CHAPTER 5

Digital Libraries

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The Domain and Its Origins

This is the third time that digital libraries have been the primary focus of a chapter in the *Annual Review of Information Science and Technology* (*ARIST*) and, not surprisingly, it reflects a third perspective. Five years ago, Fox and Urs (2002) reported on the literature of the digital library largely as an engineering construct and a research domain. A few years earlier, Bishop and Star (1996) had examined the digital library as an emerging phenomenon within a broader review of social informatics.

Today the digital library is a reasonably mature information service application and so we can ask who uses digital libraries and how successful such applications are in serving user needs. Because services are at the core, I do not review digital collections in isolation; for the same reason, I include libraries which service some physical items in addition to digital content—"hybrid libraries." Of course, digital libraries have boundaries—not all services applied to digital objects are "library" services. The Digital Library Federation (DLF) Working Group on a Service Framework for Digital Libraries (Dempsey & Lavoie, 2005) usefully distinguishes the digital library domain from such domains as e-learning, e-research, e-archives and e-records management, e-publishing, enterprise systems within campus environments, personal users, and search engines and other open Web services. This review of English-language publications from the past four years does not systematically examine developments in any of these domains; it does, however, occasionally reflect on their intersections with digital libraries.

The term "digital libraries" emerged from the National Information Infrastructure initiative and U.S. national political discourse in 1991 and 1992, before achieving common currency among librarians in the wake of a special issue of the *Journal of the American Society for Information Science* (Fox & Lunin, 1993). Both the political and computer science foundations for discussions concerning the digital library lay in high-speed computer networks and the technical issues associated with linking and delivering collections of multimedia content. Although the vision of a singular "Digital Library" is what captured the popular

and political imagination, and was promoted especially by Vice President Al Gore in the 1992 election campaign, through the 1990s the United States government supported "digital libraries" in the plural. Large multidisciplinary teams were funded to answer technical questions about computing requirements and almost incidentally built intensively curated collections, almost exclusively for academic use. The one exception was the Library of Congress's largely privately funded American Memory project (http://memory.loc.gov/ammem) and National Digital Library Program (http://memory.loc.gov/ammem/dli2/html/lcndlp.html), which created the largest digital library of all (over 8 million objects) for public use and enabled public access over the Web.

In the pre-WWW context of 1991–1993, the period of popular discovery of the Internet and the rise and fall of gopher (which first permitted public access to remote digital resources), the focus of digital libraries on solving the technical problems faced by those building collections of multimedia content was understandable, but the orientation to discrete collections has since shifted the focus of digital library applications. More than a decade later, we are finding the core assumptions of the early 1990s—that digital library content would consist of fixed objects, that digital libraries would contain only digital works, and that individuals working alone should be the target users of digital libraries—particularly limiting as some prescient observers predicted (Levy & Marshall, 1995). The plurality of digital libraries is an ongoing technical challenge and major source of user frustration.

The Literature

Digital libraries are now crucial tools for nearly all professional communities, but the development of digital library applications is not the central focus of any single discipline. One consequence of this interdisciplinarity is that new research contributions to the digital library literature are almost always first presented at topical conferences, especially at the Joint Conferences on Digital Libraries (www.jcdl.org/index.shtml), co-sponsored by the Association for Computing Machinery (ACM) and IEEE Computer Society (IEEE-CS) division since 2001, and the European Conference on Digital Libraries, the proceedings of which are published in *Lecture Notes in Computer Science*. The International Conference of Asian Digital Libraries and the more recent International Conference on Digital Libraries, the papers of which have been published in special issues of journals since 2001, are of more regional interest but attract well over one hundred papers annually. In addition, major library association conferences include papers devoted to aspects of the digital library, especially online services, digital content acquisition and preservation, and management. Furthermore, the pre-existing conferences of information scientists, publishers, abstracting and indexing services, and online database providers all report on digital library topics from their particular perspectives.

Digital libraries are now a sufficiently mature subject to be taught in graduate school courses and, over the past four years, have been the topic of a number of monographs. Some of these are conference proceedings (Börner & Chen, 2002; Brophy, Fisher, & Clarke, 2002; Fox & Logan, 2005; Heery & Lyon, 2004; Koch & Sølvberg, 2003; Koskiala & Savolainen, 2004; Lankes, Janes, Smith, & Finneran, 2004; Lankes, McClure, Gross, & Pomerantz, 2003; Marcum, 2001; Sembok, Zaman, & Chen, 2003) but others are edited books with chapters by various authors (Bishop, Van House, & Buttenfield, 2003; Hodges, Sandler, Bonn, & Wilkin, 2003) or textbooks and treatises (Chowdhury & Chowdhury, 2003; Deegan & Tanner, 2002; Gorman, 2002; Hanson & Levin, 2002; Lesk, 2005; Levy, 2001; Lipow, 2003; Pace, 2003; Pantry & Griffiths, 2002; Rosedale, 2002; Tennant, 2004). Articles and book chapters are referenced separately throughout this review. Introductory texts presenting broad overviews that have been widely reviewed receive less attention, with preference given to more specific publications by their authors.

The core journals include *College & Research Libraries, Communications of the ACM, Electronic Library, Information Processing & Management, Information Technology and Libraries,* the *Journal of the American Society for Information Science and Technology, Library Trends,* and *Online Information Review*. Despite its irregular publication life, the *International Journal on Digital Libraries* has served as a venue for important articles from time to time.

The e-journals *ARIADNE* (www.ariadne.ac.uk), *D-Lib* (www.dlib.org), *First Monday* (www.firstmonday.org), and *Information Research* (http://informationr.net/ir), as well as the p- and e-journals *Program: Electronic Library & Information Systems* (www.aslib.co.uk/program), and *portal: Libraries and the Academy* (http://muse.jhu.edu/journals/portal_libraries_and_the_academy) publish a steady stream of announcements, project reports, and reviews that serve the digital library community. These sources also include some important articles, especially overviews.

A number of organizations frequently publish reports and play other supporting roles for digital libraries far beyond what is represented in the published record. In the U.S., these include the Council on Library and Information Resources (www.clir.org), the National Science Foundation (NSF) (www.nsf.gov), and the National Academy of Sciences (www.nas.edu), as well as the Digital Library Federation (www.diglib.org)—which hosts twice-annual forums, the presentations of which are a record of the shifting foci of the field—and the World Wide Web Consortium (www.w3.org). The Joint Information Steering Committee (JISC) in the U.K. (www.jisc.ac.uk) supports and publishes on digital libraries. In Europe, the DELOS Network of Excellence on Digital Libraries (www.delos.info) has operated during the EU Fifth and Sixth Frameworks Programmes (since 2000), with the aim of coordinating

research, standardization, evaluation, training, and international cooperation (including joint projects with the NSF).

Some Influential Recent Reports

During the past four years, a number of major reports have summarized the situation of digital libraries and articulated challenges facing the domain. These reflect the divergence of views between those who see the digital library as an institutional configuration, an engineering problem, a political challenge, and a service.

Writing for the Council on Library and Information Resources, Lougee (2002) suggested that digital libraries could allow the library profession to take on new roles in the creation and dissemination of content and in partnering with others acting as publishers. These new library roles were seen as being consonant with open paradigms and with teaching and research functions in the broader academic enterprise. Lougee described the evolution of some traditional roles, such as virtual reference services and information literacy training, to support her case. It is clear that academic librarians have accepted these new opportunities enthusiastically, seeing in them a way to reassert their importance within academia.

A report from the NSF Workshop on Research Directions for Digital Libraries held in June 2003 (Larsen & Wactlar, 2003) challenged digital libraries to become transparent and to support a ubiquitous knowledge environment in an effective manner. Their technocentric vision of infrastructures and interoperable toolsets acknowledged that "the idea of curated, network-accessible repositories—the original notion of 'digital libraries'—was (and remains) a fundamental need of scholarly inquiry" and asserted that building such digital libraries would lead to "an information ether" (p. 1). Although they talked of integrating information space into everyday life, their focus was solely on the higher education community. The workshop ultimately proposed how to transform "the conduct of disciplinary research itself," but in doing so revealed the gap between "disciplinary research" and a ubiquitous knowledge environment (p. 1). The recommendations of the workshop focused on search paradigms, metadata control orientations, and standards enforcement models.

The report of the NSF Blue-Ribbon Panel on CyberInfrastructure (Atkins, Droegemeier, Feldman, Garcia-Molina, Klein, Messerschmitt, et al., 2003) had a political objective: It called for a major investment in a national collaboratory, or grid, to fuel a revolution in scientific and scholarly activity built on a foundation of collaborative working environments, rich digital libraries, and intensive computational utilities. In order to influence the federal budget process, the report examined digital libraries in the sciences and found that they have had considerable impact as a testbed for interdisciplinary research into issues underlying cyberinfrastructure development. In this respect, it contrasted dramatically with the draft report of the American Council of Learned Societies

(ACLS) Commission on Cyberinfrastructure for the Humanities and Social Sciences (www.acls.org/cyberinfrastructure/acls-ci-public.pdf) which, although it essentially equated cyberinfrastucture for the humanities and social sciences with universally available digitized content, barely acknowledged digital libraries.

