

Online content-searchable databases of music scores, unlike text databases, are extremely rare. The main reasons are the cost of digitization, the inaccessibility of original music scores and manuscripts, and the lack of sophisticated music recognition software. The proposed research seeks to circumvent these difficulties by investigating the feasibility of using existing microfilms for digitization.

Compared to original scores, microfilms constitute more accessible and economical sources for digitization. Scanned images of music scores can be made content searchable through the use of optical music recognition (OMR) software developed by the applicant.

The objective of this study is to determine whether the quality of images scanned from microfilm, rather than from the original score, is sufficient for the subsequent OMR process. If the digital image derived from microfilm is found to be acceptable for OMR, there will be tremendous economic benefits. The cost of building digital libraries is incurred mainly in the digitization process. The cost of digitization from microfilm is far lower than that of digitization from original documents. Using microfilms may also prove highly advantageous in data collection. Original music manuscripts are scattered in libraries, museums, and archives throughout the world. The exorbitant cost of traveling to these locations can be avoided through the use of microfilm collections that already exist in many music libraries. Finally, when a local archive decides to digitize its own collection, using available microfilms will obviate the necessity of handling and thereby potentially damaging precious manuscripts.

The feasibility of digitizing from microfilm will be investigated by comparing the image quality of direct scan and microfilm scan of the same music scores. A high-quality flatbed scanner and a microfilm scanner will be used in the experiment. The principal metric is the recognition rate of the OMR process, although visual inspection of the image may be sufficient in some cases. Various types of music scores representative of different historical periods and microfilms produced from different sources and ranging in quality will be studied. The project will concentrate on music from the Medieval and Renaissance periods (including lute and guitar tablatures), because access to original sources from these periods is particularly difficult and because the software must be trained to recognize notation systems outside the common music notation system in current use. It is important to note that no other OMR software is capable of handling the types of music notations specific to Medieval and Renaissance music.

The applicant, one of the leading experts in OMR, has developed various systems since 1986. The current OMR system is integrated into a document analysis system called Gamera, an open-source software that has been used in the Levy Sheet Music Project at the Johns Hopkins University among other projects. The unique feature of Gamera is its ability to learn new symbols through exemplar-based learning algorithms enhanced by the use of genetic algorithms.

The new challenges for this research program include creating a powerful image preprocessing system to deal with poor-quality images, developing a notation file format for Early Music, and designing and implementing a graphic interactive music editor to verify and edit the results of the OMR process.

If the quality of images scanned from microfilm is sufficient to obtain reasonable results using the OMR system, a vast amount of music can be made searchable, creating an incredible resource for music scholars and musicians throughout the world. Moreover, the results of this research will encourage music librarians and archivists everywhere to make music more accessible to the general public.

## **Feasibility of digitizing Early Music on microfilms for the creation of large-scale content-searchable database**

### **Objectives**

Unlike text, online content-searchable databases of music scores are extremely rare. The major reasons for this are: the cost of digitization, the inaccessibility of original music scores and manuscripts, the lack of sophisticated music recognition software, and the copyright issues. The proposed research is an attempt to circumvent these problems by examining the feasibility of using microfilms for digitization.

Compared to scanning the original source, microfilms are more accessible and economical sources for digitization. By using an optical music recognition (OMR) software developed by the principal investigator (PI), scanned images of music scores can be made content searchable, and by creating diplomatic transcription of the music scores, the problem of copyright can be avoided.

The objective of this proposed research program is to determine whether the quality of images created from microfilms, rather than from the original, is sufficient for the subsequent OMR process.

### **Context**

The proposed research is a part of a larger research infrastructure with goals to develop and evaluate practices, frameworks, and tools for the design and construction of worldwide distributed digital music libraries (Bainbridge et al. 2001). Over the last few millennia, humans have amassed an enormous amount of information and material that is scattered around the world. It is becoming abundantly clear that the optimal path for acquisition is to distribute the task of digitizing the wealth of historical and cultural heritage material that exists in analogue formats, which may include books, manuscripts, music scores, maps, photographs, videos, analogue tapes, and phonograph records. In order to achieve this goal, libraries, museums, and archives throughout the world, large or small, need well-researched policies, proper guidance, and efficient tools to digitize their collections and to make them available economically. The research conducted within the infrastructure will address unique and imminent challenges posed by the digitization and dissemination of music media. The infrastructure is necessary because of the impending need for research into properly designing digital music libraries. Most contents of music libraries have not been converted to digital formats, mainly because of the difficulties involved in digitizing music scores and analogue recordings (Choudhury et al. 2001).

