The development of the Medical Literature Analysis and Retrieval System (MEDLARS)*

Cheryl Rae Dee, PhD

See end of article for author's affiliation.

DOI: 10.3163/1536-5050.95.4.416

Objective: The research provides a chronology of the US National Library of Medicine's (NLM's) contribution to access to the world's biomedical literature through its computerization of biomedical indexes, particularly the Medical Literature Analysis and Retrieval System (MEDLARS).

Method: Using material gathered from NLM's archives and from personal interviews with people associated with developing MEDLARS and its associated systems, the author discusses key events in the history of MEDLARS.

Discussion: From the development of the early mechanized bibliographic retrieval systems of the 1940s and to the beginnings of online, interactive computerized bibliographic search systems of the early 1970s chronicled here, NLM's contributions to automation and bibliographic retrieval have been extensive.

Conclusion: As NLM's technological experience and expertise grew, innovative bibliographic storage and retrieval systems emerged. NLM's accomplishments regarding MEDLARS were cutting edge, placing the library at the forefront of incorporating mechanization and technologies into medical information systems.

Highlights

- Historical documents from the archives of the National Library of Medicine (NLM) and interviews with key Medical Literature Analysis and Retrieval System (MEDLARS) people provided a chronology of NLM's computer-based bibliographic storage and retrieval systems.
- Foremost among the NLM products were the Index Mechanization Project, the phototypesetter Graphic Arts Composing Equipment (GRACE), MEDLARS, *Abridged Index Medicus*/Teletypewriter Exchange Network (AIM-TWX), MEDLARS II, and subsequently MEDLINE.

Implications

- The development of MEDLARS provides background for understanding current bibliographic retrieval systems.
- NLM's pioneering systems demonstrate NLM's commitment to indexing and developing rapid access to the world's literature.

INTRODUCTION

The US Congress established the National Library of Medicine (NLM) to assist the advancement of medical and related sciences [1]. In response to its Congressional mandate, NLM provides electronic and print access to reliable health information in the form of catalogs, bibliographies, indexes, and online databases [1, 2] to aid in the dissemination and exchange of scientific information [1]. During the last fifty years, the health sciences field has produced an explosion of biomedical research and related publications to the extent that NLM accelerated investigation of new information technologies [3] to ensure the world biomedical community's access to scientific information [4, 5].

This paper sketches the chronology of the mechanization and computerization of medical indexes and bibliographic searching beginning with the early mechanized systems (1940s) and going forward to the introduction of the online computerized bibliographic search systems (1970s). The paper focuses on NLM's development of new methods for processing, organizing, and disseminating health information and illustrates how the library's experience and expertise developed NLM's Medical Literature Analysis and Retrieval System (MEDLARS) and MEDLARS II. The paper presents a selective rather than a comprehensive discussion of the events and systems leading to MEDLARS given the complexity of factors involved in MEDLARS' development.

EARLY STEPS TOWARDS INDEX MECHANIZATION

The chronicle of NLM's commitment to delivering information to health care professionals is deeply rooted in early historical indexing. NLM's indexing tradition began with Dr. John Shaw Billings, the first director of the Library of the Office of the Surgeon General of the US Army 1867–1895 (later named the National Library of Medicine) [6]. Dr. Billings formulated the library's mission to acquire, catalog, and index the literature of the medical sciences [7] and compiled the first medical index [8], the 1879 *Index Medicus* [9], followed in 1880 by the Library of the Surgeon General's Office *Index-catalogue* [10]. The library subsequently published a no-

* This research was funded in part by the National Library of Medicine.

table series of comprehensive printed biomedical indexes from 1916 to 1959 [11–13]. Around the close of World War II, the *American Library Association (ALA) Survey of the Army Medical Library* challenged the library to modernize the printed indexes and recommended a renewed effort to analyze the functions of the three major indexes [14]. Specifically, the indexes were the American Medical Association's *Quarterly Cumulative Index Medicus* (1927–1956) [11], *Current List of Medical Literature* (1941–1959) [12], and the Army Medical Library's *Index-Catalogue* of the Library of the Surgeon General's Office [13], all of which were significantly behind their publication deadlines [15, 16].

The labor-intensive process to produce the printed indexes in the mid-1940s demonstrates the reason for the indexes' publication delays and the ALA recommendation. Processing began by typing the subject and author entries on individual three-by-five inch slips. Then the individual slips were numbered, arranged, and hand-mounted by a shingling technique pioneered by the US Department of Agriculture Library and the Library of Congress. Following the preparation of printer's plates for the monthly issues, the staff interfiled by hand thousands of subject and author slips to form the six months' accumulation of an index. Seymour Taine, the library's chief of the bibliographic services division (1951–1964), reported that the production process was an ingenious technique, but the half million slips needed in a six months' volume of *Current List* approached the utmost limits of the process in terms of size and offered scant prospect for expansion or improvement [15]. The slow, labor-intensive, and repetitive indexing process [17] suggested that much of the work could be done by the machines [18] being tested and used in industry.

Scott Adams, NLM deputy director (1960–1969), described the national information retrieval environment in the 1950s as ''frenetic'' [7]. The serious application of computers to bibliographic information retrieval began with slow serial searches of small files of bibliographic records on magnetic tape [19]. Notably, Johns Hopkins University's Welch Medical Library Indexing Project, supported by the Armed Forces Medical Library [20], was credited as one of the first major studies of the application of machine methods for indexing the medical literature [16].

US Senators and Congressmen expressed their impatience with the library's inability to use the imaginative solutions proposed by academia and industry to solve problems with science information retrieval [7]. In response to their concerns, Dr. Frank B. Rogers, Army Medical Library and NLM director (1949–1963) [8], confirmed that NLM ''felt acutely the need to improve upon its bibliographic techniques . . . and to provide for the publication of *Index Medicus* and its byproducts [21].''