If a major report on cyberinfrastructure can overlook digital libraries, how are we to measure their impact? One way is through user studies. In her report on "Use and Users of Electronic Library Resources," Tenopir (2003) reviewed over 200 user studies of digital libraries reported between 1995 and 2003. These studies examined almost exclusively how faculty and students used academic libraries. With few exceptions, they did not measure the impact of those uses on academia and revealed virtually nothing about public or nonacademic users or uses. The literature of digital libraries does not address the impact of changing social practices as the Pew Internet and American Life Project has done over the past five years. In 2004, the Pew study found that search engines had radically changed the way people in the United States live and work, essentially by putting a digital library—the public Web—at their fingertips. Nearly one third of those who use search engines cannot imagine what they would do without them (Fallows, 2005): This is certainly a measure that libraries of any kind, digital or physical, would love to achieve.

Taken as a group, these major reports suggest that digital libraries are still firmly tethered to their academic roots and have had substantial impacts on scientific communications. However, they have not yet been acknowledged to have fundamentally changed the nature of scholarship in the humanities and social sciences and have been nowhere nearly as revolutionary as the Web in changing information-seeking behavior at large.

Ecology

The Digital Library, a singular, uniform, ubiquitous, and comprehensive digital information resource, has been a feature of prevailing political rhetoric in the U.S. and the U.K. for a decade, but the professional discourse, with few exceptions (Keller, 2004), has been largely about *digital libraries*. Because digital libraries are many and various, users experience them differently depending on whose "door" they walk through.

Discipline- and Subject-Based Digital Libraries

The predominant organization of digital libraries today is by their intellectual content or disciplinary focus. The users we know and the languages they speak are specific to disciplines (Lee, Na, & Khoo, 2003). Typically, funding is directed by agencies whose mandates are limited to a group of disciplines in science, medicine, or the humanities. We may be able to demonstrate that use is less related to the discipline served than

it is to the availability of suitable resources, but the fact remains that resources are available for building digital libraries relating to specific disciplines (Törmä & Vakkari, 2004).

It is not surprising, therefore, that most detailed descriptions of digital libraries have been published in disciplinary journals with the intention of introducing them to their clientele rather than critically analyzing them from the perspective of information professionals. Nevertheless, the examination of features and tools developed to serve the needs of specialized communities could, in principle, cross-fertilize developments in other fields.

Digital libraries that are built around disciplinary subject matter can present barriers to access by nonspecialists, even when the content might be of interest to many disciplines and different types of users; for example, reports in journals in mathematics focus on the disciplinary use and benefits of a mathematics digital library (Adams, 2003; Lozier, 2003; Miller & Youssef, 2003). A digital library of classical protestant texts (Prest, 2003) contains content that could be of general interest, but the modes of access provided and the services supported are not designed to attract the general public or nonspecialists from other disciplines. Experience has shown that, when nonspecialist users are attracted to a digital library, as has occasionally been the case for digital medical libraries used by both general practitioners and the public, they have needs different from those of professionals, and serving these disparate needs presents challenges (D'Alessandro, Kreiter, & Peterson, 2004). For example, when a digital library of herbals is structured as a service designed to support scientific research, this limits its utility for chefs (Agosti, Benfante, & Orio, 2003).

Genre- and Format-Based Digital Libraries

Implementing digital libraries for particular media provides some technical advantages to support functions, interfaces, and archiving. Researchers, and the public at large, have prior experience with repositories dedicated to specific genres or formats and generally find national-level collecting institutions of this sort convenient. Countries may follow this path because national laws on copyright deposit provide for different agencies to receive texts, sounds, and motion images, as has been the case in France. Australia, for example, has created a national digital music library (Ayres, Burrows, & Holmes, 2004) and a national digital image library (Campbell, 2002). The nature of content management for academic digital libraries could change significantly if digital recorded culture were comprehensively available through national libraries worldwide and the content were open (subject to appropriate licenses) for access by digital library search engines.

Institutional Repositories

Disciplinary and format- or genre-based digital libraries may serve individual researchers well, but they could also undermine the library mission within the university. University librarians are struggling to identify a future role that the library can play within the larger institution (Atkins, 2003). One recent development in digital libraries has been to make "institutional repositories" an intrinsic part of an architectural strategy. Proponents (e.g., Lynch, 2003c) argue that if the management of radically distributed resources takes place in part by encouraging the development of institutional repositories, the identity of the institutional library and the university's commitment to its responsibility for curating digital resources are enhanced. This strategy, like that of distributed archiving, of which it forms a critical element, has a natural synergy with, and indeed might be necessitated by, new publishing paradigms in which individuals are enabled to "publish" without the gatekeepers or publishers who were the traditional collators of library content. Early experience suggested that the users of digital libraries were not very interested in contributing to institutional repositories (Smith, Rodgers, Walker, & Tansley, 2004). More thorough research comparing developments in many countries and examining the rapidly evolving nature of institutional repositories, however, gives those advocating the importance of this ecological niche cause for optimism (Lynch & Lippincott, 2005; van Westrienen & Lynch, 2005).

At the heart of the institutional argument is the economics of digital libraries. Resource sharing between institutions, new economics of publishing, and business models for digital library services all combine to drive thinking into institutionally oriented planning processes (Greenstein, Lawrence, Miller, & Dunlap, 2003). Real digital libraries, it is argued, must be grounded in institutions and in sustainable business models, not in grants and research efforts (Lynch, 2003a).

Mission- and Audience-Directed Digital Libraries

In contrast to the repository orientation, the digital library itself is increasingly viewed as a service (Bonn, Hodges, Sandler, & Wilkin, 2003) and, to some, invisibility is the ultimate goal (Borgman, 2003b). If digital libraries are to evolve this way, they will have to be constructed to support specific types of activity or missions and will not be readily identified with institutions or collections. Systems built around work processes are focused on serving those needs and are evaluated in terms of their success by those engaged in the tasks they are designed to support (Meyyappan, Foo, & Chowdhury, 2004). Increasingly we are learning how work methods and technical capabilities are discipline-specific (Adams & Blandford, 2002).

Digital libraries supporting distance education instruction are an instance of mission-directed libraries (Ho, 2004; Zia, 2004), as is CITIDEL (Fox, 2004), the NSF-funded consortial portal to educational

resources related to computing and information technology. Other educational digital libraries, such as the National Science Digital Library, are broad programs under which a wide range of research is taking place, most of which is not directly related to the development of methods for delivery of educational content (Arms, Hillmann, Lagoze, Krafft, Marisa, Saylor, et al., 2002; Prey & Zia, 2002; Zia, 2004).

One of the few well-studied cases of building digital libraries for user communities without a disciplinary orientation is that of digital libraries for children (Druin, 2005; Druin, Revelle, Bederson, Hourcade, Farber, Lee, et al., 2003; Hourcade, Bederson, Druin, Rose, Farber, & Takayama, 2003; Hutchinson, Rose, Bederson, Weeks, & Druin, 2005). Having a targeted audience enables these digital libraries to design more satisfactory intellectual access methods and tools to exploit target resources. Audience orientation emphasizes services over collections.

Content

Primary Objects

Most content available in digital libraries has been born digital. Although the first decade of digital library research projects in the U.S. and Europe digitized some content in order to have material with which to test engineering solutions, digitization per se has not been considered scientifically interesting and, until very recently, it has not been conducted on a massive or comprehensive scale. Studies showing that older data have value even for the hard sciences (Liu, 2003) and that the digitization of "cultural heritage" is crucial to its future study (Sutton, 2004) were not sufficient to expand the pace of conversion from analog to digital. But institutional and national pride seem to be. Since December 2004, when Google announced plans to digitize and index the full text of more than 10 million volumes from five university libraries, there has been considerable reaction worldwide. Whether they welcomed or rejected it, the announcement led national libraries to examine the scope and speed of their current digitization plans. Before the end of 2005, major libraries, such as the British Library, the Bibliothèque Nationale de France, the Library and Archives of Canada, and the University of California Digital Library, had announced exponential increases in their text digitization programs. Together with the Open Content Alliance (www.opencontentalliance.org), which could well create the first comprehensive, public-domain digital library, these developments have engendered a realistic expectation that nearly everything ever printed might be available in digital form within a decade or so. Mechanisms such as the recently approved "info" Uniform Resource Identifier (URI) scheme will ensure that legacy content metadata is intellectually integrated into digital libraries (http://info-uri.info).