There are two major problems in digitizing scores: one is the inaccessibility of source materials (many scores exist in a single copy), which are archived in various parts of the world; the other is the lack of optical music recognition (OMR) software—which is similar to optical character recognition (OCR)—to convert the scanned image of music to computer-readable format. (The current common practice with text conversion, for economic reasons, is to use human typists in offshore countries. This is possible because it is relatively easy to train people to type characters without knowing the language. This strategy will not work in the case of music, however, since it takes considerably more time to train people to read music, especially obsolete music notation of the past.) Microfilm copies of music scores are often readily available, however, and if OMR software can be developed to convert microfilm image to computer-readable format, then both of these problems can be solved, resulting in searchable full-text

databases. The costly high-quality scan of the original scores, such as those done by the excellent DIAMM project (Wathey et al. 2001), can be added as they become available over time.

Although OMR research has been active for closed to forty years, a very little attention has been paid on recognition of early music notation, with the exception of an early work by Canadians, McGee and Merkley (1991), and more recently by a group from Portugal (Pinto et al. 2000, Vieira et al. 2001, Pinto et al. 2003). Furthermore, there has been no work reported on music recognition system based on microfilm sources. The microfilms have been used for digitization of other types of documents, however (Chapman et al. 1999). Given that only the well-trained music historians can transcribe the music from this era and that eventually all this music will be digitally stored, it is essential that some computer-aided methods of entering this vast amount of information to the computer are needed.

Developing optical music recognition systems has been my central to my research for over 15 years and I have significant expertise on the subject. Yet, like other researchers in this area, I have been dealing mostly with the modern music notation system. Earlier European music notation systems contain variety of music symbols not found in the modern counterpart and the documents from this era are often in poor condition. Although much of experience I've gained from studying modern notation will be useful, the differences will be challenging and interesting.

A tremendous economical benefit can be reaped if the digital image derived from microfilm is found to be acceptable for OMR. This is because the cost of digitization from paper is at least ten times that of digitization from microfilm, and furthermore, the majority of cost in building a digital library is in the digitization process. Another enormous advantage of using microfilms is in data collection. Most of the original historical music manuscripts are scattered all over the world in various libraries, museums, and archives, whereas many music libraries already have collection of microfilms, thus avoiding the cost of traveling. Finally, if a local archive decides to digitize its own collection and if microfilms of the collection already exist, the handling of and the potential damage to the precious manuscripts can be avoided. The knowledge gained from this research will also be useful for computer-aided digitization of other old documents without any music.

## **Methodology**

The feasibility of using microfilm for OMR is investigated by comparing the image quality of the direct scan and the microfilm scan of the same music scores. It has been shown that the image quality of the digitization can greatly affect the accuracy of OMR process (Riley and Fujinaga 2003). A high-quality flatbed scanner (Epson 1640XL) and a microfilm scanner (Minolta MS6000) recently acquired by the Music Library will be used for the experiment. The principal metric is the recognition rate of the OMR process, although visual inspection of the image may be sufficient in some cases. Various sources of music scores from different historical periods and microfilms from different sources and of varying quality will be studied.

The OMR system for the project will be based on the Gamera application development environment (Droettboom et al 2002). The program is a toolkit for the creation of customized structured document recognition applications by expert users. It allows a user, with particular knowledge of the documents to

be recognized, to combine image processing and recognition tools in an easy-to-use, interactive, graphical scripting environment. Additionally, the system can be extended through a C++ and Python plugins (MacMillan et al. 2002).

The greatest strength of this system is its ability to learn almost any kind of symbols. On the other hand, it does take considerable amount time in training the system by exposing to it a wide variety of symbols that it may encounter in the particular set of documents that it is asked to recognize. These, in our case, are the Early Music notation symbols. Some initial tests in the removal of the stafflines, which is important for the subsequent processing, and the classification of unknown symbols show great potential (see Figure 1 and 2). Another challenge for this project is to deal with the poor quality of the microfilm images. Various digital image-processing algorithms available will be researched and adapted to improve the quality, which in turn will improve the recognition rate of the classifier.