THE NATIONAL LIBRARY OF MEDICINE'S INDEX MECHANIZATION PROJECT

The labor-intensive process to prepare the printed indexes and the technological advances in the information retrieval environment [15] convinced NLM to seek new methods to produce its comprehensive indexes. The NLM Index Mechanization Project (July 1958–June 1960) [22], funded by the Council on Library Resources, was NLM's first mechanized project to provide rapid bibliographic access and effective management of the scientific literature [17]. Under the NLM management of Seymour Taine, the Index Mechanization Project focused on two objectives: (1) an improved system of index publication and (2) a by-product bibliographic retrieval system [15].

The publication component of the Index Mechanization Project used the time-saving Eastman Kodak Listomatic camera, a high-speed, precision machine capable of photographing text imprinted or typed at the top of an IBM punched card. The system created a negative film to be read and processed for a photo-offset plate, which allowed the camera to photograph a typical monthly issue of the NLM *Current List of Medical Literature* in a single day. The Listomatic camera could photograph the annual accumulation of approximately a million punched cards in about two weeks [15]. The project's publication component successfully met the objective of composing and publishing NLM publications. [23].

NLM, however, abandoned the Index Mechanization Project's second objective of producing a bibliographic retrieval system [23]. The *Index Mechanization Project Report* explained that a retrieval system could not be successfully grafted onto a publication system. Instead, an index mechanization project should start with the design of the retrieval system and then proceed with the publication system [24]. The *NLM Annual Report for the Fiscal Year 1961* further concluded that far more sophisticated machines than typewriters would be required before an effective retrieval system could be achieved [25]. Director Rogers reported, however, that in spite of the ill-fated bibliographic retrieval system, NLM derived valuable experience from the mechanization project, which he anticipated would be of greater significance in the long run than the project's successful publication capabilities. The project also provided NLM with the impetus to investigate the application of more sophisticated mechanized techniques [23]. Dr. Rogers later observed that the NLM staff involved in the project did not realize that it was sowing the seeds of MEDLARS [26].

MEDICAL LITERATURE ANALYSIS AND RETRIEVAL SYSTEM (MEDLARS)

Based on the Index Mechanization Project under the leadership of Director Rogers, NLM began planning a computer-oriented bibliographic retrieval and publication system [27, 28] called MEDLARS, an acronym for Medical Literature Analysis and Retrieval System [28]. Director Rogers remarked that it was difficult to state precisely the point in time when MEDLARS was born [25], but NLM formally began work on MEDLARS with written specifications and performance capabilities using a computer with the bibliographical

Table 1
Medical Literature Analysis and Retrieval System (MEDLARS) primary development objectives (1960)

1. Improve the quality, size and processing time required to prepare *Index Medicus*;
2. Search a bibliographic database promptly (a maximum of two days) in broad medical subject areas to create special selected bibliographies on a recurring basis;
3. Search a bibliographic database for patrons upon request, with multiple subject, language, and time parameters;
4. Add monographs, non-journal sources, and serials to the existing journal articles in *Index Medicus*;
5. Increase the depth of indexing terms per article from two (2) to ten (10) terms per article;
6. Increase the coverage of the literature;
7. Keep statistics and analyze MEDLARS operations.

search and retrieval system as the top priority [26] and the publication system as a secondary priority [16].

In 1960, NLM made a formal grant proposal to the National Heart Institute (NHI) to underwrite the MEDLARS computer system. Dr. Martin M. Cummings, AHIP, FMLA, then associate director for research grants at the National Institutes of Health (NIH), recently explained [29] the unpublished details of a grant complication that almost doomed MEDLARS. When NLM sought grant funding from NHI, an auditor questioned whether one government agency could ''grant'' part of its Congressional budget allocation to another government agency. Two years earlier, Dr. Cummings, as director of research for the Veterans Administration (VA), and Dr. Ernest M. Allen, associate director for the Extramural Program at NIH, allowed NIH to give grants from their federal budget to qualified VA hospital researchers. Thus Associate Director Cummings with support from Dr. Allen, then deputy assistant secretary for health, judged that the NLM MEDLARS grant should be awarded based on the 1958 precedent-setting decision [29].

With the funding issue resolved, NLM developed innovative objectives and specifications for MEDLARS [24, 30–32] (Table 1) and sought proposals for a two-year developmental program for the study, design, installation, and trial operation of MEDLARS. In August 1961, NLM selected the General Electric Company (GE) from among twenty-five contenders [26]. GE divided the project into three phases:

- Phase I: the preliminary design of the system
- Phase II: the detailed design, programming of the computer operations, and specifications for special equipment
- Phase III: the implementation of the computer system

NLM used input transition Flexowriter typewriters to convert all of the 1963 journal material from the library's existing system to punched paper tape format for entry into the computer [33].

By January 1964, the MEDLARS Honeywell 800 computer subsystem had been planned, acquired, installed, and preliminarily tested [29, 34, 35] (Figure 1). The Louisville, Kentucky, *Courier-Journal Magazine* [36] credited NLM Director Rogers for the concept and design of the MEDLARS program. Dr. Cummings praised Director Rogers for the foresight to anticipate

Figure 1
Honeywell computer

Caption from Feb 1975 *NLM News*: The Honeywell computer, historic workhorse of MEDLARS I, was responsible for processing over 10 years of *Index Medicus* and numerous other bibliographies used throughout the world. It processed thousands of demand searches during the years before online searching took over. The system was also instrumental in providing data which led to the development of its own successor, MEDLARS II.

