Creating the Digital Music Library

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A Proposal by Indiana University to the National Science Foundation

Program Announcement NSF 98-63: Digital Libraries Initiative, Phase 2 (DLI2)

1.0 Introduction

1.1 The Digital Music Library

Digital representations of music present unique challenges to the design of a digital library system, in which a single musical work may be represented in a wide range of formats. One Beethoven piano sonata, for example, may exist in a music library in several dozen audio recordings by different performers, in several editions of printed scores issued by different publishers or even the same publisher, and in a variety of digital score notation formats. Conveying each of these formats, editions, and performances of the piece coherently within a digital context poses technical challenges, yet each representation is essential to a true digital music library. The full value of the digital music library will be realized as the library becomes a collection both of digital content and of networked services that make the content integral to music instruction and research.

The material in a digital music library presents a complex array of copyright challenges that affect the rights of composers, performers, publishers, and recording companies. The establishment of a digital music library will rely on the multiple limitations and exceptions applicable to musical compositions, recordings, and performances, and the potential for a digital music library to itself be a protectible work.

Moreover, a digital library of music serves a diverse group of users--students, teachers, and scholars of music, as well as a public interested in private study and listening--that has thus far been largely ignored by those conducting digital library research, development, and studies of usability.

Past digital library efforts in music have addressed some of these problems: Indiana University's VARIATIONS project [8][20A][21] and the EC-sponsored JUKEBOX project [23] have addressed aspects of digital audio storage and delivery. Projects at Johns Hopkins [42] and Duke [30] have dealt with access to historical collections of printed sheet music. The University of Surrey's Project PATRON [44][52] has provided access to music in the form of audio, video, and score images to a local user base through a common web interface. Case Western Reserve's Musical Scores project [4] developed a user interface to link musical score images with sound files. (Additional research dealing more specifically with the digital representation of music scores is discussed in section 4.1, below.)

While much research has been done, there is as yet no single integrated digital music library that delivers what we will build. Indiana University's development of a Digital Music Library (DML) will advance substantially beyond prior efforts in this field, in terms of the *collection* that is made accessible, the *system* and functions that are implemented, and the *users* who are served.

1.2 Collection, System, and Users

The DML will provide users access to a *collection* of music in several formats from a range of musical styles and types. Users will listen to sound recordings of musical performances; browse and display images of published scores; view encoded score notation files; have notation translated into MIDI format for audio playback; retrieve documents and text files that relate to musical works; read historical, biographical, and critical essays; and make use of active links that connect a musical work in one format to a representation in a different format.

As a digital library *system*, the DML will have two chief aspects. First, as an integrated multimedia library system, the DML will provide navigation, search, and retrieval functions for a large and diverse information space. This will include bibliographic search; advanced search based on descriptive metadata; retrieval and synchronized playback of recorded music, MIDI files and encoded music notation files; access to structural metadata for manipulation of and navigation within individual recordings or other music representations; access control and authentication services; and administrative metadata for rights management.

Second, the DML will provide a software framework to make digital music objects (music sound recordings, score notation files, text files, etc.) accessible to music instructors and application developers, using a component-based programming architecture. This framework will serve as the foundation for developing and delivering software applications that integrate the collections of the DML into teaching and research in the field of music.

The DML will serve a large number of *users* and several user types. Students and scholars of music will search, navigate, and retrieve information from the DML system. Music instructors will use the DML and its associated software framework to develop instructional applications such as lectures and exercises, and music students will use these applications to engage in active learning, both individually and collaboratively. Music librarians will use the DML to build collections of music and music-related information in multiple formats, and make selected materials available to library patrons, for example in the form of online "reserve" listening lists.

The DML will provide access to users in two chief geographic categories: (1) students, faculty, librarians and library patrons at Indiana University; and (2) users at several remote locations in the U.S. and overseas. Remote locations include: University of Illinois at Urbana-Champaign, University of Massachusetts at Amherst, Northwestern University, King's College-London, Loughborough University, Oxford University, and Waseda University. More locations may be added, as needed, during the project. Additionally, access will be made available to the general public, likely to a subset of the DML's collection, as permitted by copyright or licensing restrictions.

Indiana University's development and demonstration of this integrated digital music library testbed for access and instruction will significantly advance the state of knowledge and practice in digital libraries. This project will seek to move digital libraries into a new phase -- beyond creating, organizing, and disseminating digital objects -- to the seamless immersion of digital content into the education and research process.

2.0 Project Description: Overview

In response to Program Announcement NSF 98-63, Digital Library Initiative-Phase 2 (DLI2) Indiana University (IU) proposes:

1. To establish a Digital Music Library (DML) **testbed system**, using IU's highly successful VARIATIONS digital library application as a foundation, greatly expanding it with additional representations of music in other media, additional metadata and new software tools for enhanced intellectual access and navigation, and by providing and demonstrating new capabilities for remote network access.
2. To develop **applications** for education and research in the field of music that are based on the evolving collections and functions of the DML.
3. To use the DML for **digital library research** in these key areas: usability and instruction, and intellectual property implications for various representations of music.

IU is uniquely qualified in each of these areas to address the program goals outlined for DLI2.

Testbed System Research and Development. The DML project will focus on three chief areas of research and development: system architecture, including content representation and metadata standards; component-based application architecture; and network services. We will test and evaluate commercial technologies, primarily for multimedia and storage management; develop custom software solutions for the needs of the music library community; integrate commercial and custom software products; and test and evaluate prototype systems for music instruction and library services, locally at Indiana University, and at a number of satellite sites, in the U.S. and overseas. DML testbed research and development will be supported by IU's University Information Technology Services organization, an international leader in advanced networking initiatives and applications.

Applications. Applications using the DML for music education and research will be designed and developed by faculty from the IU School of Music, widely respected as one of the world's leading institutions for the study of music. Researchers from the human computer interaction (HCI) laboratory in the IU School of Library and Information Science will be a partner in application design. Applications will build on a successful track record of pedagogical software development and innovation in music education and research at IU, which includes of the Multimedia Music Theory Teaching project <http://theory.music.indiana.edu/mmtt/>, the Music Fundamentals Online project <http://theory.music.indiana.edu/mfo/>, and the development of courses in music for non-majors using instructional software from the *On*course project <http://oncourse.iu.edu/>. Applications will also provide library users with intellectual access and advanced navigation capabilities to the DML, substantially improving upon and advancing beyond the capabilities of the VARIATIONS digital music library system <http://www.music.indiana.edu/variations/>.

Research. The DML will serve as a rich foundation for research in instruction, usability, and intellectual property rights. Research will be closely coordinated with testbed and application development, so that research outcomes will be incorporated into testbed and application development activities. Usability research will be integral to creation of the DML. Formative user testing will be conducted throughout the project, with results incorporated in the design process; summative user testing will be employed for periodic and overall evaluation of the system design. Copyright research will help identify particular content for inclusion in the DML. Early stages of the research will identify categories of works that are in the public domain and without copyright restrictions; later stages will identify the possibilities for providing access to protected works under the law and under licensing agreements, including design features that may satisfy these requirements. The DML will also be made available to additional investigators through "satellite site" agreements, as a testbed for digital library research at other institutions and in other fields.

