

A Retrospective on Optical Music Recognition Research

DDMAL



Ichiro Fujinaga

Music Technology Area, Schulich School of Music

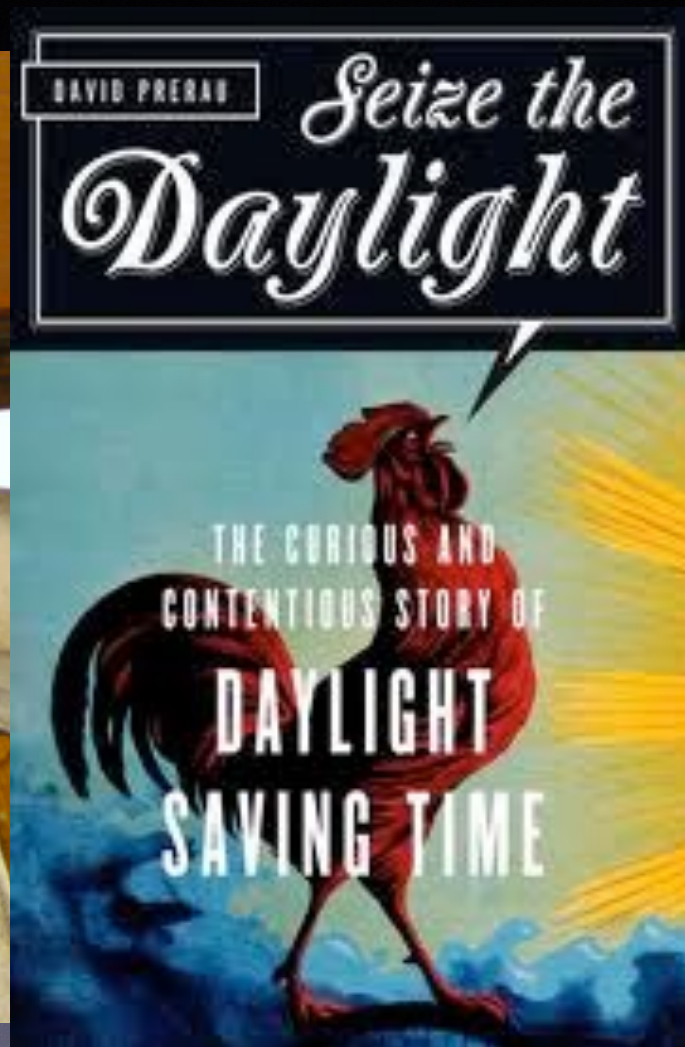
McGill University

The Pioneers



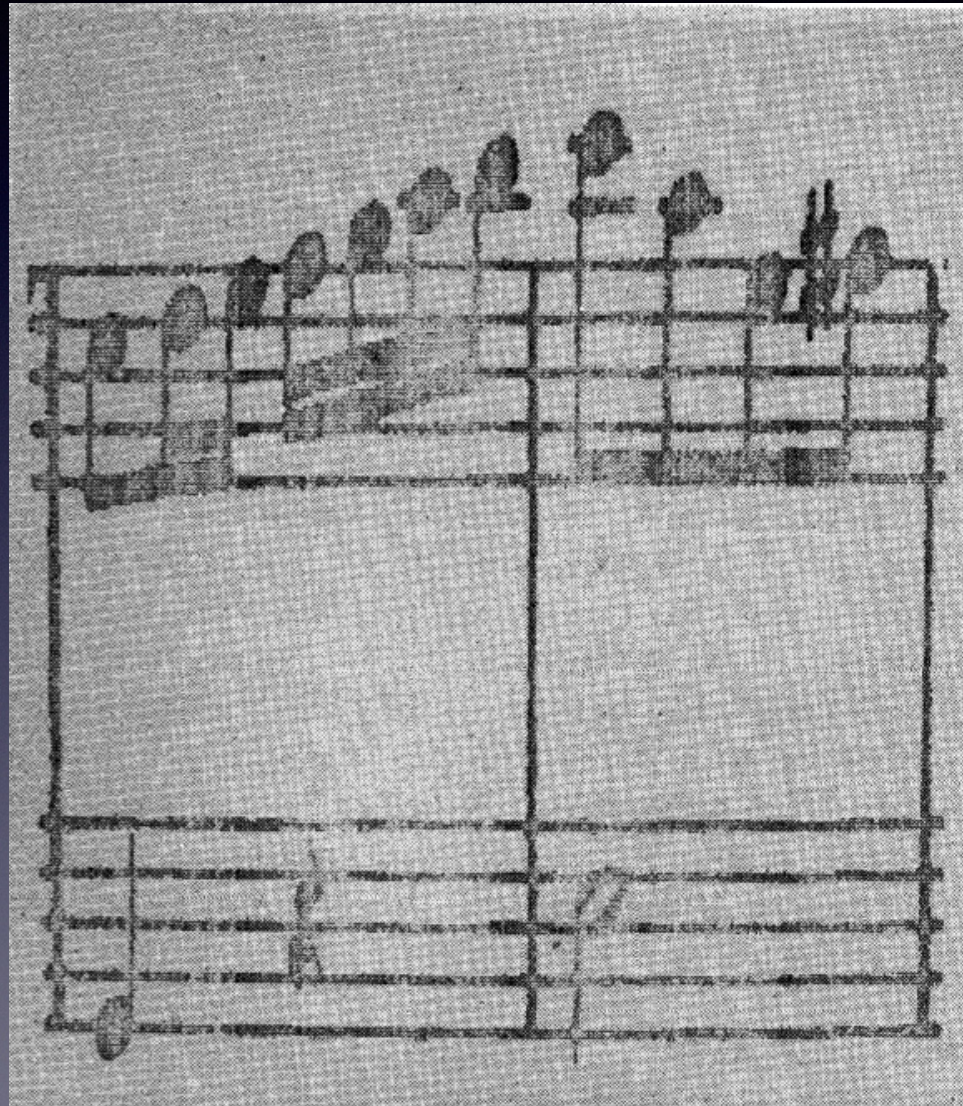
Denis Pruslin AKA The Tool
David Prerau

Baker House, c. 1959



Denis Pruslin with
grandson Kevin, 2010/11

The first published digital scan of music (1970)



Review by Michael Kassler (1972)

