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Review

Toward a medical information collective: trends in the development of digital libraries in medicine

Introduction and Background

A medical library is a place where everyone related to bio-medicine goes to throughout their lifetime. The sheer amount of collections in medical libraries easily captivates the hearts of knowledge seekers, whereas it is the amount of information that often prevents people from getting the exact knowledge they seek for. Today's medical libraries not only host volumes of books and journals, but they also possess a rapidly growing collection of digital works that may soon surpass their physical counterparts. Long before the age of information technology, Wells envisioned an information collective called "World Brain" as: "…an efficient index to all human knowledge, ideas and achievements, to the creation, that is, of a complete planetary memory for all mankind. And not simply an index; the direct reproduction of the thing itself can be summoned to any properly prepared spot." [1] This vision was followed during the early days of computer technology as functions and responsibilities to be carried by "the libraries of the future" [2]. In 1997 it was predicted that these visions will be realized in 2010 [3]. The Digital Libraries Initiative announced in 1994 (now in phase two) by the United States National Science Foundation, marked the beginning of a new era for digital libraries [4]. In 1998, the Digital Library Federation defined "digital libraries" as "organizations that provide the resources, including the specialized staff, to select, structure, offer intellectual access to, interpret, distribute, preserve the integrity of, and ensure the persistence over time of collections of digital works so that they are readily and economically available for use by a defined community or set of communities" [5]. Rapid advances of information technology and the Internet revolution have made the vision an impending reality through the building of digital libraries around the world that are connected with the high-speed Next Generation Internet.

Defining digital libraries in medicine (DLM) may take more than just stating that they are one of the instantiations of the generic digital libraries. DLM need to host collections of digital works that are inherently large in size and number, heterogeneous in structure and complex in correlation. Objects stored in DLM have grown far beyond electronic journals and textbooks to include images, audios, videos, bio-signals, three-dimensional models, gene sequences, protein sequences and even health records [6,7].

The concept of DLM expanded and evolved as information technologies advanced at the speed depicted by Moore's law [8]. The exponential growth of the Internet and its global availability, together with high-speed networks and high-capacity database management systems, are continuously redefining every aspect of DLM. Three major trends were observed in the course of this evolution, namely, aggregation, virtualization and integration. Aggregation describes the effort to collect all the relevant information into designated databases so that users can access them as collectives of information rather than pieces of data. Virtualization refers to the shift from emphasizing physical space and location of a library to the information services it provides through the Internet/Intranet-ready environment. Integration of electronic health records into DLM represents a new trend to not only shorten the link between medical literature and clinical practice, but also populates a DLM with real patient data. These trends will enrich the concept of DLM, while new approaches to information retrieval must be devised to handle the tremendous work of locating information in this medical information collective – the DLM of the future.

Aggregation of Digital Collections

Contemporary DLM do not just collect digital works, they aggregate these collections into standardized databases with proper metadata. Aggregated data that can be hosted in DLM include (but not limited to) literature databases, gene sequences, protein sequences, three-dimensional molecular and anatomical structures, audios and videos.

One of the major examples of a literature database is MEDLINE, which originated from a project of the United States National Library of Medicine (NLM) in 1966 called MEDLARS (Medical Literature Analysis and Retrieval System) [9]. MEDLINE, as one of the databases produced by this project, now contains more than 10 million citations that increase at a rate of 400,000 each year [10]. Other major biomedical literature databases include BIOSIS Previews and EMBASE. The former is an effort of a non-profit organization and now contains more than 13 million citations and is adding 550,000 more each year [11]. The later is a commercial database that claims 12 million citations and grows at 550,000 or more per year [12].

DLM that store genetic and protein sequences are best exemplified by Entrez from the National Center for Biotechnology Information (NCBI) at the NLM [7]. Previously a set of online tools for genetic researchers, today's Entrez represents an extraordinary effort to couple biomedical literature directly with the building blocks of life itself. It provides an integrated interface for users to access cross-indexed literature citations with genome/protein databases. A graphical representation of chromosomes and three-dimensional structures of proteins are also available for further exploration. This repository contains a huge collection of 10 billion bases of nucleotide sequences from 4700 species and more than 10,000 three-dimensional structures of known proteins.

One of the most ambitious projects for the digitization of the human anatomy also came from the NLM. The Visible Human Project is an outgrowth of the NLM's 1986 Long-Range Plan to create a set of complete, anatomically detailed, three-dimensional representations of the normal male and female human bodies [13,14]. Cross sections of CT, MR and digitized cryosection images (at 4096x2700 pixels) of representative male and female cadavers have been made available online. The male was sectioned at one-millimeter intervals and the female at one-third of a millimeter intervals. An online database called AnatLine is now in its beta test stage to serve fully indexed images from the visible human project. Various DLM from all over the world are also devising innovative databases to host these digital human body collections.