This proposal will address a community of users in the arts and humanities -- students, teachers, and scholars of music -- who have not previously been the focus of attention in digital library research and development. The project will engage an interdisciplinary team of scholars with essential subject area knowledge and support them with an expert team of librarians and information technologists. Research in usability, instruction, intellectual property, and the educational impact of digital libraries will be broadly applicable within the subject domain, and many of the findings may be generalized to digital library applications in other disciplines. Testbed and application development achievements will be applicable or generalizable to digital libraries throughout the arts and humanities, as well as to other fields involving rich content and representations in multiple media, especially those involving time-based and synchronized media. Access will be provided to students and scholars of music at locations across the U.S., and in the U.K. and Japan, as part of the project's "satellite site" program for demonstration and evaluation of the DML. This proposal builds on IU's demonstrated commitment to the continued development and operation of digital music library services; access to the collections and systems developed here will be sustained beyond the end of this project.

3.0 Digital Music Library Scenarios

One can best understand the inspiration for this project by imagining how a digital music library will be used. From undergraduates and professors to lifelong learners, the Digital Music Library (DML) will integrate information and the means of access in ways that were never before possible. Following are brief scenarios describing a few of the possible uses of the Digital Music Library.

Scenario 1: A typical music library patron

Claire is an undergraduate voice student whose teacher suggests that she find a copy of the aria "Batti, batti" to use in her next lesson. She types "batti batti" into the DML's search form and retrieves a hotlinked list of twelve sound recordings, two vocal scores, and one full score of Mozart's opera *Don Giovanni*, each containing an inner link to the aria. Further links to reviews and critical commentaries on the work are also presented. She selects one of the piano-vocal scores to view on the screen while listening to a recorded performance of the aria. After deciding she'd like to work on the aria, she prints a copy of the public domain score and takes it with her to the practice room.

Scenario 2: The professor as teacher

Professor Smith teaches an undergraduate course in music theory. Using the digital collections and software tools of the Digital Music Library, she now can create assignments that include meaningful comparative studies. She selects the musical form tool (called the "Digital Timeliner"), then she listens to an audio file and segments it by means of mouse clicks that mark timepoints in the audio stream. These segments are displayed on a timeline as a series of consecutive "bubbles," each of which can be heard by clicking on it. In this way, her students can compare segments (which might be measures, phrases, or larger sections) for similarities and differences. Using the music score tool, her students will be able to select any segment of a score and hear it, either as a recorded performance or as a MIDI (Musical Instrument Digital Interface) sound source. By putting each of the four parts of a string quartet example on a separate track, for example, Prof. Smith can suppress any track and have students improvise a new part for the example using a MIDI keyboard. Students can improvise in time with the music, save their improvisation, then play back the "re-composed" example. Students can also practice transcribing music from recordings (as many jazz musicians do) to learn about musical style, structure, and improvisation.

Scenario 3: The student as active learner

William is an undergraduate enrolled in Prof. Smith's course. His assignment is to create a hypermedia presentation showing the various forms of the keyboard dance suite as manifest in compositions during the period 1700-1750 in Germany, France, and Italy. As part of his presentation, he is to discuss the order of movements, metric scheme, and general differences in style of the individual dances. William searches through the Digital Music Library for pertinent examples. He accesses online music dictionaries for definitions and examples, as well as relevant articles and citations within databases. He locates particular composers and specific compositions in the digital database to which he listens for general style differences. Within his assignment, he cuts and pastes listings of different suite movement organizations and then links each one to a particular composer and a particular composition. To submit his assignment, he sends it electronically to Prof. Smith who will, in turn, post her comments within the body of the presentation and send them to William. William can then archive his assignment within his electronic portfolio, from which eventually he will be able to develop a CD-ROM resume containing examples of his work.

The Digital Music Library will enable these and other scenarios, which cannot be realized with current technologies, to become realities by making available a complete range of digital library services for music.

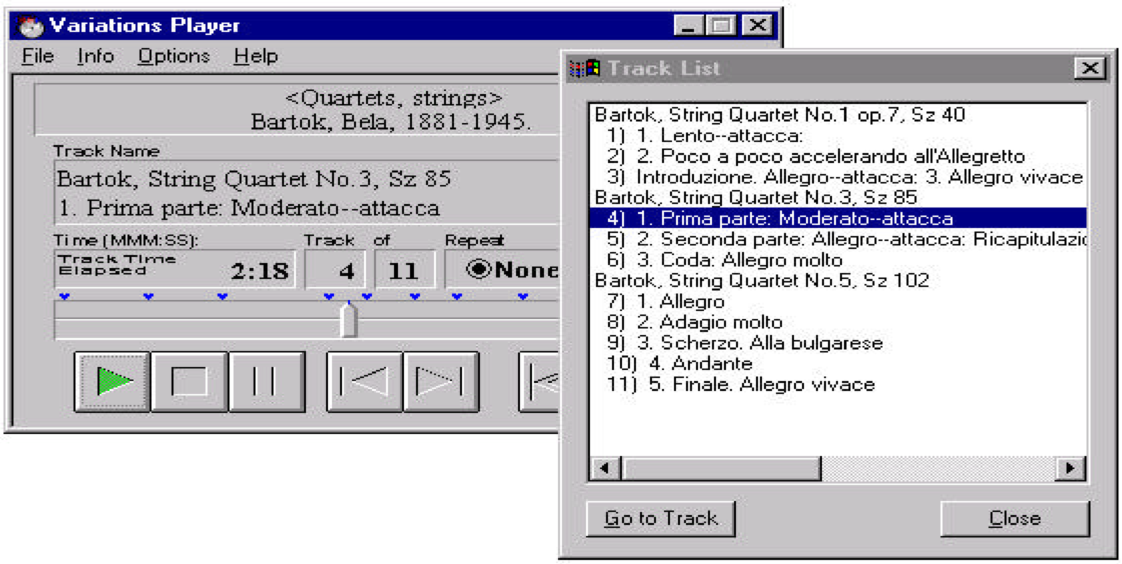
4.0 Research and Development: Creating a Testbed System

Development of the Digital Music Library (DML) testbed system will focus on five chief areas:

1. Specification of *content formats* for the library.
2. Definition of descriptive, structural, and administrative *metadata* elements and structures for music, drawing on existing descriptive metadata in the MARC-based online catalog.
3. Development of *repository services* for storage, management, search, and retrieval of digital objects.