Primary digital objects in many formats will soon populate digital libraries much larger than the curated collections that have been built

to date; researchers are therefore developing methods to handle massive quantities of content without human descriptions. Brute force approaches to these large collections (Cacheda, Plachouras, & Ounis, 2005) compete with methods to tease structure and genre out of scanned images of texts or full-text documents, to increase precision in retrieval, to improve understanding of context, and to exploit linkages between elements of the structure of documents (Muehlberger, 2002; Rauber & Merkl, 2003). Distributed architectures and access using content-based image retrieval (CBIR) (Tang, Avula, & Acton, 2004) are still attracting substantial research for massive image collections but these high-tech solutions seem oddly less successful than allowing user annotation in collaborative workspaces (Pisciotta, Dooris, Frost, & Halm, 2005). Music, too, can be retrieved automatically with waveforms (Clausen, Kurth, Maller, & Ribbrock, 2004), but evidence suggests that organizations which take into account work processes might better support regular users (Notess, Riley, & Hemmasi, 2004). Similarly, it seems that for huge volumes of texts, images, sound files, and video (Kim, Kim, & Hwang, 2003), or even video alone, better data models coupled with architectures to exploit them are needed (Lee, 2003; Salembier & Smith, 2001; Wang, Xing, & Zhou, 2003). It seems that huge quantities of data will require more than fast processors and clever engineering algorithms to become useful to general audiences.

The objects in digital libraries have two somewhat paradoxical properties: They are not fixed, and the metadata that describe and control them are often treated as objects in their own right. Treating metadata as a first class object, like any other resource (Karadkar, Francisco-Revilla, Furuta, Shipman, Arora, Dash, et al., 2004), creates new social and scholarly publishing opportunities and structures. Treating the annotations as first class objects, for example, enables them to be organized and annotated recursively, in the same way as any other object in the library (Agosti & Ferro, 2003; Frommholz, Brocks, Thiel, Neuhold, Iannone, Semeraro, et al., 2003; Liu, Lim, & Goh, 2002). Because metadata can then be cited, it is possible for some members of a digital library community to emerge as expert metadata authors—the kind of role once reserved for librarians or scholarly editors—just as some individuals can be respected reviewers in the Amazon.com community or have trusted profiles on e-Bay. These benefits were documented in an image library study, where metadata from a number of different professionally sanctioned schemas were augmented with user- and user group-contributed annotations (Attig, Copeland, & Pelikan, 2004). Research into how social tagging might be harnessed to generate folksonomies that contribute to retrieval by augmenting controlled vocabularies is a potential mechanism for offering broader access to museum objects than is typically provided by professional indexing (Bearman, Trant, Chun, Jenkins, Smith, Cherry, et al., 2005).

Adding shifting layers of personalized and group-annotated content on a foundation of digital library objects, which are themselves constantly

changing, supports Levy's continuing assertion that digital library objects will not succeed if they treat their holdings as fixed content (Levy, 2001, 2003; Levy & Marshall, 1995). At the same time, it is a strong reminder that the primary object of interest is different for each user and that what constitutes data and metadata is simply a matter of perspective.

Value-Added Metadata and Indexing

If metadata is the answer, what is the question? Unrealistic expectations have been associated with metadata, in spite of decades of pre-digital library experience that revealed the limitations of cataloging, indexing, summarizing, and other modes of surrogation. The digital library literature includes many superficial exhortations to adhere to metadata standards (Bekaert, Van de Ville, Rogge, Strauven, De Kooning, & Van de Walle, 2002) along with very sophisticated models of how metadata namespaces can inform service models through schema mapping and semantic enhancement (Huang, Ke, & Yang, 2005). All too often both treat subject classification as objective and imagine that users share an understanding of indexing terminology that will improve retrieval. When we see how complex some systems need to be to take metadata from multiple sources and do with it what end-users probably assume it already does—that is, collocate like items—the challenge of universal digital libraries seems insurmountable (Candela, Castelli, & Pagano, 2004). Hope persists that metadata will overcome heterogeneity even when empirical findings are negative (Weiss-Lijn, McDonnell, & James, 2002). But lacking demonstrable successes on a significant scale, we are often left to celebrate the consensus building of the metadata standardization process (Weibel, 2005) or the intellectual rigor of the end product (Salembier & Smith, 2001).

Hughes and Kamat (2005) have suggested that all we need may be better interfaces to the metadata; other researchers have held that we should accept that there is a specific metadata schema for each particular user (Ismail, Yin, Theng, Goh, & Lim, 2003). One strategy for managing a multiplicity of formats, each carrying its metadata according to its own standard, is to build repositories for any type of content with arbitrary XML metadata descriptors that could serve as a uniform structure in which digital libraries are stored (Amato, Gennaro, Rabitti, & Savino, 2004). In the abstract, this approach seems to have special virtues in archival environments where the objects entering the repository are of arbitrary formats, although it conflicts with all encapsulating approaches, such as the Open Archives Information System (OAIS) reference model, which are currently the preferred strategies for archiving.

As digital libraries grow and their data become more heterogeneous and designed to serve a more diverse community of users, there is a definite trend toward obtaining ever more metadata from more sources to support distinct uses. The title pages of books may contain all we need

for descriptive cataloging, but they do not carry the equivalent of the MPEG-7 (Moving Pictures Experts Group) header on which systems of multimedia digital library storage and retrieval are constructed (Lee, Kang, Myaeng, Hyun, Yoo, Ko, et al., 2003). Complex metadata and content packages describe and control anything from standard product labeled drugs to curricula, instructional Web sites, demonstrations and quizzes, and course blogs (Gold, 2003). So much has been written about these complex data-plus-metadata objects in the field of learning objects, for example, that they recently required a review of their own (Hanisch & Strasser, 2003). We can expect metadata to become increasingly important in applications that support richer services as users and content become more diverse. In the past few years we have seen growing adherence to the Metadata Encoding and Transmission Standard (METS); it is to be hoped that additional robust models and standards will enable greater interoperability among metadata schemes in the digital libraries of the near future.

One category of metadata that does not yet seem to have a literature of its own, although applications are increasingly being built to use it, is metadata about the use of digital library objects in the digital library environment. This kind of metadata, the basis for recommender systems and social tagging applications, is central to exploiting non-verbal indexes that depend on relations established in another dimension to indicate similarity. Like co-citation analysis and concept mapping, which are related methods for retrieval, exploiting this kind of metadata will support new methods of access. Interest in how these data are represented for possible sharing between repositories is bound to grow.

Technology

Architecture

One central technical problem of the digital library is providing effective access to heterogeneous, distributed, digital content. If content remains distributed at the point of its creation, we must have tools to search and retrieve content automatically in all its possible technical formats and present it seamlessly to the end user. Recognizing the complexity of distributed libraries and the need to communicate promising solutions, the Library of Congress recently launched the Distributed Open Digital Library (DODL) program (Marcum, 2004).

The first decade of digital library evolution was dominated by federated databases and distributed searching as the architectural solution to the challenges of access. With the dramatic success of search engines and the rapid adoption of the Open Archives Initiative-Protocol for Metadata Harvesting (OAI-PMH), architectures that build centralized metadatabases by federating metacontent have come to be preferred in the past several years. Architects of some universal digital libraries, such as the Open Content Alliance, are even beginning to revisit the

realm of central databases with full content and metadata served from one system.

Today digital library assets are widely distributed. Case studies demonstrate (Mischo, 2001) that they include publisher-controlled data sources, the Web, secondary and tertiary information resources, local information, personal digital libraries, and institutional repositories; they are likely to include at least some paper-based content, a feature typically attributed only to "hybrid" libraries. Content from all these sources is required to serve users. In theory, all these distributed databases could employ the same standards and use their descriptive vocabularies in the same way (Bekaert et al., 2002; Lee, 2004), thus effectively acting as a single system. Because of their common "Web server" platforms, one could argue that Web sites work this way and that the digital library is another "portal" (Campbell, 2003); however, the Web certainly does not employ any descriptive content standards, and the dynamic—indeed chaotic—state of its content challenges the notion of libraries as storehouses for persistent and authoritative resources.

No matter how a search is performed, a search mechanism must resolve how to recognize and negotiate for the content it needs (Ding & Sølvberg, 2004). Most digital library developers feel that distributed content will work only if we can reliably find and persistently use the content, and can depend on favored solutions that have a built-in level of social agreement as their architectural strategy. Currently, digital libraries acquire content through deposit, obtain access to it under subscription, or acquire it through harvesting (it or its metadata) from distributed resources. Since 2001, OAI-PMH is increasingly being used. Federated search services still primarily employ the older Z39.50 search protocol to search on demand, although efforts are underway to create better metasearch protocols (www.niso.org/committees/MS_initiative.html). Some researchers advocate industry-standard protocols as crucial to long-term distributed library success (Apps, 2004; Congia, Gaylord, Merchant, & Suleman, 2004). In spite of their tremendous success within the digital library community, the OAI-PMH and Z39.50 protocols are only used in this niche market.

