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VARIATIONS: A Digital Music Library System at Indiana University

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ABSTRACT

The field of music provides an interesting context for the development of digital library systems due to the variety of information formats used by music students and scholars. The VARIATIONS digital library project at Indiana University currently delivers online access to sound recordings from the collections of IU's William and Gayle Cook Music Library and is developing access to musical score images and other formats. This paper covers the motivations for the creation of VARIATIONS, an overview of its operation and implementation, user reactions to the system, and future plans for development.

Keywords

Digital libraries, music libraries, digital audio.

1. INTRODUCTION

The VARIATIONS project at Indiana University Bloomington currently provides online access within the William and Gayle Cook Music Library to over 5,000 sound recordings from the library's collections. Unlike many digital library projects whose primary goal is to provide broader access to unique and/or archival collections, VARIATIONS began building its digital collection from standard musical repertoire identified as central to the teaching mission of the Indiana University School of Music. Approximately 1,600 talented music students from all over the world pursue their musical studies each year at this highly respected institution whose instructional program features a full opera program, over 1,000 performances per year, and a full range of academic and performance studies. The William and Gayle Cook Music Library, opened for occupancy in January 1996, is a state of the art facility designed to combine new technologies with access to traditional materials in support of all levels of music research and study. Online sound access, representing the first phase of the VARIATIONS project, quickly became an essential component of library services in support of the instructional program of the School of Music after its implementation in April 1996. Presently, VARIATIONS provides access to an average of 500 sound recordings per day for library users and the database is growing at a rate of up to 75 hours of music per week. Selections from a broad range of musical material including operas, songs, instrumental music, jazz, rock, and world music make up the VARIATIONS database.

Digital library projects focusing on music content are relatively rare, although several do exist. Examples include the EC-sponsored JUKEBOX [6] and HARMONICA [7] projects, the University of Surrey's Project PATRON [14, 21], and a variety of online musical score image collections (often focusing on popular sheet music collections) [3, 13]. In addition, a number of projects within the IR community have focused on representation of music notation and content-based searching of notation databases [1, 9, 15]. VARIATIONS is somewhat unique in dealing with a large collection of audio rather than notation content and a user base of students actively using the digital library as a replacement for some of the functions of a traditional university music library.

Although VARIATIONS primarily serves as an electronic reserves system for sound recordings at present, development efforts are underway to complete the original vision of the project as a database containing a variety of music information objects, both local and global, accessed through a graphical user interface. Sound recordings from the Hoagy Carmichael Collection held by the IU Archives of Traditional Music will be added to VARIATIONS as part of a project funded by a grant from the federal Institute of Museum and Library Services [10]. In addition, a prototype application for viewing musical scores and sound recording liner notes online will be tested with users during 1999.

The remainder of this paper covers the motivations for the creation of VARIATIONS, an overview of its operation and implementation, user reactions to the system, and future plans for its continued development. This paper serves to update the information presented by Fenske and Dunn shortly after the project's initial implementation in 1996 [4]. Additional information is available on the project's home page [11].

2. BACKGROUND

The original vision for the VARIATIONS project, articulated in a 1990 paper by Michael Burroughs and David Fenske [2], evolved from an interest in applying new multimedia technologies to music research and instruction. The term VARIATIONS, derived from the musical form *theme and variations*, was used to describe a system that would integrate a database of music information

objects (text, images, scores, sound, and a catalog) with a graphically oriented hypermedia user interface. Since music students and researchers typically study their art in a variety of informational formats, the model provided a way to address relevant pedagogical and library service challenges while offering an excellent vehicle for research into new multimedia technologies.

It was decided to focus on sound in the first phase of the project for several reasons:

- Students in the IU School of Music listened to sound recordings in the Music Library as an integral part of their coursework and typically requested retrieval of over 5,500 sound recordings per month from closed stacks.

- In order to preserve fragile formats, libraries frequently distributed sound to patrons from behind a circulation desk or dubbed copies for patron use. VARIATIONS was seen as an updated version of this basic practice.

- In the early 1990s, others had solved some problems associated with online access to text and graphics but no one had successfully provided high-quality networked access to large databases of sound.

Course reserves, a collection of sound recordings representing class assignments, were identified as a logical starting point for building the database. Some of the justifications were:

- Usage statistics showed that nearly half of sound recording use came from course reserves.

- Individual sound recordings were often used in multiple classes.