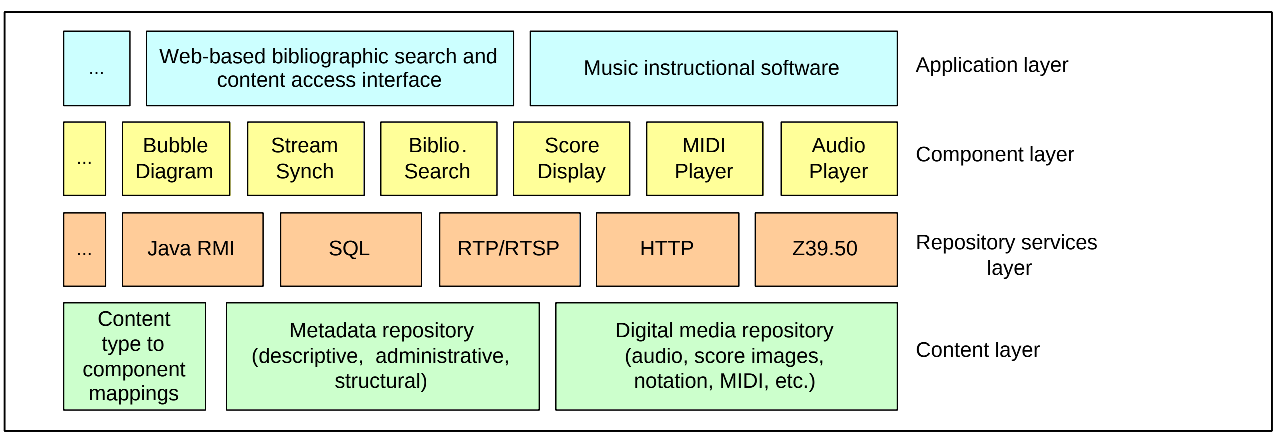
4. Design and development of a component-based *application architecture* to allow use of the DML as a platform for developing domain-specific applications in the area of music which have access to the content of the library.
5. Design of *network services* to provide access to the audio content of the DML, including investigation of network performance requirements, and examination of various network architectures for support of applications at different levels of quality.

Development of the DML will make use of, and greatly expand upon, the VARIATIONS digital sound recording library system at Indiana University. The current system provides a subset of the services that are needed for the DML: the architecture consists of an "archive server" which manages an automated tape library on which the audio content is stored, a streaming media server which caches content from the archive server and streams it to users, a web server which stores administrative and structural metadata for the recordings, and a Windows sound player (see figure: Player Application) which uses this metadata to allow direct access to "tracks" within a sound file.



VARIATIONS Player Application

The DML testbed system architecture will greatly expand upon this existing system to add facilities for storage and delivery of music in formats beyond audio: score images, music notation files, and MIDI (Musical Instrument Digital Interface) files. Mechanisms will be added for authentication, authorization, and access control, as well as storage, search, and retrieval of enhanced administrative and structural metadata. A layered view of the proposed DML system architecture is shown below.



General DML Architecture

The base layer of the library consists of repositories for digital content and metadata. Access to these repositories is presented through a set of interfaces and network protocols. Users will interact with the library through applications written directly to this repository services layer, or through instructional or research applications developed by composing a set of software components for access to the library in an application framework such as JavaBeans [37].

4.1 Testbed Research and Development: Content Formats

The format currently used by VARIATIONS for sound files is MPEG-1 layer 2, a lossy compression method using perceptual audio encoding. Because much existing content is already encoded in this format, we plan to continue its use in the DML, but will also evaluate the quality and capabilities of other audio compression technologies, including MPEG-1 layer 3 ("MP3") [61], Dolby AC-3 [62], and MPEG-2 AAC, as potential replacements for MPEG-1 layer 2 with lower bitrate requirements.

The digital representation of a musical score is very complex. A score can be represented in terms of its typography (location of dots and other symbols on sets of horizontal lines), its "logical" content (pitches arranged in both horizontal-melodic and vertical-harmonic-streams, linked to a timeline measured in bars and beats), or its performance content (a stream of codes indicating the beginning and ending times for notes, measured in some kind of clock time) [58]. To represent the physical layout of the page, we will rely simply on scanned score images in standard image file formats such as TIFF, GIF, and JPEG. To represent the logical content of the score, we will select from among a small number of data formats that show promise for becoming open standards, including NIFF [51], SMDL [49], and MuseData [29]. To represent music for performance playback, we will rely on MIDI, the only de facto standard musical representation.

An existing set of audio files (5000+ titles) and score image files in VARIATIONS will be drawn upon to populate the DML's audio and image collections, with selections based on user need and intellectual property restrictions. In the case of notation and MIDI formats, we do not propose to encode a large body of music, but to facilitate the integration of our work with existing collections, to provide groundwork for the future encoding of such data, and to provide for interchange between various formats that might be useful to application developers and researchers. (One example of such an existing collection is the compilation of over 2500 movements that have been encoded by the Center for Computer-Assisted Research in the Humanities at Stanford University [10].)

4.2 Testbed Research and Development: Metadata

Traditional cataloging standards such as USMARC and AACR2 provide access to physical collections and can continue to play a role in providing access to digital library collections, particularly converted collections for which MARC-based cataloging already exists. A digital library collection, however, requires additional metadata elements to enable discovery, identification, and navigation of digital content and to enable enhanced forms of access and advanced application possibilities.

Metadata is commonly divided into three categories [46]:

- *Descriptive* metadata is used for object discovery (searching/browsing) and identification.
- *Structural* metadata is used to assist in the display and navigation of a particular object, and includes information on the object's internal structure.
- *Administrative* metadata represents management information for an object, including information related to the creation of the digital object (file format, equipment used, date created, etc.) and intellectual property rights management information.

IU's current VARIATIONS digital audio library system uses USMARC bibliographic records, stored in IU's online catalog system, as its primary form of descriptive metadata. These catalog records are supplemented by structural and administrative metadata in the form of "track files" which contain titles and descriptions of the individual tracks on each recording and their corresponding start times in the digital audio file, so that a specific work or selection may be selected, and so that digital playback may be positioned at the start of, or within, a specific segment of the recording.

The DML will continue this strategy, deriving the primary descriptive metadata elements (such as composer, title, uniform title, subject, etc.) from existing MARC bibliographic records for sound recordings and printed scores. These will be supplemented by administrative metadata elements that will be defined as part of this project. We plan to survey and adapt existing work in administrative metadata, including that of the Digital Library Federation's Making of America II project [46] and others [1] [2], with particular interest in rights management information.

Perhaps most importantly, we propose to specify and develop structural metadata for music which enables the following services for users of the DML:

1. Navigation to specifically defined locations within a sound file, score image file set, or score notation file (i.e., tracks on a recording, movements within a score).
2. Relation of multiple representations (e.g. sound files, score images, notation files) of the same work. When a user is accessing one version of a work, links will be available to the other representations.
3. Association of multiple representations of the same work by linking particular locations, i.e., the opening passage of the second movement of Mozart's Symphony No. 40 on a recording will be linked to the same passage in a score image or notation file.
4. Association of multiple representations of the same work with greater specificity by linking them together at the measure or note level.

Not all musical works in the DML will contain the same degree of structural information. Only a small fraction will likely be linked as in level 4 above, but for those that are, applications will be able to use of this structural metadata to synchronize playback of multiple linked representations such as a sound file and score.

Input from students and faculty of music, librarians, and library patrons will define the specification for DML structural metadata. As a basis for this specification, we plan to examine existing standards and data formats that may be applicable to representing complex time-based information, particularly SGML/XML applications such as HyTime [12][32] and Standard Music Description Language (SMDL) [49].

