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Chant Editing and Analysis Program: A Tool for Analyzing Liturgical Chant

Abstract: Until recently, Old Hispanic chant was rarely subjected to close musical analysis, in part because it is preserved in unpitched notation. Although we can read the contours of the melodies—the up and down movements—they cannot be reliably transcribed into modern notation. This paper introduces the Chant Editing and Analysis Programme and shows how it facilitates analysis of the repertory.

Keywords: Old Hispanic chant, Mozarabic chant, medieval notation, musical analysis

The Chant Editing and Analysis Program (CEAP) is a digital tool developed for the analysis of Old Hispanic liturgical chant, sung on the Iberian Peninsula from the seventh century until its suppression at the Council of Burgos (1080).[1] Notated manuscripts copied between the ninth and eleventh centuries are mostly incomplete and

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[1] The development of this software was funded by European Union's Seventh Framework Programme (FP7/2007–2013)/ERC grant agreement no. 313133; a Philip Leverhulme Prize, 2010–13; AHRC follow-on funding for Impact and Engagement, grant AH/P002757/1; and AHRC Standard Grant AH/S006060/1. For transcription work and development of the neume taxonomies and fonts, we are particularly grateful to students in Hornby's Medieval Music Palaeography unit in 2018 and 2020, as well as Elsa De Luca, Raquel Rojo Carrillo, Marcus Jones and Emily Wride.

come from the northern Christian kingdoms; a few twelfth- to fourteenth-century notated manuscripts survive from Toledan parishes. Until recently, Old Hispanic chant was rarely subjected to close musical analysis, in part because its notational signs, neumes, do not show exact pitch.[2] Although we can read the contours of the melodies—the up and down movements—they cannot be transcribed into modern notation.[3]

We developed CEAP in an effort to address questions that emerged in our early work about Old Hispanic chant's melodic grammar and notation. Old Hispanic chant includes neume combinations that recur across the tradition, indicating probable melodic formulas. Few Old Hispanic genres, however, seem to be derived wholly from formulaic type-melodies. Rather, the notation suggests that most Old Hispanic chant

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[2] Exceptions include Brou, "Le joyau des Antiphonaires Latins;" Brou, "L'Alleluia dans la liturgie mozarabe;" Randel, "Responsorial Psalmody;" Randel, *Responsorial Psalm Tones*; Nadeau, "Pro sonorum diversitate;" Zapke, *El antifonario de San Juan de la Peña;* Hornby and Maloy, *Music and Meaning*; Rojo Carrillo, *Text, Liturgy, and Music*; Maloy, *Songs of Sacrifice*.

[3] Maessen, *Calculemus et cantemus,* has used computer-assisted pattern matching to reimagine the Old Hispanic melodies for modern performance. The aims of his machine-readable transcriptions are very different, as is the precise information encoded. The McGill-based *Cantus Ultimus* project has made progress in automated neume recognition, with great potential for speeding up our transcription process. On their encoding procedure, see most recently De Luca *et al.*, "Capturing Early Notations." A separate project with similar aims is underway at the Complutense University, Madrid, led by Carmen Julia Gutiérrez.

genres consist of individual melodies, with smaller melodic formulas occurring in particular contexts. When we began working on Old Hispanic chant, it became clear that a complete identification and tracing of these formulas was beyond human pattern-matching capacity. CEAP holds notational information in machine-readable format, allowing us to compare large amounts of data. The tool works in combination with our own knowledge and understanding of the tradition and typically helps us to test hypotheses rather than generating them. By using CEAP, we can identify recurring neume combinations systematically, across genres, and assess the contexts in which they occur, establishing principles of melodic grammar within and between manuscripts.

CEAP is also a tool for notational research. The neumes found in the earliest complete Old Hispanic manuscript, the tenth-century León, Cathedral Archive 8 (L8), are extraordinarily rich and varied, raising questions about the use and function of particular shapes. (See Figure 1 for an illustration) Using the CEAP transcriptions, we can begin to assess how specific neumes function within a single manuscript and across the wider corpus, revealing a distinctive Iberian culture of musical literacy.

Figure 1: L8, folio 32r.