In order to correct and edit the results of the OMR system, a suitable editing system must be developed or modified from an existing music editor that can deal with Early Music notations. Also, a suitable notation file format will be required to store the results in a database (Barton 2002).

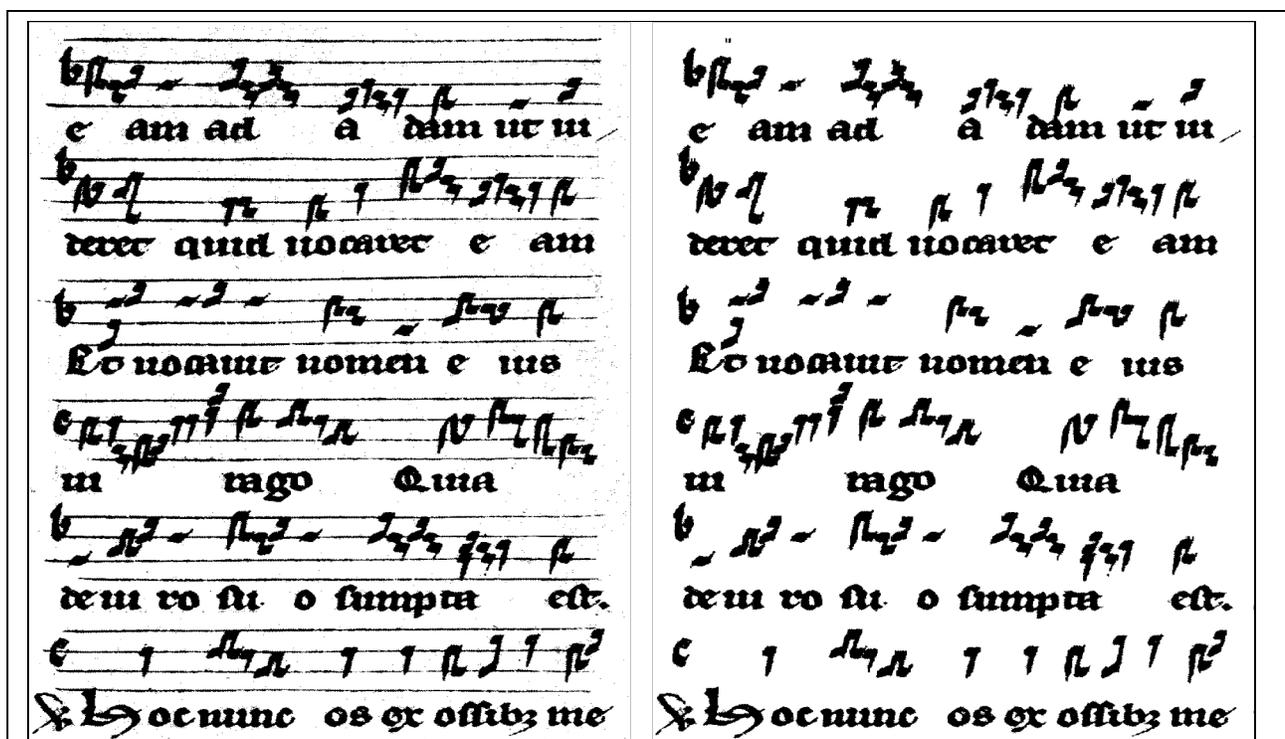


Figure 1. Staffline removal process allows the system to easily separate the symbols (neumes) to be recognized the subsequent classifier system.