- Many reserve sound recordings were dubbed onto cassette tape to protect fragile originals and to provide limited additional access to the materials. In many cases the audio quality of these tapes was poor due to amateur recording practices, use of inexpensive tape, and deterioration over many playbacks.

- Observations of usage patterns for reserve sound recordings revealed that large numbers of students would want to listen to the same few items in any given day. A system with the ability to offer multiple access to the same file at any one time would fulfill patron demands much more effectively than the traditional system of circulating tapes.

The emergence in the early-to-mid-1990s of high-fidelity PC audio hardware, streaming multimedia servers, hierarchical storage management systems, and the World Wide Web made such a system possible. We created a prototype model of this concept in 1995 using an undergraduate music theory and literature course that was taught every semester to about 200 students. The prototype premiered on April 1, 1996, received favorable feedback on usability, and forms the basis of the operational system in use today.

3. USER ACCESS

The current VARIATIONS system allows the user to access sound recordings in either of two ways: course reserve list or catalog search.

3.1 Course Reserves

The most common scenario for use of VARIATIONS occurs when a student needs to listen to a particular recording for a class assignment. Typically, the instructor of the course has asked Music Library staff to place the recording on reserve, which means ensuring that the work has been digitized and is listed on the course's reserve list web page. To access a reserve recording, the student goes to a computer workstation in the Music Library, launches a web browser to the Music Library's home page, clicks on the "Course Reserves" link, selects the course number and instructor from a list, and then selects the recording from a list of reserve items for that course organized by composer and title.

3.2 Catalog Access

The other major access scenario occurs when a user wants to locate a recording of a particular piece of music for research or study independent of any particular class assignment. In this case, access is provided through IUCAT, Indiana University's statewide online library catalog system, based on NOTIS LMS software. Almost all recordings which reside physically in the Music Library are already represented by standard USMARC bibliographic records in IUCAT. Rather than invest much human labor in creating a new database with its own search capabilities and idiosyncrasies, we chose to repurpose this existing database with which many users are already familiar. This decision also provides the benefit of allowing users to search for recordings without knowledge of whether they are available online. If a desired item is not available online, the search produces a call number which may be used to retrieve the physical recording from the shelf. If it is available online, the search also results in a World Wide Web URL for the item, displayed along with the other bibliographic information. Following standard practice, the URL is stored in the 856 field of the MARC bibliographic record, designated for electronic access by the Library of Congress. While the search interface to IUCAT is currently character-based and command-driven, IU is planning to move to a graphical web-based catalog interface which will allow even easier navigation from the catalog to online collections.

In either scenario, the user ultimately arrives at a web page which lists the sound files available for a given recording, with information below each file about what musical works, or segments of works, are contained in each. When the user clicks on a sound file, a *VARIATIONS Player* application launches and begins playing the file through headphones attached to the workstation. Using the player, the user may navigate within the file by dragging a slider to a desired point, moving backward and forward between segments or "tracks" within the file, selecting a particular track by name, and a variety of other means. Multiple players may be opened at once by a single user to facilitate study of comparisons among multiple recordings, and multiple users may use the same sound file at once, each having independent random access control within the file.

4. TECHNICAL IMPLEMENTATION

VARIATIONS is really more of a system integration project than a pure software development project. Throughout the life of VARIATIONS, one of the main design principles has been to use as many off-the-shelf hardware and software products as possible, rather than developing in-house or contracting out the development of a custom solution solely for IU. The components developed by IU specifically for VARIATIONS serve to glue the off-the-shelf products together to create a functional digital library system. We believe that this has resulted in a system that can be supported using fewer staff and which is more financially sustainable than one developed from scratch. This approach also led to the involvement of IBM as a technology partner on the project. IBM was selected primarily because they were able to provide the largest number of components needed for the system, including server hardware and software, desktop PCs, and networking equipment. Lack of "finger-pointing" between vendors over compatibility issues was seen as a benefit when working with a project involving many emerging technologies.

4.1 Audio Capture

Audio capture for VARIATIONS is performed in-house by student technicians in the Music Library's User Services department. Audio source materials in the library's collections exist in a variety of analog and digital formats, including long-playing phonograph record (LP), open reel tape, cassette tape, digital audio tape (DAT), and compact disc (CD). Three Windows NT-based digital audio workstations are used for conversion, equipped with audio digitization hardware (Event's Echo Gina PCI card) and software (Sound Forge XP from Sonic Foundry and Disc-to-Disk from Microtest).

