CYBERINFRASTRUCTURE-ENHANCED SCIENCE AND DIGITAL GOVERNMENT: PATHFINDERS AND FELLOW TRAVELERS

Daniel E. Atkins
School of Information and
Dept. of Electrical Engineering and Computer Science
University of Michigan, Ann Arbor
atkins@umich.edu

http://dgrc.org/dgo2005

A Keynote Address for the Sixth Annual National Conference
on Digital Government Research
May 15-18, 2005, Washington, D.C.

CYBERINFRASTRUCTURE-ENHANCED SCIENCE AND DIGITAL GOVERNMENT: PATHFINDERS AND FELLOW TRAVELERS

Daniel E. Atkins
School of Information and
Dept. of Electrical Engineering and Computer Science
University of Michigan, Ann Arbor
atkins@umich.edu

Abstract

The NSF community and other US and non-US science and engineering research funding agencies have recognized that ever more powerful, ubiquitous, and integrated information and communication technology nows offers the potential to transform the conduct of scientific and engineering research and allied education. The platform for such transformation has been dubbed "cyberinfrastructure"(CI for short) and is the basis for cyberinfrastructure-enabled science, or e-science[1]. Cyberinfrastructure provides reliable services and knowledge on which to build specific instances of organizational forms called for example, collaboratories, grid communities, or community portals.

This talk will review the emergence and status of the "cyberinfrastructure movement" and draw parallels with the emergence of the field of digital government. It will suggest that there is complementary between these lines of endeavor, and that they stay in touch as pathfinders and fellow travelers into the broad application of advanced information technology to facilitate, or potentially revolutionize, complex and important human endeavor.

[1]It could just as well be called "digital science" but this label is not widely used. A Google search for this phase leads you primarily to Kodak digital photography equipment.

Introduction

Good morning. I am very pleased to be invited to address leaders of the digital government R&D community. This is an area of research that I think is very important and I have observed with great interest. I am delighted to be with you.

In a way, I participated in an applied project in digital government many years ago before the term was coined. I was PI of the NSF EXPRES project in 1980s (a joint project of Michigan, CMU, and BBN). EXPRES was an experimental precursor to the NSF FASTLANE project. FASTLANE has become an award winning example of the use of the web to facilitate more efficient (and I would say more pleasant) interaction between a government agency and its constituencies.

Although the EXPRES project included provision for electronic proposal submission and review -- the research focus at the time was on distributed collaborative authoring and. It was a precursor to what came to be called a *collaboratory.* So in a small way, the EXPRESS project was a common root for projects in both digital government and collaboratories -- now part of the bigger agenda I will call CI-enhanced science and engineering.

This reminiscence about the EXPRES Project is actually appropriate to my theme to day -- that R&D in the areas of digital government and cyberinfrastructure-enhanced research (including for example "collaboratories') have much in common in both the challenges, the opportunities and the complex socio-technical initiatives required to achieve the promise.

More background on the topics I will briefly address today are available on blog site I have recently created A copy of my remarks including pointers to the references I mention will be available there. My so called "CLEAR site" is at deatkins.blogs.com (note blogs is plural). CLEAR is an acronym for Cyberinfrastructure-enabled Learning, Engagement And Research.

The theme of you Conference on Digital Government is **Emerging Trends** with a particular focus on four topics:

1. the nature of digital government research as a new interdisciplinary field that spans computer science and social science
2. the unique collaborations between university researchers and their government partners
3. the breadth and depth of current digital government projects
4. outcomes and impacts of digital government research in the public sector

There are many parallels between these themes for digital government and a similar conference that might be held on the topic of what could be called "digital science" but is more generally called e-science (originally e = electronic, but not usually means *enhanced* or *enabled*) , or cyberinfrastructure-enhanced science, which I will abbreviated ce-science.

1. like digital government research, ce-science research is intrinsically interdisciplinary and spans computer science, social science, and all fields of application in science and engineering.

