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# e-Research and the Ubiquitous Open Grid Digital Libraries of the Future

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***Abstract***

*Libraries have traditionally facilitated each of the following elements of research: production of new knowledge, its preservation and its organization to make it accessible for use over the generations. In modern times, the library is constantly required to meet the challenges of information explosion. Assimilating resources and restructuring practices to process the large data volumes both in the print and digital form held across the globe, therefore, becomes very important. A recourse by the libraries to application of successive forms of what can be called as Digital Library Technologies (DLT) has been the imperative. The Open Archives Initiative (OAI) is one recent development that is expected to assist the libraries to partner in setting up virtual learning environment and integrating research on a near universal scale. Future extension of this concept is envisaged to be that of Grid Computing. The technologies driving the 'Grid' would let people share computing power, databases, and other on-line tools securely across institutional and geographic boundaries without sacrificing the local autonomy. Ushering an era of the ubiquitous library helping the e-research is thus on the card. This paper reviews the emerging technological changes and charts the future role for the libraries with special reference to India.*

**Introduction**

It would not be an exaggeration to say that the library as an institution has played an important role in the progress of civilization. Collection and preservation of variety of information and organizing that for efficient retrieval is considered as the hallmark of its continued sustenance. The part played by the library to pass on the knowledge to generation after generation without discrimination and distortion, has certainly contributed to human advancement. Over the years, the library has also undergone transformations with regard to collection development and practices in tune with the socio-technical changes. The decisive point of departure in the character of the traditional library can be attributed to the advent of information technology in general and computer technology in particular. According to a recent report, humanity produces 250 megabytes of data per person per year on our planet. Only 0.003 percent of this annual output is in print form; most is in the form of images, sound, and numeric data and with more than 90 percent stored digitally [23]. No wonder the library is constantly required to adopt new digital technology means for information processing and disseminating.

The information technology progress is so penetrating and pervasive that it is now possible to obtain basic information on any topic by accessing databases across the world within reasonable time and cost. The not so distant future homes of tomorrow would have a minimum of a 100 computers embedded in all kinds of appliances and amenities [14]. In such a highly computer mediated society, the routine work of libraries and librarians would be taken over by computer programs. Such programs will find information no matter where it is stored and will match it to the needs of the user, and further correlate it with other information to make new and useful synthesis. The form and quantum of information that can be shared anywhere on the globe has naturally raised the issue of survival of the very concept of library, which was traditionally perceived in the form of brick and mortar structure. Libraries have no doubt made use of the advances in information technology right from a stand-alone computer system to computer networking to the web and Internet and also modified the services accordingly. It is clear that libraries will have to remain relevant by meeting the demands of patrons in the forthcoming information plenty era.

The aim of this paper is to examine the emerging technological changes and assess their impact on the library. To that end an overview of the technological progress leading to the development of what is termed as cyberinfrastructure is first presented. Its implications for the research and library and information services are next discussed. Likely further development resulting in grid computing, which can lead to happening of ubiquitous library is dwelled upon. An attempt is made to portray the changing needs of the library in the new milieu with reference to the Indian scholarship.

## Cyberinfrastructure

With the advent of digital technology, libraries are required to balance the collection development of print, non-print, and digital material and to redesign the services accordingly. The basic change this new technology has introduced is in reducing the physical material component of information while increasing the message part. The question is: where the spiral of technological development would lead? In this regard, it is noteworthy that each succeeding

technology development has helped the preceding one to consolidate and that is how it would continue [9]. The evolutionary role played by technology in the library in general is depicted in Figure 1.