As would be expected, analog sources prove more difficult to work with than digital ones. For analog sources, the process of digitization is roughly equivalent to that of dubbing a cassette copy of an original. Recording levels must be carefully adjusted and the playback of the original item must be closely monitored for skips and other problems. As an item is being digitized, the technician must note the timings of track breaks so that these access points may later be made available to users of VARIATIONS. The process of capturing audio from a CD, on the other hand, is more like copying a file. If the CD is undamaged, there is little chance of an error occurring in the conversion process. Precise track start times may also be extracted directly from the CD rather than keyed in by the technician.

Whether the source is digital or analog, we use an audio sampling rate of 44.1 kHz and sample size of 16 bits with two channels (stereo). The two primary reasons for selecting these parameters are that they are the same as those used by audio CDs and are supported by audio playback hardware commonly found in most PCs. The file format used is Microsoft's WAV, which is almost a de facto standard for digital audio on PCs. The format is well-documented [16] and is supported by a variety of software tools on multiple platforms. At this point, we are not using any automated means of noise reduction on digital copies of analog recordings, but nothing we are doing should prevent us from undertaking that task in the future using previously digitized files.

The track start times for the recording are recorded in a text file by the technician, along with the track descriptions present on the original item's label, jacket, or accompanying booklet. This "track file" and the sound file are transferred to a temporary holding area on an IBM RS/6000 AIX server. Each night, a batch job runs on this server which compresses these CD quality WAV files into MPEG-1 layer II format, at a compression ratio of approximately 3.6:1, using software provided by IBM. This compression step is performed mainly to reduce the need for storage space and network bandwidth while preserving most of the quality of the original. The selections of compression format ratio were based on the subjective opinions of a number of faculty, students, and library staff who did comparison listening to original and compressed versions of a variety of works. MPEG-1 layer II is a lossy perceptual audio encoding method developed based on psychoacoustic models of how the human mind interprets sound. If a low enough compression ratio is used, most of the information removed from an audio stream by an MPEG audio encoder represents sound which cannot be perceived by most people. At the time the system was originally developed, MPEG-1 layers I and II were the only significant options available for high-quality audio compression. Within the past few years, MPEG-1 layer III (or "MP3" as it is popularly known) has emerged as a growing force in the Internet audio world, along with a variety of other contenders such as Dolby AC-3 [20] and MPEG-2 AAC [19]. Over the coming year, we plan to investigate these formats as possible replacements for MPEG-1 layer II. We are retaining the original WAV files on tape for potential future recompression.

4.2 Content storage and distribution

Conceptually, objects stored in VARIATIONS can be thought of as consisting of a metadata file plus one or more sound files (see figure 1). Each object has a unique seven character alphanumeric name that matches the ID of the IUCAT bibliographic record which describes it. The names of the sound files consist of the seven character object name plus a unique one-character sequence identifier.

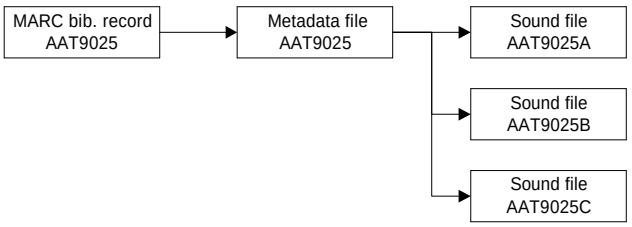

Figure 1: VARIATIONS information architecture

Metadata is commonly divided into at least three types: descriptive, administrative, and structural [5]. In VARIATIONS, most descriptive metadata used by users for purposes of searching and identification is found in the original USMARC bibliographic record (including composer, title, performer, subject headings, etc.). The VARIATIONS metadata file is an ASCII text file using a locally defined structure that is stored on our web server. This file contains additional metadata elements which supplement the MARC record, including administrative information regarding the digital files (format, size, date digitized, digitizing technician,

etc.) and structural information including the names and time offsets of tracks found in each of the sound files, derived from the track files created in the audio capture process. This structural information is required in order to give the user the same level of access as having the record or CD in hand.

A two-level storage hierarchy is used in VARIATIONS for the digital audio files themselves. An *archive server* stores the primary copies of all sound files on tape cartridges in an automated tape library, while a *playback server* caches the most recently used sound files on a hard disk array for fast access and streaming delivery to clients. This hierarchy reflects the typical usage patterns of an academic library, in which only a small portion of the collection is in use at any given time.