PERSPECTIVES OF NEW MUSIC FALL-WINTER 1972

Review: Optical Character-Recognition of Printed Music: A Review of Two Dissertations

Michael Kassler

Page 250 of 250-254

OPTICAL CHARACTER-RECOGNITION OF PRINTED MUSIC: A REVIEW OF TWO DISSERTATIONS

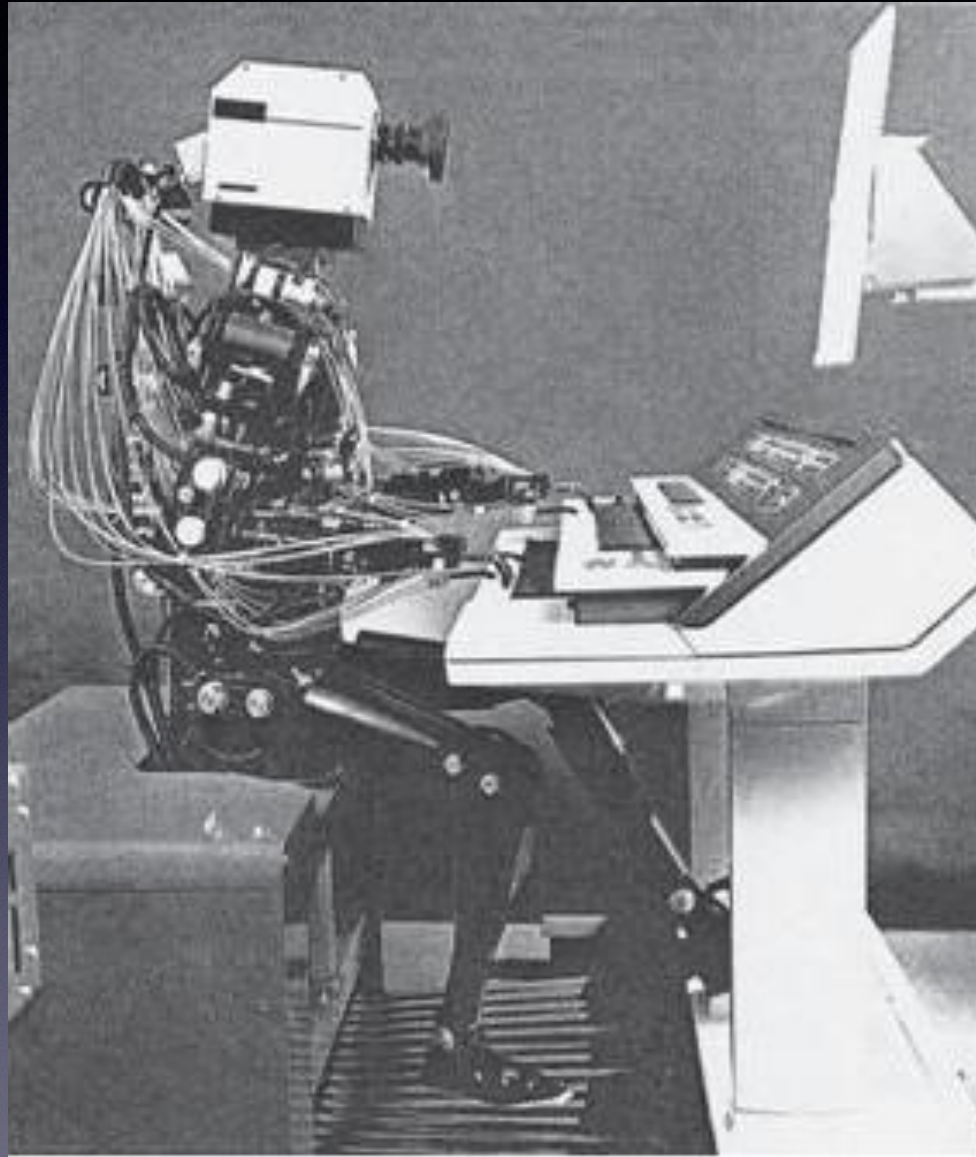
AUTOMATIC RECOGNITION OF SHEET MUSIC. By Dennis Howard Pruslin. Sc. D. Dissertation, Massachusetts Institute of Technology, 1966.