To date, no comprehensive standards exist for music or audio-specific metadata. The DML project will contribute a set of proposed standards and practices that have the potential for adoption by others in the digital library community and may also be useful for those working with other time-based media. Development of such standards will allow greater future interoperability among digitized collections.

4.3 Testbed Research and Development: Content and Metadata Repositories

At the heart of the system architecture will lie repository services for the storage and retrieval of digital objects (audio, image, notation, MIDI) and metadata for those objects. Standard supported interfaces will be defined (APIs and network protocols) for access to the system's object repository and metadata repository services by applications.

These interfaces will provide services including the following (protocols to be used are indicated where known):

- Search for a recording or score using metadata; obtain DML object name in the result set (Z39.50, SQL)
- Retrieve metadata for a selected item by name (Z39.50, SQL)
- Play back a sound file by name, including access to a particular segment by time offset or track number/description (RTSP – Real Time Streaming Protocol, HTTP, others)
- Access score image set by name, including access to a particular measure or page (HTTP)
- Access MIDI file by name, including access to a particular segment (HTTP)
- Access music notation file by name, including access to a particular segment (HTTP)
- Retrieve structural/administrative metadata for an item (HTTP)
- Store or modify structural/administrative metadata for an item (FTP, SQL)
- Load sound file, score image set, MIDI file, or notation file into the system. (FTP)
- Access control/authentication/authorization

A web-based search/retrieval user interface and a set of administrative tools for content loading and metadata editing will be implemented directly on top of these defined repository interfaces, but they will not serve as the primary access method to the library for developers of instructional and research applications. Instead, a set of software components will sit on top of the repository interfaces for use in user applications that access content from the library (see figure: General DML Architecture). One of the underlying development principles for the DML is that we will rely on existing commercial or freely-available products wherever possible and concentrate any original software development efforts in areas that are unique to the project and subject-domain.

To support the metadata standards defined by the project, a robust infrastructure for metadata repository services will be built to allow for creation, editing, searching, and retrieval of metadata elements and records. A variety of alternatives exist for use as a basis for these metadata repository services, including existing MARC-based online catalog systems with Z39.50 interfaces, relational database systems, XML-based database/repository systems, or some combination of the above.

Services for audio storage and delivery are a key part of the object repository architecture. The delivery component of the current VARIATIONS system is based on a commercially available media server (IBM VideoCharger) to stream MPEG-1 layer 2 format sound. This model allows for access control and prevents users from copying sound files out of the library system. It also allows for more functionality to be implemented on the server side, supporting greater user interaction, particularly for large files. But this model and technology require relatively high bandwidth (384 kilobit/second per stream) network connections to deliver high fidelity audio. The recent popularity of the "MP3" format has resulted in technology companies, with recording industry support, developing encrypted download technologies such as Liquid Audio's Liquid Music System, AT&T's a2bmusic, and Microsoft's MSAudio, all of which limit use of the downloaded file (number of plays, time window in which the file may be played, computer on which the file may be played, etc.). In addition, IBM is currently testing its Electronic Music Management System, which provides a framework for audio distribution over the Internet, including support for encryption and copy control. As a result of much of this activity, the Secure Digital Music Initiative (SDMI) Forum was recently formed by representatives of the music and technology industries to try to establish an open standard for digital music security.

These activities center on audio delivery and access control, but do not address the other system services needed for a digital music library, including access to music in forms other than audio, structural and administrative metadata for music, and methods for access by applications to library content. In the DML, we will continue to use commercially available streaming media technology for audio repository services and delivery, including evaluation of lower bit-rate audio technologies for access over slower or less reliable network connections. We will also plan to evaluate download mechanisms and encrypted download technologies, for use in situations where high-quality audio is needed but network bandwidths are insufficient for streaming.

4.4 Testbed Research and Development: Application Architecture

Different communities of users will have different uses for the content of a digital library: music theorists want to analyze, explore and compare different compositions and performances; music instructors want to provide illustrative examples and instructional activities; students want to browse possible scores and audio recordings for private study. Supporting these various communities raises several design considerations:

- How can the DML provide a framework of digital content, system services, and software functions necessary to develop domain-specific applications for music instruction and information access?
- How can a component programming architecture be used to simplify construction of applications that use DML elements? [37] [17]
- How can different media such as audio recordings, musical scores, and score annotations be synchronized for playback? [39] [31]
- What are the advantages and limitations of using a component architecture in developing a synchronization framework?

When an application references digital content in the DML, there is an expectation that the library and its content are available in a reproducible manner whenever the application is run. This "referential integrity" will be essential if the DML is to support a community of application developers and users. We propose the creation of a set of software components in an application framework, such as JavaBeans, for use in pedagogical applications. The primary set of components to be developed in this project will include:

- Audio player
- MIDI player
- Score image display
- Score notation input/editor
- Score notation player
- Digital Timeliner (bubble chart)
- Text display
- Score notation / image / audio synchronization

Among our key design goals is the extensibility of the framework and its ability to evolve over time in response to user-community needs. The component-based view of the library presented to users may be augmented with additional domain-specific components for representing and manipulating content. Developers will be able to use existing components to build domain-specific applications or be able to add new representations and capabilities to the library by creating new components, building on protocols and interfaces for metadata and content access and authorization/access control provided by the system. An association mechanism will be established to link components to the specific library content types which they are capable of representing or manipulating; for each item in the library, users will be able to browse a list of components that can be used with that item. In the third year of the project, we plan to evaluate extending the set of components to an additional framework, such as Microsoft's ActiveX or the Object Management Group's Common Object Request Broker Architecture (CORBA) [59]. This project will build upon prior work in component-based, object-oriented digital library architectures, such as the one proposed by UC Berkeley for the Digital Library Federation's Making of America II project [45].

4.5 Testbed Research and Development: Network Services/Architecture

The digital delivery of high fidelity, real-time audio capable of meeting interactivity requirements of pedagogic and library applications places significant demands and constraints on the underlying data networks. Meeting these conditions requires a study of network performance requirements of digital music library applications and development of an architecture that maps the performance requirements to quality-of-service (QoS) design decisions for LAN, campus, wide area intra- and inter-networks.

The Network Services/Architecture area of study will address the DLI2 program goal, "development of the next generation of digital libraries, to advance the use and usability of globally distributed, networked information resources." We will quantify the requirements of pedagogic high fidelity, real-time audio applications, develop guidelines for appropriate network infrastructures, implement testbed networks and measure their validity. The issues to be examined are:

1. What are the network performance characteristics required by digital music library applications? What bandwidth, latency, jitter and loss characteristics must be provided? What tiered architectures are appropriate for supporting the applications at different levels of quality expectation, e.g., local campus, Internet2, commodity Internet, K-12 and home delivery?
2. How do the applications behave when appropriate network performance is not provided? What information, feedback, or sensing capabilities may be useful in the design of applications?
3. What are the appropriate mechanisms to meet end-to-end network performance requirements of the applications? Differentiated Services (DS) [7] is under development as a standard for implementation of network QoS. Vendor implementations of DS are immature and don't extend end-to-end, i.e. beyond backbone and inter-networks to the LAN. Can switched bandwidth in the LAN deliver proper LAN QoS or should frame prioritization (802.1p) or precedence be employed? What are the policy and operational considerations in establishing, maintaining and debugging inter-network QoS contracts? How will end-to-end signaling for QoS be performed? Should applications signal via RSVP-like mechanisms? Can LAN-based mechanisms be mapped to activate backbone and inter-network DS and vice-versa? What is the appropriate DS per-hop behavior (PHB) for achieving QoS for high fidelity, interactive audio? Is the deterministic Expedited Forwarding (EF)[36] or statistical Assured Forwarding (AF) PHB[28] appropriate?
4. What are the appropriate measurement methodologies to confirm application performance and network conformance to QoS specifications?
5. Given competition for WAN resources, is local mirroring or caching of audio content a preferred alternative to end-to-end streaming? Can "channels" of content to be mirrored be reasonably defined based on the needs of pedagogical applications in use at particular remote sites? Can a network-based distributed storage system such as the Internet2 Distributed Storage Infrastructure Initiative (I2-DSI) [5] [33] serve as a platform for delivery of DML services to satellite sites?