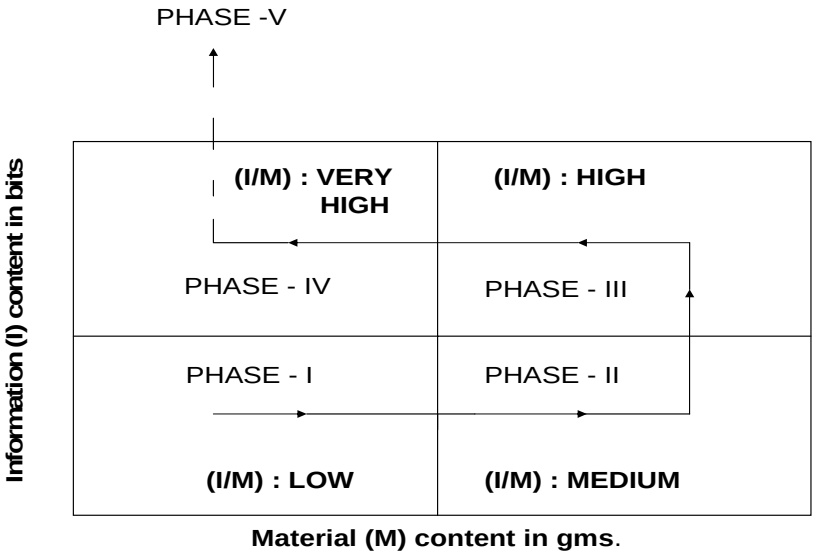


Figure 1: Information and Material Component Changes in the Library

Phase - I: Hand written manuscripts
Phase - II: Paper based books & journals
Phase - III: Non-print material like microfilms & audio-visual films
Phase - IV: Digital CD/DVDs & web pages
Phase - V: Open access initiative & grid computing?

It is clear from Figure 1 that we are currently in Phase - IV where the web is more than a technical tool and is expected to garner meaning to data, and create meaningful analysis of semantics [35]. No wonder more and more people today are living on the net.

This has set up the need for extending the infrastructure based on distributed computing and information and communication technologies. Such infrastructure would cultivate the richness of human experience, the diversity of human languages and cultures, and the full range of human creativity. Referred in Atkins Report as the "Cyberinfrastructure", it aims to empower radical new ways of conducting research through the applications of information technology mainly in the science and engineering, but also equally efficiently applicable to the arts, humanities and the social sciences [18]. These are the glimpses of Phase – V depicted in Figure 1 that would be characterized by the Open Access Initiative (OAI) and Grid Computing.

Physical infrastructure that is embedded and hidden in our usage of high-speed networks and advanced computing forms one layer. Intangibles like software, design processes, data, information, and knowledge constitute another layer. The cyberinfrastructure layer in the broadest sense constitutes the *in-between* layer of enabling hardware, algorithms, software, communications, institutions, and personnel. By integrating both these layers, the cyberinfrastructure layer develops and deploys applications that contribute to enhancing total quality of information processing.

***Impact of cyberinfrastructure on the scholarship***

The cyberinfrastructure empowers multidisciplinary research communities by bringing them together to work with computer and information scientists and engineers. It promotes collaboration or in other words grid community or network community or e-science/e-research communities [26]. These collaborating or grid communities are composed of research teams, digital data and information libraries, high performance computation services and arrays of sensors linked together to easily form virtual organizations that cross institutional boundaries in order to work together to solve a problem. The US National Virtual Observatory (NVO) <http://www.us-vo.org> illustrates one of the best examples of the growing importance of digital science. Without constructing a new telescope, but simply creating a large repository of observational data and a set of tools for manipulating these data, astronomers have created what they call "the world's best telescope". This non-telescope is expected to yield major new discoveries by aggregating and manipulating for each small path of sky, data collected at many different times by many different telescopes, at many different wavelengths. The NVO also opens up opportunities for major discoveries from scientists or amateurs from all corners of the world.

Teams or individuals in such technology mediated distributed work environment would be able to move across traditional disciplinary boundaries to collect and make use of widely scattered information leading to a qualitative change in the way research is done and the type of knowledge that results. They would be able to access the entire published record of studies online, be able to combine raw data and new models from many sources and utilize the most up-to-date tools to analyze, visualize, and simulate complex inter-relations. Such grid or collaboratory workspace built on the cyberinfrastructure would overcome the differences in age, experience, race, or physical limitations acting as barriers currently in many instances. The cyberinfrastructure thus makes possible more ubiquitous, comprehensive knowledge environment to enable individuals to have access to quality information and facilities for discovery and learning. They would contribute to the universal education too by providing rich material resources, sharing experiences and expert mentoring to students, faculty, and extension workers located anywhere, subject to requisite access.