2. ce-science research and application requires unique collaborations between university researchers, their academic institutions, and government research sponsoring organizations

3. ce-science research is an organic, bottom up movement and there is now much to be reported about the breadth and depth of grass-roots projects creating and applying cyberinfrastructure to scientific research and allied education. Numerous projects are mentioned in the CI Panel report and there have been dozens of discipline specific workshops on the topic Ce-science in the last 2 years.

4. and we are starting to build a knowledge base on the outcomes and impacts of ce-science research including notions of why projects succeed and fail. We are making some baby steps towards creating principles of design for CI-enabled research communities.

5. (CI-enhanced) scientific research and learning, or e-science as it is called in Europe, is a priority of a growing number of research sponsoring organizations world-wide. It is also serving as a harbinger of broader impact on the humanities and on the conduct of knowledge-based activities more broadly, including the future of higher education, especially the future of the research university. CI-enhanced knowledge communities offer the potential for enabling a new wave of global-scale collaboration across multiple disciplines, geography, and institutions. It could empower a revolution in what science explores, how it is done, and who participates. Realizing this potential will, however, also require a new wave of commitment to collaboration between the complex array of stakeholders necessary to create, deploy, sustain, and apply cyberinfrastructure in transformative ways. CI both enables and requires a new wave of collaboration.

In this spirit I will briefly described the "cyberinfrastructure movement" as I see it, and will suggest that digital government research and CI research are both pathfinders and fellow travelers into the application of information technology to facilitate or potentially revolutionize complex and important human endeavor.

Some background

In 2001 leaders of the NSF began using the term cyberinfrastructure. The term *infrastructure* emerged only in the 1920s to refer to the roads, bridges, rail lines, and similar public works that are required for an industrial economy to function. The new term *cyberinfrastructure* denotes systems of information and communication technologies, together with trained human resources and supporting service organizations that are increasingly required for the creation, dissemination, and preservation of data, information, and knowledge in the "digital age." It is a great deal more than boxes and wires. Traditional infrastructure is required for an industrial economy; cyberinfrastructure is required for a knowledge economy.

Although the word "cyberinfrastructure" does not roll off the tongue, it is currently useful to emphasize: 1) that we must now invest in IT as institutionalized, sustained, evolving but robust infrastructure; and 2) that "cyber" infrastructure has some important different properties than traditional "built" infrastructure. On the negative side, it generally depreciates much more rapidly that bricks-and-mortar infrastructure, but on the positive is generally more sharable and general purpose.

Converging Technology Trends

I think most of us are familiar with the technological trends that provide the underpinnings for the cyberinfrastructure movement. In the interest of time I will skip this section but will return to it if asked at question time.

(Red material was left out of talk due to time constraints)

We are in an era of distributed computing with huge and growing rates of raw computing power available from innovation in circuits and parallel architectures. Tera- and soon peta-flops of computer power support computational science, now a full partner to discovery along side theory and experimentation. Parallel computation in multi-core processor chips, in clusters of physically proximate machines, and in grids of machines across high speed optical networks will continue to provide exponential growth in computation rates. And parallel supercomputing is complemented by pervasive and increasingly powerful handheld digital appliances linked through wireless networks.

Most information is now born digital and growing at an estimate rated of 30% per year (Lyman & Varian, 2003). Massive retrospective conversion is proceeding at a surprising rate and was recently given a big boost by the partnership between Google and several leading research libraries (including the University of Michigan) to digitize 10 million volumes over the next 6 years (Carlson & Young, 2004). Most libraries are now a hybrid of print-on-paper and digital and a growing number are accepting that digital will eventually dominate. International digital library R&D is fueling the emergence of a global information infrastructure. Open source software and open content projects are broadening participation in the provision of content and use of digital libraries.

The issue of long-term preservation and access to digital objects is now finally being addressed seriously, for example, in joint efforts between the U.S. NSF (Hedstrom et al., 2002) and the Library of Congress (Library_of_Congress) and in the U.K. (Lord & Macdonald, 2003).

A major finding of our Panel was the growing importance of the long term preservation and curation of scientific data and the feeling that new institutions and investments need to be provided in this area

The interface between humans and the digital world has evolved to be more pervasive, nomadic and immersive. Both virtual and augmented reality (Vallino, 2002) are becoming significant to scientific visualization and discovery. The integrated span of tab-size, hand-size, and wall-size interfaces is making real the late Mark Weiser's vision of ubiquitous computing (Weiser) and is the bases for much of the "anywhere and any time" attributes of CI-enabled knowledge work.