Research issues will be addressed through the following means:

We will develop a network laboratory testbed to simulate various bandwidth, latency, jitter and loss characteristics. The bounds of network service parameters required to support digital music library applications will be determined and benchmarks established. QoS mechanisms will be introduced and tested under simulated load. A white paper will be published detailing the results of research into the characteristics of network performance required by high fidelity interactive audio for digital music library applications.

We will develop measurement methodologies and tools for validation of network services. Network node and protocol statistics will be monitored and specific DML applications will be instrumented, and we will publish a white paper describing the measurement methodologies. We will develop network design guidelines which describe the requirements and recommendations for implementing networks supporting digital music library applications and will publish these guidelines in a white paper.

We will implement a campus and inter-campus wide area intranet testbed network for the support of the DML. Design decisions will be evaluated and validated through measurement of network and application performance. DML satellite sites will be incorporated into the testbed network. The internetworks connecting these sites range across national and international Next Generation Internets and the commodity Internet. The satellite sites will provide opportunity to exercise interdomain QoS and validate network design decisions in internetwork environments.

A final report of the activities and results of the Network Services/Architecture Area of Study will be published. Activities in this area of study will be aligned with existing industry initiatives such as the Internet2 QBone[53], the IETF Differentiated Services Working Group[18] and the measurement activities of the National Laboratory for Advanced Network Research (NLANR) [50]. Work on mirroring and caching will be accomplished in cooperation with the I2-DSI project, which is developing mechanisms for content replication and name resolution and is deploying a set of servers in the United States, accompanied by partner servers in several international locations, to support advanced applications in research and education.

5.0 Digital Music Library Applications: Music Teaching and Learning

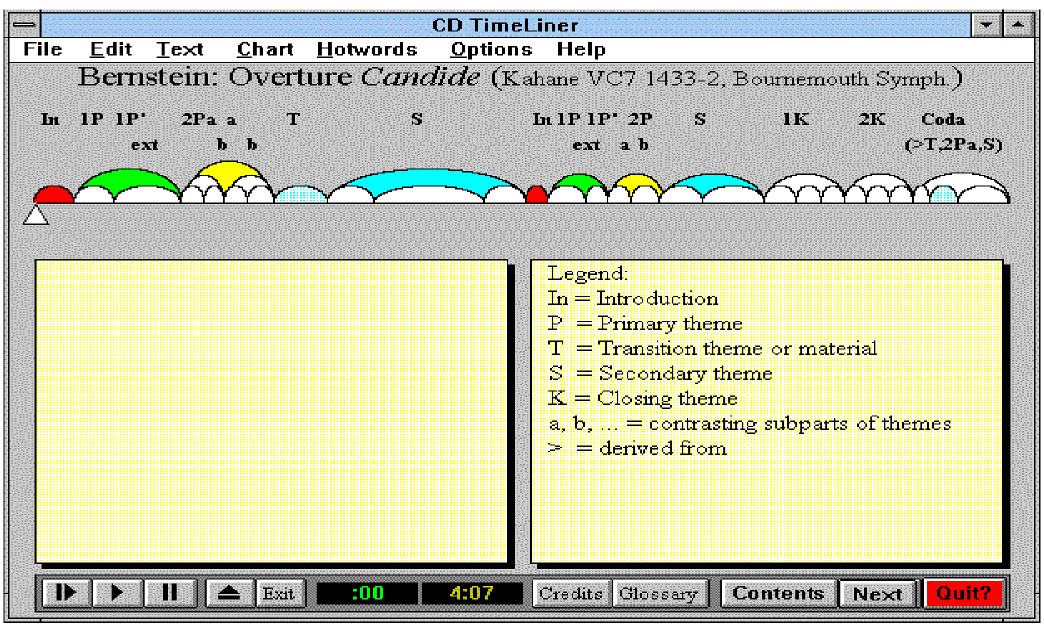
In this project, we plan to develop software tools and applications to support music teaching, learning, and research. The promise of a successful Digital Music Library can be realized only when users are able to integrate access to digital library content easily with other interface elements in the creation of class presentations, learning activities, and publications. These software components include: digital audio, representations of music that reflect its formal structure and relationships among those formal elements, editable reproductions of the score, annotations of the score (to label chords, individual pitches, to add text selectively), display of text and graphics, and the ability to synchronize these elements selectively.

Such integration requires a flexible software environment that will allow faculty with modest computer skills to create lessons efficiently, and will provide students with highly interactive learning experiences in music. Such an environment will also facilitate new ways of conducting and presenting music research. This proposal will address the question: "How will the tools and resources of the DML serve the needs of these users?"

The tools and resources will enable support of *first order learning*, that is, learning through direct experience [41]. Students will be able to assemble materials at a workstation and to see and hear their results immediately. They will be able to experiment, try alternatives, and work collaboratively with colleagues who have access to the same resources. Music learning can thus be appropriately contextualized, and teachers will be able to guide students in active learning environments rather than simply disseminate information to passive audiences. As one example, suppose that students were assigned the following exercise:

> Develop a "bubble" diagram for Leonard Bernstein's *Overture to Candide*, in which each of the discrete sections of the composition is shown in its relationship to other sections hierarchically. Label each section according to its function.

Such an exercise is common in traditional music learning contexts where the student would use paper and pencil to draft and redraft the diagram, relying on his or her memory of a recorded performance and/or the score notation. Typically, such diagrams do not reflect the temporal proportions of the composition, and once drawn the diagram is static. Now compare the traditional paper-and-pencil solution with the diagram shown below:



The diagram above was created using an early version of the now commercial software product called *Cap-Media* < http://www.cap-media.com/>. Each "bubble" in the diagram is shown proportional in time to the others and reflects the specific timing of the audio recording used. Moreover, each bubble is "hot," so the user can select it and the associated segment from the recording will play. The cursor tracks in time with the performance so students can visualize, as well as hear, the form of the composition as it unfolds.

