Special Topics

Encoding Neumes and Mensural Notation

The term *neumes* encompasses a broad range of notational phenomena in medieval and Renaissance music. From a representational viewpoint, medieval neumes normally preserve pitch information but lack either durational information or a secure basis on which to interpret it. Pitches may be joined in *ligatures* that assume a range of composite shapes. In mensural notation rhythmic indications are more highly evolved but complex. The coloration of neumes and the tempus and prolation signs at the start of a piece must be correctly observed to produce an accurate modern transcription.

The representation of neumes has been accomplished in various ways, usually in a way tailored to the representation of one particular repertory. Yet a sufficient number of dedicated solutions has accrued to provide some basis for a broadened view of the subject. As a supplement to our 1987 review article on music representation, we have collected available information on existing approaches to the encoding of neumes.

As in other contexts, the best choices for encoding methods must be made with due regard for both the nature of the original material and the purposes for which the machine-readable code will be used. Works may be encoded for printing, for analysis, and for long-term storage leading to multiple uses, in which case completeness of information is highly desirable. Much work on medieval chant has relied on numerical or letter-name encoding of pitches to create indices and concordances. The Bryden and Hughes *Index to Gregorian Chant* (Harvard University Press, 1969) is illustrative. It contains pitch encodings of 11,000 chant incipits. More recent work by Andrew Hughes and Richard Crocker proceeds along similar lines, although towards different goals.

A common goal of studies of monophonic repertories is to trace the transmission of melodic formulae and patterns with a view towards establishing chronological sequence, geographical spread, and paths of greatest influence. *Centonization* is a term borrowed from studies of the epic to describe the processes of melodic absorption and accretion that occurred in the oral transmission of chant repertories. *Attribute description* is often a necessary first step toward describing the general properties of a repertory. The absence of reliable means of rhythmic interpretation for many early repertories suggests an area in which the computer may eventually come to play an important role in testing diverse hypotheses.

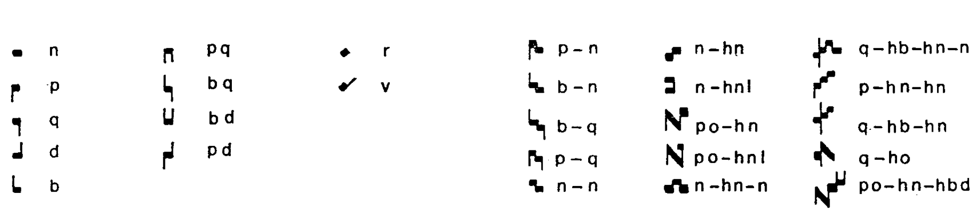
Monophonic Repertories

A long-held view of the development of European medieval music is that monophonic pieces were originally set with one note to a syllable and that as time passed it became common to set some syllables of text with a few notes and eventually to set highly significant words, such as *alleluia*, with long melismas. The theory is losing ground as an oversimplified and in many cases inaccurate one, but it is helpful in understanding the development of musical notation. Ligatures came about in order to accommodate the *neumatic* setting of multiple notes to one syllable of text.

In modern transcription, monophonic repertories are now easily encoded by many program for music printing. The earliest computational studies of medieval music, which date back to the 1960's, considerably predate the advent of this modern convenience. Among the early computer-assisted studies of medieval repertories was that of Raymond Erickson on thirteenth-century rhythm ("Rhythmic Problems and Melodic Structure in *Organum Purum*: A Computational Study," Ph.D. thesis, Yale University, 1970). A number of studies of medieval music were prepared under the direction of Ian Bent and John Morehen, in particular at Nottingham University over the past two decades. DARMS, which provides for the complete encoding of musical notation, has been the language of choice in most of these studies. A more limited numerical system of representation was used in David Halperin's two theses on troubadour music (1978) and Ambrosian chant (1986), both completed at Tel-Aviv University. Until recently encodings of medieval music were based on modern editions of the repertory.

The task of interest for present purposes is to encode directly from the source in such a way as to preserve information about the original presentation of the musical information provided and to avoid forced interpretations of notational elements of uncertain meaning. The systems cited below, which originated between the mid-1970's and late 1980's, all attempt in various ways to address that goal.

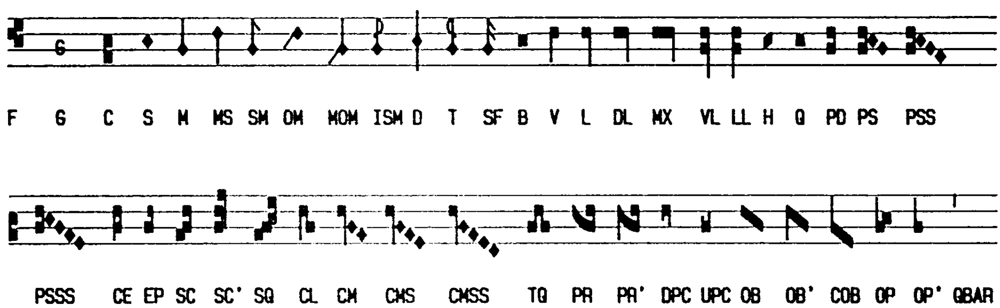
Leo J. Plenckers at Amsterdam University has successfully encoded the *Cantigas de Santa Maria* from a modern edition using a self-designed system of representation. To capture information about the shapes of neumes, ligatures, and complexes, Plenckers developed alphabetic codes suggested by the shapes of the symbols. Connected neumes and ligatures were formed by combinations of these:



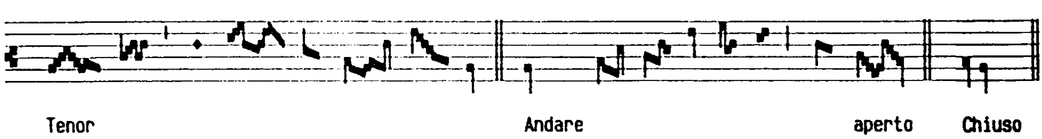
The letter *o* = *obliqua*. If the second note is higher than the first, an *h* immediately follows the hyphen; if it is left-facing, an *l* is placed after the appropriate letter. Complexes involving longer strings of these encodings are joined by the sign "+".

Plenckers was able to write a grammar for parsing the encoded songs into elements and to facilitate pattern matching. He then explored questions of pattern formation and drew attention to similarities between Algerian songs and items in this thirteenth-century repertory. The details of the system and some of the analytic results are reported in Plenckers' article "Pattern Recognition in the Study of the *Cantigas de Santa Maria*" (*Musical Grammars and Computer Analysis*, ed. Mario Baroni and Laura Callegari, Florence, 1984, pp. 59-70). The fact that the author was able to use the information analytically attests its practical value.