Advances in the digital to physical world interface are occuring in large-scale, distributed, systems, composed of smart sensors and actuators embedded in the physical world and interacting with the virtual world. Many examples of both the technology and its revolutionary application in critical scientific and social problems can be found at the Center for Embedded Network Sensing website (CENS) .

The NSF Cyberinfrastructure Advisory Panel

In part because of these converging trends, in 2002 the NSF formed a Blue Ribbon Advisory Panel on Cyberinfrastructure with a broad, three part mission. First, to provide advice on the opportunities and challenges CI presented for research communities; second to create a vision of how NSF might respond to facilitate these opportunities; and third to give advice on how the current major investments by NSF in cyberinfrastructure, largely in the form of super computing alliances, should fit into this vision. The study was motivated further by noticing increased investment by grass roots research communities in IT infrastructure, and an admission that although NSF has long supported physical infrastructure (telescopes, ocean-going research vessels, South Pole observatories etc.) it is still developing policy for building and sustaining IT-based (cyber) infrastructure.

The charge to the Panel included the realizations that Cyberinfrastructure and its use is both an object of research (science for science) as well as an enabler of research.

The panel conducted an extensive survey and held a series of hearings with close to 100 witnesses. It reviewed prior relevant panel reports, posted and requested comments on a draft report, and submitted a final report to the NSF in February 2003 entitled *Revolutionizing Science and Engineering through Cyberinfrastructure.* (D. E. Atkins, Droegemeier, K.K., Feldman, S. I., Garcia-Molina, H., Klein, M.L., Messerschmitt, D.G., Messina, P., Ostriker, J.P., Wright, M.H., February 2003).

Called for creation of an Advanced Cyberinfrastructure Program (ACP) building in scale to a $1B per year of new funding.

The report is available at http://www.cise.nsf.gov/sci/reports/toc.cfm. Last time I checked over a half million copies had been download world wide. I have been told that the report has become a blueprint for e-science programs in Europe. It has also been taken seriously at the NSF although the definition of a major initiative is still under development. Such planning including creating an appropriate internal organizational structure at NSF has become a top priority for the new Director Dr. Arden Bement and some announcements are expected soon. I will try to share news as it emerges on my blog site. (deatkins.blogs.com).

Extrapolating in large part from prior NSF investments in high-performance computing, networking, middleware, and digital libraries, general trends in the IT industry, and the vision and innovation coming from many research communities, the panel asserted the following

"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 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 panel also found that environments and organizations, enabled by cyberinfrastructure, are increasingly required to address national and global priorities such as global climate change, protecting our natural environment, applying genomics-proteomics to human health, maintaining national security, mastering the world of nanotechnology, and predicting and protecting against natural and human disasters, as well as addressing some of our most fundamental intellectual questions such as the formation of the universe and the fundamental character of matter.

Although this panel was commissioned by the NSF and concentrated on the NSF research community, it also found that similar visions and needs are emerging in research communities supported by other federal agencies, most apparently by the Department of Energy (DOE, 2002) and the National Institutes of Health (NIH).

Cyberinfrastructure initiatives by various names are now underway in many countries in the developed world. Examples include UK e-science programs (UK_Research_Councils), Canadian CANAIRE "Third Wave" (St. Arnaud), European Union 6th Framework (EU), South Africa DST (Africa-DST, 2002), and the Japanese Earth Simulator (ESC, 2002). Microsoft has just announced the new position of VP for Technical Computing Initiatives and Prof. Tony Hey -- a leader of the e-science activities in the UK is taking that position.

In addition to the march of technology, there is also a history of programmatic initiatives that have fueled the cyberinfrastructure movement. I will mention a few of them.