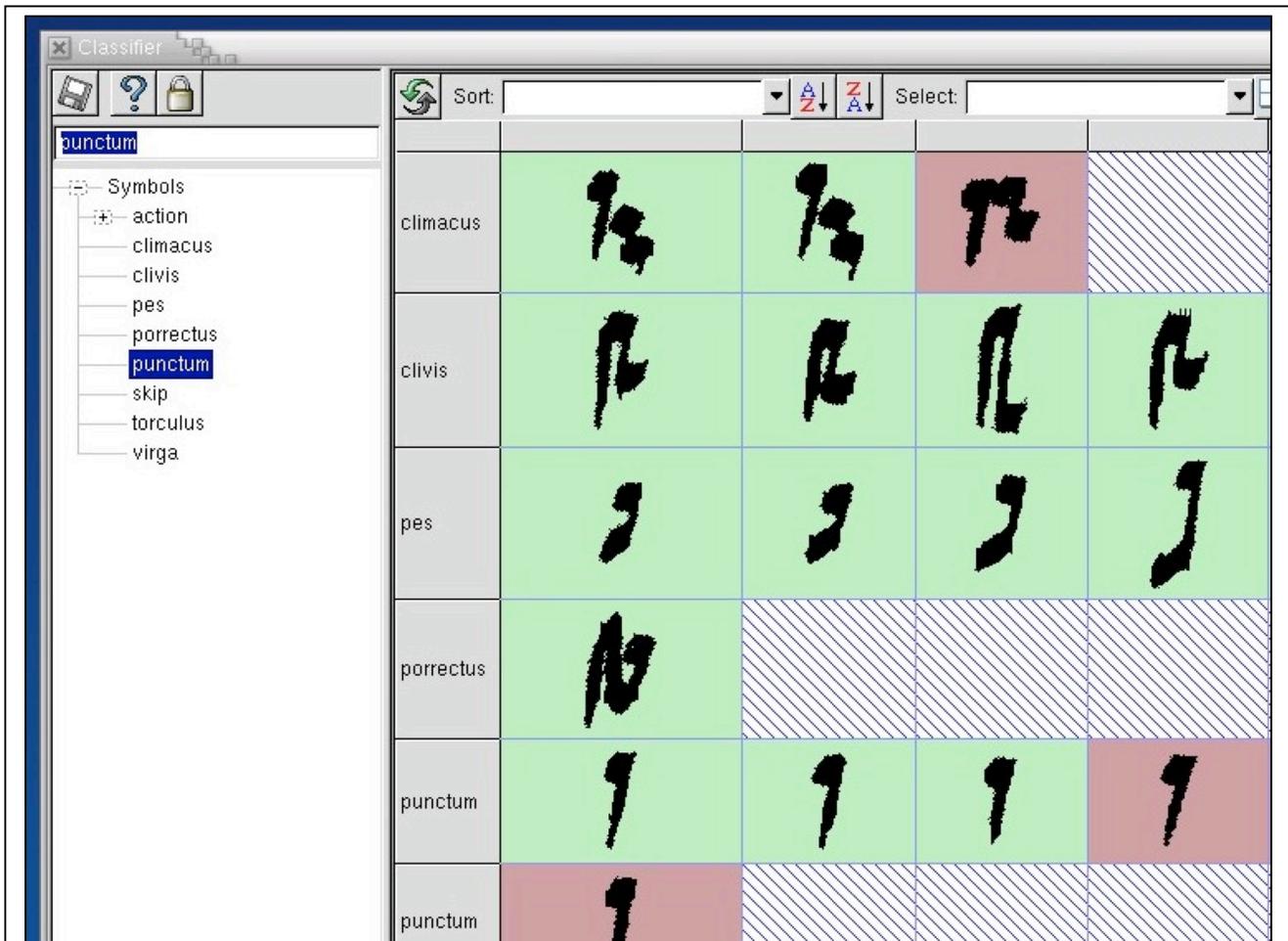


Figure 2. Classification of unknown symbols. The trained symbols are in the green boxes. The symbols in the red boxes were correctly identified by the Gamera system.

The overall schedule of the project is outlined below:

2005: Summer	Research and find microfilms and facsimiles of same score, microfilm scanner training, hardware and software setup, build project web site, research into notation file formats, test microfilm and paper scanning
2005: Fall	Finalization of notation file format, data collection
2006: Spring	Research on image preprocessing methods
2006: Summer	Image preprocessing algorithms development
2006: Fall	Image preprocessing testing
2007: Spring	OMR training / development
2007: Summer	OMR development / testing
2007: Fall	Evaluation, compile final statistics
2008: Spring	Prepare a paper suitable for peer-reviewed journal article submission

## **Communication of Results**

The progress of this research program will be annually presented and printed in the peer-reviewed conference proceedings at the International Conference on Music Information Retrieval, and/or Joint Conference on Digital Libraries. Other presentation potentials include meetings by the Music Library Association, the International Music Library Association, and the American Musicological Society. In the final year we will submit our research paper to the major publications in this field, such as, *Computing in Musicology*, *Journal of New Music Research*, *Early Music*, and *Notes*. The scientific findings of this project is planed to be presented at the International Conference on Document Analysis and Recognition in 2008. We will also maintain a project web site, which will document the progress of the project as well as demonstrating the potential of this method for the general public.