COMPUTER PATTERN RECOGNITION OF STANDARD ENGRAVED MUSIC NOTATION. By David Stewart Prerau. Ph. D. Dissertation, Massachusetts Institute of Technology, 1970.

Readers of *Perspectives* scarcely need be reminded of the pre-eminence of the written-musical domain (i. e., that domain of musical experience in which music is presented visually in one or another system of musical notation) in musicology: before Edison composers could not produce records of their work in the sounded-musical domain, and other domains of musical experience such as the tactile domain utilized in the Braille system have been employed comparatively infrequently; and even after Edison various extra-musical considerations (such as copyright law and the relatively high cost of sound-processing machinery) have joined with tradition to keep the written-musical domain a principal mode of non-transient musical communication. Within this domain various systems of musical notation have achieved various degrees of currency at various places and times, but of all these systems one—the current common musical notation ('CCMN' for short)—has dominated: virtually all music printed has been printed in one or another 'dialect' of CCMN: even music originally noted in another system generally has been transcribed into CCMN before printing.

In recent years digital computers have become more efficient and more prevalent, so that today, at least in computationally well-developed parts of the world, it no longer is unreasonable to delegate, or to plan to delegate, musical processes to electronic computing machinery. Of course, many musical processes do not involve previously recorded musical compositions: perhaps it is to the comparatively early success of a few such computer-mediated processes that an unfortunate synecdochic misidentification of 'computer music' with 'synthesizing sound through the use of a digital computer' has arisen.¹ But (and of this too readers will be well informed) central to musicology are processes that do involve prior musical compositions, and for the full delegation of these processes to computing machinery the relevant compositions must be put into computer-acceptable form. Human key-punchers can transcribe from CCMN onto (say) punch cards (at Princeton University the Masses of Josquin were so transcribed, at a rate of approximately 20 minutes per printed CCMN page), but as this task clearly requires no intelligence beyond that with which machines can be endued it is only natural to consider

1984: Wabot-2



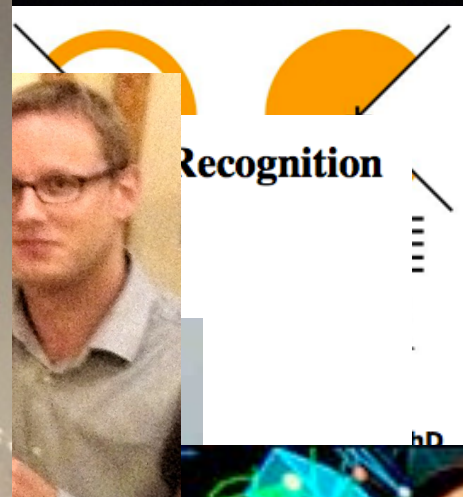
<https://www.scaruffi.com/mind/ai/wabot.jpg>

茨城県映画『EXPO'85 科学の祭典』（1985年（昭和60年度）制作） つくば科学万博 '85



<https://www.youtube.com/watch?v=4Ixxq9s2iDro>

OMR Thesis



- ❖ 1997 David Bain
- ❖ 2006 Laurent Pu
- ❖ 2009 Alicia Forn
- ❖ 2012 Ana Rebelo
- ❖ 2014 Andrew Ha
- ❖ 2016 Jorge Calvo