[[separate file included in submission: note to production please insert figure 1 near here]]

The Current State of CEAP

CEAP is a transcription and analysis tool. With each manuscript, we begin by making a library of representative neume shapes. These are generated from images in the manuscript itself, maintaining relative scale between neume images, and thus retaining the manuscript's notational proportions and flow. With the image, we encode three layers of interpretation for each neume: the melodic contour, the note shapes used, and

the connections between those shapes.[4]

Each neume represents a series of rising and falling pitches; these are encoded using a letter for each note (see Table 1). Successive neumes are usually not written in a way that objectively captures the pitch relationship between them. Even when a syllable has a single note shown with a straight line, written vertically or rising steeply, we cannot be certain whether it is high in the abstract, or higher than the preceding note, or higher than what follows (or, indeed, all three). Similarly, when a single note is written with a straight falling line, we cannot be certain whether it is low in the abstract or in relation to the preceding and/or following notes. We therefore always classify the first note of each neume as N, meaning "unknown" or "neutral." We can deduce the relative pitch heights of any subsequent notes in a neume. S signals that a note has the same pitch as the previous note. H signals a higher note than the previous note, and L signals a lower note than the previous note. Within some neumes, we cannot be certain how a note relates to the previous note. To show this ambiguity, we use U ("probably same or higher") or D ("probably same or lower").

Within Frankish notations, each note is represented by a dot, a curved line, a straight line, a wavy line, or an angle. [5] Some of these shapes can appear alone, as a

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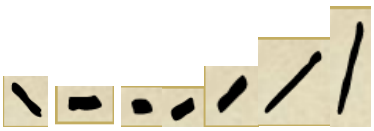
[4] We wish to record our indebtedness to scholars with whom we have developed this conceptualization: Elsa De Luca, Kate Helsen, and Inga Behrendts. Susan Rankin offered insightful feedback.

[5] On "Frankish" as a label for several early medieval Western European notational systems, see Rankin, *Writing Sounds.*

single neume signifying a single note (in the Old Hispanic manuscripts: straight line,[6] wavy line,[7] and, in some manuscripts, the curved line; see Figure 1). These shapes are combined in various ways to make longer neumes, together with other shapes that only appear in combinations signaling two or more notes (the angled shape and, in some manuscripts, the curved line). Within a neume consisting of two or more notes, the shapes can be connected together, creating in their intersection an angle or curve (either clockwise or anticlockwise), and sometimes forming a loop.[8] Alternatively, instead of an angled or curved connection, a small gap appears within a neume, smaller than the gaps we encounter between separate neumes.

NOTE TO PRODUCTION: PLEASE PLACE FIGURE 2 NEAR HERE.

Figure 2: Old Hispanic shapes signifying one note

a. Straight lines: 

b. Curved lines: 

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[6] These straight lines can appear at different angles—from vertical to horizontal—and with varying lengths

[7] With two small curves, this shape is visually similar to the oriscus (an ornamented single note) of other Frankish notations, but in Old Hispanic notation it is used in a wider variety of contexts.

[8] On the uniqueness of these loops, see Rankin, *Writing Sounds*, 120.

c. Wavy lines: 

d. Short lines joined by an acute angle ()

We assign an interpretation to each neume as we enter it into the neume library, using the abbreviations in Table 1 (e.g.,  would have the reading NH:(/:w attached to it). The resulting machine-readable code enables us to compare melodies that have related shape outlines as well as related melodic outlines. The transcription system is transferable to any neumatic notation, which will facilitate future comparative analysis with other chant traditions. Since we started developing the software in 2012, we have added multiple analytical tools.

NOTE TO PRODUCTION: PLEASE PLACE TABLE 1 NEAR HERE.

Table 1: Abbreviations used in our neume descriptions.

Abbreviation	**Interpretation**	**Category**
N	Unknown pitch with relation to the previous note	Relative pitch height
S	Same note as the preceding one	

H	Higher note than the preceding one	
L	Lower note than the preceding one	
U	Probably the same as or higher than the previous note	
D	Probably the same as or lower than the previous note	
/	A long straight shape, inclined upwards	Notational shapes
\	A long straight shape, inclined downwards	
*	A horizontal straight shape	
(	A curved shape open ends of the curve at the right-hand side of the shape	
)	A curved shape, open ends of the curve at the left-hand side of the shape	
<	An angled shape, one or both open ends at the right-hand side of the shape	
>	An angled shape, one or both open ends at the left-hand side of the shape	
~	A wavy shape	

o	Two shapes cross within a neume, forming a loop	
'	A hook is added to the end of a neume; it does not appear to indicate a note	
g	Two shapes written close together, within a single neume, with a gap between them	Connections within the neume
a	Angular connection between two shapes within a neume	
c	Clockwise curved connection between two shapes within a neume	
w	Anticlockwise (“widdershins”) connection between two shapes within a neume	