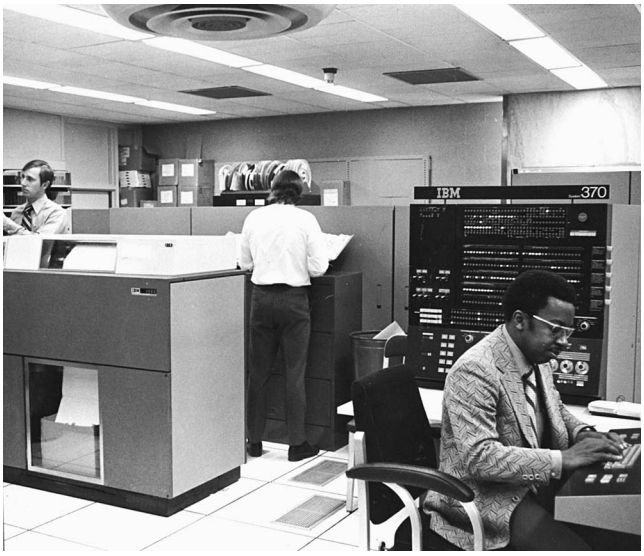
that computers could foreshorten the time required to produce the library's printed products and provide new types of bibliographic services to serve the needs of physicians and scientists [29].

MEDLARS components

Graphic Arts Composing Equipment (GRACE). When NLM Director Cummings (1964–1984) arrived at NLM in January 1964, only one unique aspect of the MEDLARS processing system, the innovative offline computer-driven phototypesetter GRACE [37]—designed to meet the high-speed, high-quality, and high-volume publication requirements of MEDLARS [6]—was not operational [29]. Director Cummings and the NLM staff worked diligently to put actions in motion to complete GRACE. Their success was marked by the August 1964 publication of *Index Medicus* using GRACE. GRACE consisted of three distinctive components: (1) a magnetic tape unit from the Honeywell computer that read the tapes to be printed, (2) an electronic control unit with a console, and (3) an optical unit [38, 39] (Figure 2). GRACE accepted electrical signals in bursts of coded characters that represented a full line of legible type from the MEDLARS magnetic-tape transport unit. GRACE then set the type on film or paper to produce its publications [38]. In addition, GRACE simultaneously processed as many as thirty reference searches a day [40] with the estimated typesetting power of fifty-five Linotype typesetting operators [41].

Much of the revolutionary computerized photocomposition of today owes its origin to the development

Figure 2
IBM 370/155 master console (right) and high-speed printer (left) with NLM staff



of GRACE [29]. The Washington *Evening Star* reported that GRACE was a breakthrough in printing technology and quoted Director Cummings as saying, ''we feel that the August issue of *Index Medicus* is an historical document . . . because of its great significance both to medicine and printing'' [42]. Testimony to the Congressional Subcommittee on Appropriations reported that ''There is no comparable instrument for speed and accuracy of photocomposition anywhere in the world'' [34]. Charles Bourne, author of *A History of Online Information Services, 1963–1976,* cited the 1974 *Encyclopedia Britannica* that stated that GRACE was as much a landmark in the history of phototypesetting as the Gutenberg Bible was in printing [19].

American business and industry that used repetitive daily mass printing in their operations observed the success of GRACE. Representatives of telephone companies, Wall Street businesses, and newspapers interested in fast, computer-generated photocomposing visited NLM to observe the functioning of GRACE [29]. Archived correspondence from Director Cummings to both Melvin Day, director of the Scientific and Technical Information Division of the National Aeronautics and Space Administration (NASA) [43], and to the US surgeon general [44] confirmed that NASA used GRACE for preparing indexes for their publication, *STAR,* in 1967. After admirably serving NLM, GRACE retired to the Smithsonian Institution in 1969 [29].

Although MEDLARS used Medical Subject Headings (MeSH), by 1964 the rapid advances in biomedical sciences created some deficiencies in its use [45]. NLM engaged nonlibrarian Dr. Peter Olch, a surgeon and pathologist working at NIH, and later Dr. Norman Shumway, head of the NLM Medical Subjects Heading Section, to enrich the MeSH terminology with the latest medical concepts for both *Index Medicus* and MEDLARS [45]. NLM indexer Thelma Charen [29] and thesaurus builder and indexer Claire Schultz [46] also worked to enhance MeSH.

MEDLARS was complete with the installation of GRACE and the initial refining of MeSH. MEDLARS was heralded as the first library application of a computer to handle scientific literature [32, 47] with a digital computer and high-quality composing equipment [21]. MEDLARS was also the first large-scale information retrieval project based in a research library to provide both bibliographic access as well as copies of the documents [6]. MEDLARS produced (1) printed products, (2) recurring bibliographies, and (3) demand (nonrecurring) bibliographic searches [6, 48, 49].

- **Printed products:** MEDLARS used the high-speed phototypesetter GRACE to compile and print several NLM publications including the monthly *Index Medicus*, the annual *Cumulated Index Medicus,* the list of MeSH, and the recurring medical bibliographies. The second slower MEDLARS computer printer produced the demand (nonrecurring) search bibliographies [6, 21].
- **Recurring bibliographies:** NLM's trained search specialists periodically prepared medical bibliographies (lists of citations) for specialized consumer groups. MEDLARS then prepared for printing the bibliographies [45, 50] to be distributed by government agencies and nonprofit national professional organizations working in the specialty fields [28]. The recurring published bibliographies included, for example, the *Index of Rheumatology* for the American Rheumatism Association and the *Index to Dental Literature* for the American Dental Association and the National Institute of Dental Research [34, 51].
- **Demand (nonrecurring) bibliographic searches:** The major motivation for MEDLARS was to provide rapid computer searching of data files [48]. MEDLARS provided a resourceful method to answer individual requestors' highly complex, bibliographic questions that could not be handled efficiently by referring to the printed indexes and catalogs [4, 5, 28, 31].