The SCRIBE system developed by John Stinson, John Griffiths, and Brian Parish at La Trobe and Melbourne Universities in Australia has been used in the encoding of approximately 3000 monophonic works (ballades, caccie, lays, virelais, rondeaux, *et al.*) from the fourteenth century. The latest version of the support software facilitates the encoding of approximately 20 neume shapes. Searches for neume types may be conducted. Analytical work with this repertory has extended to contour comparisons with chant from earlier centuries, including the tenth, for which striking resemblances have been found in the fourteenth-century material. There is now a capability to produce round stemless noteheads with slurs indicating the ligatures of the square notation. Two- and three-note ligatures have codes derived from chant nomenclature: Pd = *podatus*, Pr = *porrectus*, etc. The codes currently in use are these:



Below we see a SCRIBE transcription [in black neumes on a staff of six red lines] of the tenor of Landini's ballata "Gia ebbi libertate" and the source on which it is based:



In a dissertation study currently underway, Hilde Binford-Walsh at Stanford University is using *SCORE* to encode Aquitainian chant. Her interest is in establishing a melodic grammar. She encodes both neume shapes and absolute values and performs numerous statistical tests on the resulting data.

The work of Catherine Harbor and Andy Reid at Royal Holloway and Bedford New College in the UK on a program called *PLAINSONG* is devoted to the entry and use of black neumatic notation on a four-line stave. The range of neume forms provided supports work with both printed and manuscript repertories. There is also a facility for entering episemata [strokes added to neumes to denote elongation] of varying lengths either above or below the neumes, as appropriate. Printing capabilities are discussed on p. 70.

PLAINSONG includes two analytic modules, both of which can operate at varying levels of detail. A variant module compares up to 30 versions of a chant against a master version and prints each item in schematic form, with or without text underlay, under the master. A similarity search module compares a given chant quotation with a series of materials in files specified by the researcher and reports potential matches. Comparisons of neumes, text, melody, and episemata are all supported. Further information is available from Catherine Harbor, Computer Centre, Royal Holloway and Bedford New College, Egham Hill, Egham, Surrey TW20 0EX, UK (C.Harbor@vax.rhbnc.ac.uk).

Polyphonic Repertories

Mensural notation defined durational relationships on two levels—that of *tempus*, the basic beat, and that of *prolation*, the number of subdivisions within the beat. Modern 12/8 time could be said to have a tempus of 4 and a prolation of 3. Because of the tiered nature of this system, the graphic image of a note did not fully define its value. That had to be computed with reference to tempus and prolation signs given at the start of a work. Various systems were devised to express more clearly the appropriate relationships. In white mensural notation, noteheads could be filled or void. In more elaborate systems, red notes (either filled or void) could be used in conjunction with black notes (either filled or void). The invention of dots of addition in the early sixteenth century led to the gradual decline of mensural notation. Much of the music of the preceding, highly illustrious decades is preserved in mensural notation. The idea of mensuration lingered in the "colored" notation of the seventeenth century. Filled whole notes and void eighth notes occurred in passages which contradicted the accentuation scheme suggested by the meter signature [an example is shown on p. 103].

Considerable attention has been devoted to the encoding of mensural notation. Norbert Böker-Heil's work on the Renaissance *Tenorlied*, resulting in a three-volume edition (Kassel: Bärenreiter, 1979-86), involved the encoding and printing of mensural notation and provided extensive support for its analysis [see the 1988 *Directory*, pp. 122-125]. A provision for sound output has subsequently been added.

Tom Hall's *FASTCODE* was in use at Princeton University in the 1970's and early 80's to encode white mensural notation of the fifteenth and sixteenth centuries, particularly in the works of Josquin and Lassus. Hall's system supported note values from the *semifusa* (the equivalent of sixteenth notes) through the perfect *maxima* (the equivalent of twelve semibreves) and could accommodate time changes local to one voice.

Other programs with the ability to print mensural notation include *SCRIBE, SCORE, Subtilior Press, WOLFGANG,* and *ALPHA/TIMES*. *Subtilior* [shown in 1989] creates an electronic facsimile rather than an actual encoding of the source. *ALPHA/TIMES* can produce a facsimile [p. 35] but it supports encoding and searching. These two programs run on the Macintosh. *SCRIBE* is oriented more toward storage and retrieval of information [described above] than towards printing of mensural notation, but its two-color plotter output makes a very attractive facsimile. *SCORE* and *WOLFGANG* both provide both facsimile and modern notation options for mensural notation together with complete encoding. [An example from a preliminary version of *WOLFGANG* is shown on p. 35.] The three last-named programs run on the IBM PC.

Many kinds of historical and analytical research on repertories of the Renaissance require, in addition to an adequate code for the symbols encountered in the source, an articulate understanding of implied durational differences between elements that are graphically the same. One carefully rationalized approach to the encoding of mensural notation that exhibits this important quality was devised by Lynn Trowbridge as a set of extensions to DARMS for thesis research carried out at the University of Illinois in the late 1970's. We are reproducing here, with the author's permission, the salient points of this system because they are of potentially broad applicability to other projects.

Trowbridge's *Linear Music Input Language* for Analysis

Trowbridge's immediate task was the encoding for a large repertory of fifteenth-century chansons. The *Linear Music Input Language* (1980) that he used to encode this repertory is a modified subset of DARMS that facilitates dealing with the durational complexities of the music. The logic underlying his system could fruitfully be applied to the encoding of any repertory with the same characteristics. While we cannot fully reproduce the manual here, we should like to call attention to some general elements of the approach.

> *Voices.* In specifying the voice part being encoded, Trowbridge specified the total number of voices in the work. He differentiates between a *Cantus Superius* in a two-voice texture, a *Cantus* in a three-voice texture, a *Cantus* in a four-voice texture, and a *Superius* in a five-voice work. Although this is irrelevant to representation *per se*, it has enviable strengths for analytical studies.

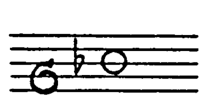
Staff placement codes follow customary DARMS practice. The bottom line of any staff is "1"; DARMS has no true pitch code. Clef codes, preceded by an exclamation mark, are formed by coupling the line number with the sign C, F, or G (!3G, !7C). In key codes (introduced as !K), a flat is a minus (-) and a sharp is a plus (+), and a numeral indicates the number of pitch classes affected. !K1- introduces a work with one flat.

Meter involves two variables—tempus and prolation. Perfect (triple) tempus was expressed by a circle, imperfect (duple) tempus by a C (understood to be an incomplete circle). Numerals were used for perfect (3) and imperfect (2) prolation.

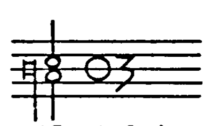
In Trowbridge's system, the representation of tempus and prolation is treated as if the music were in modern notation. The following meter codes are employed:

2/4	C	2:4	6/4	⌽, C3	6:4
3/4	O	3:4	9/4	O3	9:4
2/2	C2, ¢, Ↄ	2:2	6/8	Ͼ	6:8
3/2	O2	3:2	9/8	⊙	9:8

Composite examples of the encoding of clef, key, and meter signatures are as follows:



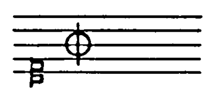
!3G !K1- !M3:4



!5F !M9:4

!3C !K1- !M2:4

!7C !K2- !M2:2



!1C !M6:4

!7F !K1- !M3:2

It is one thing to have such coding tools available but quite another to interpret the music correctly in each metrical context. To address this problem, Trowbridge developed a table of codes (W = whole, H = half, Q = quarter, etc.) to be used for each durational species in relation to the original note shape (fusa, semiminim, etc.) in each respective meter. In this table Dot. = dotted, Per. = perfect, Imp. = imperfect, and Col. = colored.