2000: Gamera

- ❖ Fra
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- ❖ Im
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- ❖ Sy
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Generalized Algorithms and Methods for Enhancement and Restoration of Archives

Gamera @ Peabody

- ❖ Designed and built by Karl McMillan and Michael Droettboom (started fall 2000)
- ❖ Master's students at Computer Music Department at Peabody Conservatory of Music, Johns Hopkins University
- ❖ Both worked at Digital Knowledge Centre, Johns Hopkins University Library
- ❖ Both graduated in 2002

Gamera developers

❖ Karl McMillan

- ❖ Expert of Security
- ❖ Worked at Tru
- ❖ CTO at RAKI

❖ Michael Droer

- ❖ Science software
Institute (NA)
- ❖ Still active in



linux)

Flat

escope Science

Birth of Gamera

Gamera: A Structured Document Recognition Application Development Environment

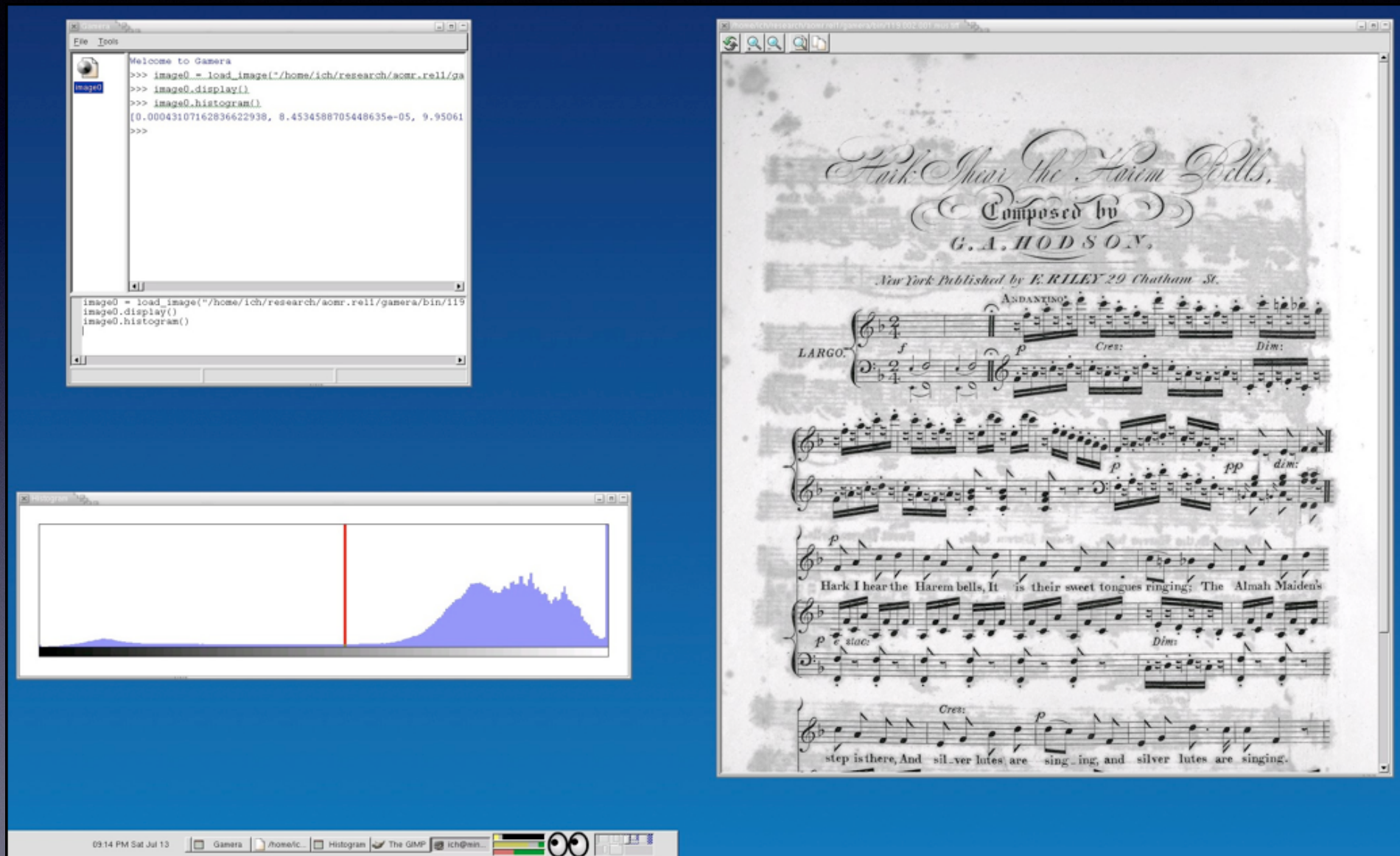
Karl MacMillan, Michael Droettboom, and Ichiro Fujinaga