The archive server consists of an IBM 3494 Tape Library Dataserver containing two IBM 3590 Magstar tape drives, attached to an IBM RS/6000 J30 SMP server running IBM's ADSTAR Distributed Storage Manager (ADSM) software. Each 3590 tape cartridge holds 10 GB of data and the tape library contains approximately 200 cartridge slots, for a total storage capacity of 2 TB or over 9,000 hours of compressed audio. An analysis showed that, for our application, tape was preferred over optical jukebox technology. Because of tape's poor random access performance and optical technology's poor data transfer rates, neither is sufficient for direct streaming from source media to client workstation when access by multiple simultaneous clients is required. Thus in either case a sound file must be copied to hard disk for playback, and the faster sequential read performance of 3590 tape combined with its lower cost per megabyte caused us to select tape rather than optical.

The playback server is an IBM RS/6000 59H system with 120 GB of SCSI hard disk storage, connected to the archive server by a 155 megabit/second ATM link. The disk storage on the playback server acts as a cache of the most recently used audio files from the full collection of files stored on tape in the archive server. Initially, this server ran IBM's Multimedia Server for AIX software but was recently upgraded to VideoCharger, a successor product from IBM. Both Multimedia Server and VideoCharger use a file system known as Tiger Shark [8], which provides for striping of multimedia files across multiple drives, replication of files across multiple drives and servers, and scheduling of real-time reads and writes to guarantee quality of service. The primary difference between the two is that Multimedia Server used the NFS (Network File System) protocol for streaming network delivery while VideoCharger utilizes RTP (Real Time Protocol) for network delivery and RTSP (Real Time Streaming Protocol) for control (play, pause, stop, seek, etc.). These IETF standards-track protocols [17, 18] are emerging as a common means for streaming multimedia delivery and control for a variety of multimedia client and server products, most recently in Apple Computer's QuickTime version 4.

The software which links the archive and playback servers together was developed at IU, as we were unable to find any LAN-based streaming multimedia servers in 1995 which interfaced directly with hierarchical storage management systems such as ADSM. This software component, known as the VARIATIONS Retrieval System, or VRS, logically sits in-between the web browser on the client and the VideoCharger CGI script used to initiate a new playback session on the server, and intercepts requests for access to audio files. Requests for files which are not present on the VideoCharger playback server initiate an ADSM client process to retrieve the file from the archive server (see figure 2). IBM has since introduced such support in VideoCharger, but at the present time we are still using our custom solution because moving to IBM's support would require migration of over one terabyte of existing sound files. In addition, our solution allows us to front our ADSM-based audio file store with a variety of different media servers (e.g., test versions of VideoCharger and other MPEG-capable streaming media servers).

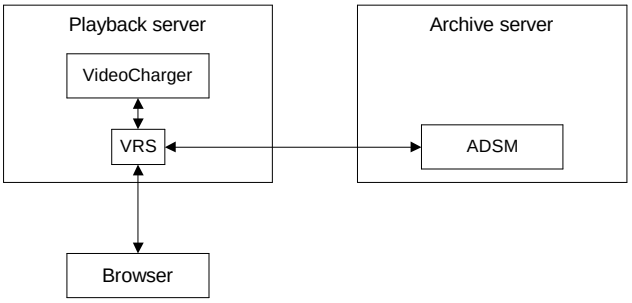

Figure 2: VideoCharger-ADSM interface

We expected that we might need to make adjustments to the hardware configurations of the servers once we observed actual usage patterns, but performance has in fact been better than expected. For the time period of May 1, 1998 to May 1, 1999, the hit rate of files found on the playback server was 83% and the average user wait time for a tape retrieval was under three minutes.

4.3 Clients

User access to VARIATIONS is provided from approximately 60 Windows NT Pentium-based PCs located in the Music Library. These workstations not only provide access to VARIATIONS, but also provide users with access to general purpose applications (word processing, e-mail, spreadsheets, etc.), bibliographic databases, and music applications (ear training, music notation, composition, instructional CD-ROMs). For VARIATIONS, these machines are equipped with high-quality sound cards and headphone amplifiers as well as the Microsoft ActiveMovie MPEG decoder, IBM's VideoCharger client software, and the VARIATIONS Player helper application.