In interoperability research reports, we are too often presented with either metadata harvesting options (Ravindranathan, Shen, Goncalves, Fan, Fox, & Flannigan, 2004) or federated searching approaches (Campbell, 2002; Ding & Sølvberg, 2004; Eason, Harker, Apps, & MacIntyre, 2004) independently of each other. But we know that interoperability has to function on several levels (Arms et al., 2002). So it is welcome that investigations of ways to combine harvesting and federated searching have begun to appear (Congia et al., 2004). An alternative approach uses complex rules to mediate between the different repositories in a federated library, effectively making them distributed resources under the control of one system (Lee, 2003); however, it is likely to be difficult to attain this level of cooperation between systems in the real world. Promising evaluative work is being conducted comparing various

approaches to federating content. If put into practice, these findings could improve any federated library service (Simeoni, 2004), including the application design challenges OAI-PMH presents for ongoing harvesting and post-processing of data (Anan, Tang, Maly, Nelson, Zubair, & Yang, 2003).

The federated library has been made significantly more complex by "sociable" and personalized computing. Just when ways to bring together content or views of content emerge, groups of users with common interests want tools to fence off areas of their own in which to collaborate, annotate with their own meanings, and re-use, or even republish, content (Candela & Straccia, 2004). The logical conclusion of such a project is personal libraries, with personal software agents in charge of acquiring the content, making the federated vision a radically distributed one in which the clients for services are an audience of one (Cho, 2004).

Knowledge Architecture

Among researchers, there is disagreement about what knowledge architecture will best make heterogeneous resources useful to diverse users. Some argue that collaboration toolsets are the way to create more useful digital libraries for each user community (Bieber, Engelbart, Furuta, Hiltz, Noll, Preece, et al., 2002; Renda & Straccia, 2002), although the added value from collaboration is effectively closed. Others suggest that ontologies will prove to be the method of overcoming even linguistic boundaries (Brisaboa, Parama, Penabad, Places, & Rodriguez, 2002), thus effectively opening up content to anyone. Ontology-oriented researchers assert that agents can overcome differences among schemas of distributed datasets (Yang, Rana, & Walker, et al., 2002), but socially oriented researchers argue that, as digital libraries succeed, users will necessarily become more remote, unknown, and unpredictable. In the latter group's view, more effort will need to be expended to understand users' needs and tasks, so that data and services can be modeled to meet heterogeneous needs (Borgman, 2003a; Borgman, Smart, Millwood, Finley, Champeny, Gilliland, et al., 2005). Actual users will benefit if they can build deeper communities of use around their datasets.

These strategies require different approaches. Building tools for a digital library to deploy an ontology service layer (X. L. Zhang, 2004) is quite different from modeling user tasks for a music metadata model (Notess et al., 2004). Social strategies involve developing and refining tools to display connections made by users and are essentially pragmatic and incremental. Creating ontologies to bridge meaning across disparate groups is a fundamental problem, even without introducing machine understanding. We each belong to a number of communities that have their own worldviews and languages and the concepts in those domains may have distinctive meaning that, for the time being, only humans can distinguish (Star, Bowker, & Neumann, 2003). We can construct systems

that allow multiple schemes of knowledge to co-exist (Krowne & Fox, 2003), but this still begs the question of where a user obtains the understanding to move among them.

Application Systems

Several major groups of digital library researchers have created model digital library applications with tools that enable content holders to implement basic digital library environments with only modest technical support.

Fox and his numerous collaborators have promoted applications built on their 5S model of the digital library space, which employs formal methods to direct the design of digital libraries, purportedly even by nontechnical staff who are willing to express requirement variables formally (Fox, Goncalves, & Shen, 2005; Goncalves, Fox, Watson, & Kipp, 2004; Kelapure, Goncalves, & Fox, 2003; Zhu, Goncalves, Shen, Casse, & Fox, 2003). These applications are said to demonstrate the benefits of the 5S formal descriptions of digital library architectures (structures), content definitions (streams), clients (societies), service models (scenarios), and perspectives (spaces). If not yet exactly full-scale digital libraries in a box, these are, at least, boxes of useful components (Fox, 2003; Fox, Suleman, & Luo, 2002; Hussein, Fox, Kelapure, Krowne, & Luo, 2003).

Witten and his colleagues are working on generalized digital library "generators" that can create a variety of different libraries based on values of parameter settings (Bainbridge, Don, Buchanan, Witten, Jones, Jones, et al., 2004; Witten, Jones, Bainbridge, Cantlon, & Cunningham, 2004). They have been particularly active in Third World settings where significant success has been reported with some implementations of the Greenstone software. Their solutions are pragmatic and the approach is, overall, less theoretical than the 5S model.

Probably the most influential tool for digital library implementation over the past four years has been the Fedora open source library for a digital repository (www.fedora.info). Fedora does not claim to create full-blown digital libraries for nontechnical authors; various Fedora implementations have been reported throughout the literature, validating its claim to be a robust, generalizable platform (Dong, Xing, Zhou, Zhang, & Jiang, 2004; Pyrounakis, Saidis, Nikolaidou, & Lourdi, 2004).

The continuation and widespread implementation of projects to open and modularize digital library source code could prove a tremendous boost to the field. This would enable the construction of digital libraries in settings otherwise unable to support them, creating common structures for interoperability and advancing a profile of what functions ought to be supported.

Digital Libraries within General Computing Environments

Digital libraries are implemented within standard database and network service environments. As a consequence, every year a considerable quantity of research is reported on solutions to general computing problems as they apply to digital library applications, such as pre-fetching content to speed up display for end-users (Hollmann, Ardö, & Stenström, 2003), fault tolerance and security in Web-based digital libraries (Di Giacomo, Martinez, & Scott, 2004), and data security (Yague, Mana, Lopez, Pimentel, & Troya, 2002).

Authorization systems, which are of interest in general computing and central to digital library implementations, have been the focus of a great deal of work over the past decade (Adam, Atluri, Bertino, & Ferrari, 2002). Recently, JISC decided to abandon its ATHENS authentication service in favor of Shibboleth (http://shibboleth.internet2.edu), making it and the NSF Middleware Initiative the most widely deployed toolsets (Morgan, Cantor, Carmody, Hoehn, & Klingenstein, 2004). Because they have increasingly adopted the same authentication infrastructure, digital libraries could potentially solve a major problem of the Internet—identity control and management. More widely accepted solutions to authentication serve the interests both of groups such as the Attention Trust (www.attentiontrust.org), which are lobbying for individuals to have greater control over their digital identities, and of those in the augmented social network community, who are emphasizing the positive benefits of being "recognized" and having one's preferences and interests respected wherever one goes in virtual space.

Interfaces

Some interface issues, even though they feature in other domains as well, have particular resonance within digital libraries. We know that complexity often contributes to confusion and that the multiple layers of systems, data, and services in digital libraries are certainly capable of causing trouble for end-users unless design principles are followed rigorously (Bates, 2002). Usefully, some are beginning to trace digital library interface design principles back to human cognitive processes and extract possible guidelines for digital library interfaces from fundamental research in cognition (Rapp, Taylor, & Crane, 2003). Such work will be increasingly important if we try to scale libraries beyond the small communities for which they are now optimized.

Heterogeneous content, of course, includes content in many languages but multilingual systems are still the exception rather than the norm and strategies for multilingual digital libraries are just being developed (Lu, Wang, & Chien, 2003). A variety of programs and tools for multilingual digital libraries development is available through the Cross-Language Evaluation Forum (CLEF) at DELOS (Peters, 2005). As the Greenstone digital library project demonstrated, systems that operate effectively in several languages, or whose content is in multiple languages, require

metadata management, interfaces, and end-use tools in several languages (Bainbridge, Edgar, McPherson, & Witten, 2003). But this seems a bare toehold in the face of proposals to create distributed libraries for, and for preservation of, the world's 6,500 languages (Lu, Liu, Fotouhi, Dong, Reynolds, Aristar, et al., 2004) and presumably for their literatures and users. Researchers have demonstrated some success in querying federated databases in several languages (Brisaboa et al., 2002), but years of multilingual thesaurus development have demonstrated that it is hard for such systems to scale successfully.

Digital libraries are being implemented as utilities for the general public; it is thus necessary to consider the range of abilities and disabilities of the public and how these affect use. Few digital library studies report specifically on these issues (Craven, 2003), but entire digital library research teams have been assembled, for example, at the University of Toronto (www.utoronto.ca/atrc/research.html), to design the array of interface tools required for universal accessibility.

Of course, digital libraries do not pose unique interface challenges (Hunter, Falkovych, & Little, 2004). Even when articles on interface design directly reference digital libraries, they are not the only application: For example, advice on page icons for digital library catalogs applies equally to other interfaces displaying page icons (Janssen, 2004). But as the use studies cited later in this review emphasize, we need to understand better the interaction between usability factors and the success of digital libraries. It is time to go beyond usability factors in digital libraries (Jeng, 2005) and ask users what usability really means to them (Koohang & Ondracek, 2005).