Show Pitches

This tool enables us to export information about the chant melody, ready to use in publications. We can export a series of melodic readings for each syllable (in terms of NHL), automatically generated based on the note shapes we imported, removing the possibility of typographical error. We can also export a table showing the number of notes per syllable (“melodic density”) or the melody’s rise and fall (“melodic shape”), with NHL converted into numbers. These can be imported into Excel and converted into

charts.[9] The melodic density charts show at a glance which syllables are lingered on in the melody and which are recited syllabically. The melodic shape chart is particularly useful in communicating with those who do not read neumes fluently. Both types of chart are useful for comparing different versions of a melody at a glance.

Find Exact

This function allows us to make a simple search of the database, finding exact matches of neume strings. For some manuscripts (especially L8), our menus include separate neume images to represent subtly different ways of writing a neume shape. Two or more of these can be classified as "closely related" for the purposes of this search, to find more likely matches. This search function helps us find examples of exactly the same neume string (in a recurring neume combination, for example); we can then explore the formal or textual circumstances under which a recurring neume combination occurs, or how it is usually approached or followed melodically. "Find exact" is also useful when we want to find all instances of a particular neume in order to compare it across a manuscript; this can help us to determine whether the neume shape occurs in particular combinations with other neumes, and thus how it might function within the melodic grammar. This search function can also help us to identify particular scribes in conjunction with paleographical work on the manuscripts, such as Elsa De Luca's ongoing work on L8 and current doctoral work being undertaken on other manuscripts by Emily Wride and Marcus Jones.

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[9] For examples of both kinds of chart, see Hornby and Maloy, *Music and Meaning*, 188–200.

Find Similar

A major challenge of undertaking computer-assisted analysis with a repertoire preserved only in unpitched notation is that we lack the firm anchors of pitch. In melodies preserved in pitched notation, an analyst can easily correct for a note being present in one version of a melody but not in another. When melodies are preserved in unpitched neumes, however, a variant of just one more note more or less will prevent a "find exact" match from being successful. "Find similar" searches allow for small variants of neume shape or number of notes when searching for matches, giving each match a score that reflects its approximate level of closeness. As detailed below, "find similar" searches are based on the rise and fall of the melody together with the note shapes and connection types between them. We can use this search function to find matches between manuscripts; this helps us to establish how the melodic language is used across the corpus. "Find similar" helps us to identify closely related (but not identical) neume combinations. Using this function, we have identified networks of more-or-less related neume combinations in the repertoire, rather than just rigid formulas used in an unchanging way.

Use of CEAP in Melodic Analysis of Old Hispanic Chant: A Case Study

The ninth- to eleventh-century Old Hispanic manuscripts exhibit two closely related melodic traditions, one associated with León and the other with the Rioja.[10] The earliest and most complete manuscript, L8, uses an especially wide variety of neume shapes to represent the same contour, and many (but not all) of these shapes appear in the other manuscripts. The melodic and notational commonalities between these manuscripts

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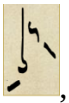
[10] Randel, *Responsorial Psalm Tones;* Hornby and Maloy, "Melodic Dialects."

point to a reliance on common exemplars.[11] With the help of CEAP, however, we can trace certain distinctions between manuscripts and changes over time. A "find exact" search allows us to trace the use of a particular shape within a manuscript and to determine how it functions within the melodic grammar of that manuscript. With a "find similar" search, we can assess how widely that neume is spread throughout the manuscript corpus and whether its function changed.