Collaboratory - The concept of a co-laboratory, or collaboratory —a laboratory without walls built upon distributed information technology—was defined at an invitational National Science Foundation (NSF) workshop at Rockefeller University (Wulf, 1989) in 1989 and later elaborated and sanctioned in a National Research Council report (NRC, 1993) published in 1993. Interdisciplinary research to create, deploy, and evaluate specific collaboratories has been funded by NSF, NIH and DoE..

KDI - In the late 1990s the NSF launched a Knowledge and Distributed Intelligence (KDI) initiative to explore reshaping relationships among people and organizations, and transforming the processes of discovery, learning, and communication based in part on the explosive growth in computer power and connectivity (NSF-KDI, 1999). Many of the funded projects focused on distributed and multidisciplinary collaboration facilitated by information technology (IT). Fortunately, this initiative consisting of 71 projects funded over two years has been studied by Cummings and Kiesler (Cummings & Kiesler, 2003). This recent study showed that there is still much to be done to successfully coordinated IT-linked projects distributed over geographic and organizational distance (distance matters), but it also showed that multidisciplinary projects were superior to unidisciplinary in producing new ideas.

Digital Libraries - In the early 1990s the NSF, launched the Digital Library Initiatives (NSF-DLI1; NSF-DLI2). These R&D initiatives linked with similar activities in Europe and Asia have produced insights, architectures, tools, unique digital collections, and an interesting array of evocative test beds – for digital library systems. International digital library research initiatives also seeded the establishment of digital library production activities in universities, catalyzed formation of content federations, and helped launch spectacular commercial successes including Google. These initiatives have also created an international interdisciplinary R&D community drawn from computer and information science, social science, librarians, publishers, and a host of disciplinary specialists from the sciences, engineering, and humanities.

The fundamental issue of long-term preservation and access to digital objects is now finally being addressed seriously, for example, in joint efforts between the U.S. NSF (Hedstrom et al., 2002) and the Library of Congress (Library_of_Congress) and in the U.K. (Lord & Macdonald, 2003).

A major finding of our Panel was the growing importance of the long term preservation and curation of scientific data and the feeling that new institutions and investments need to be provided in this area

The GRID - In 1999 Ian Foster and Carl Kesselman published the concept of the grid, "a new concept for computing infrastructure." The concept focused initially on the aggregation of distributed computers to provide re-allocation and load balancing for computers analogous to that of the electricity power grid. The concept has since evolved to include all of the functions of a collaboratory – linking computation, information, people, and instruments. An expanded version of the Grid book was published in 2003 (Foster & Kesselman, 2003).

ITR - The Information Technology Research (ITR) program begun in the 1990's at NSF initially funded basic research in computer science and engineering. It was later opened to the entire NSF research community and supported collaborative projects in the creation and use of advanced IT. The ITR program augmented the collaboratory program in providing the opportunity for grass roots research communities to create prototypes of CI-enhanced science communities including many cited in the Cyberinfrastructure report (the "Atkins Report").

Cybrinfrastructure and the Future of Higher Education - A growing number of academic leaders now see this nascent revolution in research as a harbinger for other fields and ultimately the entire academic enterprise. The U.S. National Academies of Sciences has been conducting a series of workshops and studies around the topic of CI and the future of higher education. The OECD based in Paris has recently begun similar explorations for the 30 nation group it represents. Cutting across all of these studies is the notion that *CI* offers a vast array of new place- and time-independent opportunities for augmenting how the fundamental mission of teaching/learning, scholarship/research, and service/engagement is carried out. Restricted notions of "distance learning" in higher education are broadening to using IT to facilitate the complete work of communities in knowledge creation, dissemination, and use. The CI relevant to research is essentially the same for higher education at large -- the collaboratory may be the tooling for university of the future.

The American Council of Learned Societies (ACLS) has initiated a Commission on Cyberinfrastructure for the Humanities and Social Sciences (ACLS, 2005) to explore the implications of cyberinfrastructure for the humanities and social sciences with a final report expected later this year.