Peabody Conservatory of Music
Johns Hopkins University
1 East Mount Vernon Place, Baltimore MD 21202
email: {karlmac,mdboom,ich}@peabody.jhu.edu

- ❖ First paper presented at the 2nd International Symposium on Music Information Retrieval (ISMIR: October 2001) in Bloomington, IN


Early Gamera Screenshot (Linux)

ca. June 2002



Original Gamera Website

ca. December 2002

<p>rapid access</p> <ul style="list-style-type: none"> Introduction Authors Software Screenshots Papers Imaging Links 		<p>Software framework for the creation of domain-specific recognition applications</p>
<p>Introduction</p>	<p>This page describes the Gamera system, being developed at the Digital Knowledge Center at Johns Hopkins University. The project is funded in part by the National Science Foundation, the Institute for Museum and Library Services, and the Levy family. Please review the papers and software below for more information.</p>	<p>News flash! Large parts of Gamera are currently being rewritten. The major advantages of this are faster compilation- and run-times, portability to Windows, Mac OS-X and Unix, and a richer plugin system. We plan on making version 2.0 available once the code base stabilizes.</p>
<p>Authors</p>	<p>Ichiro Fujinaga</p> <hr/> <p>Michael Droettboom</p> <hr/> <p>Karl MacMillan</p>	
<p>Software</p>	<p>Download: Gamera 1.0 can be downloaded here (gzipped tarball).</p>	

2001–2008: Evolution of Gamera



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Project: Gamera: Summary

[Summary](#) | [Admin](#) | [Home Page](#) | [Tracker](#) | [Bugs](#) | [Support](#) | [Patches](#) | [RFE](#) | [News](#) | [CVS](#) | [Files](#) |

Gamera is a framework for the creation of structured document analysis applications by domain experts. It combines a programming library with GUI tools for the training and interactive development of recognition systems.



:Python Foundry

- Development Status: **4 - Beta**
- Environment: [Cocoa](#) (MacOS X), [Win32](#) (MS Windows), [X11 Applications](#)
- Intended Audience: [Developers](#), [Education](#), [Information Technology](#), [Science/Research](#)
- License: [GNU General Public License \(GPL\)](#)
- Natural Language: [English](#)
- Operating System: [MacOS X](#), [Windows NT/2000](#), [Linux](#)
- Programming Language: [C++](#), [Python](#)
- Topic: [Graphics Conversion](#), [Artificial Intelligence](#), [Information Analysis](#)

Developer Info

Project Admins:

[abrzecz](#) /


[mdboom](#) /

Developers: 4

[\[View Members\]](#)

Project UNIX name: gamera

Registered: 2004-01-12 10:13

Activity Percentile (last week): 63% 

View project activity [statistics](#)