The VARIATIONS Player is a Microsoft Visual C++ Windows application developed by IU in order to provide the user with navigation capabilities within a sound file. The player retrieves the metadata file from the server along with the audio so that it may display information to the user about track names and start points (see figure 3). The player controls playback of the audio file from the server using an API provided by IBM's VideoCharger client software. We are in the process of adapting the player to use Apple's QuickTime 4 API for RTP/RTSP streaming. These workstations are networked using a combination of 25 megabit/second ATM and 10 megabit/second switched Ethernet. In planning the system, we made the assumption that ATM would be quickly adopted by multimedia networking vendors as a preferred technology, given its ability to provide quality of service guarantees. However, the Internet explosion

Figure 3: VARIATIONS Player

	Reserve Sound Recording Circulation	General Collection Sound Recording Circulation	VARIATIONS Player Launches
July-Dec. 1995	16000	16875	0
Jan.-June 1996	18782	12345	6028
July-Dec. 1996	7289	14882	53719
Jan.-June 1997	9024	13663	55905
July-Dec. 1997	4241	15087	80144
Jan.-June 1998	4722	13395	81941
July-Dec. 1998	4797	13235	89690

Table 1: Traditional sound recording circulation vs. VARIATIONS use

due to the emergence of the web, along with slow deployment of ATM to the desktop by customers due to ATM's high cost and complexity, have caused the multimedia networking industry to remain with IP rather than moving toward ATM. New workstations in the Music Library are being connected via Ethernet and we expect the library's ATM network to actually be decommissioned within the coming year.

5. USER REACTION

Our primary means of analyzing user reactions to the system have been:

- Usage statistics for VARIATIONS and circulation statistics for the physical collection.
- Comments and questions sent in via an online feedback form linked from many web pages within VARIATIONS.
- Informal comments from students and faculty to library staff. Observations by library staff.

Table 1 presents usage statistics for reserve sound recordings, general sound recordings, and VARIATIONS sound recordings from July 1995 through December 1998. We can make some observations about this data and suggest questions for further study.

A brief glance at the VARIATIONS usage statistics shows that library patrons are generally using VARIATIONS more as the months go by, are using it very heavily during certain periods, and are listening to far more sound recording titles than they did using traditional formats. The patterns of very high and very low usage coincide with the typical demands of the academic semester and were observable in more traditional settings as well. From a library service perspective, the extremely high usage patterns (we have observed over 4,000 player launches per day during exam weeks) suggest that VARIATIONS is making it possible for the Music Library to offer a much higher level of service to students who study for exams at the last minute than we were able to do in the past. Casual observation of student behavior also indicates that some students have figured out ways to use VARIATIONS to compare and contrast various compositions on their study list, a favored pedagogical technique that was more difficult when they were limited to only one reserve tape at a time.

Circulation of reserve sound recordings in traditional formats has also declined dramatically since VARIATIONS became operational. The Music Library continues to offer faculty members the option of placing traditional materials–either cassette anthologies or library-owned recordings–on reserve and most of them take advantage of this option. The statistics indicate that, when given a choice, students are using VARIATIONS rather than traditional materials. Lack of sufficient VARIATIONS-capable workstations during peak times probably represents the greatest obstacle to removing the traditional backups, a move that would be desirable from the standpoint of efficient use of library staff time.

One of the more interesting revelations from the usage statistics is that circulation of traditional sound recordings from the general collection, presumably those used for individual study and research rather than for class assignments, has remained relatively stable over a five-year period. One possible explanation is that students are using VARIATIONS largely for reserves rather than for personal study and research. Another possibility is that students are simply doing more listening.

The comment forms associated with the application have provided helpful information throughout the development and implementation process. Some of the comments take the form of problem reports such as "I tried to play this file and it wouldn't work" or "There seems to be a skip in the sound file. Could you fix it?" In general, the number of digitizing problems or track metadata errors is remarkably low given the fact that the digitizers are work-study students. Most problem reports reflect software and hardware problems with individual PCs rather than with the VARIATIONS system itself. Users also use the form to send general comments about the system, both positive and negative. Most of the negative comments refer to expanded access: the desire to have the application available from Macintosh computers, remote access, more computers in the Music Library, and, early in implementation, the desire to have more materials available online.

Informal comments from students and faculty have generally been positive with regard to the pedagogical possibilities of the project, the high quality of the audio, and the improvement in library services as a result of the project. Library staff have noticed a remarkable decline in stress levels during exam weeks since students who formerly lined up at the circulation desk now cluster around the computers and help themselves to listening examples.