As a case study, we consider this special shape within L8,  , one of twelve different neumes encoded in CEAP that represent the contour NHHLL in L8. The results presented here are based on the chants currently transcribed into CEAP and may not present a full picture of each manuscript. They nonetheless allow us to form preliminary conclusions about the function of this neume that can be tested as further chants are added. This neume has two unusual features: the tight curve that represents the last two notes of the contour NHH and the wavy shape of the penultimate element. In previous scholarship, both of these have been posited as performance nuances.[12] A "find exact" search reveals that the case study neume from L8 occurs only 20 times in

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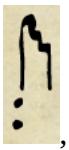
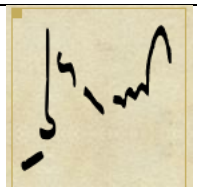
[11] Hornby and Maloy, "Fixity, Flexibility;" Randel, *Responsorial Psalm Tones*; Maloy, *Songs of Sacrifice*, 192–211.

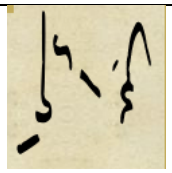
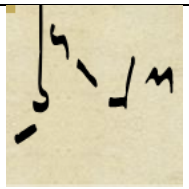
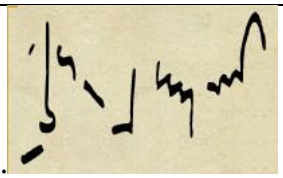
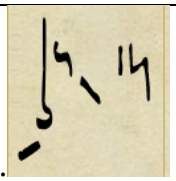
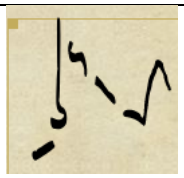
[12] González Barrionuevo, "Relación entre," 37, 75–78, considers the sign representing the second and third notes to be a pes "initio debilis," with a weak beginning, and the wavy shape of the penultimate note to be an oriscus. The oriscus has been variously interpreted as a note repetition, an irregular semitone, or a rhythmic indication.

CEAP, whereas other shapes for the NHHLL contour occur far more frequently.  , for example, occurs eighty-one times in the database, and  occurs thirty-five times. These two alternative shapes, moreover, appear in a very wide variety of melodic contexts, whereas the use of the case study neume is far more circumscribed. The twenty instances of our neume occur in five different melodic contexts in L8, shown in Table 2. Each neume combination in Table 2 appears multiple times in the repertory, thus constituting a melodic formula. In each of these contexts, the case study neume is the first element of a longer neume combination over one syllable of text (a melisma). Each of these melismas, moreover, occurs on the final syllable of a word and marks the end of a verbal clause (in musical parlance, a cadence). Thus, our neume shape serves a very specific role within L8's melodic grammar, marking the first element of a cadential melisma on the final syllable of a musical phrase.

NOTE TO PRODUCTION: PLEASE PLACE TABLE 2 NEAR HERE.

Table 2. Neume combinations that appear in conjunction with sample neume in L8.

Formula	Number of occurrences in L8 in CEAP as of September 2020
a. 	7

b. 	2
c. 	5
d. 	2
e. 	1
f. 	3

A “find similar” search for the complete formulas in Table 2 can reveal whether other shapes representing NHHLL are used in the same melodic contexts. Limiting the search to results with the “same neume and syllable boundaries” reveals the closest matches. For example, a search for the series of three neumes that constitute formula C in Table 2 reveals that other neumes representing NHHLL are used in the same context as the case study neume. These alternative neumes are shown in Table 3. Neume 1 occurs four times as the first neume in formula C. It represents a contour identical to our case study neume, but here the second and third notes are written with two separate penstrokes, lacking the putative performance nuance associated with the case study neume. A “find exact” search for neume 1, however, reveals that it is also used as the

first element in another formulaic context, where our case study neume never appears; neume 1 thus has a wider variety of uses than the case study neume. Neumes 2 and 3 in Table 3, used occasionally in formula C, each have different ways of writing the second and third notes (or the movement between them), possibly indicating the performance nuance of a salicus (neume 2) or a quilisma (neume 3).[13] Thus neumes 2 and 3, together with our case study neume, probably indicate *some* type of special performance at this point in the formula (but not the same nuance), whereas neume 1 lacks any indication of such nuance. It is unclear whether these variants reflect different ways of visually representing similar practices or subtly different performance practices among different scribe/singers. Future collation with Elsa De Luca's ongoing paleographical study of L8 might help to shed light on this question. Neume 4 in Table 3 indicates a different contour at the beginning than the other neumes, a pitch repetition (indicated by NS). This version of formula C tends to occur in a different context than the other instances: in four of the six cases that use neume 4, formula C is the final section of a very long melisma.[14] CEAP allows us to establish melodic functions for particular neumes and assess whether other neumes are functionally equivalent.