Tools for visualization of search set results are in demand (Kampanya, Shen, Kim, North, & Fox, 2004). Buzydlowski, White, and Lin (2002) have presented a simple co-occurrence analysis to collocate items retrieved from the *Arts & Humanities Index*. A more complex visualization simultaneously mapping in geographic and conceptual space was reported for geographic data using GEOVibe (Cai, 2002) and ranked information retrieval (Larsen & Wactlar, 2003). Perhaps more promising than global visualizations are simple associations that combine semantic links with usage patterns and other data to suggest possible extensions to a search. As with the Amazon.com "long tail" (Anderson, 2004, p. 170), such systems have the capacity to stir up connections that might otherwise have remained submerged (White, Lin, Buzydlowski, & Chen, 2004). If users can play a role in structuring the relations maps, these associations may have personal retrieval advantages even though this would limit their generalized applicability (Buchanan, Blandford, Thimbleby, & Jones, 2004).

Functions

Search

To date, the core function in digital libraries has been searching. Do digital library users want Web-like searching as some studies suggest (Wolfram & Xie, 2002)? Will a combination of keywords and browsing together with a few post-retrieval knowledge-based functions (Feng, Hoppenbrouwers, & Jeusfeld, 2005) serve their requirements? Or will all the tricks of information retrieval as practiced before the Web, from sophisticated Boolean query formulation to proximity searching, be necessary to improve searching in digital libraries (Buzydlowski et al., 2002; Rasmussen, 2004)? One approach to answering these questions is to study real users in a variety of settings, but of course, we are not sure whether findings from one digital library and its clientele will be applicable elsewhere. In the coming years, it may be possible to build on ethnographic studies of users of digital music libraries (Cunningham, 2002) together with studies of the users of geographic information services (Guan, Zhou, Chen, Chen, An, Bian, et al., 2003) in order to move analysis to the next level.

Although we can alter the search environment to provide traditional Boolean capabilities and study how users employ them, we must ultimately ask how actual users experience retrieval (Blomgren, Vallo, & Byström, 2004). In addition, we need to know more about potential (that is, non-) users. The broad public, often a target of digital library applications, is rarely the subject of detailed retrieval studies: A useful exception is found in an evaluation of MEDLINEPlus (Lacroix, 2001). Such studies suggest when to add different content, different indexing, and/or different tools, reminding us that search problems can originate in content, system, service, or users.

The favored approach to improving retrieval in distributed digital libraries is to create better metadata and search it more intelligently. Metadata models are appearing in almost every discipline to categorize the descriptive content so as to yield effective retrieval results (Crosier, Goodchild, Hill, & Smith, 2003). Field-specific digital libraries, such as those serving the geographical community with specialized metalanguages, have solved many of these problems. To learn from them we need to determine how much the success reflects the nature of geographical data, some of which can be formally represented. Work on place names demonstrates that this is not always an explanation (Weaver, Delcambre, Shapiro, Brewster, Gutema, & Tolle, 2003), and other research points to the underlying social cohesion of the institutional actors, rather than to the technology, as the source of success (Guan et al., 2003). Metadata need not be descriptive of the content. Contextual metadata, describing groups that share work processes and workflow process models, are more useful than content descriptors in some instances (Klas, Fuhr, & Schaefer, 2004). Search problems can be "solved" by restricting the community for which the solution is designed

and defining success in terms of supporting the perspectives of the control language.

When a broader universe of users is targeted, other approaches may prove more useful. In one study, the collections targeted for searching were subjected to probabilistic analysis in an effort to reduce semantic uncertainty in the result set (Larson, 2003). We can take comfort in the thought that software might automatically recognize meaning in context (Ciravegna, Chapman, Dingli, & Wilks, 2004), but the reality is that this is the same complex problem that faces the Semantic Web (Kim, Choo, & Chen, 2003). Intelligent agents, armed with ontologies, could do some of the work (Medina, Sanchez, Chavez, & Benitez, 2004), but of course they will succeed only to the extent that ontology bridges intellectual perspectives in content description.

Some researchers suggest that in heterogeneous collections, controlled vocabularies and shared ontologies are unachievable; accordingly, they recommend brute force, full-text indexing (Arms & Arms, 2004). Research also suggests ways to use peer-to-peer networks to compute relevance in large text libraries (Lu & Callan, 2005). Others, who think the problem is more a lack of quality control (Kelly, 2004), would prefer to improve efficiency in searching. Attempts to improve searching for names, reflecting both controlled and uncontrolled approaches, help clarify whether the issue is simply lack of standards enforcement (Feitelson, 2004; Hong, On, & Lee, 2004; Wu, Na, & Khoo, 2004).

Fortunately, many of the problems attributed to searching, whether on the Web or in digital libraries, can be solved by allowing humans to use their intelligence. Browsing and annotation overcome many of the limitations of initial machine retrieval (Kornbluh, Fegan, & Rehberger, 2004). But because people are involved, these approaches will not necessarily scale well. In the Kepler environment, for example, users can both exploit and make—by browsing, annotating, and authoring—OAI metadata (Maly, Nelson, Zubair, Amrou, Kothamasa, Wang, et al., 2004). By deploying group authoring and document utilization functions, multiple individuals can be engaged, allowing more content to be handled. This may seem to be a good digital library environment for those on the inside, but it begs the question of extensibility. A more general metadata enhancer, citation analysis, is employed in some digital library contexts (He, Hui, & Fong, 2003); of course, its applicability is limited to certain classes of content. In a restricted domain (e.g., experimental context), we can put several such strategies together to create a retrieval negotiator that interacts with users in the retrieval process: It is far from clear that this would be extensible to large-scale applications (Mustapha, 2003).

As has been the case for 20 years, some researchers argue for the use of intelligent agents, but the claims are often more impressive than the results (Andersen, Andersen, Degemmis, Licchelli, Lops, & Zambetta, 2003; Detlor & Arsenault, 2002). There is a prima facie argument that personalization features should take the place of reference librarians because the use of human intermediaries does not scale well

(Chowdhury, 2002b), but the alternatives that have been studied do not scale well either. One study proposed combining intelligent harvesting agents, annotating retrieved sets, and "teaching" learning systems about additional strategies and further annotation after interacting with users (Ciravegna et al., 2004). The potential of Wikis (online, collaboratively built and edited information sources) is attracting significant research attention (Frumkin, 2005). We have seen that knowing more about what makes intermediation work could help (Southwick, 2003), but our inability to predict, for example, the huge success of social bookmarking suggests we are still far from understanding why some knowledge building is satisfying.

When it comes to searching, our objective may be wrong. Framed by years of retrieval in physical libraries, the digital library is still retrieving an "item," typically a journal article, in response to a user query rather than returning the information that the user needs (Kortelainen, 2004). If so, it may be harder than first thought to make the transition to intelligent search agents (Weiss-Lijn et al., 2002). Tools that allow users and contributors to mark up objects in digital libraries at arbitrary levels of granularity and embed meanings in them are advocated by, for example, Kumar, Bia, Holmes, Schreibman, Siemens, and Walsh (2004). This content is intended to reside in digital libraries composed primarily of larger chunks of metadata. Those who have struggled with Standard Generalized Mark-up Language (SGML) marked-up content and structure-aware queries know that relying on user-generated mark-up is not a panacea (York, Wulfman, & Crane, 2003).

Retrieval is still a goal, but digital libraries will need to take the user far beyond current practice (Lagoze, Krafft, Payette, & Jesuroga, 2005; Lynch, 2003a). For the user, success in "searching" is evaluated not by how well the single step of submitting terms and obtaining a set of results works but by how well the end-to-end process, including browsing the results and reviewing items retrieved, satisfies the information need (McKay & Cunningham, 2003). Suggestions that such contextual refinement can be automated are not completely convincing (Neuhold, Niederee, Stewart, Frommholz, & Mehta, 2004); nonetheless, research continues into automatic linking of various kinds of content in order to reduce manual metadata entry and augment user experiences (Melucci, 2004; Péter, 2004).

Most users would like the digital library to call their attention to content that might be important to the task at hand. How can a system best do so? Recommender systems exploit the notion that language and terms applied to objects in a digital library are socially constructed and that, as such, the contexts of assignment are always part of understanding their meanings (Tuominen, Talja, & Savolainen, 2003). Hwang, Hsiung, and Yang (2003) have incorporated a simple recommender system—people who asked for x, also asked for y—into a university thesis and dissertation system. Embedding such functions in digital library services has proved equally popular (Krottmaier, 2002). Systems may

also improve experiences for users by ranking search results, a practice that lies somewhere between retrieval functions and recommender systems. Claims are made for automatic ranking based on various characteristics and techniques (Manolopoulos & Sidiropoulos, 2005; Mutschke, 2003), but no recent studies have examined user satisfaction with different methods of ranking.

Using, Personalizing, Sharing

Users of digital libraries want to exploit the content they retrieve in subsequent applications; personalization and collaboration systems have been explored as means to enable such uses as well as to customize interactions. At their simplest, user profiles filter the system or shape the service so that one's view, or interface, is personalized when one logs into the digital library (Zeng, Zheng, Xing, & Zhou, 2002). This kind of collection personalization can be assisted by server-side tools that profile the content of the library, maintain personal filters, and customize retrieval mechanisms (Jayawardana, Hewagamage, & Hirakawa, 2001). Ways for users to change their perspectives, and hence their interface and knowledge representations, in mid-stream take personalization further (French, Chapin, & Martin, 2004); such flexibility also introduces problems for systems designed to "know" what interface a user needs (Semeraro, Ferilli, Fanizzi, & Abbattista, 2001). Personalization features linked to artificial intelligence are said to enhance user profile-driven filtering services (Gentili, Micarelli, & Sciarrone, 2003).