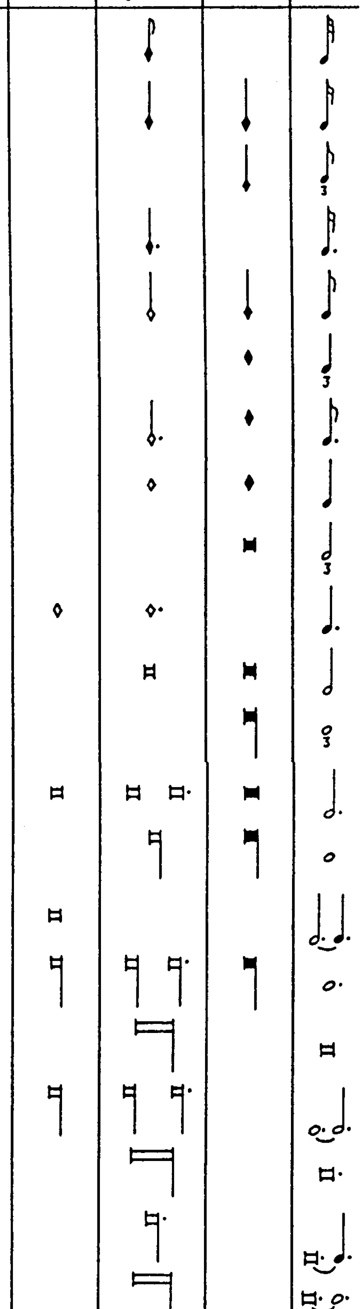
Note shapes	2/4 C	3/4 O	2/2 ¢ C2 Ↄ	3/2 O2	6/4 Φ C3	9/4 O3	6/8 Ͼ	9/8 ⊙
Fusa	T	T	T	T	T	T	T	T
Semiminim	S	S	S	S	S	S	S	S
Dot. semiminim	S.	S.	S.	S.	S.	S.	S.	S.
Col. minim	&2/3 E*	E	&2/3 E*	&2/3 E*	E	E		
Col. min. (+ SBr)	S	S	S	S	S	S		
Minim	E	E	E	E	E	E	E	E
Dot. minim	E.	E.	E.	E.	E.	E.	E.	E.
Col. semibreve	&2/3 Q*	Q	&2/3 Q*	&2/3 Q*	Q	Q	Q	Q
Col. SBr (+ min.)	E.	E.	E.	E.	E.	E.		
Imp. semibreve	Q	Q	Q	Q	Q	Q	Q	Q
Per. semibreve							Q.	Q.
Dot. semibreve	Q.	Q.	Q.	Q.	Q.	Q.		
Col. breve	&2/3 H*	H	&2/3 H*	&2/3 H*	H	H		H
Imp. breve	H	H	H	H	H	H	H.	H.
Per. breve		H.			H.	H.		WJE
Dot. breve	H.		H.	H.				
Col. long	&2/3 W*	W	&2/3 W*	W	W	W.		
Imp. long	W	W.	W	W	W.	W.	W.	BJQ
Per. long				W.		BJQ		
Dot. long	W.	BJQ	W.		BJQ		BJQ	B.JQJE
Imp. maxima	B	B.	B	B.	B.	B.JWJH	B.	B.JWJH

By using three units to represent the smallest note encountered, Trowbridge avoided fractional parts in the representation of colored (e.g. triplet) notes. The numerical value of each note is shown in the following table:

Note shapes	2/4 C	3/4 O	2/2 ¢ C2 Ↄ	3/2 O2	6/4 Φ C3	9/4 O3	6/8 Ͼ	9/8 ⊙
Fusa	3	3	3	3	3	3	3	3
Semiminim	6	6	6	6	6	6	6	6
Dot. semiminim	9	9	9	9	9	9	9	9
Col. minim	8	12	8	8	12	12		
Col. minim (+ semibreve)	6	6	6	6	6	6		
Minim	12	12	12	12	12	12	12	12
Dot. minim	18	18	18	18	18	18	18	18
Col. semibreve	16	24	16	16	24	24	24	24
Col. semibreve (+ minim)	18	18	18	18	18	18		
Imp. semibreve	24	24	24	24	24	24	24	24
Per. semibreve							36	36
Dot. semibreve	36	36	36	36	36	36		
Col. breve	32	48	32	32	48	48		72
Imp. breve	48	48	48	48	48	48	72	72
Per. breve		72			72	72		108
Dot. breve	72		72	72				
Col. long	64	96	64	96	96	144		
Imp. long	96	144	96	96	144	144	144	216
Per. long				144		216		
Dot. long	144	216	144		216		216	324
Imp. maxima	192	288	192	288	288	432	288	432

Each possible numeric representation appears once in the following summary table:

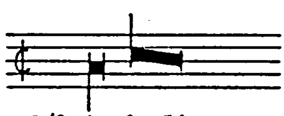
LMIL code	Proportional representation	Note shapes			
		Perfect	Imperfect	Colored	Modern
T	3				
S	6				
&2/3 E*	8				
S.	9				
E	12				
&2/3 Q*	16				
E.	18				
Q	24				
&2/3 H*	32				
Q.	36				
H	48				
&2/3 W*	64				
H.	72				
W	96				
WJE	108				
W.	144				
B	192				
BJQ	216				
B.	288				
B.JQJE	324				
B.JWJH	432				



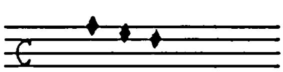
Another area of difficulty that Trowbridge resolved is the encoding of non-equivalent rhythmic groupings, such as triplets. Such a group is introduced by an ampersand (&). A reduced fraction in which the numerator indicates the number of rhythmic units actually occupied and the denominator the number of rhythmic units actually specified is employed. The pitch and rhythm codes (disregarding coloration) are then given for each member of the group. An asterisk (*) closes the encoding. Some examples follow.

&2/3 2H 3Q* 4H

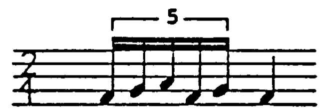
&2/3 7H 6E 5* 3Q 4



&2/3 4W 6Q 5*

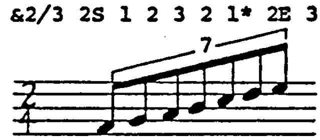


&2/3 9Q 8 7*

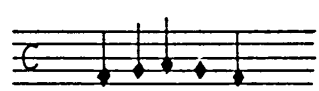


&4/5 2S 3 4 2 3* 2Q

&2/3 2S 1 2 3 2 1* 2E 3



&4/7 2E 3 4 5 6 7 8*

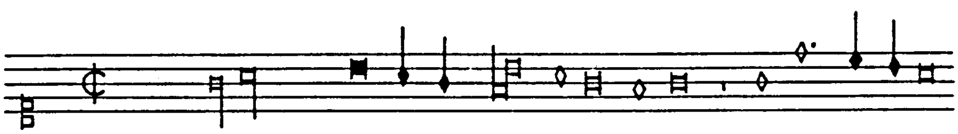


&2/3 2E 3 4 3Q 2E*

This system allows the exact rhythmic value of each member to be obtained by multiplication of the value of each unadjusted rhythmic symbol in the group by the reduced fraction described above.