Homeland Security The NSF has sponsored workshops on cyberinfrastructure research for homeland security (Cal-(IT)2_Project, 2003). The definition of homeland security included preparedness, response, recovery, and mitigation in the context of threats and emergencies created by man or nature. There was general consensus that research and development in advanced CI is critical to homeland security. Special requirements in this application include mobility and rapid federation of customized, on-demand, ad hoc virtual organizations (including people, equipment, and information). There is the potential for multi-use collaboratories that normally support ongoing research and education but can be mobilized and linked with other discipline-specific collaboratories in response to emergencies.

Impact on civil society - The nonprofit, nongovernmental, voluntary, and community-based sectors of society are generally not using the term cyberinfrastructure, but they are increasingly exploring the role of information technology in building and supporting virtual communities. One area of growing interest is the role of CI in building and sustaining networks of engaged institutions, including higher education. The engaged institution is committed to direct interaction with external constituencies and communities through the mutually beneficial exchange, exploration, and application of knowledge, expertise, and information. These interactions enrich and expand the learning and discovery functions of the academic institution while also enhancing community capacity.

Framework for cyberinfrastructure-enabled knowledge communities

Although some people equate cyberinfrastructure with super computing the concept as developed in our report is much broader and includes a comprehensive set of services that should enable specific research communities or projects to create functionally complete CI-enhanced knowledge communities. By functionally complete I mean .....

The major components on cyberinfrastructure include

1. **High performance, global scale networking** built as a hybrid of traditional packet switching and the newer point-to-point optical "lambda" networks.

2. **A special type of software called "middleware",** that makes it much easier to build community specific, inter-institutional virtual organizations in efficient, secure, and trustful ways.

3. **High performance computation services** capable of simulating complex phenomena such as galaxy formation or social-physical models of global warming.

4. **Data, information, knowledge management services** federating vast networks of digital libraries, archives, and museums (LAMs) providing content and sustainable knowledge management services. They include comprehensive collections of literature, data sets, and a large variety of multimedia objects. Preservation, interoperability and re-use of scientific data is a high priority in many research communities and there is a growing unmet need for people and institutions to provide long-term curation and continuos access.

5. **Observation, measurement and fabrication services** including arrays of networked scientific instruments and sensors to measure and observe our world and beyond.

6. **Interfaces and visualization services** to support interaction between humans and the IT environments in ways that are natural and exploit the full range of human sensory capabilities.

7. **Collaboration service** to enable distributed teams to work together as well or even better than they can in physical proximity.

A community-specific, customized knowledge environment can ideally be created efficiently and effectively using facilities, tools, and toolkits provided at the cyberinfrastructure layer.

Attributes of cyberinfrastructure-enhanced knowledge communities

One view of cyberinfrastructure is that it augments the world of physically proximate modes of learning and research communities that have, for example, defined universities as we now know them. CI offers the potential to reduce constraints of time and place. Imagine if you will a 2 by 2 matrix representing the four variations of same and different, time and place. CI provides ways to access people, information, and facilities --- the core resources of learning and research -- in all four quadrants of time and place. It relaxes constaints of time and distance. Same place, has been the dominant model but CI-enhanced knowledge communities can augment their activities with two other quadrants of different place, same time or different place different time. We are not predicting or advocating that knowledge-based institutions like universities (or governments at multiple levels, for that matter) move totally into cyberspace. But we are suggesting that communities that do not exploit all of these regions may be at a competitive disadvantage.

The NSF CI report includes many examples and references to the application of cyberinfrastructure to the creation of collaboratories, grids, and e-science communities. To convey a more tangible idea about the effect of a ci-enabled science on the practices of a specific science research community I will survgey a bullet list of vignettes of payoff from a ten year collaboratory experiment with a space physics and upper atmospheric research community funded by the NSF and centered at the University of Michigan. More details on the Space Physics and Atmospheric Research Collaboratory (SPARC) is available at (SPARC).

