-research can transform the work of social scientists and how social scientists can help to shape e-research capabilities and outcomes (chapter 6). The risks they identify underscore the importance of research on the social factors shaping e-research. An essay by Rob Procter further explores how e-infrastructures can best support the social sciences. Jonathan Zhu and Xiaoming Li's essay illustrates the degree to which computational innovations take the availability of much data for granted, which is not always the case in the social sciences in some contexts, such as in rapidly developing nations—China, for example.

In chapter 7, Paul David and Michael Spence consider the institutional infrastructures for global research networks in the public sector. Building on the findings of a survey and case studies of e-science projects, the authors argue that "soft" institutional infrastructures are required to facilitate the formation and conduct of collaborative public-sector research projects, especially those that aim to be truly global in scope. Connected essays investigate two key aspects of such infrastructures that need special attention: ownership of research data or processes (Piper and Vaver) and the role of authorship in protecting the integrity of scientific collaboration (Pila).

Bill Dutton and Tina Piper address in chapter 8 the politics of privacy, confidentiality, and ethics relating to e-research, including the main directions in which existing research practices are challenged (e.g., how more open collaborative methods might lead to changes in institutional arrangements that better protect ethical standards). Michael Parker then examines such ethical and moral dimensions in detail, and Jane Kaye examines their implications specifically in genomics. Julia Lane directs her related essay to the technical and institutional issues involved in protecting personal data.

Broader Implications for Research Part IV draws together the key dimensions of the developments discussed in the book. It starts in chapter 9 with an analysis by Jenny Fry and Ralph Schroeder of how e-research might reconfigure the boundaries within research landscapes. They describe key dimensions of the variation across disciplines and how these dimensions influence the use and impact of e-research. In the only essay tied to this chapter, Paul Wouters focuses on the implications of these developments for research agendas more generally.

In chapter 10, Annamaria Carusi and Marina Jirotka discuss the potential of new virtual forms of organizing research through concepts such as VREs and collaboratories. They assess to what extent these concepts may foster new forms of collaboration. They identify different types of VREs and evaluate their implications for research practices across the disciplines. Matthew Dovey contributes an essay on the future of VREs.

Paul David, Matthijs den Besten, and Ralph Schroeder investigate in chapter 11 the scope and limits of ICT-enabled support for more open forms of research. Using findings from e-science projects, they propose a framework for helping to understand where, when, and to what extent openness in research may be expected to advance in harmony with the growing deployment of wider e-research capabilities. In their related essay, Gustavo Cardoso, João Caraça, Rita Espanha, and Sandro Mendonça provide a broad perspective on the international politics of open access. A specific example of this issue is the basis of John Wilbanks and Hal Abelson's essay on the differences between open access and open viewing.

The main book chapters conclude with Marcus Ynalvez, Ricardo Duque, and Wesley Shrum's explanation in chapter 12 of why e-research outcomes will depend on how

researchers' choices in specific localized contexts reconfigure the nature and dynamics of the social interactions involved in knowledge production using digital technologies. Based on their studies of the shaping of research in developing nations, their conclusions reinforce this book's overarching theme of the significance of the ways in which RCNs are being used to reconfigure access to information, expertise, and experience in worldwide research.

A final coda summarizes briefly some of the major issues and themes raised by the contributions to this collection, emphasizing the need to focus on the ends of research in the design and use of RCNs, such as the quality of research, rather than on technically defined outcomes derived from features enabled by the technologies, such as collaboration or data sharing.

Notes

1. Major overviews of research-centered innovations in the sciences and humanities include Hey and Trefethen 2003, Atkins 2005, and Olsen, Zimmerman, and Bos 2008.

2. Treatments of the role of e-research on the practices of scholars include Hine 2006 and Borgman 2007.

3. For instance, *Knowledge Lost in Information* is the title of a major report on digital libraries sponsored by the U.S. National Science Foundation (2003).

4. We use the term *research-centered computational network* to indicate the high computational element of the "big science" projects that gave e-research its strong momentum in the early twenty-first century and that continue to play a significant role in e-infrastructure developments.

5. This definition has been attributed to Professor Malcolm Atkinson, the United Kingdom's e-Science envoy. See http://www.rcuk.ac.uk/escience/default.htm.

6. See http://www.openscience.org.

7. See http://sciencecommons.org.

8. See http://sciencecommons.org/projects/data/.

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