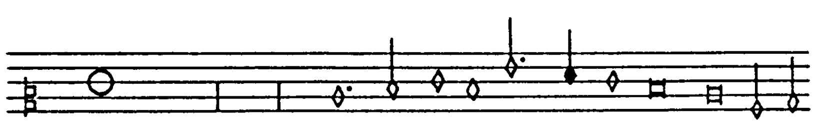
The solutions to some common problems encountered in the encoding of white mensural notation are indicated in the following encoding, which is interleaved with a transcription of the source:

`!3C !K1- !M3:47Q 7 9E. 8T 7 8Q 7E 6 5Q 4 RE 5 4 6E. 7S 8E 7 8 9Q`

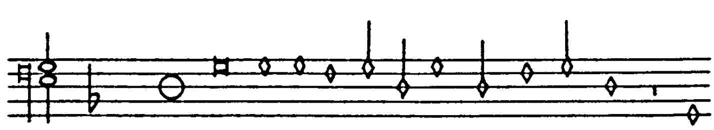


`!1C !M2:2 5W 6 &2/3 7H 6E 5* 4Q 7 6 5H 4Q 5H RQ 5 9Q. 8S 7 6H`

`!7C !K1- !M3:47Q. 6E 8 9 30Q. 9S 8 9E. 8S 30Q RE 7 8 7 5S 3 4E 3H`



`!3C !M3:4 RW. RW. 3Q. 4E 5Q 4 7E. 6S 5Q 4H. 3H 1E 2`



`!7F !K1- !M3:48H 8Q 8 7 8E 5 8Q 5E 7Q 8E 5Q RQ 1`

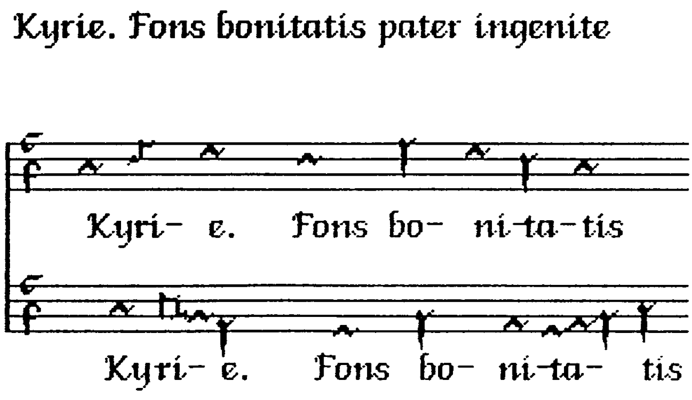
The complete LMIL manual is contained in Trowbridge's thesis, *The Fifteenth-Century French Chanson: A Computer-Aided Study of Styles and Style Change* (University of Illinois, 1982), UMI #8209635, pp. 275-89. An abridged version of his findings was published as "Style Change in the Fifteenth-Century Chanson" in the *Journal of Musicology*, IV/2 (1985-6), 146-70.

Printing Mensural Notation

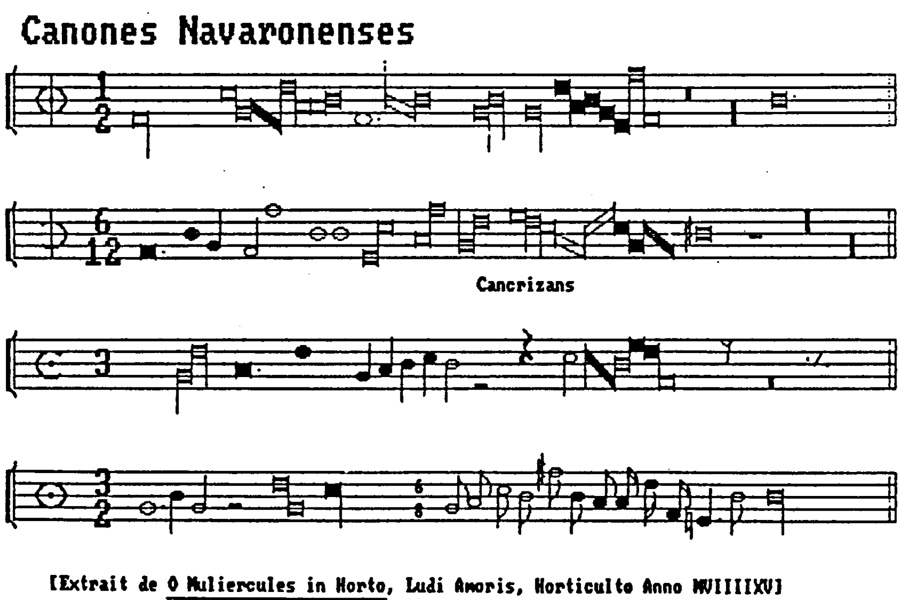
From systems that support the printing of mensural notation [see pp. 26-7 above], we provide a few examples of developments over the past ten years.

White mensural notation in score from Josquin's "Planxit autem David," produced via plotter by Tom Hall's FASTCODE, *c.* 1981. In this example, a change from ⦶3 to ₵ is represented. "SQ." indicated two square neumes, as opposed to one *obliqua*, in the original source.

Red [here grey] and black mensural notation produced with a pen plotter by SCRIBE *c.* **1988.** Note shapes can be represented as black, red, void, or red-void.



Transcription of polyphonic manuscript (St. Gall) showing neumes on four-line staves produced by Christoph Schnell's ALPHA/TIMES *c.* 1987.



Set of canons with complex mensural relationships produced by Etienne Darbellay's WOLFGANG *c.* 1986. See also p. 103.

Optical Recognition of Musical Data

There are several approaches to optical recognition of musical data, a topic that *Computing in Musicology* has followed for several years. Intelligent recognition of musical information must be distinguished from the capture of bit-mapped images as graphics information only. Intelligently scanned data can be manipulated and channeled to formats and uses different from the original one. In principle, optical recognition of musical data builds on the foundation of text scanning procedures. In text each character has a single identity and the number of characters is finite. Except in ligatures, characters appear as separate entities. Their meaning is the same, regardless of the context. The exact formation and size of an individual character varies from font to font, however, and many hundreds of fonts are encountered.

A simple approach to character recognition of both alphabetic text and of musical text is that of *template-matching*. The templates are based on particular fonts. Recognition programs are easily confused by graphic input that varies from font-specific descriptions in memory. This suggests that they are serviceable in situations where the material at hand is self-consistent but limited in value for handling typographically diverse materials.

A contrasting approach is that of *geometrical analysis* of graphic features such as lines, angles, orientations, and curvatures of scanned objects. Recognition is based on algorithmic matching. This approach overcomes the problems of exactness encountered in template-matching but elicits new areas of confusion in attempting to distinguish, for example, between b's and h's, l's and 1's, or O's and 0's. These kinds of misreadings are so subtle that they are difficult to detect in proofreading. Uncorrected errors can lead to bizarre results in processing of data.