The importance of visualization of music is made clear by Rudolph Arnheim, who wrote [3]:

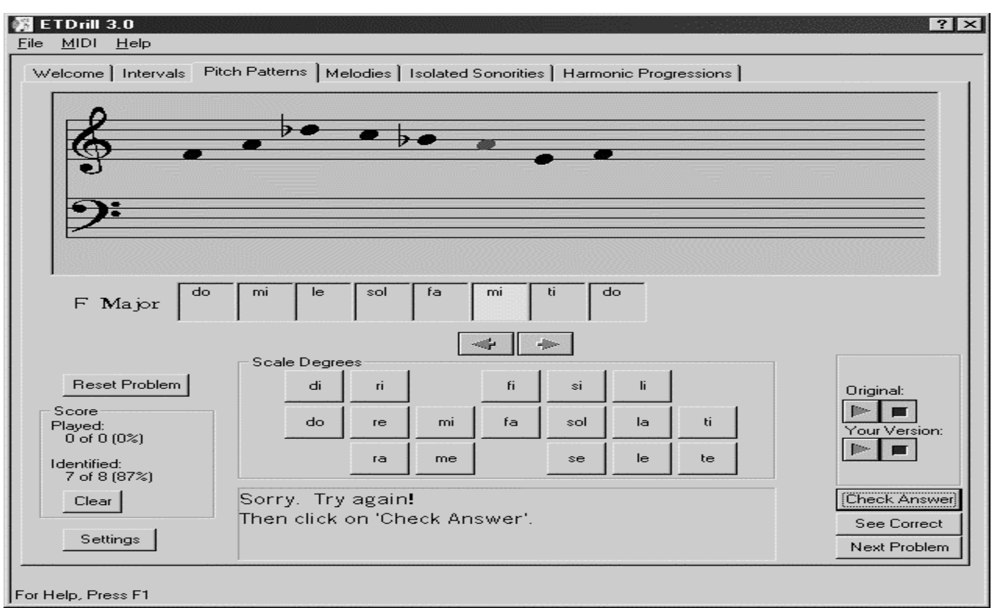
> "In order to comprehend an event as a whole, one must view it simultaneously, and that means spatially and visually, [which] leads to the curious paradox that a piece of music, in order to be surveyed as a structural whole, must be perceived in some kind of visual image."

The tools developed in this project will build on the kind of visualization tool used to develop the illustration. Whereas commercial products for timeline development are tied to specific CDs, which limit analysis to a single performance, users of the DML will apply these tools to multiple recorded performances stored in the library's collections, enabling comparison among them. In addition, users will be able to link annotations, music score segments, and other graphic objects with particular time points within each audio file, thereby providing a rich context for study of musical compositions.

Similarly, a "synchronization" tool in the DML that enables users to coordinate one or more streaming media sources with other time-based representations would support other pedagogical innovations. Using music scores as reference objects, for example, users could select a portion of a displayed score and have it played, thereby accommodating selective listening activities. Or, with a MIDI version of the score, users could "re-compose" a score segment and play back their re-compositions from MIDI sound sources. Students, for example could improvise a new melody to a MIDI version of a composition, save their improvisation, and play it back to compare with the original [cf. 43]. In this way students develop skills both in improvisation and in style imitation, which are powerful learning processes that are usually poorly accommodated in traditional classroom environments.

The Indiana University School of Music's Multimedia Music Theory Teaching (MMTT) Project <http://theory.music.indiana.edu/mmtt/> will provide an initial testbed application for the capabilities of the DML. This project will develop a set of tools and building blocks that allow music theory instructors to construct their own multimedia documents for in-class teaching and self-directed learning. Instructors will assemble application components through which they can play music selections, view scores interactively, and assess students' abilities to hear, understand, and categorize music. Several representations of a selection, such as score, digital audio, MIDI, and timeline diagrams, can be presented simultaneously and all components in the application may be synchronized so that position-dependent semantics (*i.e.* where one is in the selection) are communicated to all components referencing the selection.

The figure below shows ETDrill, a prototype of the component-based approach to this problem. In a typical scenario, an instructor will build this application by selecting from a palette of components provided by the DML: a score display component, score player component, MIDI keyboard input component, assessment component, and others. Each component will display its interface and attributes, and the instructor can define active connections among the various components.



Prototype of a component-based application.

Because it embraces the various types of digital media required in music theory instruction—as well as the ways to represent and coordinate these different media—the MMTT project will provide an ideal testbed for demonstrating the capabilities of the Digital Music Library as a platform for instructional applications.

The tools and resources developed within this project will be useful for general students as well as for those striving for music careers. We propose to develop a "Music for the Listener" course that focuses on the nature of music, as well as on non-Western and Western music in a broad historical survey. "Music for the Listener" will be developed for Web delivery in different versions using the course management tool *On*course <http://oncourse.iu.edu/>. The first version will be enhanced by use of DML resources, as well as by inclusion of digital images from various collections to which IU has access. A second version will be developed for delivery to remote learners. Finally, as more DML tools are developed, both local and distance versions of the course will be further enhanced through their use.

The DML will also support the work of music scholars by permitting ready access from a single workstation to materials usually located in multiple locations within a library. The tools will allow scholars to create multimedia presentations and publish them electronically in such sources as the Society for Music Theory's *Music Theory Online* <http://smt.ucsb.edu/mto/mtohome.html> and other online publications. And as described above, the DML will make it possible for scholars at remote locations to have access to the kinds of resources normally accessible only in large music libraries.

6.0 Digital Library Research

Research is fundamental to every aspect of this proposal. Testbed Research and Development activities (section 4.0) will lead to new understandings in the areas of digital library content representation, metadata, system architecture, application architecture, and network services. Use of the DML in development of pedagogical applications (section 5.0) will demonstrate the integration of a digital library in support of education and research. This section highlights two key areas of digital library research that are essential to the DML, and have applicability to other digital library development endeavors: usability and user-centered design, and intellectual property rights. Research in these areas is important to the overall design of this project, as the results of usability testing and IPR analysis will be integral factors in shaping the design of the DML.

6.1 Research: Usability and Instruction

The DML will serve five general types of users, each with specific requirements and skills: music faculty members (as instructional developers); students (in courses developed by these faculty); music librarians (who build collections, use metadata); music library patrons, including users from the general public (who access collections); and system designers (who create DML applications). Each user type will receive specific attention in our research, which will focus on two major issues: usability and instruction.

Usability Issues

The overarching research question for research in usability is:

"How can we design interfaces to music digital libraries that are usable and acceptable to all user types?"

Specific questions that we will answer in this project include:

a) How do we offer users control of searchable and interlinked sound and text in a single interface?

A DML offers a number of presentation formats that are mode-specific. Controlling the temporal delivery of music, for example, differs from moving through text. The various interface mechanisms to control each may be solved easily, but combining the modes will require more elegant solutions than simply adding features. We will test alternatives in the Usability Lab and select those that demonstrate the best fit to relevant users.

b) How do we represent DML information space to support accurate navigation and retrieval?

The DML offers a potentially overwhelming amount of multimedia information to users. To date, it is known that navigation difficulties and disorientation are a commonly reported problems for users of such technologies [19]. We will examine various representational structures and navigation aids such as link trails, overviews, and frames to minimize the cognitive overhead on users.

c) How do we make the creation and modification of instructional tools as easy as possible?