Digital library services can also alert users to content or events taking place in collaboration spaces. The standard model of user profiles has been tied to narrowcasting designed to generate proactive streams of content, in one case with personalization supported by the metadata headers in MPEG-7 (Wang, Balke, Kießling, & Huhn, 2004). Doubtless many users subscribe to RSS (Rich Site Summary/Really Simple Syndication) feeds and MyLibrary (http://dewey.library.nd.edu/mylibrary) supports them. However, no reports of their use by digital libraries were found in the literature in spite of the fact that KnowLib carries a regular meta-feed of digital-library-related RSS feeds (http://dbkit02.it.lth.se/rss/showDigLib.phtml#62).

Personalization can also be applied to functions that enable users to interact with content, such as annotating, modifying, formatting, and integrating. Tools that support "active reading"—highlighting, underlining, marking, filing, making glossaries, and summaries, for example—are all elements of personalizing if they persist for future interactions by that user. Tools to enable users to manipulate data in Extensible Markup Language (XML) (Chang, 2005); to cluster retrieved groups and, through typed annotations, prepare them for subsequent uses (Constantopoulos, Doerr, Theodoridou, & Tzobanakis, 2004); and to classify and share them (Frommholz et al., 2003) are being developed as integral features of digital libraries. All these functions together serve as

an environment in which digital library materials, once retrieved, can be reused effectively (Goh, Fu, & Foo, 2002). Personal annotations have been tied back to metadata (Agosti & Ferro, 2003; Agosti, Ferro, Frommholz, & Thiel, 2004) so that users have personalized workspaces that can build communities, receive recommendations based on what others do, and construct shared knowledge structures (Candela & Straccia, 2004).

Because environments in which users actually work must bring together content in various formats, the toolsets developed for post-retrieval analysis, use, personalization, and collaboration are necessarily integrated. Image annotation and linking within environments also heavy in textual content have been a focus of several longer-term undertakings that are now reporting success (Attig et al., 2004; Pisciotta et al., 2005; Thiel, Brocks, Dirsch-Weigand, Everts, Frommholz, & Stein, 2005).

In the future, perhaps the most important class of personalization tools will be those that enable users to rediscover resources they have used previously. Bookmarks were the first such application, and the success of social tagging has raised the functional requirement. Use of the resources can lead to personal or group views being made available for later use; it can also feed content and annotations directly back into the digital libraries (Liu et al., 2002). Recent work has both modeled the varieties of these interactions between users and digital libraries and implemented numerous scenarios (Neuhold, Niederee, & Stewart, 2003). A set of studies at Microsoft on how readers have historically shared information through "clippings" has articulated requirements for digital libraries to promote the sharing of "encountered" information (Marshall & Bly, 2004, p. 218). As social software registers increasing success on the public Web, such functions will doubtless grow in importance in the digital library domain.

All personalization raises issues of privacy and control over identity. Digital libraries are likely to be affected by the interests of users in managing their digital identities so that they are portable and persistent (as proposed by the AttentionTrust.org) as well as in limiting identity-bearing information to avoid loss of control over records of their interactions.

Services

Traditional Library Services

Processes that have traditionally been internal to the library—acquisition, cataloging, and circulation—are all undergoing change in the digital library environment. In addition, many new services are imaginable in digital libraries. Kelapure et al. (2003) explored a scenario-building exercise based on abstract models of such services, but it is not clear how they will fit into institutional roles.

Acquisition

Most librarians would argue that the digital library requires selection of content by librarians and obtains its value from that selection (Wallace, 2004). Such models of selection can be implemented in purpose-built digital libraries by putting URLs in library catalogs (Burke, Germain, & Van Ullen, 2003) or by implementing versions of "others also use" recommender systems (which first proved their popularity on the Web) in front of legacy library OPACs (Geyer-Schulz, Neumann, & Thede, 2003). In any of these implementations, traditional questions about content acquisition still play a role and will continue to do so as long as the digital library is institutionally based (Miller, 2002), even though the toolsets employed in collection development may be quite different (Mitchell, 2005).

Research is pointing the way to some machine-assisted acquisition or content development mechanisms (Nicholson, 2003). But the roles of collection development staff (Dorner, 2004) are related to organizational policy and participation in a variety of different types of consortia. Collaborative agreements, for example, may have greater impact on acquisition processes than the simple fact of acquiring digital assets. Studies of how library consortia are serving to aggregate content and services in more cost-effective ways (Pandian, Jambhekar, & Karisiddappa, 2002) will be crucial to the reconfiguration of core library processes.

Cataloging

Some digital library contents are, of course, digitized books and online journals for which there is traditional cataloging, but digital libraries are also collecting some very different sorts of objects (Okerson, 2003). Cataloging online resources by engaging content creators in creating metadata was the initial impetus for the Dublin Core Initiative (http://dublincore.org). We have discovered, however, that content creators and non-librarians, even when provided with a highly simplified metadata model, do not catalog. Since then, social bookmarking has attracted widespread popular attention. Flickr.com has become popular with photographers, deli.cio.us is acting as a recommender system for Web pages, and LibraryThing (www.librarything.com) is a cross between a home book-cataloging site and a dating service. These have been reported in the digital libraries literature (Hammond, Hannay, Lund, & Scott, 2005), but experimentation by digital libraries into the benefits of social tagging is just beginning (Bearman et al., 2005; Lund, Hammond, Flack, & Hannay, 2005). It has yet to be seen if, or how, vocabularies generated as folksonomies contribute to improved retrieval.

A potentially important contribution to digital library cataloging will be the deployment of smart scanners, with learning capability, to segment print images and mark up digitized pages of print as part of large-scale retrospective scanning efforts now planned in many countries. For

example, METS records in the ALTO (Analyzed Layout and Text Object) scheme can be generated from image processing software yielding full text marked up not only with descriptive cataloging but also with structured tables of contents, indexes, and citations.

Reference

The benefits of collaborative online library reference services is an area of considerable debate (Berube, 2004; Borbinha, Kunse, Spinazze, Miutschke, Lieder, Mabe, et al., 2005; Chowdhury, 2002b; Jane & McMillan, 2003; Lankes et al., 2004; Lankes et al., 2003). The OCLC/Library of Congress collaboration, which has capitalized on efforts by hundreds of libraries, is the most analyzed of these services (Gottesman, Kresh, & Takagi, 2004; Penka, 2003). Like smaller collaboratives, the benefits it provides are not technology-driven per se but rather are delivered by time shifting, interest sharing, or on the basis of some other labor-related efficiency (Jin, Huang, Lin, & Guo, 2005). For the user, the benefits may be more social or psychological than purely instrumental. Theng (2002) argues that reference is a therapeutic system that helps users understand their needs and explores how digital services might fulfill them.

Circulation

The superficially contradictory notion of circulation in digital libraries, an intersection of past practice, current legal constraints, and future functions, is illustrated by electronic reserves (Jacoby & Laskowski, 2004), a practice that reveals students' use of digital libraries for shifting both time and place. Virtually all aspects of the service—from copyright issues through technical practices—are covered in one or another chapter of Rosedale's (2002) text. As with any digital library problem involving copyright, it is useful to compare local practices and policies with what happens outside the U.S. (Trosow, 2005).

New Library Roles

Not only are digital libraries transforming traditional library practices, but they also have the potential to generate new roles for academic libraries.

Hosting Scholarly and Scientific Collaboration

Supporting "knowledge communities" is a major objective of digital library developers, but not all tools used to build communities on the Web are being adapted to digital libraries. The historical aversion to talking in the library may be responsible for the collective failure to introduce chat rooms. Libraries, including public libraries, could support private portals and host community blogs, yet few such public content creation functions have been undertaken in the digital library domain.

Perhaps more will be reported soon; the widespread popularity of instant messaging among students evidently carries over into successful digital library services when tried (Desai, 2003).

Digital libraries are beginning to exploit social computing methods in order to enable users to collaborate. For example, after retrieving digital objects, users can work together or separately in digital libraries interfaced to the National Library of Singapore's systems (Goh et al., 2002). The Collaboratory for Annotation, Indexing and Retrieval of Digitized Historical Archive Material (COLLATE) system, serving historical archives in Europe, supports the accumulation of interactions with documents to build a collective trace that can feed into uses others make of the documents. Thus a discussion forum, for example, attaches the topics to the documents it discusses, adding metadata and a context for future retrieval (Frommholz et al., 2003). Such systems are also building real (i.e., non-virtual) communities of people by supporting the needs of day-to-day life (Bieber et al., 2002).