The optical scanning of music cannot build entirely on these approaches, because the symbols used in musical notation are so much more numerous, their visual grammar so much more complex, and their meanings sometimes determined by contextual clues. Even the question of what constitutes an object is confusing. A single pitch is a discrete sound object. Its representation can comprise several graphics objects such as a notehead, a stem, and a flag or beam, for example. An isolated notehead means little as a "recognized" object, because from it we cannot determine pitch without intelligent information about a preceding clef sign and staff position, nor can we determine duration without information about its coloration, its stem (if any), and any possible flags.

To overcome these problems, researchers have explored the technique of *bounding* groups of objects, such as a series of eighth notes connected to a common beam, and defining the contents hierarchically from most to least comprehensive. The demarcated area is called a bounding box. They have explored foreground-background separation (i.e., removing the staff lines to expose the notes), background enhancement, tests of identity by rotation and/or slanting of objects, and a host of other image-processing techniques. Since the automatic recognition of the 26 characters of the Roman alphabet is still an imperfect art, we do not anticipate a fully accurate technique of automatic recognition of musical information soon. Yet activity in this area of research has significantly increased in the past year, and the various approaches employed will undoubtedly be of value in clarifying the circumstances under which different procedures are most appropriate. We offer below reports from several groups and individuals working in this area.

University of Surrey/OUP

The work of Nicholas Carter, R. A. Bacon, and T. Messenger at the University of Surrey in Guildford, England, is firmly focused on the acquisition of printed music in common musical notation. The project is sponsored by Oxford University Press.

The work is conducted in a hybrid environment of UNIX and DOS. Development of the recognition software takes place under UNIX on a Sun386i workstation. Input is via a Hewlett Packard ScanJet flatbed scanner interfaced with the workstation. Output is in the form of a file compatible with the SCORE music publishing program, which operates under DOSWindows on the Sun386i. [Sample input and output were shown in last year's issue of *CM*, pp. 32-3.]

Currently a wide range of models for use in the recognition process is being constructed. A provisional vocabulary of symbols is to be devised from the first volume of the complete works of C. P. E. Bach (Vol. 24, Ser. I, containing solo keyboard music), which was brought out recently by OUP. The contents have been divided into a training data set and a test data set. The aim of the work is to enable conversion of existing printed music into machine-readable form, thus enabling applications such as electronic publishing, computer-based editing, musicological analysis, and automatic production of Braille music.

Among publications relating to this project are Carter's Ph.D. thesis, "Automatic Recognition of Printed Music in the Context of Electronic Publishing," which was completed at the University of Surrey in 1989, and "Automatic Recognition of Music Notation" by Carter and Bacon in the pre-*Proceedings of the International Association for Pattern Recognition Workshop on Syntactic and Structural Pattern Recognition* (Murray Hill, NJ, June 1990), 482.

University of Wales/Cardiff

The work on optical character recognition for printed music notation that has been in progress for three years at the University of Wales College of Cardiff is based on an IBM PC AT and uses an IBM 3117 flatbed scanner. One of the particular objectives is to develop a low-cost system that might be affordable to small printing companies or individual musicians. The overall objectives are otherwise the same as those described above.

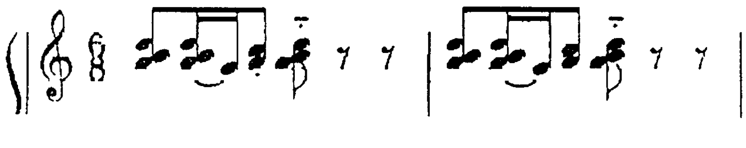
Much of the research has concentrated on finding computationally efficient methods of determining the identities of each musical symbol. The recognition of single-line melodies now approaches 95% accuracy. More complicated examples involving chords have an accuracy rate between 80% and 95%.

A current focus is on contiguous objects, such as the noteheads shown in the accompanying illustration. The printout of the results of the program is an ordered list of the musical objects that have been identified. The order is by the sequence in which the symbols appear from left to right in the music. The only error in this example is that four of the staccato dots were ignored by the system. The duration column computes the number of sixteenth notes involved.

This research has been undertaken for a Ph.D. thesis that, it is anticipated, will be completed before the end of 1990. The project will continue at least until September 1992.

Music to be scanned by the Cardiff program:

Stage I—Removal of staff lines



Stage II—File listing of scanned objects:

Symbol Identity	Duration	Horizontal Position	Pitch of Note or Symbol		
Barline		55			
Clef		83			
Time Signature		122			
S Beamed Group	2	177	d'	a	b
B Slur		218			
Beamed Group	1	220	d'	a	b
E Slur		245			
Beamed Group	1	251	g		
Dot		278	f		
F Beamed Group	2	278	c'	a	
Note	2	312	a	d'	b
Tenuto		320			
Dot		320	g'		
Rest	2	360			
Rest	2	403			
Barline		443			
S Beamed Group	2	477	d'	a	b
B Slur		517			
Beamed Group	1	518	d'	a	b
E Slur		545			
Beamed Group	1	551	g		
F Beamed Group	2	578	c'	a	
Note	2	613	a	d'	b
Dot		620	g'		
Tenuto		621			
Rest	2	659			
Rest	2	703			
Barline		742			

Bar 0 - 0 beats
Bar 1 - 12 beats
Bar 2 - 12 beats

Note that staccato dots are given a pitch value to represent their placement on the staff. Note also the processing order of the graphic elements in the different presentations of the a-b-d' chord.

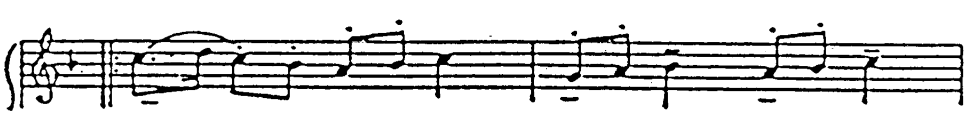
Waseda University

An automated recognition system for reading musical scores forms part of Waseda University's "Music and Vision" research program, a fundamental tenet of which is that visual aspects of music are of comparable informational importance with acoustic aspects of music. The automated recognition of notated music relies on a computer vision technique. The illustrations following show several stages in the recognition process. Note that in this approach staff lines are added to clarify placement. The reading time for a commercially available nursery song with three real voices is about 10 seconds. Once the data acquisition has been performed, wider applications are possible in the fields of computer music and music information processing.

The musician robot WABOT-2, developed at Waseda University, reads a musical score in real time and plays the electronic organ with its ten fingers. [Scanned music from this system was shown in the 1986 issue, p. 34]. The principal source on WABOT is S. Ohteru et al., "Automated High Speed Recognition of Printed Music" in the *Proceedings of the International Conference on Advanced Robotics* (1985), 482-577.