View list of [RSS feeds](#) available for this project

Latest File Releases

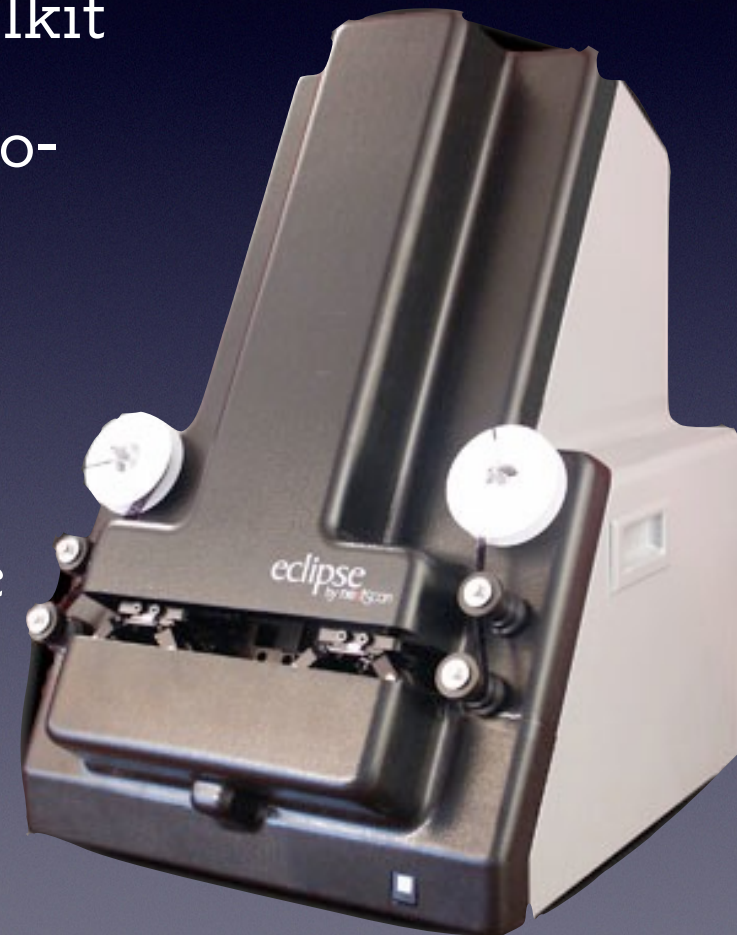
Package	Version	Date	Notes / Monitor	Download
gamera	gamera-2.2.0pre2	August 17, 2004	 - 	Download
gamera-video	1.0	January 13, 2004	 - 	Download
toolkit-skeleton	2.2.0pre2	September 8, 2004	 - 	Download
wxPython-Gtk-X11	wxPython-Gtk-X11-2.4.2.4	July 21, 2004	 - 	Download

[\[View ALL Project Files\]](#)