Typically, the role of annotation has been to personalize database content (Neuhold et al., 2003), but in many implementations it also serves to support collaborative work (Agosti et al., 2004); indeed, mechanisms have been constructed to permit entire personal annotation systems to be made visible to groups (Candela & Straccia, 2004). Efforts to bootstrap annotation through text mining and other semantic analysis processes can complement social methods (Ciravegna et al., 2004). The richness of annotation has created a need to model annotation types and create faceted annotation systems (Constantopoulos et al., 2004). Annotation can, of course, be in any genre. Audio, video, and graphics can be combined to annotate each other or texts. In the case of image annotations, users are building text information on top of objects that originally had no associated textual content (Attig et al., 2004; Chang, 2005; Pisciotta et al., 2005); combinations of methods including feature extraction and collaborative annotation have been shown to work together successfully (Thiel et al., 2005).

Archiving

Before the digital age, librarians engaged in preservation activity to prevent decay of their special collections even though they did not conceive of their libraries as archives. Now, however, because the viability of digital libraries depends on their content's preservability, uncertainty surrounding whether we can maintain digital content over time is leading libraries to adopt some archival functions.

Recent years have witnessed limited progress but no breakthrough in digital preservation. The OAIS Reference Model has been more broadly accepted (Frommholz et al., 2003). The processes of encapsulation and capture at the time of creation still have technical advocates (Gladney, 2004), including this author, although some archivists hope to delay control until a later date. In general, strategies to have smarter objects and dumber repositories seem to be emerging (Nelson, 2001; Nelson & Maly,

2001). This type of strategy permits format migration, either on an ongoing basis or on the fly (Lots of Copies Keep Stuff Safe [LOCKSS]), which has generally favored in recent NSF/DELOS (Ross & Hedstrom, 2005) and National Academy of Sciences Computer Science and Telecommunications Board (NAS CTSB) (Sproull & Eisenberg, 2005) reports as the most likely means of ensuring reliable and usable content over time. Because formats will carry metadata about their technical and content characteristics, some researchers contend that this metadata will address aspects of archival access and use (Bekaert, De Kooning, & Van de Walle, 2005; Bekaert et al., 2002). Substantially more archival process metadata will need to be carried as well; however, the history of metadata migrating successfully with format migrations is not encouraging. The only confident actors are engineers charged with storing the data, who believe that developments in data grids have nearly solved their problems (Moore, Rajasekar, & Wan, 2005). Unfortunately, most others have concluded that archival preservation of digital artifacts is not primarily a technical problem but, rather, is one of those difficult issues that individuals, institutions, society, and law must solve (Kenney & McGovern, 2003). Even if one assumes that the technologies will continue to work into the future, managing the policies and collaborations that could ensure preservation is itself a major challenge (Hiiragi, Sakaguchi, Sugimoto, & Tabata, 2004).

Important foundational work is being done in the National Digital Information Infrastructure Preservation Program at the Library of Congress (Fleischaeur & Arms, 2005). Recent reports of the Archive Ingest and Handling Test (AIHT) illustrate the difficulty still associated with the post hoc ingestion of even a relatively small group of digital records into long-term preservation repositories; however, they also validate the general strategy of the AIHT approach, if archival control is not implemented until some point after the creation of the record rather than built into the record creation and transmission process (Abrams, Chapman, Flecker, Kreigsman, Marinus, McGath, et al., 2005; Anderson, Frost, Hoebelheinrich, & Johnson, 2005; DiLauro, Patton, Reynolds, & Choudhury, 2005; Nelson, Bollen, Manepalli, & Haq, 2005; Shirky, 2005). The draft report of the Research Libraries Group (RLG) and National Archives and Records Administration (NARA) Task Force on Digital Repository Certification (RLG & National Archives and Records Administration, 2005), which was out for comment at the end of 2005, is expected to make a substantial contribution to defining the parameters of the social issues involved in digital archiving and permit libraries that are willing and able to commit to this role to do so with sound standards in place.

Social Impacts

Users

Anyone can be a user of a digital library; users can be any age, have varying degrees of prior knowledge, and speak any language. However, most digital libraries are constructed with certain users and their needs in mind (Koskiala & Savolainen, 2004). For the most part, digital library users are adults with academic or professional interests in information, who are connected to high-speed networks and able to employ many post-processing systems to analyze what they find in the digital library for use in educational settings (Bieber et al., 2002). We need to know more about whether these users return month after month, year after year, and, if so, how their use of the resource changes (Cherry & Duff, 2002; Koohang & Ondracek, 2005).

One particular challenge is that when we conduct user evaluations, we study those who actually use a service but miss those who might use a service but do not (Monopoli, Nicholas, Georgiou, & Korfiati, 2002). We need to find ways to learn more about non-users in order to make digital libraries effective for all. In some cases, potential users may be easy to identify—for instance, in an academic health sciences library (Bracke, 2004) or a private law firm (Reach, Whelan, & Flood, 2003); however, in most cases the client base is not as clearly delimited.

Perhaps understanding more about why users come to digital libraries can help us understand the roles the digital library plays in their worlds (Assadi, Beauvisage, Lupovici, & Cloarec, 2003). A dozen position papers by attendees at a recent JCDL workshop studying "digital library users in the wild" explored many of the underlying questions (Khoo & Ribes, 2005) but left more unanswered. Paradoxically, as digital library use becomes integrated into day-to-day activity in a supportive way, it becomes more invisible, and users are increasingly unaware of the paths they took to and through it.

Ethnographic studies of academic and research library users in Slovakia (Steinerová, 2003), mixed method research on higher education digital services provision in the U.K. (Banwell & Coulson, 2004; Banwell, Ray, Coulson, Urquhart, Lonsdale, Armstrong, et al., 2004), comparative content analysis of written evaluation of physical reference service and virtual reference services in Canada (Nilson, 2004), and qualitative methods applied to situated use assessments in Illinois (Bishop, Neumann, Star, Merkel, Ignacio, & Sandusky, 2000) are among the approaches reported by researchers seeking to understand why users did, or did not, use digital libraries and what they felt about their experiences. Additionally, a range of in-depth usability studies have been conducted in non-laboratory but quasi-experimental use contexts focusing on specific features of digital libraries, such as a "my e-journal" personalizer and aggregator in Denmark (Hyldegaard & Seiden, 2004), the use of music library tools (Notess, 2004), and broad studies of technical strategies such as whether integrated interaction is actually

preferable to common interaction (Park, 2000). These studies are valuable to systems designers, especially interface developers within the context of a particular digital library.

Evidence that the user responds more to social than technical factors has been present in general computing for a long time and so it is not surprising to find the theme appearing in studies of the users of digital medical libraries (Gosling, Westbrook, & Coiera, 2003). Users encounter boundaries that designers did not envision and perceive as boundaries some of the features that have been built into systems intentionally for security, to guide the user, or even to enhance effectiveness (Marshall, 2003). It has been suggested that users are dissatisfied because the digital library does not enable them to express themselves creatively rather than because it failed to find what they were seeking (Lee, Theng, & Goh, 2003).

User expectations are changing. Until now, it was assumed that the user operated as a "library patron" with respect to the library. Putting the digital library into the classroom (Jose, Braddick, Martin, Robertson, Walker, & MacPherson, 2002) or integrating it into other work processes changes assumptions about what the user is doing and how the digital library functions. Calls for greater focus on both users and staff in digital library research are welcome, but, as case studies show, comparability of results and, therefore, conclusions is complicated (Marchionini, Plaisant, & Komlodi, 2003). Interactions between technical, social, and personal variables are complex and constitute one of the more promising and dynamic areas developing in digital library research (Thong, Hong, & Tam, 2002).

Digital libraries influence user needs and methods of communication. The full range of issues associated with changing patterns of scholarly communications and bibliometrics was the subject of a recent *ARIST* chapter (Borgman & Furner, 2002) and will not be revisited here. It is useful, however, to note that some digital libraries, such as preprint libraries (Huwe, 2002), data repositories (Borgman et al., 2005; Brase, 2004), and primary source archives (Bruder, Finger, Heuer, & Ignatova, 2003) are not simply used by scholars in their communications but were explicitly designed to promote the transformation of scholarly communication. Evidence suggests that they are working. An influential report found that the online availability of an article in full text increases citations (Lawrence, 2001); however, recent refinements of that study have suggested that, at least in some fields, the reason for the increases in citation may be that the articles are available earlier and that articles deemed more important are selected for online presentation (Kurtz, Eichhorn, Accomazzi, Grant, Demleitner, Hennekin, et al., 2005).

Uses

Methodologically, research to discover which features of digital libraries contribute to success often involves using Web server logs (Tarr,

2001). Web server log analysis can be likened to archeology—what the users leave behind is being examined for implied meanings (Nicholson, 2005). A self-referential use of Web server log analysis occurs in the i-DLR site at the University of Missouri, which is the subject of research into how it can improve, including how the site uses Web log analysis in conjunction with a full range of other research methods (Kassim & Kochtanek, 2003). Analysis of Web logs can reveal user communities, for whom services or interfaces can then be tailored (Papatheodorou, Kapidakis, Sfakakis, & Vassiliou, 2003). Sophisticated data mining strategies are needed to obtain useful information from voluminous logs (Zhang, Gong, & Kawamura, 2004).