Digital resources, tools and networks have influenced not just the way scholars make sense of human cultures and societies, but also the way these understandings are communicated to students and the general public by employing powerful information envisioning tools. The coming decade would see further transformations as masses embrace a digitized cultural heritage in new and sophisticated ways [12]. The arts, humanities, and the social sciences have vital contributions to make in designing, building, and operation of such digital knowledge spheres.

The significance of these disciplines is realized because they represent the human infrastructure that is necessary to drive the technology-based applications further. Social scientists have therefore an important task of understanding the way human beings behave, formulate and bring to practice, policies, tools and resources essential for the realization of any infrastructure (Cyber or not)[13, 18]. Discussion on the cyberinfrastructure would also be incomplete without thinking about structures of knowledge, of the academy, and of the society at large. In this context, it is important that our cultural memory institutions like, libraries, archives, and museums make the best use of these technological advances.

While much early adoption of computation resources did come from the sciences and engineering disciplines – "e-science" was a shorthand term for changes related with information technology in the scientific disciplines. More recently, the terms e-research and e-scholarship are also being used in recognition of similar technological and transformative shifts sweeping across the humanities, the social sciences, and the arts.

## Global Cyberinfrastructure

e-Research cannot reach its full potential without cyberinfrastructure. The conduct of science and research is a global enterprise that transcends geographic boundaries, disciplines and educational levels. The routine ability to work with experts from all over the world, to use resources distributed in space across international boundaries, and to share and integrate different types of data, knowledge, and technology being generated in real-time from all around the world is becoming more realistic. It is the development and deployment of compatible cyberinfrastructure (a.k.a. Grid) linking together computers, data stores, and observational equipment via networks and middleware that form the operative information technology backbone of international research teams.

There are three intertwined strands of a global cyberinfrastructure [16]:

i. *Cyberenvironments*: that provides researchers with the ability to access, integrate, automate, and manage complex, collaborative projects across disciplinary as well as geographical boundaries.

ii. *Cyber-resources*: that ensures that the most demanding scientific and engineering problems can be solved and that the solutions are obtained in a timely manner.

iii. *Cybereducation*: to ensure that the benefits of the national cyberinfrastructure are made available to educators and students throughout the world.

International collaborations are taking place, as is seen from the PRAGMA testbed [4]. The Pacific Rim Application and Grid Middleware Assembly or PRAGMA is a multidisciplinary distributed team of researchers from the University of Zurich, University of California, San Diego, and Monash University in Australia. These organizations have come together to focus on ways to practically create, support, and sustain international science and technology collaborations.

While we all know the pioneering efforts in this area started off with the USA, as evident in the Atkins report [6], international collaboration for research in several areas has also set the stage for grid initiatives in many other countries like Brazil [32]. In Europe, the "Research Infrastructure" supports the provisions of highest quality computing and communications infrastructure. This has resulted in the establishment of high-capacity and high-speed communications network for all researchers in Europe by GEANT [17, 19] and specific high performance Grid-enabled advanced test-beds.

South Africa, with its national ICT strategy, realized a need for a comprehensive national approach to maximize its potential economic contributions through the cyberinfrastructure [1]. Key examples that constitute the need for high-performance computing initiatives in the country were in the areas of biotechnology for simulation of design and processes in the major infectious diseases like HIV/AIDS and Tuberculosis; technologies to protect the natural resources and ensure food security; and resources for poverty reduction.

Japan has a Cyber Science Infrastructure (CSI), whereby it aims to design and deploy next-generation high-speed networks for collaborative research projects from different universities [33]. With scholarly databases and digital libraries, a proper plan and funding it aims at evolving the nation's scientific information infrastructure.