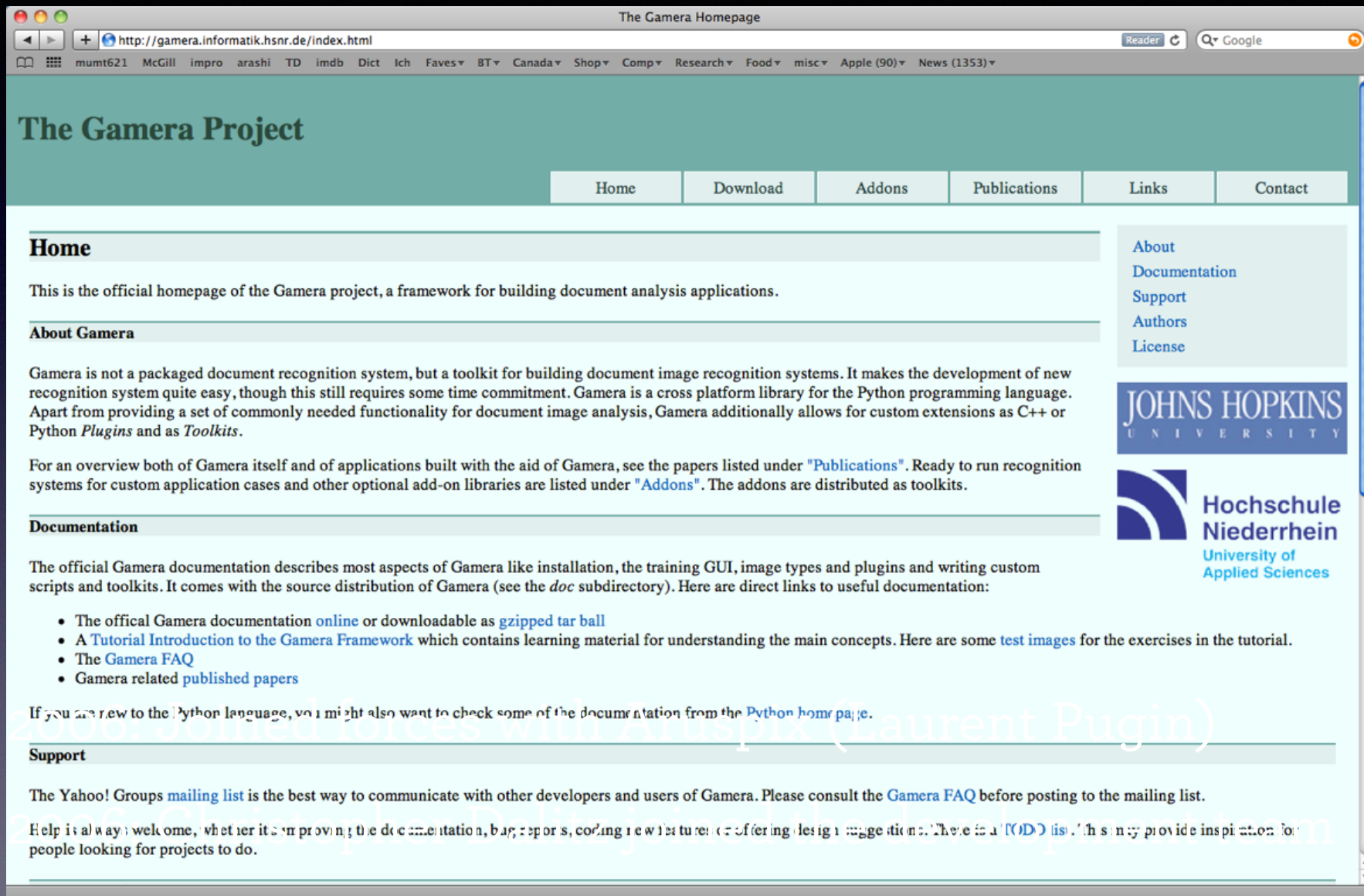
2005: GEMM

(Gamut for Early Music on Microfilms)

- ❖ Based on GAMUT: Gamera-based Automatic Music Understanding Toolkit
- ❖ Possibility of OMR for music on microfilms
- ❖ Almost all old Western music are on microfilms
- ❖ Efficient digitization using automatic microfilm scanner (Eclipse 500: 590ppm)



2001–2008: Evolution of Gamera



2008: Website moved to: <http://gamera.informatik.hsnr.de>

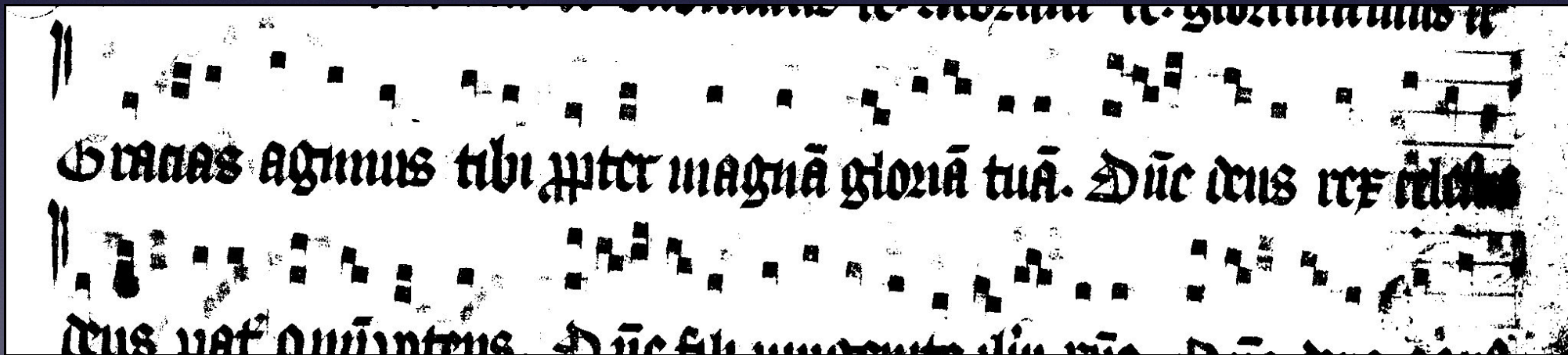
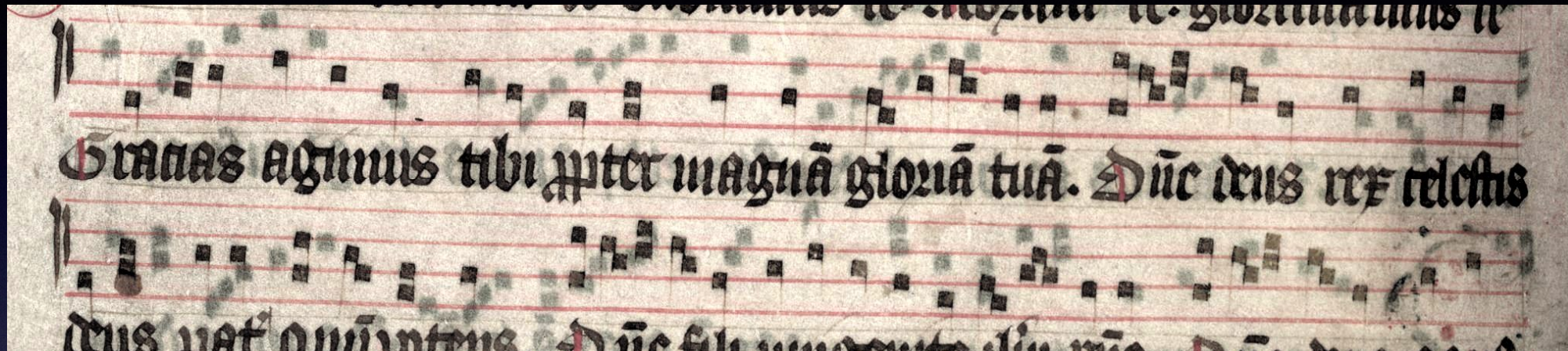
Some Features of Gamera c. 2008