Other facets of research by this group, which includes Takebumi Itagaki and Masayuki Isogai as well as Sadamu Ohteru at Waseda University and Shuji Hashimoto at Toho University, are a bilateral translation system to facilitate conversion between printed and Braille music and automatic recognition of dance patterns in real time. In the latter case a data base of choreographies is under development through a program for automatic recognition of dance notation. [For information on dance notation software, see pp. 107-11.] *Standard Music Expression (SMX)*, one of the representation schemes used in this research, was shown in the 1987 *Directory*, pp. 16-7.

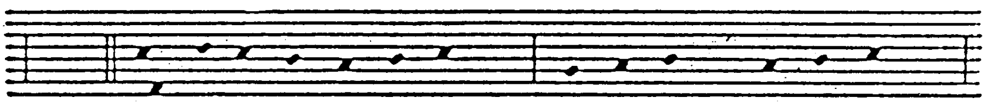
(a) Original music:



(b) Normalized picture:

(c) Determination of notehead locations against an expanded staff:

(d) Individual symbols captured:



(e) Output of score data after analysis:

Musical Interval	C0	C2	C0	BA	B9	BA	C0	B7	B9	BA	B9	BA	C0
Sound Type	01	01	02	02	02	02	04	02	02	04	02	02	04
Sound Duration	12	06	0C	0C	0C	0C	18	0C	0C	18	0C	0C	18

Intervals: in the left column, A, B, and C are octave designations. In the right column, pitches are represented as chromatic units in hexadecimal notation. Numeric 0 = pitch 0 = C, irrespective of tonality. Numeric A = pitch 10 = B♭ and numeric B = pitch 11 = B♮.

Sound types: 1 = unaccented, 2 = staccato, 4 = tenuto.

Sound durations: these are indicated in two-digit hexadecimal notation, from which rhythmic relationships can be deduced. Hex 6 = decimal 6, hex 12 = decimal 18, hex 0C = decimal 12.

University of Ottawa

At the University of Ottawa, William McGee and Paul Merkley have been engaged both in research on optical scanning and on uncovering the many layers in the process of the transformation from cheironomic to diastematic notation in medieval music. The broad aim is to provide a fast, error-free method of entering musical samples into a format that permits statistical analysis, string searches, editing, and printing on IBM PC compatibles. Although this account concentrates on their work with medieval manuscripts, the research extends to common notation from printed sources.

Cheironomic notation, which is thought to have originated in the eighth century, is not pitch-specific. It tells the reader only whether the next note is higher or lower and with what vocal nuance it should be sung. It is believed that the singers for whom this chant was intended were already familiar with the basic melodies, which were transmitted orally, and that the notation was merely a stimulus to correct performance.

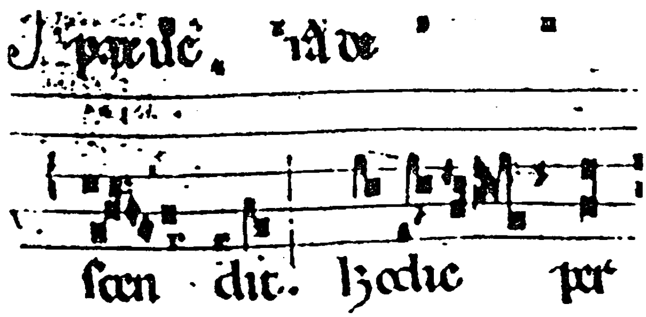
In later *diastematic notation*, pitch is specified but there is little allowance for the expression of nuance. Its function was to preserve and aid in the transmission of the repertory. Although the neumes it used were originally unlined, colored and dry-point lines were added gradually and by the eleventh century clefs and staves had come into regular use. The forms of individual neumes changed as the background developed.

To develop a scanning system for early medieval music, the Ottawa researchers began with lined notation of chant with neumes in square notation, which presents few difficulties of syntax. They first remove the lines. The quality and distortion of the material are such that this procedure involves sampling a number of positions along presumed lines. For the interpretation of individual neumes, pattern recognition and thin-line coding procedures have both been explored. Through vertical and horizontal assessment based on the latter, square neumes can be detected by their resemblance to their counterparts in cheironomic notation. Bounding boxes are used to create a dynamic dictionary of neume shapes; the dictionary facilitates component identification, which involves pattern-matching procedures.

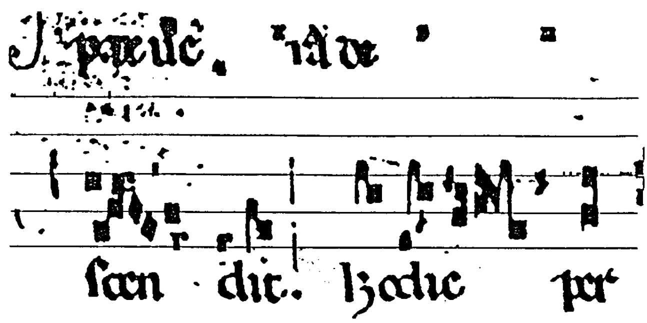
The original scanning is done with a Hewlett Packard Scanjet flatbed scanner interfaced to an IBM PC XT computer. Interpreted output is converted to a DARMS file and printed with *The Note Processor*. Research on the scanning of music in common musical notation is also in progress.

The materials shown on the following page were scanned from *Paléographie musicale* (Tournai, 1889--) materials relating to the "Justus ut palma florebit" family, a text cycle set to different melodies. Paul Merkley, who provided this information, is the author of *Italian Tonaries* (Ottawa, 1988) and "Tonaries and Melodic Families of Antiphons," *Journal of the Plainsong and Medieval Music Society* (1989).

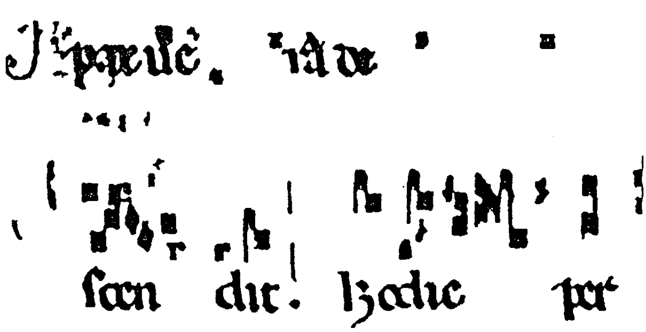
(a) Original image:



(b) Image corrected by straightening staff lines:



(c) Image with staff lines and other visual irrelevancies removed:



Three stages in the scanning of medieval music.