GARUDA is India's national grid initiative [27]. It is a collaboration of physical and natural science researchers and experimenters on a nationwide grid of computational nodes, mass storage, and scientific instruments. In its Proof of Concept phase, Garuda (eagle, and in Hindu mythology the mount of Vishnu, the preserver of the universe) will connect 17 cities across the country to bring "Grid" networked computing to research labs and industries.

## Cyberinfrastructure and Libraries

The cyberinfrastructure program offers an exciting opportunity to reformulate many information processes both at an individual and institutional levels. A possibility for a 'universal, omnipresent and ubiquitous' library that empowers access to and the understanding of, the breadth and depth of human culture and experience is thus envisioned. An insight into the response by the libraries in modifying their services over the years and what role they would play in future needs consideration as given below.

### *Libraries, yesterday, and today*

Library and information services have always been seen as part of a wider provision of research and learning support. In the last decade or so, infrastructure development to create system-wide efficiencies included creation of systems that brought together services and data holdings from different libraries. Focus was on integrated library systems, more openly available abstracting and indexing services and electronic journals. In the web environment, the common pattern of provision became multiple websites, each with a stand-alone interface, and databases that were hidden behind these interfaces.

These efforts had always been on enhancing the effectiveness of technologies in libraries, however, the long-term issue is how technology will influence the way library users behave and what they expect [37]. This follows from the fact that more and more applications are now web-based, which allows a free flow of data from users, by users, to users. Organizations are using a central web-based application to create workflows that pivot around the web. People and organizations are sharing components, problems, and work. Social networking through blogs, wikis, and IM (instant messaging) is increasing.

In this milieu, when analog media are being replaced or overtaken by digital media, an increasing number of users are finding the web more than just a form of creative expression. There is an increasing expectation by the web users and the younger generations in particular, to find resources of interest "on web", where by 'on-web' means being found on one of the major search engines. All this is leading to a creative renaissance where relationships between the humans and their web-experience are being enriched and extended by co-creation and on-demand services and supplies [24]. Service providers like eBay and Amazon are using web technologies to integrate user requests, delivery, experience, and location to give users the ultimate experience for their demands. They are leading them to believe that they have prospered the complete web, thus all resources available for their needs. These service providers are using the omnipresence of the web by assimilating features like RSS feeds into a user's workflow, reminding him of his past web experience to their present offerings, so as to use these for furthering their future web service range.

Libraries traditionally have prided themselves at nurturing relationships through registering the borrowing habits of users on the one hand and selective dissemination of information services and current awareness services for them, on the other. To this extent, libraries have been successful in establishing a symbiotic relationship. In contrast to the prevailing seamless information environment, library resources even to this day remain fragmented both within and across libraries. For example, on the contrary to the above web experience of a user, the links in discovery – locate – request - deliver of a library resource are still not clear, making it impossible to track the status of an item easily. Library services and resources have failed to bring library content in workflows and on web (as RSS for example), making them inaccessible or un-discoverable. The ecosystem of resource sharing amongst libraries that we see in shared cataloging platforms, messaging and document delivery systems, are not flexible, though virtual reference services and the recent experiences with FRBR are an exception [34]. They do not allow the library data to be moved out of the library systems or to be placed in user-systems. This is also due to the stringent copyright controls enforced by content owners, ever since the rise of the digital media [15, 37].

These technological trends are not debilitating however, for they provide libraries an opportunity to bypass the stringent software and service environments, by using more affectively, the open archives metadata harvesting protocol thereby, allowing metadata and pointers to data to migrate from one system to another. Open Archives Initiative (OAI) has its roots in an effort to enhance access to e-print archives as a means of increasing the availability of scholarly communication. The fundamental technological framework and standards that are developing to support this work are, however, independent of both the type of content offered and the economic mechanisms surrounding that content. They promise to have much broader

relevance in opening up access to a range of digital materials. OAI-PMH harvesters can incrementally gather records contained in OAI compliant repositories and use them to create services covering the content of several repositories.