Sometimes what we want to know about online use is relatively straightforward. For example, Australian researchers asked whether clinicians' use of a database created for them was related to their care of patients (Westbrook, Gosling, & Coiera, 2004). Following backlinks to identify the sources that referred users to a digital library (and even what they were seeking at those sites) can provide insight into what user needs are being served by the digital library (Thelwall, 2004). Query term analysis and content analysis of comments and full-text questions presumably addressed to a reference librarian can help a digital library service identify not only the topics in which its users are interested but also the kinds of ancillary data that they expect to find in conjunction with their searches. For instance, the National Library of Medicine's MedlinePlus service found that it needed to acquire links into clinical trials and pharmacopoeia databases in order to deliver what health consumers assumed they would find in one-stop shopping (Lacroix, 2001).

Beyond the metrics of use, there are more qualitative evaluations that go to the heart of assessing the kinds of applications and services that are being created, the social expectations that they engender, and their sustainability (Borgman, 2002). Van House (2003, p. 271) applied actor-network theory to understanding the impacts in situated contexts, arguing persuasively that "designing effective digital libraries ... requires understanding knowledge work and the way that it is not only supported but potentially changed by digital libraries." Evaluations of use, often employing participatory-action research methods, explore whether digital libraries enable social outcomes that are desirable (Bishop, Mehra, Bazzell, & Smith, 2003). Most radically, we could even ask whether use of a digital library actually increases knowledge. It is not clear what evidence exists that physical libraries increase users' knowledge, but the ambivalent findings of one study of digital libraries provide food for thought (Madle, Kostkova, Mani-Saada, & Weinberg, 2003). If people with real-world motivations use digital libraries to acquire knowledge upon which they need to act and, after doing so, they have less understanding of the facts than before they began, is there a fundamental problem with digital libraries, with the specific library

design with which they interacted, or with the idea that more information contributes to better decision making?

Organizational Impacts

Digital libraries have an impact on the organizations in which they are built—they require staff and cost money—and generally they change roles and practices within the organization. They are designed to support education, research, and scholarly communication. And they are presumed to have a beneficial impact on society at large. Digital libraries are themselves social institutions and not mere technical constructs. They exist in the real world and are enabled by staff. Users encounter them in their work. As such, they exist within an institutional landscape that itself requires study (Agre, 2003).

In spite of the enthusiastic rhetoric, resistance to organizational change is strong. For example, professionals who embrace change in some respects also remain seriously beholden to tradition, as is evident when the Semantic Web can be seen as another opportunity to advocate authority control (Franklin, 2003) and static views or human-maintained Web pages are still the norm (Tyler & McNeil, 2003). Although there is broadly based agreement that new service paradigms embodying a wide variety of specific approaches are necessary and valuable contributions of digital libraries, many institutional costs and barriers remain (Moyo, 2004). Dempsey (2003) has argued convincingly that disaggregated library services need to be incorporated into environments where potential users actually work, rather than hidden within library portal environments.

The digital library requires new expertise. Its builders see such institutional issues as rights management, open access policies, standards adherence, and persistence as crucial to digital library success and requiring new skills and perspectives to administer effectively (McCray & Gallagher, 2001). The change has been sufficiently dramatic to call into question the educational foundations of the profession (Marcum, 2003). The extensive literature on education for the digital library has been usefully reviewed elsewhere (Saracevic & Dalbello, 2001).

Institutional Implications

Much of the digital library literature assumes that the boundaries between archives, libraries, and museums are artificial, created because each institution stored different kinds of objects, and that the eradication of content boundaries is basically a good thing as it enables unified access to collections of "information" (Barton, 2005). This perspective overlooks the very different missions and functions of these traditional institutions. Although some superficial integration has been achieved for users, the homogenization of the Web presences of "memory institution"—all with searchable catalogs, archival roles, and exhibitions—seems to this writer to have undermined rather than enriched the

quality of professional discourse in information retrieval, archival practice, and interpretation.

Cultural heritage informatics has had a salutary effect on thinking about knowledge representation issues in digital libraries (Beghtol, 2001), and cultural heritage concepts inform complex ontologies and artificial intelligence-supported searching (Abbattista, Bordoni, & Semeraro, 2003). Nevertheless, focus needs to move from the possibility of integrating abstract representation to emphasizing the concerns that cultural repositories share—such as authenticity, preservation, privacy, and appreciation for indigenous knowledge. Unfortunately, redefining archives, libraries, and museums as "memory institutions" does not seem to have helped professionals in these organizations to understand their common foundational concerns (Bradley, 2005; Chen, 2002).

Public Policy

Digital libraries raise broad public policy issues. Do they exacerbate the digital divide (Byrne, 2003; Chowdhury, 2002a)? Are they a necessary feature of national planning? If so, what place do digital libraries play in strategies for development (Vaidya & Shrestha, 2002; Witten, 2002, 2004; Witten, Loots, Trujillo, & Bainbridge, 2002)?

The National Aeronautics and Space Administration (NASA) has adopted a set of metrics to assess its distributed digital library service. These metrics point to significant economic benefits for a disciplinary community in the construction and use of such a tool (Kurtz, Eichhorn, Accomazzi, Grant, Demleitner, Murray, et al., 2005). Their impressive findings—that digital libraries increased productivity equivalent to thousands of extra workers in the field—have implications for information-intensive areas of practice, such as medical care, that should influence governments to greatly extend the scope of digital libraries' services in these areas in the coming decade.

Funding and Future Digital Library Research

Digital library funding in the U.S., which began in 1993, ran its course over the next decade. It is generally agreed that this period of direct funding by the U.S. government has ended (Lynch, 2005), but continuing direct funding is available in the U.K., Europe, and some Asian nations. Results of the productive first round of NSF funding were reported in 2002 (Fox & Urs, 2002), as were the early results from DL-2 funding, whereas final reports of the DL-2 round (www.dli2.nsf.gov/intl.html) did not become available until 2002–2004. A view of the concrete impact of these funds on digital library development is contained in the short "biographies" of digital libraries in Greenstein and Thorin (2002).

Many "research agendas" were published as these funded programs came to a close (Larsen & Wactlar, 2003). The DELOS/NSF meetings of 2002–2003 produced a lengthy set of publications in early 2005 that assessed the payoff expected for research in a variety of topical areas

(Borbinha et al., 2005; Ioannidis, 2005; Ross & Hedstrom, 2005; Smeaton & Callan, 2005). The tenth anniversary issue of *D-Lib Magazine* mixed Whig history with futurology and navel gazing (Arms, 2005; Mischo, 2005; Paepcke, Garcia-Molina, & Wesley, 2005; Weibel, 2005). As always, the images of a future of well-orchestrated and interrelated research and development sat uncomfortably beside a past characterized by opportunistic advances (Ioannidis, 2005). Nevertheless, taken as a whole, these papers outlined broad areas of consensus on future research requirements. Here, as elsewhere, participants generally agreed that digital library technology problems will recede as service challenges come to the fore, and that inherently long-term issues such as preservation, sustainability, and social impacts will require more attention (Bollen, Manepalli, Manepalli, Nandigam, & Nelson, 2005; Borgman, 2003a; Lynch, 2003b, 2005; X. X. Zhang, 2004).

The Future

So what can we expect? Digital library content will increasingly encompass all kinds of information. The proportion of past information in digital form will grow exponentially over the coming decade until nearly everything in print is available online. As a consequence, we will be forced to attend to Buckland's (2003) observation that all our digital libraries have been designed backwards, from the data we have to the users we serve, rather than from actual user needs to data. New ways will have to be found to become more responsive to a universal clientele.

I think we will be forced to do so in part because digital libraries share a technological and social space with the public Web and their success will necessarily be measured against it. Fortunately, the Web provides a readily available testbed, where users are voting with their clicks for the services and information they want. The digital library community may need to launch a collaborative "Web observatory" from which to monitor and exploit user inventions of the future, so that innovations such as BitTorrent and podcasting, which were validated within weeks by millions of users, can in the future be leveraged rapidly in digital libraries. The astonishing success of search engines on the public Web (Fallows, 2005) has challenged leading proponents of digital libraries to think anew about what digital libraries can be beyond a mechanism for search and access (Lagoze et al., 2005). The next big challenge that the Web will pose to digital libraries is reflected in the Web 2.0 services model which, if widely adopted, would render obsolete digital libraries that are equated with single digital collections and bundled toolsets (Miller, 2005).

Finally, the needs of society for confidence in a stable and shared knowledge base will grow as the malleability of content and the fragility of digital documents become more evident. We need to heed Levy's (2003, p. 38) call for study of the sociotechnical basis of emerging library services to ensure that they are providing "communicative stability." That

many users find the dynamic content and changing functions and services of the Web an emotionally consistent social space, while perceiving the digital library setting as discontinuous, suggests that, for digital libraries to succeed, they will need to become more tightly woven into the fabric of everyday life.

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