To obtain a demand bibliography, physicians, health scientists, educators, and students completed a MEDLARS search request form at NLM or mailed the form to NLM [4]. Medical librarians trained as MEDLARS search specialists performed the requested computer searches [51]. Typists converted the search to machine-readable form on punched paper tape that was read into the computer [21]. The computer then performed a time-consuming search of the entire file of magnetic tapes in sequence to retrieve all of the citations on a given subject [4]. NLM prepared pamphlets to assist patrons with the MEDLARS demand search service [52] and provided detailed descriptions of MeSH, subheadings, and the indexing procedures [53].

The MEDLARS data processing system. MEDLARS required high-speed data processing equipment to meet the time requirements and volume of work. Hundreds of published and unpublished pages of detailed procedures and instructions in a wide assortment of manuals and pamphlets described every aspect of

MEDLARS. The following brief overview summarizes the basic elements of the three main subdivisions of the MEDLARS' data processing system: (1) input and conversion subsystem, (2) computer manipulation subsystem (retrieval subsystem), and (3) output subsystem (publication) [21, 31, 32, 40, 50].

1. The **input and conversion subsystems'** operation combined the intellectual talents of librarians with the processing and storage capabilities of the computer [54] and included three basic types of input: (1) citations from the literature with relevant descriptors (known as unit records); (2) master-file data (MeSH, etc); and (3) operating procedures and instructions for computer operators [6]. Charles J. Austin, NLM head of the data processing section (1962–1966), explained that the input subsystem received and prepared journals with indexing, monographs with cataloging, and search requests. The process began with a staff of indexers assigned to a specific number of new journals from which the indexers selected the articles. Indexers created the journal articles' unit record together with their MeSH terms. Catalogers received non-journal documents such as monographs and performed somewhat similar functions [6]. The input typist transformed the unit record to machine-readable form on punched paper tape using a punched-tape typewriter and then integrated the information on a data sheet prepared by an indexer with journal information and codes that allowed the computer to recognize the unit records' elements. The unit record was then verified by proofreaders, corrected, and returned for preparation of a correction tape that was entered into the computer [51]. Similarly, NLM librarians (literature analysts) designed search requests for demand bibliographic searches with logical search combinations to prepare search requests for patrons. A typist transformed each search into machine-readable form for the computer [6].

2. The **computer manipulation subsystem** (also called the retrieval subsystem) centered on the Minneapolis-Honeywell 800 digital computer. GE designed seven intricate programming modules that were large groups of machine instructions for the computer system. Essentially, the computer accepted the unit records on paper tape, spliced into batches (thus the term batch-mode processing). The computer checked the unit record for correctness, compressed the unit record to facilitate subsequent processing, and stored the unit records on magnetic tape in chronological sequence for at least five years [32, 50]. In response to both demand and recurring search requests, the computer searched its accumulation of unit records for those that qualified for the search retrieval and then edited and composed the retrieved records for output on magnetic tape [21].

3. The **output/subsystem** (also called the publication subsystem) converted citations and descriptors characterizing the citation into photosensitive film to produce the MEDLARS printed products. Technically stated, the output system transformed the magnetic-tape output of the computer manipulation subsystem into exposed film to two new printers used to print the MEDLARS products from the stored magnetic tapes [21]: first, GRACE, the offline high-speed computer phototypesetter [37] for the high-volume publication requirements such as *Index Medicus* and the recurring bibliographies [6, 33], and second, the standard medium-speed mechanical printer for demand bibliographic searches requested by patrons [6, 21, 38] (Figures 3 and 4).

Figure 3
Computer room at the National Library of Medicine

MEDLARS' reception

MEDLARS generated enthusiastic public interest. The *Wall Street Journal* reported that MEDLARS was the first large-scale computer system for storing and retrieving scientific information in use at NLM, keeping track of tens of thousands of medical journal articles received each year. ''Without a [MEDLARS] computer, it would be time-consuming and often impractical to search through the printed materials for the required medical information'' [55].

The Courier-Journal Magazine announced that NLM ''was the largest collection of medical literature ever assembled anywhere in the world . . . and within these walls stands mighty MEDLARS and GRACE—two names destined to change the entire concept of rapid assembly and retrieving of information'' [36]. Miles noted in *A History of the National Library of Medicine* that ''On the whole the system was one of the largest and most successful library automation projects. Its success marked a milestone in the evolution of modern libraries'' [8].

MEDLARS decentralization

NLM duplicated MEDLARS tapes for other medical schools and research institutions to allow the schools to economically develop the same retrieval power as NLM [34]. The recipient medical school libraries benefited from the quality control standards provided by

Figure 4
IBM magnetic tape drives of the IBM 370/155 with NLM staff

NLM's centralized data input into MEDLARS and the reduction of duplicate labor to input the data in their libraries [29, 34]. NLM's decentralization of MEDLARS began with a contract to the University of California at Los Angeles and then the University of Colorado. NLM later added MEDLARS stations at Harvard University, Ohio State University, and the Universities of Alabama and Michigan. Further decentralization of MEDLARS came about through the Medical Library Assistance Act of 1965 that authorized funding to establish eleven regional libraries, each of which became a MEDLARS center. By 1978, NLM had expanded the international MEDLARS databases presence to eleven countries, specifically, Australia, Canada, France, Iran, Italy, Japan, Mexico, South Africa, Sweden, West Germany, and the United Kingdom [56].