1. Shared, tele-instruments and sharing of expertise on their use;
2. Rapid response to unexpected natural events (e,g, solar flare) and ability to mount opportunistic data gathering campaigns;
3. Multiple instruments and eyes on the same events and increased fusion of complementary expertise;
4. Previously isolated observational instruments federating into a global scale observational platform;
5. Enhanced cross-mentoring/training between team members (faculty and students);
6. New & earlier opportunities for grad students to interact with and be known by the leaders of their field;
7. Enhanced participation by faculty and students at other than the lead institutions; support for "legitimate peripheral participation;"
8. Used to provide authentic, inquiry-based learning in undergraduate and pre-college level geo-science courses;
9. Supported distributed workshops for post-campaign data analysis;
10. Enabled data gathering session recording and re-play for delayed participation by others around the world and supported hand-off of experiment management to in normal working hours around the world;
11. Data-theory closure – built deeper ties between the experimentalists and the theoreticians/modelers (models were run in data campaign to predict where to steer the instruments for more effective observation);
12. Provided a "living specification" to stretch vision of possibilities for others.

Challenges of institutional and social infrastructure

As I expect this audience knows very well, Cyberinfrastructure creation and use has both technical and social dimensions that must both be addressed in an integrated way. The field of computer-supported cooperative work (Grudin, 1994) is long established as fundamentally interdisciplinary. The KDI (Cummings & Kiesler, 2003) study reviews some of the social barriers to distributed collaboration (Young, 2004) and more recently Paul David has written explicitly about the topic of technological, institutional, and social infrastructure issues of e-science (David, 2004). David elaborates on the assertion that fulfilling the promise of e-science (CI-enhanced science) will require a lot more than innovation in technology and in the design on new systems and tools by scientists and their organizations. "No less important will be appropriate institutional contexts (i.e. informal norms and formal rule structures) to facilitate collaboration with communities of scientific and technical researchers – both on the ground and in cyberspace." Included in his definition of institutional and social infrastructure are the following:

- formal institutional infrastructure and legal support layer (intellectual property, corporate, contract law);
- research funding agencies and foundations administrative regulations and monitoring apparatus;
- host institutions statutory regulations, administrative rules, and internal contractual relations governing rights and responsibilities of researchers;
- informal community norms of scientific and academic work groups – governing data access, publication credit, relations with colleagues, staff and students, human subjects policy, etc.

In summary then, "the institutional and organizational environment of e-science encompasses a wide and diverse array of interrelated social, economic and legal factors that create both incentives for and constraints upon individuals and collective actions and that thereby shape the production, utilization, consumption, and governance of e-science capabilities and artifacts."

I imagine this last statement would work just fine if you replace the phase e-science by digital government.

In March of this year the NSF hosted an workshop on Cyberinfrastructure and the Social Sciences. The workshop was organized around the following

Six sub-themes

CI-mediated interaction (Bajcsy/Rubin)

CI tools (Brady/Snavely)

Organization of CI and CI-enabled organizations (Berman/Fountain)

Economics of CI (Mackie-Mason/Wolski)

Malevolent uses of CI (Fienberg/Sastry)

Impact of CI on jobs and income (Haltiwanger/Wright)

This was an excellent workshop and may be a turning point in the scale-up of the SBE communities participation in the analysis, synthesis, and application of CI-enhanced knowledge communities. The final report from the the workshop was just related this keep and is available at deatkins.blogs.com

A new wave of collaboration: requirements, opportunities, and challenges

So There is a growing consensus, at least in many science communities, that the integration of IT-based services into an advanced common (or at least interoperable) infrastructure has the potential to revolutionize the conduct of research and allied education..

But creating, using, evolving, and sustaining a pervasive CI that is relevant to broad sectors of higher education will itself require an extraordinary wave of collaboration between many types of providers and stakeholder. It involves architecture and processes that identify and exploit commonality, and accommodate heterogeneity through middleware and open standards. It includes the shared creation and re-use of software, information, facilities, and best practices to promote cost-effectiveness and efficiency. It requires a tight coupling between R&D in computer and information science, appropriate social and behavioral disciplines, and pioneering application areas.

While promising significant new opportunities the emergence of CI-enhanced knowledge communities will also pose considerable challenges as they drive profound transformations in existing organizations such as universities, national and corporate research laboratories, and funding agencies such as NSF. Cyberinfrastructure will also have major applications for other stakeholders of science and technology, such as the federal government, business and industry, education, health care, and other knowledge-intensive activities.