Many medical libraries store audio/video tapes and Laser Disks since medical teaching relies heavily on audiovisual materials. Advances in the digitization and compression technologies such as MPEG (Moving Pictures Experts Group) for video and MP3 (MPEG-1 Audio Layer-3) for audio have enabled DLM to store large amounts of audiovisual material in digital form within reasonable storage capacity. Furthermore, streaming media technologies such as RealVideo and Windows Media Technologies make it possible to serve such contents on the Internet with limited bandwidth. Databases of endoscopy and echocardiography videos, as well as heart sound and lung sound audios, are good examples of DLM collections.

Aggregation of digital collections into databases makes it possible for DLM to provide their services completely online, which leads to the next trend of "Virtualization" described in the following section.

Virtualization of Services

A library is one of the few examples in a medical institution that can potentially be "virtualized", that is, provide all its services online through the Internet/Intranet infrastructure. There are several reasons that medical libraries want to be as "virtualized" as possible, namely, space limitations, journal costs, accessibility and logistics difficulties. Space is always limited in medical institutions, especially in Asian countries where land is exceedingly expensive. It is not uncommon for a medical school in Taiwan to spend as many as twenty times the annual library budget just to obtain the space to locate its library.

Many articles have discussed the high-rising cost of biomedical journals in recent years and how it has affected the ability for a medical library to satisfy the need of its users [15, 16, 17, 18]. A number of authors have proposed electronic journals as one of the key solutions to this problem [16, 19, 20]. A traditional medical library's office hours poses a significant accessibility problem to most clinicians that do not work on a nine-to-five time schedule. More often, a clinician goes to a library only to find that it is already closed. This accessibility restriction is especially frustrating to medical professionals in training who have the most unpredictable schedules and also need libraries the most. Logistics problems increase exponentially along with the size of a traditional medical library. It is understandable why journals are always out for binding and books are not on the shelves, when one considers how labor-intensive it is for people to manually check out and put away thousands of volumes a day from and to a collection of hundreds or thousands across acres of space. This difficulty also aggravates the accessibility problem mentioned above.

Thanks to the rapid penetration of Internet availability and progress on electronic journals and textbooks, medical libraries are now providing more “virtual” services to overcome the space, cost, accessibility and logistics problems. Rather than expanding physically to host more collections, database servers and Web servers are installed to provide 24-hour access to make electronic literature available. Electronic inter-library loans and online document delivery services are replacing subscriptions to expensive biomedical journals. It can be argued whether electronic journals cost less than their paper counterparts, however, the consensus is that digital libraries occupy less space, provide better accessibility and cause fewer logistics problems than physical libraries [17,19]. These characteristics of virtual libraries make them especially appealing to countries with limited space or costly human resources. One successful example is the Health Information Research Network (HINT) established by the National Health Research Institute in Taiwan [21]. It represents a governmental effort to service the biomedical community by building a completely virtual DLM on the Internet. HINT now hosts 24 literature databases (including MEDLINE, BIOSIS Previews, EMBASE, Cochrane Database of Systematic Reviews and other major biomedical literature databases) that are indexed directly with 95 full-text journals and 9 electronic textbooks. Seven thousand accounts were provided free to all medical professionals and researchers in Taiwan. Although not a physical library, HINT provides access to tens of millions of medical citations for more than 55,000 search sessions every month and has become one of the busiest medical libraries in Taiwan [22]. Another prominent example of a completely virtual DLM is the well known Virtual Hospital from the University of Iowa which hosts 131 medical textbooks and booklets on its Web site with 20,000 visitors a day [23, 24].