Libraries, therefore, need to build on services that save time, and are built around user workflow. The library requires playing a more active role in user environment for example, in ways that supports their learning and/or research objectives. A lot of information services are being bundled, re-mixed and pushed on networks. Libraries need to investigate and implement new technologies that may enhance the library system's presence in this webby world. The evolution of e-Learning practices is something that libraries need to understand and evolve practices around. Once synchronous with distance learning, it primarily includes not only courses that are online and taught over a distance but those traditional classroom activities with electronic elements. e-Learning is changing the way faculty and students access, create, and use information. [28]. It is providing the library community collaborative opportunities to bring learning resources via podcasts or multimedia webcasts to a student's personal web-home. Libraries with functional institutional repositories or OAI complaint services can enhance services and usefulness in such e-Learning programs. The cyberinfrastructure also, can play an important role, by providing the necessary infrastructure to, not only mount, integrate and disseminate the course materials over networks but to be intelligent enough to integrate it with a personal information space, like an individual's digital dairy.

Another way of incorporating library services into the web-world is to gathering resources like contents and services, and to configure, shape and integrating them with the social networking sites, RSS aggregators, bookmarks, toolbars, plug-ins or into personal digital identities of users. It is the turn of libraries now to adapt their services to the network flows. All this is required as winning measures for libraries, as also to attract the ever crucial and increasingly scarcer user attention.

***Future role of libraries***

The future high power network scenario provides libraries an avenue to enhance their capabilities and provide better services to act as a ubiquitous library, especially in the cyberinfrastructure environment.

A repository in the cyberinfrastructure environment would not only hold passive information (for e.g., 'documents' and 'data') but also behavioral artifacts like software (called artifacts because of their dual role, as a human- and machine-readable information artifact and as a behavioral artifact resulting from its execution) [26]. It is important to note that, the line between the passive and behavioral artifacts is blurring with software today capable of translating audio or video to any standard representation for display or playback. There is a strong need for the long-term preservation and curation of data, information (represented by data and its descriptive and structural metadata), the logic processes and the algorithms generated in the scholarly studies. The library could provide an important input to content creation to support user discovery by consolidation of metadata of different disciplines, say, for comparative collection analyses. Exposing such data to search engines and other services and offering "alerts" is another library function. Libraries can also provide access services in the cyberinfrastructure enabled e-

Research environment. They could aid users of digital artifacts to find the relevant resources like their instruments and machines, link it to their own machines and in configuring, executing, and using any associated software. Some progressive organizations could also extend their functions to data stewardship, which includes provisioning of facilities, acquiring, installing, operating, and maintaining the physical storage and networking infrastructure. It could also include backup, replication, and mirroring operations on data to ensure its long-term integrity and preservation. Libraries could also get involved with the public and institutional policy issues, such as in the responsibilities of researchers to obtain public funding to add their data to repositories. Libraries could get involved in research underlying the possible liability, privacy, free speech, and security aspects.

Grid technologies are facilitating new Digital Libraries (DLs). These technologies not only provide more general and secure solutions for the implementation of DL infrastructures, but they also offer a new environment for the realization of more efficient DLs services. This can be termed as the Phase 2 of the DL development. Certain capabilities like virtual digital libraries can also be more effectively implemented on a Grid infrastructure [10, 22]. DLs in such secure environments would be monolithic systems that serve distributed communities and capable of applying complex transformations on the digital objects, like translation services, authority registries, transcript generators, etc and services that support the user activity, like recommenders and co-operative work supporting tools.

The future of online information would be dominated by small collections maintained and indexed by small groups. Digital libraries will store community knowledge, and the great mass of objects on the net will be stored in these repositories. New indexing techniques and federation across collections along with semantic interoperability would be a must [24]. Besides these, as the quantum of information increases in the cyberspace, tools that ensure that boundaries between private and public information remain intact might be needed. Digital Library Technologies (DLTs) focusing on authentication systems that not only measure the quality of information being discerned, but also measure the depth of its permeability from private to public domain and vice-a-versa, are therefore needed [8]. Besides quality the two most critical integrity issues with web-based information are: *provenance* - where does an object come from and how has it changed (tampered with) over time, and *persistence* - how long will an object last and how to make it last longer.