NOTE TO PRODUCTION: PLEASE PLACE TABLE 3 NEAR HERE.

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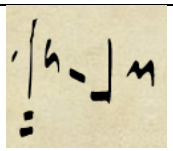
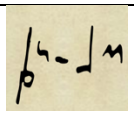
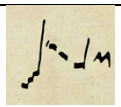
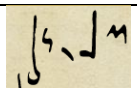
[13] A salicus is a notational shape used to indicate a three-note rise whose ornamented second note is written with a particular wavy shape ('oriscus'). A quilisma is a notational shape that also indicates a rise. It may have signalled that the rise included a short middle note, or an ornamented middle note.

[14] On the sectional structure of melismas and this formula, see Maloy, *Songs of Sacrifice*, 136–46.

Table 3. Neume shapes that appear in the same contexts as the case study neume.

Neume and contour	Number of occurrences with formula C in L8 (as of September 2020)
1.  NHHLL	4
2.  NHHLL	1
3.  NHHLL	2
4.  NSHLL	6

CEAP also allows us to determine how the case study neume is used in other manuscripts. Despite the many melodic and notational similarities across the early manuscript corpus, we can trace regional differences in the use of particular neumes and changes to music writing practices over time. Salamanca MS 2668 (Sal), written in 1059, is a *liber horarum* that belongs to the León melodic tradition but contains a largely different repertory of chants.[15] Our case study neume occurs only twice in this manuscript, once in formula C and once in formula F. For formula C, Sal's scribes prefer a shape identical to neume 1 in Table 2. All four uses of this neume in Sal occur in conjunction with formula C. This confirms that neume 1 and the case study neume

[15] Sal preserves the night office; L8 has day offices and the mass.

are functionally equivalent in Sal, as they are in L8, occurring in the same melodic contexts. Sal's scribes, however, introduce a new variant into this neume shape,  . This neume is nearly identical to the case study neume but lacks the wavy penultimate penstroke. This neume occurs once as the first element of formula C; the other four instances occur in a different context, as the first element of a non-formulaic melisma. In summary, the case study neume is used less frequently in Sal than in L8. Sal has a stronger tendency to use one of L8's alternative shapes (neume 1 in Table 2), and Sal introduces a new variation of the case study neume, which is sometimes used in other contexts. The analysis both confirms Sal's continuity of notational practice with L8 and points to changes over time.

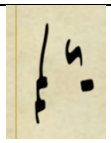
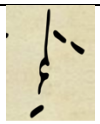
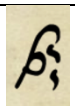
A "find similar" search for the case study neume reveals that the other eleventh-century Old Hispanic manuscripts, from the Rioja, do not use this neume, but instead employ a related set of shapes. Santo Domingo de Silos MS 4 (S4), copied in 1052, uses two different shapes in the same formulaic contexts, neither of which has an exact match in L8 (see Table 4). Neume 1 in Table 4 appears twice in S4, as the first element of Formulas A and F. L8 has a closely related neume, with an extra note at the beginning (see column 2 of Table 4). In L8, however, this shape does not have the same specificity of function as the case study neume, and it is never used in the formulaic contexts shown in Table 2. S4 also has a broader use of these neumes. Neume 2 in Table 4 appears only twice in S4, both times with Formula C. Although its first element, with the v-shaped opening, is a common way to write the NHH contour in L8 and Sal, these manuscripts have no equivalent of neume 2. Thus, the common principles of the notation were extended and applied in different ways in the León region and in S4.

London, British Library add. MS 30845 (BL45), a tenth- or eleventh-century

manuscript copied at San Millán de la Cogolla, reinforces this impression. In neume 3 in Table 4, the initial loop is a common way of writing NHH in L8 and Sal, but neither manuscript uses that shape within a NHHLL neume. Within the limited data provided in CEAP, neumes 2 and 3 have functions very similar to the case study neume in L8 and their use is similarly circumscribed. This observation can be tested as more data is entered into CEAP. As this case study shows, CEAP is an indispensable tool for discerning the functions of specific neumes within a manuscript and tracing their regional differences.

NOTE TO PRODUCTION: PLEASE PLACE TABLE 4 NEAR HERE.

Table 4: Neumes similar to the case study neume in selected Rioja manuscripts.