Integration with the Electronic Health Record

Although current DLM host an array of ever-growing electronic journals and textbooks, the next wave of collection may come from Electronic Health Records (EHR) generated by hospitals and clinics. No matter how intricately a textbook describes a disease, there is no comparison to real patient cases when it comes to clinical teaching. The EHR contains real-world manifestations of a disease spectrum that may include progression, remission, transition, morphing and co-morbidity which are difficult to express in the literature. On the other hand, the best timing for medical professionals to query against a DLM is when they need a certain piece of information to support their decision in treating or diagnosing a patient [23]. This two-way integration of the DLM and EHR was best described by Humphreys in her article recently appearing in the Journal of the American Medical Informatics Association [25]. She stated, “Although aggregations of health data can be profitably viewed as components of a digital health library, connecting individual electronic health records to other electronic information in the digital library remains a highly desirable goal”. Three types of connections were identified to enable this integration, namely, technical connections, organizational connections, and conceptual connections. Humphreys described technical connections in terms of computing equipment, telecommunications, platform-independent software, logon procedures, and access controls. These kind of connections are becoming widely available due to the prevalence of Internet connections and Web browsers. Organizational connections refer to mutual agreements both in and between institutions to provide or obtain access to information on different systems. Complicated by the licensing issues of literature databases and privacy concerns of EHR, organizational connections would still require continuous effort and innovative approaches to achieve. Conceptual connections address the interlinking and cross-indexing issues of the heterogeneous information systems among DLM and EHR in healthcare organizations. The development of digital library standards and health data standards make it more likely that these will take time to align. Projects like the UMLS (Unified Medical Language System) go one step further in mapping most popular vocabularies from both sides and hence provide a “middleware” for the fusion of DLM and EHR [26].

Several studies have shown that MEDLINE significantly affected clinicians in their diagnoses, tests, treatments and advice to patients, especially when it is available at the point-of-care [27, 28, 29]. Studies also support that it was beneficial for students of medicine to provide patient simulations and case scenarios abstracted from clinical records [30]. With these connections in place, this trend of integration will become clear and greatly influence the perspective of DLM and knowledge-based information provision in the process of patient care.

Information Retrieval in DLM

As DLM continue to rapidly aggregate and integrate new forms of data and information into their collections, the difficulty of retrieving a specific piece of information from this collective increases substantially.

Sophisticated information retrieval (IR) methods were devised with the advance of database management systems in the past decades, especially for relational databases that have many commercial applications. Unfortunately, standard relational database schemas do not sufficiently model the diverse aspects of biomedical information which the DLM host. The search problem is further complicated by the fast-growing collection of full-text journals, genetic-related codes and digital audiovisual materials.

Searching Full Text

Advanced information retrieval methods, such as vector-space and probabilistic retrieval techniques are effectively used in full-text databases [31], but word-based search alone is apparently inadequate in the context of bio-medicine due to its inherent ambiguity and uncertainty. Many medical vocabularies are best described as incomplete, overlapping and inconsistent because of the long-evolving history of medicine. To ease the problem of IR in biomedical literature, the NLM developed MeSH (Medical Subject Headings) as the standard indexing system. MeSH is a hierarchical data structure with 19,000 main headings and over 300,000 biomedical terms [32]. Although MeSH improves a user's capability to search the biomedical literature, one study found that novice searchers have a precision of only 38% even with the help of MeSH when searching MEDLINE [33]. Following the MeSH effort, the UMLS project furthered the development of a framework that maps medical vocabularies used for literature and clinical medicine and thus enabled more complex IR techniques across aggregated databases [34,35].

Searching Biological Data

Searching and mapping through the huge gene databases (that doubles every 14 months) or the protein databases (with detailed 3D structures) requires a considerably different approach [36]. The basic problem is that sequences are important both as a set of elements grouped together and as individual elements. Any given position in a sequence can be important because of its own identity, its role in a larger subsequence or its role in a large set of overlapping subsequences, all of which have a different significance. For these reasons, researchers in bio-informatics are developing object-oriented databases in which a sequence can be queried efficiently in different ways for different purposes. Queries against these databases often involve sequence alignment, structure alignment or structure/function prediction. Questions ranges from the straight-forward "is there a sequence in the database similar to the one entered?" to the complex "where can a drug of this structure dock into a molecule like that?" In order to develop algorithms for IR from these specialized databases, researchers need in-depth knowledge regarding the characteristics of the biological information stored as well as proficient computer-science training. They are now recognized as affiliated to the fast-growing field of Bio-informatics.