While I am not an expert in your field of digital government, and I am quite certain that much of what I have described about the the opportunities and challenges of research, development, provisioning, and long term support of CI-enhanced science applies as well to CI-enhanced government. I hope that our communities can find and exploit common ground around research agendas, new knowledge gained in theoretical and experimental projects, and building of advanced testbeds.

But perhaps our biggest common need is to work together to build broad constituencies for gaining the new investments recommended in our report for the technical and social research necessary to create and apply cyberinfrastructure in principled ways, to innovation in both our science and our governance --- both critical to our collective future .

Thank you.

References

ACLS. (2005). Commission on cyberinfrastructure for the humanities and social sciences. from http://www.acls.org/cyberinfrastructure/cyber.htm

Africa-DST, S. (2002). Dept. Of science & technology - south africa: South africa's national research and development strategy. from http://www.dst.gov.za/legislation_policies/strategic_reps/sa_nat_rd_strat.htm

Atkins, D. E. (2004). Transformation through cyberinfrastructure-based knowledge environments. In W. H. Dutton, B. Kahin, R. O'Callaghan & A. W. Wyckoff (Eds.), *The economic and social implications of information technology (in press)*. Cambridge, MA: The MIT Press.

Atkins, D. E., Droegemeier, K.K., Feldman, S. I., Garcia-Molina, H., Klein, M.L., Messerschmitt, D.G., Messina, P., Ostriker, J.P., Wright, M.H. (February 2003). Final report of the nsf blue ribbon advisory panel on cyberinfrastructure: Revolutionizing science and engineering through cyberinfrastructure. from http://www.nsf.gov/cise/sci/reports/toc.jsp

Cal-(IT)2_Project. (2003). Workshop on cyberinfrastructure research for homeland security, 25-27 feb. 2003. Retrieved 25-27 Feb. 2003, from http://web.calit2.net/RiskReduction

Carlson, S., & Young, J. R. (2004, Dec. 14, 2004). Google will digitize and search millions of books from 5 leading research libraries*. The Chronicle of Higher Education,* p. http://chronicle.com/free/2004/2012/2004121401n.htm.

CENS. Center for embedded networked sensing. from http://cens.ucla.edu/

Chillingworth, M. (2004). Springer embraces open access and choice. *Information World Review*, http://www.iwr.co.uk/iwreview/1156517.

CREW. Collaboratory for research on electronic work (crew). from http://www.crew.umich.edu

Cummings, J., & Kiesler, S. (2003). *Kdi initiative: Multidisciplinary scientific collaborations*. Arlington, VA: U.S. National Science Foundation.

D-LIB. D-lib magazine http://www.Dlib.Org/. from http://www.dlib.org/

David, P. A. (2004). *Towards a cyberinfrastructure for enhanced scientific collaboration: Providing its "soft" foundations may be the hardest part. Http://siepr.Stanford.Edu/papers/pdf/04-01.Html:* Stanford University Institute for Economic Policy Research.

DOE. (2002). U.S. Department of energy national collaboratories, http://doecollaboratory.Pnl.Gov/history.Html. from http://doecollaboratory.pnl.gov/history.html

Duderstadt, J. J., Atkins, D.E., VanHouweling, D. (2002). *Higher education in the digital age: Technology issues and strategies for american colleges*. United States: Am Coun on Educ Praeger Greenwood Publ Grp Inc.

ESC. (2002). Earth simulation center. from http://www.es.jamstec.go.jp/esc/eng/

EU. Eu sixth framework program (2002-2006). from http://europa.eu.int/comm/research/fp6/index_en.html