EVALUATION

Patron feedback on the usability of MEDLARS demonstrated NLM's need to engage Dr. F. W. Lancaster, an outside consultant to NLM, to perform a major evaluation of MEDLARS' bibliographic searching capability [57]. Dr. Lancaster was a respected and objective outsider who had developed an effective method of evaluating systems like MEDLARS, which was, at that time, searching by centralized processing of written requests in a batch mode. Members of the NLM Board of Regents opposed Dr. Lancaster's 1965 evaluation, concerned that the evaluation would damage the reputation of NLM if the evaluation revealed negative results. The Lancaster evaluation, however, proved to be objective and useful [29], revealing that MEDLARS searching operated with 58% recall and 50% precision and pointing out the need for more careful indexing and further vocabulary development [58]. William Hubbard Jr., NLM Board of Regents chairman (1965–1967), recently stated that librarians completing MEDLARS searches needed additional training [59] to translate the patrons' demand searches into MEDLARS computer language and codes [47]. In response, NLM refined MEDLARS indexing and developed additional MEDLARS training programs [29].

The Lancaster evaluation resulted in one of the earliest publications with empirical bibliographic recall and relevance data [60] and became recognized as the first large-scale evaluation of any computer-based information system [61]. The evaluation was important for the development of MEDLARS II [47] and became a prototype for future information system evaluations [62].

MEDLARS II

The workload on the pioneering MEDLARS system—combined with the explosive growth of scientific literature, tremendous expansion of medical research, and medical specialization in the mid-1960s—had increased to the extent that MEDLARS was no longer able to efficiently provide the services users expected [4]. MEDLARS could not meet the two-day delivery requests for the demand search and recurring bibliographies. In fact, the average time from a user request to information delivery reached two weeks [45]. The time-consuming MEDLARS batch-mode searches [63] eventually exceeded the capacity of NLM's human resources dedicated to providing searches, forcing NLM to declare a six-week moratorium on new requests for demand searches [64]. Director Cummings described the times as a ''cybernetic revolution bringing forth complex, sophisticated computers and other automated equipment to be applied to library development'' [56]. Consequently, NLM began to plan for a new, upgraded MEDLARS system using new emerging computer technology.

NLM hired the Auerbach Corporation to draw up specifications for a new system for the online search and retrieval of bibliographic records [45]. Computer Sciences Corporation (CSC) was contracted to develop and support programming for MEDLARS II but failed to meet its schedule and cost estimates and provide the necessary searching capabilities as expected [65, 66]. To remedy the problem, Director Cummings asked for support and moved to utilize System Development Corporation's (SDC's) work with *Abridged Index Medicus*/Teletypewriter Exchange Network (AIM-TWX), discussed below, as the way to the future of MEDLARS II. Director Cummings subsequently contracted with SDC to complete MEDLARS II [65]. Dr. Cummings recently added that the CSC design for MEDLARS II would only have resulted in a more efficient but out-of-date batch mode system. Therefore, the library decided to seek new designs and devote its

resources to creating a complete online information retrieval system [29].

The new plans for MEDLARS II included a high-speed IBM 360/50 [66]. However, at that time, smaller computer companies complained that the government bought only IBM equipment and protested NLM's effort to acquire IBM equipment. Dr. Cummings recently pointed out that the NLM Board of Regents significantly contributed to the solution to the IBM problem. With the support of Alfred Zipf, NLM Board of Regents chairman (1969–70) and the Bank of America's vice president for technical affairs, who built the first computer to mechanize the banking industry, NLM successfully argued in favor of procuring IBM equipment for MEDLARS II [29].

Abridged Index Medicus/Teletypewriter Exchange Network (AIM-TWX)

Parallel to NLM's work on the new MEDLARS II system, NLM investigated alternative information systems. Kent A. Smith, FMLA, NLM executive officer (1971–1979) and NLM deputy director (1980–2004), recently explained, that in the mid-1960s, Director Cummings wanted to convert NLM from a traditional medical library to an active biomedical communications center [65]. Seeking that goal, Director Cummings contacted US Senator Lister Hill and Congressman John E. Fogarty to seek their help in creating a research program and facility. Upon Senator Hill's retirement in 1968, Director Cummings, with Senator John J. Sparkman's help, created a Congressional resolution naming the program and the proposed facility after Senator Hill: the Lister Hill National Center for Biomedical Communications (LHC) [65, 67]. LHC, NLM's research and development component, was directed first by Dr. Ruth Davis from 1968 to 1970 [45, 8]. Dr. Davis recently commented that Davis B. McCarn, LHC deputy director (1967–1978), designed the first experimental online prototype system, AIM-TWX [68], specifically for the rapid retrieval of bibliographic information [69, 70]. AIM–TWX was developed by SDC [45] and named from a combination of two components of the system, the NLM publication *Abridged Index Medicus* (AIM) and the communications system Teletypewriter Exchange Network (TWX). AIM-TWX became the first national medical information service available from any teletypewriter or TWX terminal in the country for the price of a telephone call. AIM-TWX was experimental and, compared to the entire MEDLARS file, contained only clinically oriented information from the leading 100 English language journals [66]. The research, however, from AIM-TWX provided a model for future development of information retrieval systems at NLM, particularly MEDLARS II [29] and the future MEDLINE system.

Completion of MEDLARS II

Reinforced by the success of their own NLM online AIM-TWX, NLM recognized that library automation was nearing development of true online systems and continued to redesign a new online retrieval system for MEDLARS II [66]. In 1971, NLM engaged SDC to complete MEDLARS II [19]. SDC's major enhancement of MEDLARS II was the shift to online, interactive searching and retrieval, a vast improvement over the batch mode capability of the original MEDLARS.

Table 2
MEDLARS timeline

1958–1960	Index Mechanization Project
1960–1964	MEDLARS development
August 1964	MEDLARS completed
1964	MEDLARS decentralized
1964–1966	Lancaster evaluation
May 3, 1970	*Abridged Index Medicus*/Teletypewriter Exchange Network (AIM-TWX) pilot operational
January 3, 1970	MEDLARS II completed

The new MEDLARS II included the powerful, fast-operating IBM 360 series computer system, [45], an automated library system with an automated acquisition and cataloging system [71], an improved indexing and searching aid (online MeSH), an ability to provide chemical compound and toxicological searches, and a high-performance graphic image storage and retrieval system [19, 47, 72]. MEDLARS II, like the first MEDLARS, continued to be a huge database that stored all the references to the medical literature indexed by NLM since 1964. The new system also provided the technology to more rapidly deliver medical information for on-demand searches and continued to produce all of NLM's publications [73]. On January 3, 1975, the upgraded system was complete, and NLM's computer staff tested the MEDLARS II system and accepted it on behalf of the library [8].