In continuing the development of VARIATIONS, we plan to conduct user surveys and usability tests to ensure that new features added to the system continue to enhance the learning experience for its users.

6. CONCLUSIONS AND FUTURE WORK

VARIATIONS has been successful in providing improved access to the IU Music Library's sound recording collection for its existing user base, particularly for course reserve listening. However, this is a small step towards what a true digital music library might offer. We plan to continue to enhance the VARIATIONS system, building upon our experiences to date as well as those of other music digital library projects.

This work will include fulfilling the original vision of VARIATIONS by expanding the range of data formats to include liner notes, musical score images, notation files, and video recordings. While image scanning, and to a lesser extent digital video, are fairly well established technologies, music poses particular challenges in each area. In the case of music score images, the primary problem is that of reducing the resolution of the image so that the entire height of a score page may be displayed on a screen at once while still remaining legible. We are about to deploy a prototype set of scanned public domain opera scores to gauge student opinion regarding their usability. In the case of video, especially for items such as opera performances, our experiments to date using MPEG-1 video compression have not been very successful, primarily due to lack of sharp detail. It is our hope that MPEG-2 and successor technologies will be more suitable, but these will require higher network bandwidths and file

sizes and more expensive compression hardware. We are working with IBM's Digital Library software to examine its suitability for use in integrating access to multiple information formats such as images, audio, and video. In addition to adding information formats, we would like to explore the integration of existing content-based search tools, such as those mentioned earlier, into the system in addition to the current bibliographic search capabilities. Such tools would allow users to search for motifs, chord progressions, etc., across sets of notation files and/or sound files.

We also plan to expand access to the system beyond the walls of the Music Library to students working elsewhere on the IU Bloomington campus. We plan eventually to provide access to remote student users in their homes or on other IU campuses across the state of Indiana, and perhaps to students and scholars elsewhere in the world. The relatively high sustained bandwidth requirements of high fidelity compressed audio (128-384 kilobit/second) and video (1.5+ megabit/second) streams would have prevented their use even a few years ago in most campus networks, and continue to pose problems for dial-up and remote Internet connections. Delivery of VARIATIONS services will require the use of high bandwidth network backbone and access services with quality of service (QoS) and/or class of service (CoS) facilities to allow guaranteed bandwidth or higher priority service for real-time multimedia network traffic. In conjunction with Internet2 and IBM, we have demonstrated VARIATIONS operating across the National Science Foundation's vBNS (Very High Performance Backbone Network Service) backbone, and Indiana University's involvement in managing the new nationwide Abilene Internet2 backbone network should prove beneficial to our work in this area. In addition to improved network services, we will need to investigate alternative data formats and compression methods, perhaps looking at mechanisms for selecting among multiple versions of each sound file based on the level of network connectivity between server and user.

Expansion of access will also require further investigation of the intellectual property issues surrounding music and sound recordings and their use in educational settings and digital libraries. A determination will need to be made as to when fair use and other exceptions provided by copyright law may be invoked and what the most practical options are for securing permissions and licenses when these exceptions do not apply. We will also need to explore technical facilities to assist in complying with exceptions and licenses, including user authentication, access control, encryption, software controls over playback, etc. Music poses particular copyright complexities, given the multiple rights holders involved (for both the underlying musical work and the recording).

Rather than simply distributing Indiana's collections to other institutions and users, we ultimately see VARIATIONS as part of a distributed global digital music library with content contributed by many different libraries and institutions. In addition to networking issues discussed above, this will raise issues of distributed storage and caching strategies, distributed vs. centralized metadata, and unique object naming schemes.

Finally, as part of expanding the range of formats and points of access, we plan to enable users to create applications which access the VARIATIONS collection in more flexible and sophisticated ways than are presently possible. This will likely include development of an application architecture in which software components that can manipulate library content (sound players, score viewers, search tools, etc.) are accessible from the digital library in addition to the content itself. It will also require development of metadata standards for musical objects which allow structural information, including track listings, structural analyses, and links between multiple versions of the same musical work, to be stored and retrieved by these applications. Rather than our current proprietary metadata file, a standards-based approach using SGML/XML is anticipated. Faculty members at IU are currently working on a music theory instructional application which will be an ideal testbed for this enhanced functionality. [12]

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