Neume	Melodic contexts used	Similar form in L8
1.  S4	Formula A (once) Formula F (once) Many unrelated contexts	
2.  S4	Formula C (2 times)	No equivalent in L8
3.  BL45	Formula C (once) A different cadential melisma (once)	No equivalent in L8

The Development of CEAP

In this section, we discuss the choices made in designing the CEAP software. While the

program is continually changing as new research questions arise and as additional features of the notational grammar are recognized, its overall structure remains largely consistent. The two major functional areas of CEAP are the transcription editor, used for entering chant data into the computer, and the reporting and analysis tools, which work on that data. Less visible to the user, but equally important, are the overall program architecture and the form in which the data for each chant is stored.

Overall Structure

An important requirement was for the software to provide shared access to a database of chant transcriptions, allowing collaborative working between researchers at different universities (see neumes.org.uk/view). To meet this need, CEAP is implemented as a web application, hosted at the University of Bristol. Secure, password-controlled editing access is allowed from anywhere on the Internet for registered users. Visitors without passwords can view, but not modify, our data.

To protect against data loss in the event of network connectivity problems, the transcription editor transmits changes to the server as they are made. The database therefore contains the latest edits, with a lag of only a few seconds; no explicit "save" operation is required. The only user action needed is to "publish" edits when they want to make them visible to others.

Chant Transcription

An obvious characteristic of the early Old Hispanic manuscripts is that neumes are positioned relative to each other in an apparently deliberate and consistent manner. Although we do not understand the reasons for this relative positioning, we wished to record as much of it as possible in the transcriptions, to retain it for possible future analytical use. The solution is a drag-and-drop editor, using images of example neumes

derived from the original manuscript, so that we can replicate the manuscript's placement of each neume relative to the previous neume in terms of height and distance.

For this to be practical, compromises must be made. Since neumes are written by hand, each one is unique, even if it is very similar to others with the same meaning. We have copied a large set of neumes from each manuscript, presented to the user in a hierarchical menu. Because these include variations of shape and size, several distinct images are sometimes provided for neumes with the same interpretation. This allows the user to preserve much of the visual appearance of the original in their transcription. Each syllable of the text is given its own "box" to hold neumes. The user must ensure that the ordering of neumes from left to right agrees with their interpretation. Where two neumes are stacked vertically in the manuscript, the user sometimes has to transcribe the upper neume very slightly to the right of its manuscript placement, in order to preserve the neume order in the left-to-right machine-readable interpretation.

Chant text is transcribed using the keyboard and appears as modern characters. Some specific conventions must be followed to tell the software about syllable and phrase divisions. The user marks syllables manually within words by using hyphens. This allows for the non-standard syllabification in Iberian Latin. For example, words like "mee" are sometimes treated in chant as having two syllables, and sometimes as having one. Recently we have introduced special characters to indicate phrase divisions in the text, providing three levels of division: minor divisions are marked with a mid-level dot ("·"), and larger divisions are marked with single or double bars ("|" and "‖"). We provide easy ways to type these special characters on a standard keyboard.

The use of large numbers of neume images (660 in the case of the León Antiphoner) presents the problem of organizing them so that the user can find the most accurate match. CEAP is aimed at researchers and students who are well versed in

interpretations of the neumes. The menu is thus organized around the pitch direction. While most neumes are well understood, subsequent research has occasionally changed the original understanding of a family of neumes in a way that affects the reading.[16] When this happens, the assignment to menus in CEAP automatically changes.

The manual drag-and-drop process described here is currently the only way of transcribing chant data into CEAP. However, we are currently investigating whether the Optical Neume Recognition work by Ichiro Fujinaga's group at McGill University can provide an alternative route. Any errors could be corrected by the user after import into CEAP, so the automatic transcription does not need to be perfect.

Database Representation

The reasons for adopting a style of transcription that stays close to the visual appearance of the manuscript also apply to the storage of data. We keep visual appearance at the forefront of the data representation, adding interpretation only when it is needed for analysis. The primary representation of a chant within the database contains little more than the instructions for recreating its appearance in the drag-and-drop editor. Neumes are simply represented by images plus their positions within the syllable box, and the images are represented in the database by short names, such as "492" or "35-6." The interpretation information is kept separately, assigned to the same short names, and is used only when analyzing the chant data. This separation allows interpretations to be modified as our understanding changes, without invalidating the existing data.