PLANNING FOR A NEW SYSTEM

The philosophy at NLM was to plan five years in advance [29]. True to this strategy, NLM was already thinking about a new MEDLARS-type structure [73] to keep pace with new technical developments for the improved management of the biomedical literature when MEDLARS II was completed [74]. In the summer of 1979, Director Cummings appointed Joseph Leiter, NLM associate director of library operations (1965–1983), to lead a team to prepare specifications for a new computerized system that would eventually become NLM's Medical Literature Analysis and Retrieval System Online (MEDLINE) [75]. The new NLM focus on the MEDLINE system would develop into the current MEDLINE database, NLM's premier bibliographic database with over fifteen million references. MEDLINE is presently the primary component of PubMed, which was developed by the National Center for Biotechnology Information (NCBI) at NLM and provides free access to MEDLINE [76].

CONCLUSION

NLM has continued to develop innovative methods to provide rapid access to the world's medical literature. During the era discussed, NLM's pioneering systems included the Index Mechanization Project with the

time-saving Eastman Kodak Listomatic camera; MEDLARS, the computer-oriented bibliographic retrieval and publication system that included the innovative phototypesetter GRACE; AIM-TWX, the experimental online bibliographic retrieval system; and MEDLARS II, a high-performance retrieval system (Table 2). NLM's accomplishments regarding MEDLARS were cutting edge and placed the library at the forefront of incorporating mechanization and technologies into medical information systems. MEDLARS and its associated systems confirmed NLM's dedication to improving library and information services on behalf of society as a whole.

ACKNOWLEDGMENTS

The author is indebted to Dr. Martin Cummings, NLM director emeritus, for interviews from 2004–2006 and encouragement for this research; Robert Mehnert, NLM director of the office of communications and public liaison, and Kent A. Smith, former NLM deputy director, for verifying NLM facts; and Douglas J. Turk, Wanita Scroggs, Alicia Livinski, and Aubrey Saunders for bibliographic assistance.

REFERENCES

1. US Code. 42 US Code 286 (1994): National Library of Medicine. Text from: US Code Service. Available from: LexisNexis Congressional. [accessed: 27 Oct 2006].
2. US National Library of Medicine. NLM functional statement. [Web document]. Bethesda, MD: The Library, 2005. [cited 4 Mar 2007]. <http://www.nlm.nih.gov/about/functstatement.html>.
3. Cummings MM. US House. Departments of Labor, and Health, Education, and Welfare, and Related Agencies Appropriations for 1970. Part 4: National Institutes of Health. Subcommittee of the Committee on Appropriations. House, Hearing 1969 Apr 3;1126–38.
4. Cummings MM. US House. Departments of Labor and Health, Education, and Welfare and Related Agencies Appropriations for 1968. Part 4: Public Health Service (except the National Institutes of Health and the National Institute of Mental Health). Subcommittee of the Committee on Appropriations. House, Hearing 1967 Apr 13:632–53.
5. Cummings MM. Books and computers (from Billings to MEDLARS). Acad Med New Jersey Bull 1965 Mar;11:51–6.
6. Austin CJ. Data processing aspects of MEDLARS. Bull Med Libr Assoc 1964 Jan;52(1):159–63.
7. Adams S. The way of the innovator: notes toward a prehistory of MEDLARS. Bull Med Libr Assoc 1972 Oct;60(4):523–33.
8. Miles WD. A history of the National Library of Medicine: the nation's treasury of medical knowledge. Bethesda, MD: National Library of Medicine, 1982.
9. Billings JS, Fletcher R, Garrison FH. Index Medicus. Washington, DC: Library of the Office of the Surgeon General of the [US] Army, 1879–1927.
10. Library of the [US] Surgeon General's Office. Index-catalogue of the Library of the Surgeon-General's Office, United States Army. Authors and subjects. Washington, DC: Government Printing Office, 1880–1932.
11. American Medical Association. Quarterly cumulative Index Medicus. Chicago, IL: American Medical Association, 1927–1956.
12. Current list of medical literature. Washington, DC: Friends of the US Army Medical Library, 1941–1959.
13. Army Medical Library (US). Index-catalogue of the Library of the Surgeon General's Office, United States Army (Army Medical Library). Authors and subjects. Washington: US Government Printing Office, 1936–1948.
14. Metcalf KD [and others]. The National Medical Library: report of the Army Medical Library. Chicago, IL: American Library Association, 1944.
15. Taine SI. New program for indexing at the National Library of Medicine. Bull Med Libr Assoc 1959 Apr;47(2):117–23.
16. Adams S. Medical bibliography in an age of discontinuity. Chicago, IL: Medical Library Association, 1981.
17. The National Library of Medicine Index Mechanization Project. Bull Med Libr Assoc 1961 Jan;49(1 pt.2):1–7.
18. Garfield E. Some reflections on Index Medicus. Essays of an Information Scientist 1979 Dec;4(51):341–47.
19. Bourne CP, Hahn TB. A history of online information services, 1963–1976. Cambridge, MA: Massachusetts Institute of Technology Press, 2003.
20. Larkey SV. The Welch Medical Library Indexing Project. Bull Med Libr Assoc 1953 Jan;41(1):32–40.
21. US National Library of Medicine. The MEDLARS story at the National Library of Medicine. Bethesda, MD: US Department of Health, Education and Welfare, Public Health Service, 1963:1–74. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
22. Rogers FB. The origins of MEDLARS. Henry E Sigerist Suppl Bull Hist Med 1982:77–84.
23. US National Library of Medicine. Annual report for the fiscal year 1960. [Web document]. Washington, DC: US Department of Health, Education and Welfare, Public Health Service, 2005. [cited 12 Sep 2005]. <http://www.nlm.nih.gov/hmd/manuscripts/nlmarchives/annualreport.html>.
24. Taine SI. The Medical Literature Analysis and Retrieval System. Bull Med Libr Assoc 1963 Apr;51(2):157–67.
25. US National Library of Medicine. Annual report for the fiscal year 1961. [Web document]. Washington, DC: US. Department of Health, Education, and Welfare, Public Health Service, 2005. [cited 12 Sep 2005]. <http://www.nlm.nih.gov/hmd/manuscripts/nlmarchives/annualreport.html>.
26. Rogers FB. The development of MEDLARS. Bull Med Libr Assoc 1964 Jan;52(1):150–1.
27. Cummings MM. US House. Departments of Labor and Health, Education, and Welfare and Related Agencies Appropriations for 1965. Part 2: Public Health Service (except National Institutes of Health). Subcommittee of the Committee on Appropriations. House, Hearing. 1964 n.d.:592–603.
28. Cummings MM. The place of computers in the organization of medical libraries. Speech presented at: Oxford University, Oxford, England; 14 Jul 1965. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
29. Dee CR. Interview with: Cummings MM. Sarasota, FL. 2004–2006 (approximately monthly).
30. Cummings MM. Modern bibliographic control of the biomedical literature as an aid to teaching, research, and practice. Presented at: 7th Medical Symposia sponsored by the International Business Machine Corporation; Poughkeepsie, NY; 25–28 Oct 1965. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
31. Cummings MM. Modern methods of handling the world's biomedical literature. Presented at: Inaugural Scientific Program; Ramsey Hospital, St. Paul, MN; 12 Nov 1965. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.