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## **Training (Role of Students)**

The main responsibility of the PDF will be software development. I have found from past experiences that in order to create a relatively large software system that will be usable by others is to have at least one person work on it fulltime. The benefits to the PDF for joining this research group include: creating a extremely useful tool that could be used by many researchers and librarians world wide, learn how to develop a commercial-grade software, and to work in a truly interdisciplinary research project. The PDF will also gain experience mentoring graduate students.

A musicology master's student will be mainly involved in the research of music scores. The student will locate facsimile editions and modern editions of scores found on microfilms. The student will look for samples of wide variety of notational practices and of different image quality on the microfilm. The student will be responsible for the digitization of both the microfilm images and facsimile and modern editions and training of the OMR system. Thus the student will learn bibliographical research skills in finding music and will also acquire image scanning skills. Because this project involves looking at the notations from an untraditional perspective, the students should acquire new sensitivity to this repertoire.

The Ph.D. student will be responsible for a wide variety of research tasks and will act as the operation manager of this entire project. The student will perform all the necessary background research and maintain the project documentations. The student will learn how to coordinate a research project from the start to finish and work very closely with me, the PDF, and the master's student.

The Faculty of Music at McGill University offers an excellent Music Technology program designed to equip musicians with highly specialized technical knowledge and skills. This program is growing rapidly and attracting an increasing number of graduate students world wide. Four years ago, it consisted of one faculty member, two PhD students, and two master's students. This year, there are five full-time faculty members, seven PhD students, and twelve master's students. Research funds obtained by Music Technology academic staff members over the past year exceed one million dollars, which will aid in supporting the various research programs related to audio and music. The program will offer a graduate seminar on Music Information Retrieval annually, thereby providing ongoing opportunity for students to acquire skills and participate in the infrastructure. In addition, the Faculty of Music hopes to host the International Conference on Music Information Retrieval in Montreal in 2005.

Digital libraries are new and growing at an enormous rate. Highly Qualified Personnel (HQP) in this field are both desperately needed and greatly sought after in Canada. It is well known that music is one of the most difficult items to catalogue in the traditional library, and this is holding true for the digital domain as well. HQP with digital library skills are needed to manage digital media in academic, public, and corporate libraries. Numerous HQP will be required to undertake the immense task of organizing the Web, considered by many to be a gigantic, disorganized library. Since digital libraries have no borders, HQP trained in Canada will be able to contribute their expertise virtually anywhere in the world.

## 6. Previous and Ongoing Research

Since 1999 at Johns Hopkins University, I have been working with the researchers at the Digital Knowledge Center (DKC) of the Johns Hopkins Libraries. Initially, we worked on the workflow management of digitizing a large sheet music collection (Choudhury et al. 2000) culminating in developing an application called Gamera. The Gamera software is based on my earlier work on OMR technology and I am one of the principal architects of this application framework, which is publicly available, since early in 2004, as an open-source software. It has since received much attention from various document analysis researchers especially from people dealing with degraded ancient manuscripts both from musical and non-musical domains. We have published various papers based on this research and work is still ongoing. This successful project has also provided excellent training for students. In fact, two of my Master's music students at Hopkins who worked on this project as research assistants, after graduation, started work as full-time researchers at the DKC. One of them recently moved on to work as a Linux security developer for the US Federal government. He was then replaced at DKC by one of my new McGill Master's student, who just graduated.