To illustrate the nature of the data, we briefly discuss some aspects of the transcription that can be found at https://neumes.org.uk/view/1128. Behind the scenes,

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[16] See Hornby, Maloy, and Rojo Carrillo, *Liturgical and Musical Culture,* Chapter 6.

the chant data consists of a list of syllable boxes, each containing the syllable text, so the first contains the text “Al-,” the second “le-,” and so on. Each box may also contain neumes: the second one in our example has six neumes, starting with a NH labelled “307” in the database, and placed at coordinates (3,74) in this syllable’s box, measured from the top left. The height of each box is also stored in the data, since the user is able to change it to accommodate neumes placed above the normal writing space.

In the same chant, on the syllable “le-” of the final “alleluia,” the third neume looks almost identical to “307,” but it is actually a different image. This one is classified as a “456.” Neither of the two neume images comes from the manuscript notation of this chant, or even the same folio: the chant starts on the last line of 265v, but neume “456” was created from a neume on 179v and “307” was created from a neume on 279r.

Reports and Analysis

In the outputs and analysis functions, CEAP meets musicological research. As the research develops, the functions required and the techniques used to implement them must evolve. Here the data is read as a sequence of neumes to which interpretations are attached. Indeed, one type of output available from CEAP is a machine-readable form of this combined data, allowing it to be used in external analysis programs. These may implement experimental features that have not yet become part of CEAP or may be the work of collaborators at other institutions.

CEAP provides a number of simple reports and searches, which we have already described under “Show Pitches” and “Find Exact.” Greater sophistication is needed when searching for a musical formula like the one described in our case study above. We need to account in the search for the variability introduced by our decision to provide several variants of neumes that have the same meaning. Scribes sometimes chose alternative ways of writing a formula (as in our case study), with different neume

descriptions, or the formula may vary. To solve these problems, we use algorithms that can find approximate matches between sequences of neumes.

In order to allow for variations in the choice of neume, both by the scribe and by the transcriber of the chants, pattern matching works on sequences of notes, rather than whole neumes. The features shown in Table 1 are used to describe each constituent note. In each case, there is a pitch-direction letter and a stroke shape, and the connection type (possibly including a loop modifier) is treated as a feature of the note immediately following the connection.

The "find similar" function finds approximate matches between sequences of neumes represented by these note descriptions. Growing out of Emma Hornby's work with John Caldwell and Ruth Ripley, it uses algorithms that were first developed for matching biological sequences.[17] Although the underlying matching is always between sequences of notes, some options in "find similar" cause it to take notice of neume boundaries. One way this is done is by matching in two stages: comparing each pair of neumes by their constituent notes, to derive a score for that pair, and then using those scores in comparing sequences of whole neumes. While this still remains our most powerful way of searching for a specific pattern, the comparisons between notes on which it depends have become much more discriminating as CEAP has developed. Initially we used only the relative pitch directions "N," "S," "H," and "L," which provides limited information. As our understanding of the graphical shape of neumes improved, codifying the connections between note and the note shapes themselves, the amount of information contained in the neume descriptions grew, improving the

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[17] Needleman and Wunsch, "A General Method;" Smith and Waterman, "Identification."

reliability of search results. Concentrating on the sequence of notes and treating neume boundaries as features of notes gives us the flexibility to control the sensitivity of pattern matching to the division into neumes.

Current Developments

All of our approximate-matching algorithms depend on putting a numerical value, or "score," reflecting the degree of agreement or disagreement between two notes. We are now revising the way this is done, using a fundamentally different approach with a new theoretical basis. This is motivated by algorithms we have recently implemented in separate programs to identify patterns automatically that occur several times, either within the same chant or across several chants. We are also examining ways of codifying radically different styles of unpitched neumes as part of a pilot project funded by a Leverhulme/British Academy Small Grant (2020–2022). This collaboration with Ekaterine Oniani and Tamar Chkheidze (Vano Sarajisvili Tbilisi State Conservatoire) explores whether there are any parallels in how chants were built between two widely different liturgical traditions, in this case the Georgian and the Old Hispanic.