Further, managing, using and interpreting the voluminous web content would require another generation of DLTs. [17]. The cyberinfrastructure environment is well suited to the DL 2 phase in this regard. Formal understanding and modeling of the linkage patterns of the multiple communities represented on the web would further give us baseline information for effectively understanding the structure of the web [8]. Similarly, techniques for understanding how to effectively exploit user behavior are still in their initial stages and need to be generalized at the level of academic research in a cyberinfrastructure environment. The real promise of digital libraries in the cyberinfrastructure environment is that these technologies have the potential to transform the conduct of inter-disciplinary research and to foster new areas of investigation at the boundaries of existing disciplines. Promoting such an innovation requires that people have a set of flexible tools and services to gather information from multiple sources, and to manipulate on their own [24].

These are some of the issues for future research on digital libraries and their perceived application over grid technologies in the cyberinfrastructure environments for effective realization of an omnipresent ubiquitous library that is completely in digital version.

## Indian Digital Library Scenario

The Indian library scene is characterized by over 260 university libraries, 8000 college libraries, 54,000 public libraries and 9000 other institutional libraries spread across the vast geographical area. In addition there are several personal libraries with rare collections. Naturally, they are at different levels of development as far as digital status is concerned.

One of the most notable presence of organizations assisting in the transformation of academic libraries in India, and of the way they are involved in the research and development of the country has been that of the, Information and Library Network (INFLINBET) centre, an autonomous Inter-University Centre set up by the University Grants Commission (UGC), the highest University body of India. Its various programs like, the formation of e-Journal consortia, retro-conversion, web-site hosting, and creation of network resource centers in different universities and research institutions across India provide an opportunity for these organizations to come together to consolidate resources and to co-operate and collaborate for different services and systems. Likewise, INDEST, the Indian National Digital Library in Engineering Sciences consortium set up by the Ministry of Human Resource Development, has obtained nationwide prices for a number of electronic resources for its member libraries, which is helping the researchers.

Networking of research libraries with similar end objectives and associated collections is a popular approach, one that is also strongly encouraged by UNESCO. In India, there are already a few regional networks of libraries [5], like,

- Developing Library Network (DELNET)
  http://delnet.nic.in/
- Ahmedabad Library Network (ADINET)
  http://www.alibnet.org/
- Madras Library Network (MALIBNET)
  http://www.angelfire.com/in/malibnet/

Developing Library Network (DELNET) [21] is a major Indian effort on a national scale with over 950 libraries as its members, including both institutional and associate-institutional members. DELNET was established with the prime objective of promoting resource sharing among the libraries through the development of a network of libraries. It aims to collect, store, and disseminate information besides offering computerised services to users, to coordinate efforts for suitable collection development and also to reduce unnecessary duplication to the possible extent.

DELNET has been actively engaged with the compilation of various Union Catalogues of the resources available in member-libraries. It has already created the Union Catalogue of Books, Union List of Current Periodicals, Union Catalogue of Periodicals, CD-ROM Database,

Database of Indian Specialists, Database of Periodical Articles, Union List of Video Recordings, Urdu Manuscripts' Database, Database of Theses and Dissertations, DEVINSA Database, sample databases of language publications using GIST technology and several other databases

A newcomer in the arena of global information exchange, India's exposure to the Internet, electronic-mail and messaging, and other such "information/data exchange" means has been relatively recent. The surge in interest in the networking arena within India is therefore spectacular. For example, the number of operators in India offering some form of connectivity has at least doubled during the last two years. Following are a list of prominent net-based services that are currently active [36]:

1) ERNET (Educational and Research Network)
2) GPSS-GEMS (Gateway Packet Switching System)
3) UUNET (UUNET Technologies India Pvt. Ltd.)
4) BI Infotech (Business India)
5) ICNET
6) I-Net

ERNET is a government run network. It is a joint effort for the National Center for Software Technology, Mumbai, Department of Electronics, and the educational institutions (basically a couple of the Indian Institute of Technologies or the IITs). The GPSS- is under VSNL (Videsh Sanchar Nigam Limited), which is a Government of India organization (different from ERNET). I-NET is under the MTNL (Mahanagar Telephone Nigam Limited), providing leased lines webbed across India.