32. Cummings MM. The relationship of specialized information centers and research libraries. Presented at: American Medical Writers Association, Washington Chapter; Washington, DC; 3 Dec 1965. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
33. US National Library of Medicine. Annual report for the fiscal year 1963. [Web document]. Washington, DC: US Department of Health, Education, and Welfare, Public Health Service, 2005. [cited 4 Mar 2007]. <http://www.nlm.nih.gov/hmd/manuscripts/nlmarchives/annualreport.html>.
34. Cummings MM. US House. Departments of Labor and Health, Education, and Welfare and Related Agencies. Appropriations for 1966. Part 2: Public Health Service (exclusive of National Institutes of Health). Subcommittee of the Committee on Appropriations. House, Hearing 1965 n.d.:754–79.
35. US National Library of Medicine. Fact sheet: Medical Literature Analysis and Retrieval System. Bethesda, MD: US Department of Health, Education, and Welfare, Public Health Service, National Institutes of Health, National Library of Medicine, Jun 1964:1–3. US National Library of Medicine Archives, Bethesda, MD.
36. Luigart FW. Push-button brains produce . . . faster facts for doctors. [Louisville, KY]: The Courier-Journal Magazine 1964 Nov22:25–33.
37. US National Library of Medicine. Annual report for the fiscal year 1962. [Web document]. Washington, DC: US Department of Health, Education, and Welfare, Public Health Service, 2005. [cited 4 Mar 2007]. <http://www.nlm.nih.gov/hmd/manuscripts/nlmarchives/annualreport.html>.
38. Photon Zip model 900 high-speed computer photo-typesetter: product report. Wilmington, MA: Photon 900 Company, ca 1964–1966. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
39. Garrard RF. Weekly status report from MEDLARS program manager to: Taine SI, chief bibliographic services division, on progress of GRACE. Period: 9–15 Mar 1964. 1964 Mar 17:1–2. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
40. Cummings MM. Development of a National Medical Library Network. Presented at: Staff Colloquium, University of Illinois; 6 Dec 1967. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
41. US National Library of Medicine. Fact sheet: Graphic Arts Composing Equipment, Medical Literature Analysis and Retrieval System, US Department of Health, Education, and Welfare, Public Health Service, National Institutes of Health, National Library of Medicine. 1964 Jun:1–3. US National Library of Medicine Archives, Bethesda, MD.
42. Electric printer sets 609 pages in 16 hours. [Washington, DC, 1852–1981]: The Evening Star 1964 Aug 3. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
43. Cummings MM. Personal correspondence to: Day MS, director scientific and technical information division, National Aeronautics and Space Administration (NASA). 1965 Mar 19. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
44. Cummings MM. Personal correspondence to: US surgeon general on use of GRACE by National Aeronautics and Space Administration (NASA). 1965 Mar 24. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
45. Cummings MM. A brief recent history of the National Library of Medicine. In: National Library of Medicine: past, present, and future of biomedical information. Bethesda, MD: US Department of Health and Human Services, Public Health Service, National Institutes of Health, National Library of Medicine, 1986:27–40.
46. Williams RV. Interview with: Schultz CK. Line Lexington, PA; 9 Jun 1987. Chemical Heritage Foundation, Oral History Transcript # 0161. Used with permission from the Chemical Heritage Foundation.
47. Cummings MM, Corning ME. Biomedical communications: developing a mechanized library network. Presented at: The Conference on Libraries and Information Science in Higher Education; Tokyo, Japan; 18 May 1969. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
48. Cummings MM. The medical library as an active information center. Presented at: 50th Anniversary Celebration of the Houston Academy of Medicine; Houston, TX; 21 Oct 1965. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
49. Cummings MM. The computerized library. Presented at: American Association for the Advancement of Science; University of California Campus, Berkeley, CA; 29 Dec 1965. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
50. Austin CJ. The computer and medical bibliography. Presented at: The Symposium on the Computer and Its Potential in Medical Care, Seventieth Annual Meeting of the Association of Military Surgeons of the United States; Washington, DC; 4–6 Nov 1963. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
51. Taine SI. Bibliographic aspects of MEDLARS. Presented at: The Second International Congress on Medical Librarianship; Washington, DC; 16–22 Jun 1963:1–28. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
52. US National Library of Medicine. A guide to MEDLARS services. Bethesda, MD: US Departments of Health, Education, and Welfare and Public Health Service, National Institutes of Health, National Library of Medicine, 1966:1–16.
53. US National Library of Medicine. The principles of MEDLARS. Bethesda, MD: The Library, 1970:1–77.
54. Brodman E. The development of medical bibliography. Baltimore, MD: Waverly Press, 1954.
55. Federal library uses computer to store, retrieve science data: system yields all information on a subject: prepares huge monthly medical bibliography. [New York City, New York]: The Wall Street Journal 1964 Aug 3:12.
56. Cummings MM. US House. Departments of Labor and Health, Education, and Welfare and Related Agencies Appropriations for 1967. Part 3: National Institutes of Health. Subcommittee of the Committee on Appropriations. House, Hearing 1966 Mar 6:784–806.
57. Gerrard RF. Correspondence to: Cummings MM. 30 Sep 1964. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
58. Lancaster FW. Evaluation of the MEDLARS demand search service. Bethesda, MD: US Department of Health, Education, and Welfare, 1968:1–264.
59. Dee CR. Telephone interview with: Hubbard WN. Regent Hubbard, home of Cummings MM. 2005.
60. Cummings MM. Preface. In: Lancaster FW, ed. Evaluation of the MEDLARS demand search service. Bethesda, MD: US Department of Health, Education, and Welfare, 1968 Jan. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
61. National Library of Medicine. MEDLARS evaluation advisory committee minutes. 27 Sep 1966. Bethesda, MD: US Department of Health, Education, and Welfare, 1968 Jan;1–5. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
62. Cummings MM. The National Library of Medicine and quality information systems. 22–23 May 1978. Unpublished