Instructors and providers must be easily able to create, input, and modify materials within the DML. Major resistance to new technologies results from the effort or load placed on users to exploit them [16] thus one of the design goals of this project is to develop highly usable mechanisms for creating and modifying digital library materials. We will establish user requirements from the outset through iterative tests of prototype designs, both paper and working, to ensure the development of tools that can and will be used by all users. This work will be ongoing with the architecture development and will most directly involve music faculty members, music librarians (locally and in satellite sites), and system designers.

d) What constitutes an appropriate set of measures to assess the usability of this technology?
Theoretically, user-centered designers talk of measuring user effectiveness, efficiency and satisfaction with a specific interface [60], but there remain many unanswered questions about the value of these metrics. For example, do they correlate or is satisfaction independent of efficiency [e.g., 16]. In pedagogy, how appropriate is a typical effectiveness measure of task completion? Research on educational technology has largely ignored these issues and failed to demonstrate alternatives. We will determine the statistical correlation between a candidate set of indices drawn from the usability engineering and educational assessment in order to identify the most appropriate and parsimonious measures for further digital library evaluations.

Instructional Issues

Regarding instruction, we will focus on the primary research question:
"What effects does the DML have on learning and instruction in an arts and humanities education context?"

Three recent reviews of the experimental findings on user performance with multimedia and digital library technologies [40] [11] [20] all reported disappointing results as the norm and criticized the quality of the research as methodologically flawed and piecemeal. The present proposal will overcome weaknesses of this domain by adequately addressing issues of experimental control and statistical analysis, and will obtain rich data sets of performance so that we may study educational impact over time.

In addressing instructional issues, we will answer the following sub-questions:

a) How does a digital library support new forms of instruction, such as distance or distributed classrooms and active exploration and creation?
The DML will provide a resource that influences the manner in which music pedagogy occurs. While one may think first of the learners, we will also explore the manner in which instructors interact with these tools and study how remote learners can exploit the new resource. We are especially interested in understanding how instructors will use this tool, both in terms of delivery of instructional information and in terms of exploiting the potential to provide learners with sophisticated information tools outside or beyond the traditional classroom.

b) What differences in the learning process or instructional outcome are observed in the DML environment?
A crucial question to resolve is the instructional impact of the DML. We will study learners in both the DML and a control environment (e.g., a music class that is not employing the DML) to capture measures of process (information gathering, reading behavior, navigation and exploration) and outcome (test performance, quality of deliverables etc.). We will test students throughout the development cycle of the DML in both the usability lab and subsequently in situated field trials (classroom and library use). This issue most directly affects students and music librarians.

c) Does the digital library offer advantages to specific groups of learners?
One of the common findings in educational research is that there are large individual differences between learners which affect their performance and response to various instructional interventions [20]. We will test individual differences among learners across cognitive, task and environmental factors to measure to effects of such differences as ability, experience, learning style, group structure and context of use on learner performance.

d) Does the digital library enhance the instructor's performance?
Instructors or teachers are key stakeholders. The power of interlinked, rapidly accessible information delivered to a student's desktop is likely to require certain skills and abilities to exploit and may offer instructors the power to engage in new, potentially more effective, instructional activities. Coupled with this is the need to make the provision of instructional materials through the DML as simple and effort-free as possible since one of the bottlenecks in implementing instructional technology is the load it places on instructors.

General Approach

We propose a complete and combined analysis of usability and learnabilty, working on the assumption that usability is a necessary but insufficient prerequisite of learning enhancement. This overcomes the major distinction in the literature on educational technology where usability is rarely directly addressed [55]. Furthermore, we will adopt a rigorous repeated test format that combines formative and summative tests throughout the design process for each interface element as it develops.

To optimize the value of any new technology for its intended users, users must participate in the design process, and we must perform repeated evaluations throughout development. We will ground all design decisions in data drawn from tests of representative users and stakeholders, solicited at all stages of the development process for their views and preferences. While our aim is to test empirically the design using appropriate experimental controls at every stage, the creation of the DML will result in decisions about and implementations of tools and functions that have no equivalent support in current technologies. In this case, we will use the VARIATIONS project and current data on user performance (for all user types) as the control to establish baseline of current performance capability. We will extend the summative tests to incorporate semester-length evaluations in the final year so that the benefits or shortcomings of digital libraries in instructional environments can be formally assessed.

6.2 Research: Intellectual Property Rights

The creation of a digital library that provides access to music or to other works will raise complex issues associated with copyright and other legal forms of intellectual property [13]. Offering access to materials creates potential infringements of the rights of the owners of the copyrights to those works. The creation of the digital library may also result in the creation of new protectible works, ranging from underlying software to the "look and feel" of the user interface.

The substantive issues of copyright are related directly to the development, management and accessibility of digital content and collections [27]. Without addressing the legal issues surrounding the use of copyrightable content, that content cannot properly be used or accessed in the DML context [15]. Copyright law, however, is in many respects a flexible doctrine that permits creative approaches for meeting its requirements. Often the alternatives that may be permitted under the law may have differing consequences for the capabilities and opportunities of a digital library to serve various user communities, particularly in the context of education [38].

1) How does the creation and use of the DML affect the rights of copyright owners? This question will relate the various stages of creating the DML to the specific rights of copyright owners. Some of these stages and rights are as follows: Digitized work—reproduction; Access—reproduction, distribution, performance, display, and digital audio transmission; and Indexing—derivative work.

2) What exceptions to the rights of the copyright owner may be relevant to the deployment of the DML? The rights of copyright owners are subject to numerous exceptions or limitations, including the following (identified by code section): 107-Fair use; 108-Library copying [25]; 109-Public displays of works; 110(1)-Face-to-face teaching, displays and performances; 110(2)-Distance learning, displays and performances [14]; 114(a)-Public performance of sound recordings; 114(d)-Performance of a sound recording by digital audio transmission; 121-Copies for persons who are blind or have other disabilities; and 1008-Noncommercial copies of musical recordings.

3) How do the requirements of the law for complying with various exceptions affect the technical implementation of the DML? This question will ultimately pose critical research questions about the relationship between means for meeting the law's requirements and the effect of those means on the success of the DML. Examples of those relationships are as follows: Network capabilities may give rise to public performances [54]; Software limits, password controls, etc. may enable the DML to stay within fair use; User authentication may limit access while still meeting educational objectives;

4) How do the requirements of the law for complying with various exceptions affect the organization and management of the DML? The law is increasingly focused on the methods used for managing intellectual property. This question will explore management alternatives and their consequences for the DML. Examples include: Cost-benefit analysis for copyright decision making; Pragmatic difficulties for copyright decisions; Retention of copyright management information on digitized works; Circumvention of technological protection systems that restrict access to works; Online service provider liability standards that regulate terms of access; and Digital object tracking and rights management procedures.

5) How do the requirements of the law for complying with various exceptions affect the ability of the DML to meet educational objectives of the system users? This question will address the sub-points regarding: Limitation on included works; Limitation on amount of each work; and Limitation on accessibility.