A few months before taking the position at McGill, I was awarded, as a PI, a research grant valued at \$229,352US from IMLS (Institute of Museum and Library Services) for the study of preserving and creating a large digital audio library of analogue tape recordings of the Peabody Conservatory of Music. Unfortunately, because of the international move, I was unable to carry out this research as a PI, although I'm still involved with that project as a co-PI. After arriving in Canada, I decided to continue in the same research area but focus on preserving analogue phonograph recordings instead of analogue tapes. Within the past year, I have received more than \$118,000 from three different granting sources in addition to the \$600,000 CFI equipment grant, part of which will be used for the study of preserving phonograph recordings. In the pilot project to digitize early LP recordings of works by Handel, we have created a metadata schema, a digitization procedure of both the audio and the images of the album covers and record labels, and a web-based search engine and delivery system. The manual capture of the metadata and the content is extremely detailed, including things like the exact position and the size of photographs on the album covers. This data will be used for evaluating the accuracy of the automatic digitization system to be developed next year.

## 7. Budget

### Personnel

The Post Doctoral Fellow (PDF) will be hired in Year 2 and Year 3. There will be much background research and preparation will be needed before we can fully exploit a PDF. The main responsibility of the PDF will be software development. I have found from past experiences that in order to create a relatively large software system that will be usable by others is to have at least one person work on it fulltime. The tasks for the PDF will include:

- Complete implementation of reading and writing the music notation file format
- Development of a new notation editor or modify an existing one to fit the need of the project
- Implementation of Gamera software to process early music notation
- Develop various preprocessing image manipulation algorithms
- Participate in the workshops
- Supervise and mentor the two graduate students
- Work with the PI and the graduate students to write conference papers and journal articles
- Make presentations at conferences

The Ph.D. student in Music Technology will be responsible for a wide variety of tasks including:

- Compilation of bibliography related to this research
- Maintenance of the project web page and image database
- Organization of the workshops
- Ongoing documentation, writing technical reports, and preparation of research papers
- Study of existing music notation file formats
- Initial design of the notation file format
- Research into availability of existing early music editors
- Extensive research of image processing techniques, which maybe useful for this application
- Learning to use Gamera
- Assisting in the software development by working closely with the PDF

A musicology masters student will be mainly involved in the research of music scores. The student will locate facsimile editions and modern editions of scores found on microfilms. The student will look for samples of wide variety of notational practices and of different image quality on the microfilm. The student will be responsible for the digitization of both the microfilm images and facsimile and modern editions. The student is expected to have basic music transcription skills and will perform most of the symbol recognition training. The master's student will also be involved in the discussion in establishing a notational format for early music.

### Travel

In Year 1, for research purposes I will attend the International Conference on Music Information Retrieval (ISMIR) in London (September 2005) to be abreast of the newest research in this field. In Year 2, the PDF, the Ph.D. student, and I will present at least one progress report of this project at ISMIR and/or at Joint Conference on Digital Libraries. In Year 3, the Masters student and I will attend the American Musicological Society meeting in Québec City and hopefully present a report. Another important venue for us to present will be the meeting of the Music Library Association in 2007.

### **Computer Technician**

There will be at least three computers dedicated to this project in addition to laptops and a server, technical support for the computers and the network must be available. The cost of the technician will be shared by the Faculty of Music and other research projects.

### **Supplies**

Office stationaries, blank CDs, backup tapes, toner cartridges, etc.

### **Computer hardware and software**

Although desktop computers and servers valued at \$40,000 will be provided by the CFI grant for this research, I would like to offer the PDF the option of working on a laptop computer while away from the office (15" Powerbook G4 plus software).

### **Workshops**

One of the most efficient and productive methods of getting work done is to invite top people in the field to a workshop and brainstorm ideas. Three one-day workshops are planned: The first one will be held in Montreal (November 2005) with a small group of key personnels, potential participants include: Julie Cummings (McGill), Andrew Hughes (Toronto), Michel Huglo (Maryland), Thomas Kelly (Harvard), and Susan Weiss (Johns Hopkins). To minimize the travel costs, the other two workshops will be held in conjunction with other conferences where the experts in the field will be attending. In these workshops, this project will support the extra night of stay, room rental, and meals. The second workshop will be held at Early Music America Conference in Berkeley (June 2006) and the final workshop at the American Musicological Society meeting in Quebec City (November 2007). The topic of discussion in these workshops will include: evaluation of notation file format, selection of samples, review of OMR results, quality of diplomatic transcriptions, usability of the software.