Conclusion

We have gradually built CEAP since 2012, supported by funding within multiple larger grants and have built the body of transcriptions through the same period.[18] The analytical algorithms have grown with our analytical questions, and the results have become more useful as more chants have been added to the database. The history of this software reminds us that genuinely effective quick fixes are rare in the digital

[18] See note 1, above.

humanities. It takes time to generate data on which the algorithms can work, and it takes time and effort for scholars to articulate their research questions to software engineers in ways that the software engineers can translate into usable algorithms. These ongoing efforts, however, are transforming the Old Hispanic chant repertory into a machine-readable dataset that can be interrogated analytically, leading to an understanding of the melodic grammar of thousands of chants that had previously seemed intractable.

Works Cited

Primary Sources

León, Cathedral Archive, MS 8. For images see https://bvpb.mcu.es/es/catalogo_imagenes/grupo.cmd?path=26408

Secondary Sources

Brou, Louis. "L'Alléluia dans la liturgie mozarabe: Étude liturgico-musicale d'après les manuscrits." *Anuario Musical* 6 (1951): 3–90.

Brou, Louis. "Le joyau des antiphonaires latins." *Archivos Leoneses: Revista de Estudios y Documentación de los Reinos Hispano-occidentales* 15 (1954): 7–114.

De Luca, Elsa, Jennifer Bain, Inga Behrendt, Ichiro Fujinaga, Kate Helsen, Alessandra Ignesti, Debra Lacoste and Sarah Long. "Capturing Early Notations in MEI: The Case of Old Hispanic Neumes." *Musiktheorie-Zeitschrift für Musikwissenschaft* 3 (2019): 229-49.

González Barrionuevo, Herminio. "Relación entre la notación 'mozárabe' de tipo vertical y otras escrituras neumáticas." *Studi Gregoriani* 11 (1995): 5–112.

Hornby, Emma, Kati Ihnat, Rebecca Maloy, and Raquel Rojo Carrillo. *Liturgical and Musical Culture in Early Medieval Iberia: Decoding a Lost Tradition*. Cambridge: Cambridge University Press, forthcoming, 2022.

Hornby, Emma, and Rebecca Maloy. "Fixity, Flexibility, and Compositional Process in Old Hispanic Chant." *Music & Letters* 97 (2017): 547–74.

Hornby, Emma, and Rebecca Maloy. "Melodic Dialects in Old Hispanic Chant." *Plainsong and Medieval Music* 25 (2016): 37–72.

Hornby, Emma, and Rebecca Maloy. *Music and Meaning in Old Hispanic Lenten Chants: Psalmi, Threni and the Easter Vigil Canticles*. Woodbridge: Boydell and Brewer, 2013.

Maessen, Geert, ed. *Calculemus et cantemus: Towards a Reconstruction of Mozarabic Chant*. Amsterdam: Gregoriana, 2015.

Maloy, Rebecca. *Songs of Sacrifice: Chant, Identity, and Christian Formation in Early Medieval Iberia.* New York: Oxford University Press, 2020.

Nadeau, Nils. "'*Pro sonorum diversitate vel novitate'*: The Singing of Scripture in the Hispano-Visigothic Votive Masses." PhD diss., Cornell University, 2000.

Needleman, Saul B., and Christian D. Wunsch. "A General Method Applicable to the Search for Similarities in the Amino Acid Aequence of Two Proteins." *Journal of Molecular Biology* 48 (1970): 443–53.

Randel, Don M. "Responsorial Psalmody in the Mozarabic Rite." *Études Grégoriennes* 10 (1989): 87–116.

Randel, Don M. *The Responsorial Psalm Tones for the Mozarabic Office*. Princeton, NJ: Princeton University Press, 1969.

Rankin, Susan. *Writing Sounds in Carolingian Europe.* Cambridge: Cambridge University Press, 2018.

Rojo Carillo, Raquel. *Text, Liturgy, and Music in the Hispanic Rite: The Vespertinus Genre*. New York: Oxford University Press, 2020.

Smith, Temple F., and Michael S. Waterman. “Identification of Common Molecular Subsequences.” *Journal of Molecular Biology* 147 (1981): 195–97.

Zapke, Susanna. *El antifonario de San Juan de la Peña, siglos X-XI: Estudio litúrgico-musical del rito hispano*. Zaragoza: Institución Fernando el Católico, Sección de Música Antigua, 1995.