A number of libraries in India have been vigorously participating in the creation of digital content for some time. Along with the USA, and China, India is contributing to the one million books project. The Indian portal, also known as the 'Digital Library of India' <http://dli.ernet.in and http://dli/iiit.ac.in>, is expected to digitize and make available books predominantly in Indian languages free for access to all human knowledge [7]. Along with the Carnegie Mellon University, the Indian Institute of Science, Bangalore and 21 partner institutions, established technologies and processes for book selection, their scanning, cropping, OCRing and storage. Besides acting as storage of repository, the Digital Library of India has become one of the finest test-beds for Indian language processing, with research in areas of machine translation, optical character recognition, summarization, speech and handwriting recognition, intelligent indexing and information retrieval in Indian languages. The Om language transliteration package exploited the phonetic nature of Indian languages. The Universal Indian Language book reader helps user to read documents in other languages, using the similarity between many Indian languages [7]. There is also an initiative by the government of India to provide a common framework for all the digital libraries in India to coexist. A proposal to digitize music, video, sports, entertainment, and religious discourses is on the anvil.

Content and knowledge base creation efforts in India are visible in initiatives by the Council of Scientific and Industrial Research with regard to establishing the Traditional Knowledge Digital Library (TKDL), an indigenous knowledge database of the public domain traditional knowledge related to Ayurveda, Unani and Siddha system of medicine available in ancient literature.

Protection and preservation of traditional knowledge have been a matter of concern to the developing countries in general and India in particular [20]. The TKDL aims to safeguard the sovereignty of this traditional knowledge and protect it from being misused.

Similar in scope for content creation, is the work being done at the M.S. Swaminathan Research foundation in Pondicherry [11]. This foundation holds out hopes for increasing the reach and benefit of the ICTs beyond the urban centers. The pilot project involves establishment of a system in six villages to collect, maintain, update, and distribute agricultural, health, and entitlement information to improve the productivity of local farmers, to train educated youths and women in rural areas to operate information shops, and to educate the rural youth to generate locally relevant information from generic information. The ground data collected from these sources is also used in turn by various social scientists and technologists for research and further education and development.

On the dimension of promoting research and scholarship using digital technologies, efforts by university and research libraries at creating institutional repositories that open the gates of knowledge for academics, researchers and students are being explored. Advocates and enthusiasts of the initiative have been stressing the need for mandating Open Archiving and Institutional Repository (IR) initiatives in universities and national research institutes. Eprints@iisc, the electronic print archive of the Indian Institute of Science, Bangalore is probably the first OA-IR in India. With the number of IRs rising in the country, the need to create a consortium of research and scientific institutions for sharing information by establishing institutional open access archives has been stressed time and again [3]. There is a significant potential for open access publishing in India, considering the large number of publicly funded universities, institutions of higher learning and research laboratories. It is noteworthy that OpenMED, an internet archive for the medical and allied sciences, developed by the National Informatics Center, India has recently been nominated for the Stockholm Challenge Award 2006. Not only would open access increase the visibility of scientists from the South, but it would also enable them to access relevant information at affordable price.

FORSA (Forum for Resource Sharing in Astronomy and Astrophysics), an informal cohesive group of the astronomy libraries in India has a major role to play in India's efforts at creating its own Virtual Observatory (VO), on lines with the US, National Virtual Observatory (NVO) [2]. With government funding specific programs have been developed with sites mirrored for the Virtual Information Support, a tool meant to meet the information needs of the astronomical community in the country, anytime, anywhere. The geology, geophysics and earth sciences libraries in the country could take this as a cue for the formation of similar observatories for large scale earthquake, and sun-earth interaction data for aggregation, assimilation and correlation studies.