Searching Audiovisual Data

Searching through audiovisual objects (e.g. images, audios and videos) is also a highly challenging problem in IR. One approach is to attach metadata tags to all the audiovisual objects and index these tags for search purposes [37]. However, this approach will only work when the metadata is appropriately defined and information regarding these objects comprehensively entered. It will be a formidable task to tag all the existing audiovisual objects with sufficient information, particularly when lengthy digital video clips are involved. A typical medical video clip presents one or several topics in a continuous fashion, which may last for several minutes to several hours. It is difficult for a user to search "inside" a video clip for specific topics or keywords unless he or she browses the whole length of the clip, which is a very time-consuming task and is infeasible for large sets of video clips. Algorithms and formats that support searchable video were been studied in academia as well as in multimedia industries. The current development of MPEG-7, formally named "Multimedia Content Description Interface", proposes a solution to this problem. MPEG-7 is a standard for describing the multimedia content data that will support some degree of interpretation of the information's meaning [38]. The main tools used to implement MPEG-7 descriptions are the Description Definition Language (DDL), Description Schemes, and Descriptors. Descriptors bind a feature to a set of values. Description Schemes are models of the multimedia objects that specify the types of descriptors used in a given description, and the relationships between these descriptors or between other Description Schemas. The DDL provides a solid descriptive foundation by which users can create their own Description Schemas and Descriptors which cover four basic visual features including color, texture, shape and motion. At the 51st MPEG meeting in March 2000, it was decided to adopt the XML (eXtensible Markup Language) Schema Language as the MPEG-7 DDL and hence make it easy for audiovisual objects in the MPEG-7 format to be integrated within World-Wide Web platforms. Although still in the draft phase (scheduled to be released officially in January of 2001), MPEG-7 is a promising solution for searchable audiovisual objects in DLM.

Challenges Ahead

Given the speed at which Information Technology forges ahead, one can be confident that the technical challenges DLM face will eventually be resolved. However, there are social and political issues that further entangle the fate of DLM, among them, the most prominent issues being standards and copyright.

Many different levels of standards exist that concern DLM, but they have yet to achieve the level of standardization that applies to the organization, management, and sharing of printed materials. Fortunately, the Internet and Web browsers provide a *de facto* standard environment for network connections and user interface, thus making TCP/IP, HTML (Hypertext Mark-up Language) and XML excellent candidates for communication/messaging standards for DLM. MeSH is probably the most accepted vocabulary for medical bibliographic records, but it falls short for indexing other digital sources like electronic health records. Projects like the UMLS help bridge bibliographic and clinical standards by making a standard vocabulary possible for DLM in the future. It is agreed that metadata (structured data about data) play a key role for heterogeneous digital object retrieval across different sources. Proposed as a metadata standard for electronic sources, Dublin Core is now gaining momentum in the Web and library communities internationally [39]. A set of 15 tags constitute the Dublin Core, which can exist in a minimal form (called Simple Dublin Core) that uses no qualifiers regarding encoding schemas, enumerated lists of values, or other processing clues. Its simplicity and firm integration with HTML/XML make Dublin Core a favorable metadata standard for DLM. However, for a DLM to fully realize the potential of metadata, a specialized extension to biomedical digital objects must be designed. Many organizations that adapted Dublin Core, including the NLM, created additional metadata tags to respond to this limitation [37].

Copyright issues for electronic literature is at the center for much debate and argument among academia and the scientific publishing industry over the past few years. Spiraling costs and exponential increases of biomedical journals have greatly limited a library's capability to build a satisfactory collection. It is obvious that restricted copyright policy will compromise the functions of DLM if the copyright of scholarly papers stays with the publishers as happens today. Various approaches have been proposed to tackle this issue, though none have had much impact on paper-based publications so far. PubMed Central proposed by Harold Varmus, former director of the National Institutes of Health, is one of the most ambitious among these efforts [40]. He suggested that the NIH would help organize and maintain a two-tiered, freely accessible Internet server. Authors can use one of two routes to submit to PubMed Central: submission through editorial boards or submission through the general repository. For authors who choose the first route, PubMed Central acts as a gateway to submit manuscripts to the editorial board of an indicated journal and helps to make the paper freely available on its server once it is accepted. In the second route, unpublished manuscripts could be submitted and archived in a general repository after a preliminary review by appropriate experts. Manuscripts published through different routes would be clearly identified as such. All the advantages of electronic publishing could be realized in this model - easier access, better integration, expanded formatting, cost effectiveness, more detailed descriptions and data availability, and faster presentation to the public [19]. While PubMed Central was not launched as planned in January 2000, it has laid the groundwork for similar efforts that are likely to continue for years to come.

As Andy Grove, former president of Intel, points out, anytime anything important changes in a business by a factor of ten, it is necessary to rethink the whole enterprise [41]. According to Odlyzko, electronic journals operated by non-profit organizations could lower costs by as much as two orders of magnitude. Virtualization of all or part of a medical library's services may very likely contribute to significant cost reductions and higher availability. On the other hand, aggregation and integration with various health and biomedical data sources, aided by advanced IR techniques, will make a digital library in medicine the single most important source of information and knowledge. We have reasons to believe that economically affordable, universally accessible and comprehensive medical information collectives residing in virtual medical libraries around the world, will soon be an indispensable part of our digital future.

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