Finholt, T. A. (2003). Collaboratories. In B. Cronin (Ed.), *Annual review of information science and technology (available in pdf at http://intel.Si.Umich.Edu/crew/technical_reports.Htm)*.
Finholt, T. A., Olson, G. M. (1997). From laboratories to collaboratories: A new organizational form for scientific collaboration. *Psychological Science, 8*(1), 28-35.
Foster, I., & Kesselman, C. (2003). *The grid: Blueprint for a new computing infrastructure* (2nd ed.). San Francisco, CA: Morgan Kaufmann, Elsevier Science.
Globus. The globus project website, http://www.Globus.Org/about/.
Grudin, J. (1994). Cscw: History and focus. *IEEE Computer, 27*(5), 19-27.
Hedstrom, M., Dawes, S., Fleischhauer, C., Gray, J., Lynch, C., McCrary, V., et al. (2002). Report from the nsf workshop on research challenges in digital archiving: Towards a national infrastructure for long-term preservation of digital information. from www.si.umich.edu/digarch/
Holland, B. A. (2001). Characteristics of engaged institutions and sustainable partnerships and effective strategies for change. from http://www.oup.org/researchandpubs/engaged.pdf
IPL. Internet public library. from http://www.ipl.org
Library_of_Congress. Digital preservation website (www.Digitalpreservation.Gov). from http://www.digitalpreservation.gov
Lord, P., & Macdonald, A. (2003). E-science curation report: Data curation for e-science in the uk: An audit to establish requirements for the future curation and provision. from www.jisc.ac.**uk**/**e-science**curationreport.pdf
Lyman, P., & Varian, H. R. (2003). *How much information? 2003 http://www.Sims.Berkeley.Edu/research/projects/how-much-info-2003/* (Website). Berkeley: School of Information Management and Systems.
Markoff, J. (2004, Nov. 18, 2004). Google plans new service for scientists and scholars*. New York Times,* p. http://www.nytimes.com/2004/2011/2018/technology/2018google.html.
MIT-OWC. Open courseware project website: Http://ocw.Mit.Edu/. from http://ocw.mit.edu/
Nentwich, M. (2003). *Cyberscience; research in the age of the internet*: Austrian Academy of Sciences Press.
NIH. National institutes of health collaboratory project website. from http://collaboratory.psc.edu/
NRC. (1993). *National collaboratories: Applying information technology for scientific research* (No. 0309048486). Washington, D.C.: National Academy Press.
NRC-ITFRU. (2002). *Preparing for the revolution: Information technology and the future of the research university*. Washington, DC: The National Academies Press, http://www.nap.edu/books/030908640X/html/.
NSF-DLI1. Digital libraries initiative phase 1 (dli1). from http://www.dli2.nsf.gov/dlione/
NSF-DLI2. Digital libraries initiative phase 2 (dli2). from http://www.dli2.nsf.gov/
NSF-KDI. (1999). Nsf knowledge & distributed intelligence (kdi) inititative, http://www.Ehr.Nsf.Gov/kdi/default.Htm. from http://www.ehr.nsf.gov/kdi/default.htm
Shibboleth. Shibboleth project website, http://shibboleth.Internet2.Edu/.
SPARC. Space physics and aeronomy research collaboratory website. from http://intel.si.umich.edu/sparc/
St. Arnaud, B., Andrew K. Bjerring, Bernard Turcotte. *Canada's ca*net 3 and gigabit internet to the home.* Paper presented at the CANAIRE.
UK_Research_Councils. The uk research councils e-science core program. from http://www.research-councils.ac.uk/escience/
UM-SOC. Science of collaboratories project. from http://www.scienceofcollaboratories.org/
Vallino, J. (2002). Introduction to augmented reality (www.Se.Rit.Edu/~jrv/research/ar/introduction.Html). from www.se.rit.edu/~jrv/research/ar/introduction.html
Weiser, M. Ubiquitous computing website, http://www.Ubiq.Com/hypertext/weiser/ubihome.Html. from http://www.ubiq.com/hypertext/weiser/UbiHome.html
Witten, I. Greenstone digital libary software. from http://www.greenstone.org
Wulf, W. A. (1989). *The national collaboratory - a white paper, appendix a in towards a national collaboratory, the unpublished report of an invitational workshop held at rockefeller university, march 17-18, 1989 (joshua lederberg and keith uncapher, co-chairs.)*.

Young, J. R. (2004, Dec. 10, 2004). Does e-science work? *Chronicle of Higher Education,* p. http://chronicle.com/temp/reprint.php?id=gq5aud33l31rrvyk33amxgnzk37a36ah39r33p#roadblocks.