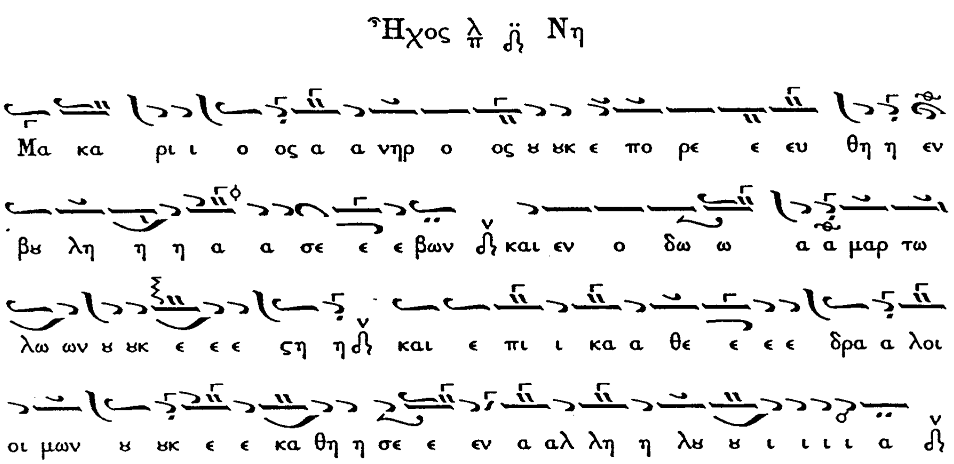
ERATTO-C.N.R.S./Paris

The focus of research into optical scanning by Dimitris Giannelos at ERATTO, a part of the Centre National de Recherche Scientifique in Paris, is concerned with capturing the graphic symbols of traditional Greek Orthodox sacred music from printed sources. His programs, for which he currently claims an accuracy rate of 80%, run on the Macintosh Plus. A version for the IBM PC is in preparation. The program will be made commercially available. Data can also be used analytically. Transcription has been fully automatic since June 1989. Output is channeled through Michel Wallet's *Euterpe* [see *Software for Music Printing*] to a laser printer.

ΜΑΚΑΡΙΟΣ ΑΝΗΡ

Πέτρου Λαμπαδαρίου τοῦ Πελοποννησίου (+1777)

συντμηθὲν ὑπὸ Μανουὴλ Πρωτοψάλτου (+1819)

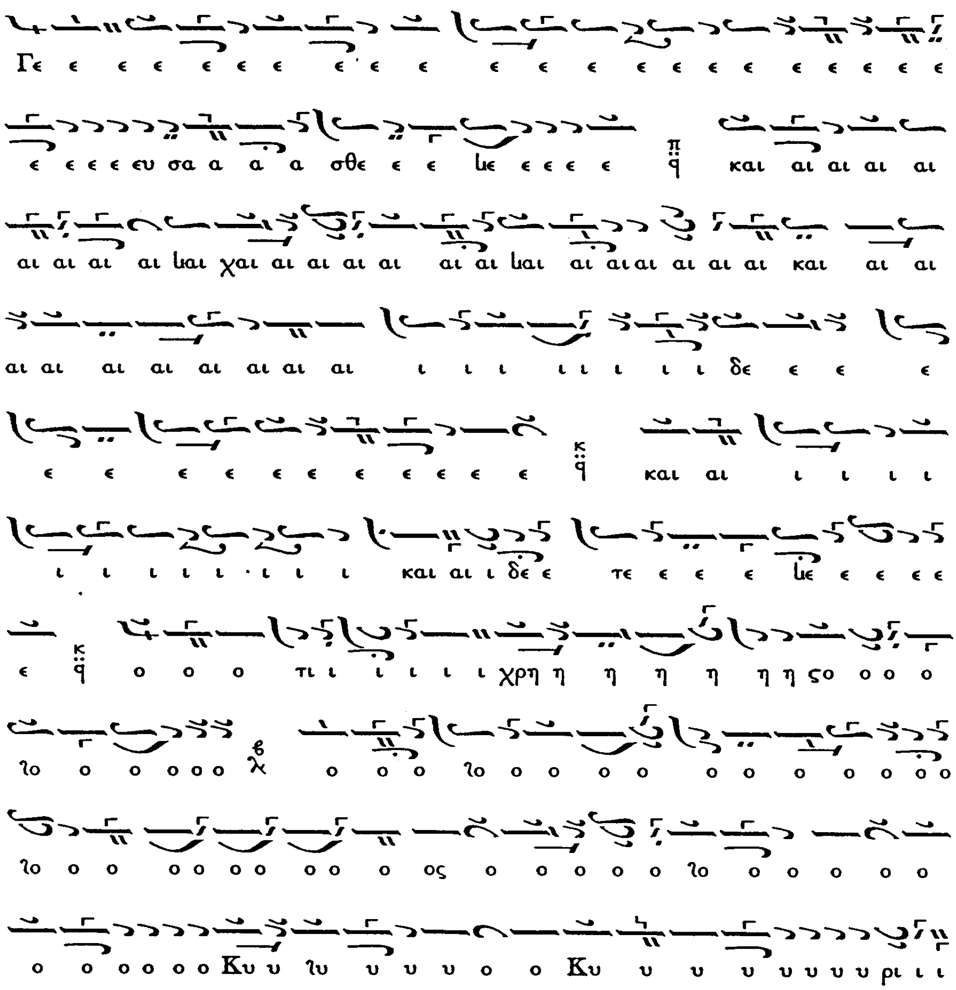


Approximate translation: "Blessed [is the] Man [by] Peter Lampadarios of the Peloponnesus arranged and abridged by Manuel Protophaltos" [a leading Greek composer of the fifteenth century]. The text for this "Sequence of the Evening" is taken from Psalm 1 and begins: "Blessed is the man who has not walked in the assembly of the impious and has not stood in the road of sinners and has not sat in the seat of the pernicious. Alleluia."

ΚΟΙΝΩΝΙΚΟΝ

Ἰωάννου τοῦ Κλαδᾶ (ΙΔ′ καὶ ΙΕ′ αἰῶνος)

Ἦχος α′ ἐκ τοῦ Κε

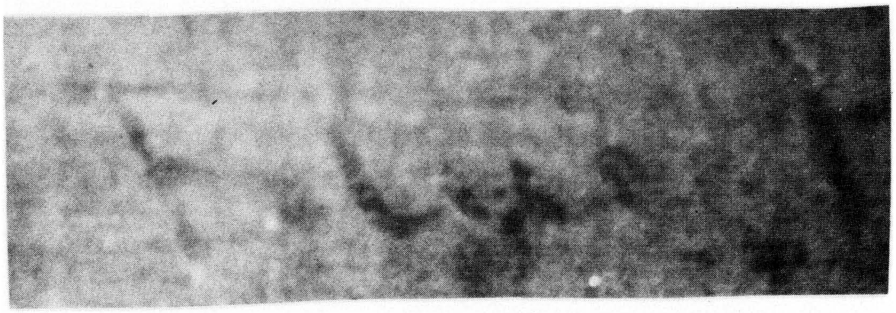


Approximate translation: "[Chant for] Communion [by] John [the son] of Klada" [a leading Greek composer of the late fourteenth century]. Stanza 1 of 25: "Take part, taste, and see that Christ the Lord…."