manuscript, US National Library of Medicine Archives, Bethesda, MD.
63. Austin CJ. MEDLARS 1963–1967. Bethesda, MD: US Departments of Health, Education, and Welfare, Public Health Service, National Institutes of Health, National Library of Medicine, 1968:1–76.
64. Cummings MM. The fate of the dinosaur. Presented at: Ninety-fifth American Library Association Conference, Chicago, IL; 18 Jul 1967. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
65. Dee CR. Interview with: Smith KA. US National Library of Medicine, Bethesda, MD, 27 Jul 2005.
66. Cummings MM. US House. Departments of Labor and Health, Education, and Welfare and Related Agencies Appropriations for 1972. Part 3: National Institutes of Health. Subcommittee of the Committee on Appropriations. House, Hearing 1971 May 12:1244–70.
67. US National Library of Medicine. Milestones in NLM history. [Web document]. Bethesda, MD: The Library, 2005. [cited 4 Mar 2007]. <http://www.nlm.nih.gov/about/nlmhistory.html>.
68. Dee CR. Interview with: Davis R. US National Library of Medicine, Bethesda, MD, 28 Jul 2005.
69. Oppenheimer GJ. Interview with: Cummings MM. [Web document]. Chicago, IL: Oral History Committee, Medical Library Association, 23 Jun 1987. [cited 12 Sep 2006]. <http://www.mlanet.org/about/history/cummings_m.html>.
70. McCarn DB, Leiter J. On-line services in medicine and beyond. Science 1973 Jul 7–27;181(4097):318–24.
71. Cummings MM. US House. Departments of Labor and Health, Education, and Welfare and Related Agencies Appropriations for 1971. Part 3: National Institutes of Health. Subcommittee of the Committee on Appropriations. House, Hearing 1970 n.d.;1324–9.
72. Cummings MM. US House Departments of Labor and Health, Education, and Welfare and Related Agencies Appropriations for 1969. Part 4: Public Health Service (except National Institutes of Health). Subcommittee of the Committee on Appropriations. House, Hearing, 1968 Mar 14: 1071–85.
73. Cummings MM. US House. Departments of Labor and Health, Education, and Welfare and Related Agencies Appropriations for 1973. Part 4: National Institutes of Health. Subcommittee of the Committee on Appropriations. House, Hearing 1972 Mar 24:1493–518.
74. Cummings MM. Operational experience: health sciences (MEDLARS). Presented at: Conference on Electronic Information Handling; Pittsburgh, PA; 7–9 Oct 1964. Unpublished manuscript, US National Library of Medicine Archives, Bethesda, MD.
75. National Library of Medicine. Fact sheet: MEDLINE®. [Web document]. US Department of Health, Education, and Welfare, Public Health Service, National Institutes of Health, National Library of Medicine. US National Library of Medicine Archives, Bethesda, MD, 2007. [cited 4 Mar 2007]. <http://www.nlm.nih.gov/pubs/factsheets/medline.html>.
76. National Library of Medicine. Fact sheet PubMed®: MEDLINE® Retrieval on the World Wide Web fact sheet. [Web document]. Bethesda, MD: US Department of Health, Education, and Welfare, Public Health Service, National Institutes of Health, National Library of Medicine. US National Library of Medicine Archives, 2007. [cited 4 Mar 2007]. <www.nlm.nih.gov/pubs/factsheets/pubmed.html>.

AUTHOR'S AFFILIATION

Cheryl Rae Dee, PhD, cdee@cas.usf.edu, Assistant Professor, School of Library and Information Science, University of South Florida, Lakeland, FL 33803

Received December 2006; accepted May 2007