6) What options are available for securing permissions or licenses for uses that are not within the scope of relevant exceptions? This question will address the sub-points regarding: Negotiations with rights holders; and Licenses with collectives—BMI, ASCAP, etc.

The methodologies for this study will involve substantial legal research to analyze an evolving law as applied to innovative circumstances of the DML. That analysis will reveal the law's requirements and alternatives for meeting them. The investigation will then relate those alternatives to the user studies that measure the effectiveness of the DML functions under diverse alternative arrangements.

Most of the tangible products of this study will be written analyses and guidelines that will be published and broadly disseminated for use and implementation not only at IU, but also at other digital library systems throughout the country. Other outcomes will include: (1) regular meetings with other investigators to pursue the interrelationship between copyright law and the effective deployment of the DML; (2) open presentations with invited guests or the public to share research findings; (3) delivery of conference papers at digital library programs; (4) research studies that relate alternatives for meeting obligations under the law to the effective implementation of the DML.

7.0 Evaluation

In creating the Digital Music Library, we identify three major objectives:

- To create a testbed system and collection
- To develop usable digital library applications for teaching and instruction
- To research the user and pedagogical impact of the DML

We will evaluate each of these objectives explicitly to measure the effectiveness of the project.

Creation of a testbed system and collection

Four criteria of effectiveness are appropriate to measure the testbed development. First, to demonstrate testbed completion, we will produce a fully documented function set. Second, we will produce and document a test suite so that the testbed system and collection might be employed by others. Third, we will demonstrate and document the provision of access to rights-cleared content in the DL. Fourth, we will measure other users' uptake of the code. To encourage this, we will offer developers' workshops that will support the transfer of this technology to other sites. In combination, monitoring progress against these criteria will provide a full and explicit evaluation of the testbed system development.

Development of usable digital library applications for teaching and instruction

Three criteria of effectiveness are appropriate to measure the application development. First, to demonstrate completed development, we will produce a documented set of tools for creation, modification and delivery of instructional materials. Second, we will document the usability test results for each application for comparison with existing technologies or methods. Third, we will measure the adoption and usage rates of these tools by appropriate users (instructors and faculty) at Indiana University, at the satellite sites, and elsewhere.

Research into the creation, maintenance and use of the DML

Three criteria of effectiveness are appropriate to measure the research impact of the project. First, we will submit all research findings for publication in peer-review journals and conferences, thereby enabling us to measure the intellectual impact of this research through publication rates and citation counts. Second, we will measure the progress of all graduate assistants towards completion of doctoral degrees based on this research project. Third, we will record and document unsolicited requests for information about this research, including invitations to present findings or submit papers and requests for site visits.

In combination, this evaluation plan will provide us with 10 indices of project effectiveness. While many of these can only be measured fully near the end or after completion of the project, each index can be related to a specific activity in the workplan (e.g., the testbed creation criteria are tied to the development sequence outlined in the workplan) and several indices can be monitored from the start (e.g., all of the research effectiveness criteria). In this way, evaluation will occur throughout the project and beyond.

8.0 Participants and Project Resources

8.1 IU Participants and Resources

Indiana University is uniquely qualified to develop and implement the Digital Music Library testbed. An outstanding team of investigators from Indiana University will direct this project, bringing together an interdisciplinary research team from the School of Music, the School of Library and Information Science, the School of Law, the Department of Computer Science, University Information Technology Services, and the University Libraries.

IU is a leader in the field of digital music libraries, with more than 5,000 hours of digitized recorded music accessible to student and faculty workstations through its VARIATIONS digital library system. The DML testbed will make use of this existing collection of digital music recordings and will enrich the collection with new content-types (e.g., score notation) and associated functional components (e.g., score visualization). The DML collection will be a mix of commercial and non-commercial recordings in a number of categories, including standard repertoire works for instructional purposes, audio recordings of public domain works, unique resources such as live performances, and others. IU has a standing commitment to building its digital music collections. No NSF/DLI2 funds are requested for digitization.

The IU Digital Library Program has additional expertise in creating digital music library applications and is presently developing a library collection and online exhibition site based on the works of Hoagy Carmichael. This project, a collaboration with the IU Archives of Traditional Music, is funded by an Institute for Museum and Library Services (IMLS) National Leadership grant <http://www.dlib.indiana.edu/collections/hoagy/ >.

The IU School of Music is widely respected as one of the world's leading institutions for musical studies. The School has an artist-faculty of 140 and more than 1,700 students. Research in the use of technology to support music pedagogy is active and has included studies of automated encoding [47] [64], automated study of music scores [e.g., 25, 48], similarity relationships among collections of notes [34] [35], and intelligent tutorials [56] [57].

Indiana University plays a lead role in national and international high-performance networking. IU was selected to operate the Abilene/Internet2 Network Operations Center, and IU is the U.S. lead in establishing the TransPAC high-performance network connection to the Asia and Pacific. These resources and expertise will provide project investigators with network connectivity and network engineering services to support research and testbed development goals of this proposal.

The commercial sector has supported digital library research and development, and Indiana University has in prior years received support through shared university research grants from IBM Corporation. Investigators on the present project have received statements of interest and support from both the commercial and non-profit research and development sector.

8.2 Satellite Sites

An essential goal of IU's DLI2 proposal is to expand greatly access to the DML testbed, providing users at other colleges and universities, and at other distant locations, the same access to and interaction with the DML content and applications as will be available to students, teachers and scholars at Indiana University. Testing, evaluation, and demonstration of such access across national and international networks is an important component of this project, addressing goals identified in the DLI2 program announcement for: "systems scalability," "interoperability," "network, communications and middleware," and "systems evaluation and performance studies."

As Network Operations Center for the Internet2/Abilene network backbone, and as U.S. project lead for the TransPAC international high-performance network connection to Asia and the Pacific, IU has the qualifications and resources necessary to design, coordinate and carry out this evaluation and demonstration. Through the volunteer efforts of several leading universities, IU will be able to carry out an ambitious demonstration program, providing a number of "satellite site" institutions with access to the DML collection and applications. Seven sites have so far agreed to participate: University of Illinois at Urbana-Champaign, University of Massachusetts at Amherst, Northwestern University; King's College, University of Loughborough, and Oxford University in the UK; and Waseda University in Tokyo. Additional sites will be added through the course of the project, as needed to meet project goals.

Each satellite site is volunteering staff time, space, equipment and network connectivity. Each site will conduct a standard suite of tests, developed to evaluate usability, interoperability, network performance, and other criteria.

8.3 Management Plan

Successful management of this project will be based on the clear assignment of responsibility, allocation of resources to complete assignments, and close monitoring of activity, progress and problems. IU will assign an Executive Investigator to provide overall project management and a Lead Technical Investigator to direct overall systems design and planning. These investigators, with the PI and co-PIs will form the Project Steering Group, responsible for establishing priorities and directing testbed development and research activities. Executive representatives of the four chief organizations involved in the project (deans of the School of Music, School of Library and Information Science, and University Libraries, and the Vice President for Information Technology) will form a Project Executive Board to address institutional management and resource matters. An external Advisory Board will be appointed to review progress, project plans, and advise the co-PIs on conduct of the project.

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