Special attention will have to be paid to bring the map database in the digital form and to make available for sharing across the cross section of users. The National Spatial Data Infrastructure (NSDI) program launched by the Department of Space in the country is a right step in that direction. It would lead to a variety of applications making the best use of the geo-referencing technologies like Remote Sensing and Geographic Information System (GIS). Integrating such a

spatial database with other databases would provide tremendous advantage for research, development, and decision-making process [30].

These current trends need to aggregate towards the common platform for a Ubiquitous Digital Library of India (UDLI). In this direction the following actions are suggested:

i. forming a consortium of institutional repositories in the country,
ii. libraries and the various library networks to be integrated and brought together with better bandwidth options now available,
iii. the library networks like DELNET, ADINET, etc, need to reach out to the general reader by making use of the very best in technologies,
iv. organizations need to harness local content for the rural poor. Further its porting on the net with capabilities like translation from the local language to the national language would help in wider dissemination,
v. efforts like the VO, need to be taken by domain specific research/special libraries or those associated with higher education,
vi. all the efforts described above, that is, from (i) to (iv), need to be integrated with the Indian efforts at creating the cyberinfrastructure grid, GARUDA,
vii. the current DL attempts in India need to focus and move towards Digital Library research phase 2, as emphasized in the future directions for DLs in the sections above,
viii. issues related to the cost of resources, the scholarly publishing process, intellectual property rights and the creation of digital resources need to be addressed to prepare suitable guidelines for practice,
ix. studies for assessing the needs of research libraries changes due to the developments in e-Science/e-Research needs to be undertaken,
x. as also, research into more imaginative roles for librarians and information managers in the digital library of the future to formulate common approaches for developing appropriate procedures and practices needs to be evolved,
xi. techniques for embedding information seeking skills in students through e-learning where appropriate, needs to be identified and imparted,
xii. novel tools for visualizing information in the new environments are also needed, and
xiii. training programs and workshops to stimulate the use of the new e-science initiatives needs to organized.

India can take advantage of the ubiquitous open grid digital library in two significant ways. On the one hand, this technology can assist in backward integration of the libraries to serve the users located in the remote parts of the country by sharing the library resources, which have so far remained inaccessible. On the other hand, e-research facilities that would be available to local researchers can help them contribute at the international level, even in the areas of frontier research. This would also make a big difference for the scholars in small towns who had hitherto worked on the basis of limited information and knowledge.

An integrated approach for infrastructure development and framing the programs and strategies for information management that can be united across disciplines and linking it to digital library with e-science, e-research and e-learning is desirable to maximize the benefits. A country like India should ensure that it does not miss out this phase of the information revolution.

## Concluding Remarks

At the end of the data-information-knowledge-wisdom spectrum begins the critical qualitative human judgment, where learning is most directly affected, and where matters of meaning and permanence are germane. This is the knowledge-leveraging framework of the cyberinfrastructure initiative. At the center of all this is the evolving science of information management. Such a ubiquitous environment has the potential to benefit more than just the industrialized nations. As noted by Wiseman, access to resources, participation in e-science and e-learning and the ability to benefit from the research and experience of the pioneers will be a significant lever to developing nations moving into the digital age [35,38].

Sight should not be lost of the fact that the advanced digital technology is expensive and in today's cost-conscious and commercial minded world a stress would be on designing service packages that would be self-sustaining. Further, there appears to be a direct relationship between the newness of technology and its fragility. Also, there are several issues related to information technology adoption by the libraries [29, 31]. For example, exploiting full potential, minimizing the dehumanizing side-effects and user-orientation issues are to be looked into.

On this background enabling those areas of the world that can least afford their own development programs must be a major long-term goal for any new global initiative. In fact, to leapfrog to overcome the digital divide in research and development applications must receive the top priority in the developing countries. The true potential of ubiquitous library and e-research would be realized only when such inclusiveness is achieved is our belief.

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