Computer Enhancement of Paleographic Information

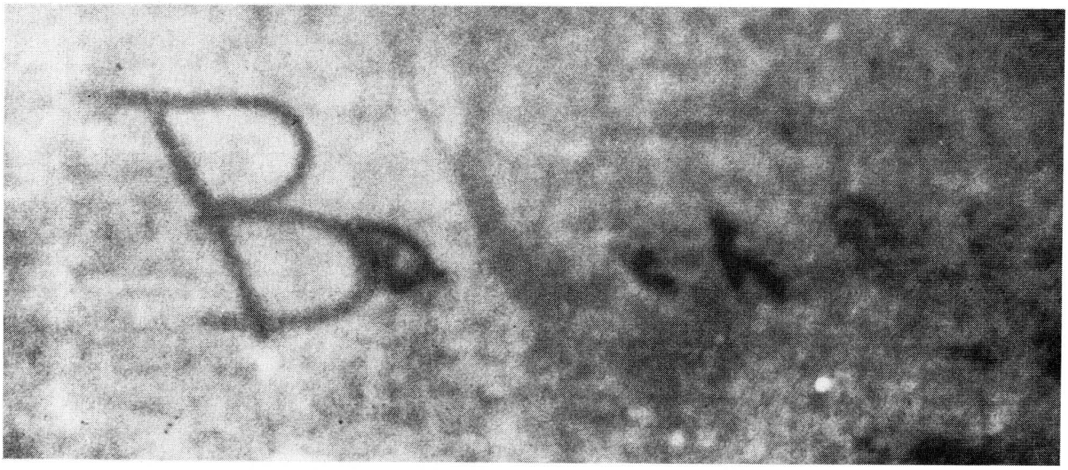
Joan S. Reis, a recently retired member of the Department of Music at the University of Cincinnati and a part-time member of the staff of the Cincinnati Art Museum, has recently raised an interesting question about the use of computer enhancement in paleographic studies. Her interest came about in an effort to demonstrate that a Gainsborough portrait acquired by the Museum in 1983, as part of the bequest of Agnes S. and Murray Seasongood, is not that of Surgeon-General David Middleton, as supposed for most of the current century, nor of Benjamin Franklin, as supposed for much of the last, but rather an unfinished portrait of Johann Christian Bach, showing him ravaged by tuberculosis near the end of his life. Bach was living in London when he died early in 1782. Thomas Gainsborough was a personal friend who had twice previously painted his portrait.

Several kinds of evidence are cited in Reis's article "A Third Gainsborough Portrait of Johann Christian Bach?" in *The Musical Quarterly* 74/2 (1990), 295-302. After the frame was removed, Elizabeth Bachelor, Assistant Director of the Museum, requested an infrared scan of the painting. Infrared reflectography, in which rays pass through the fabric, reveals details of the sub-surface. The image produced may be photographed from a monitor, producing a grainy effect and distorted edges. In this case the scan revealed some hidden writing in the upper left-hand corner. The representation below was made from a black-and-white photograph provided by Reis.



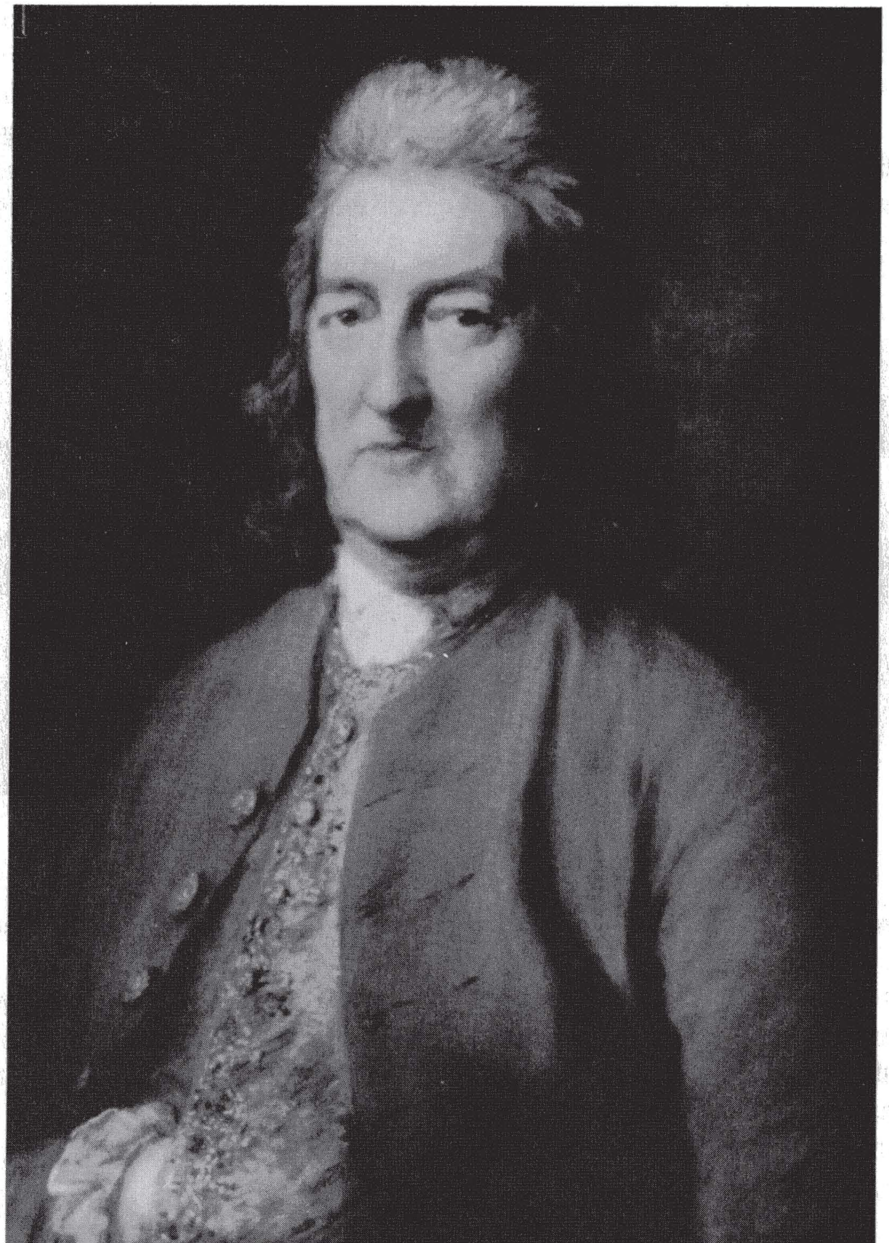
The name "Bach" before enhancement.

From an enlarged print of the negative, it was possible to make out, under paint previously covered by the frame, the letters "Ba ch". In the intervening space an enlarged thread gave the appearance of an "L". The letters are thought to have been separated to accommodate the thread. To differentiate between the thread, which had become darkened with time, and the letters transcribed, and to subdue the background, Jeffry B. Weidner of Xenas Communications in Cincinnati produced the computer enhancement shown below. This provides one of the pieces of evidence cited by Reis.



The name "Bach" in an infrared photographic enlargement after computer enhancement.

Our effort at reproducing this material further distorts the original graphic information and is conducive to an uncertain result. Those with a serious interest in the matter should consult evidence closer to the source. We offer the material to call attention to the potential value of such techniques in paleographical studies of all kinds. The portrait is shown on the following page by kind permission of the Cincinnati Art Museum.



A portrait by Thomas Gainsborough recently said by Joan S. Reis to be made of J. C. Bach in *c.* 1781. Used by permission of the Cincinnati Art Museum.