Preprocessing



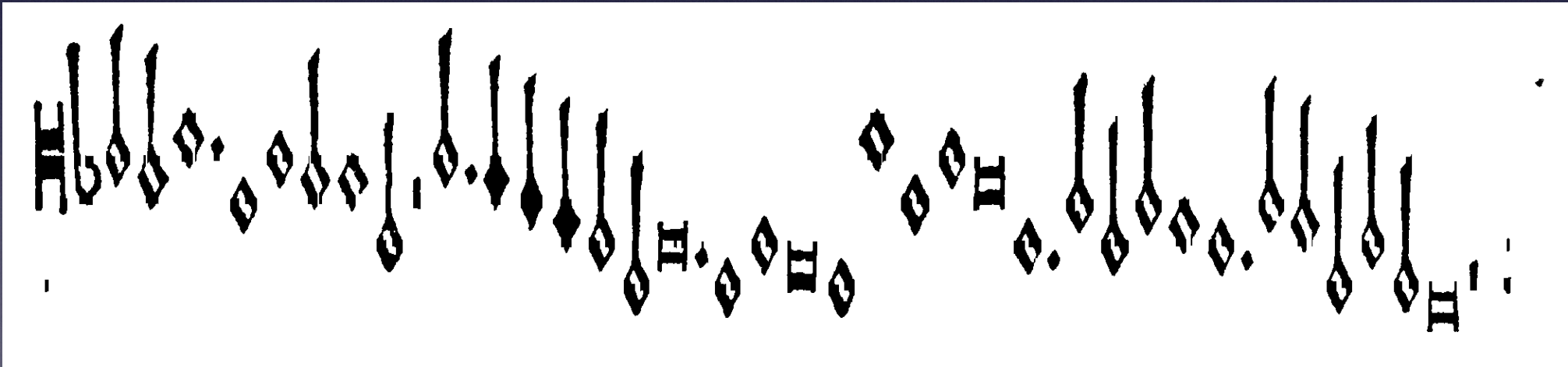
Brightness Enhancement

Preprocessing

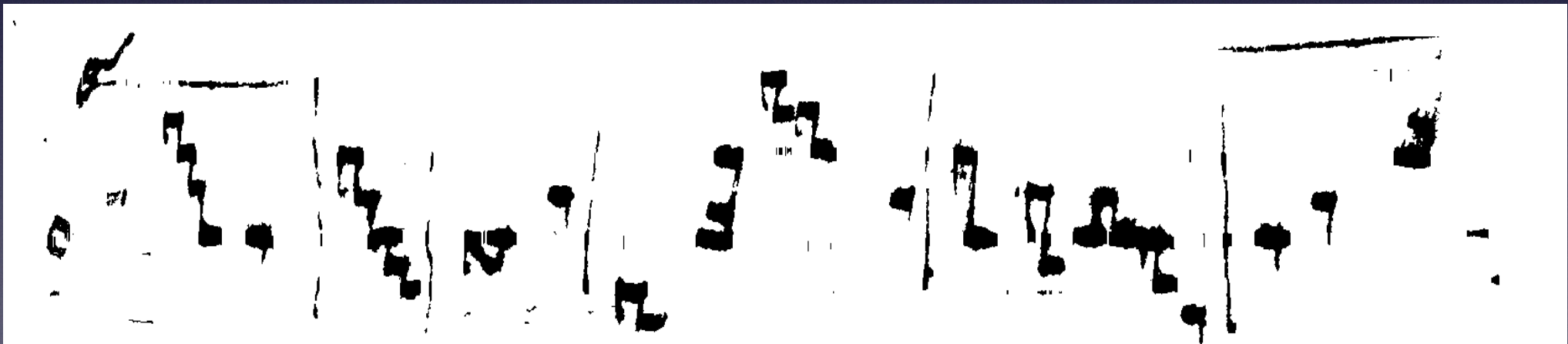


Thresholding

Staffline Removal

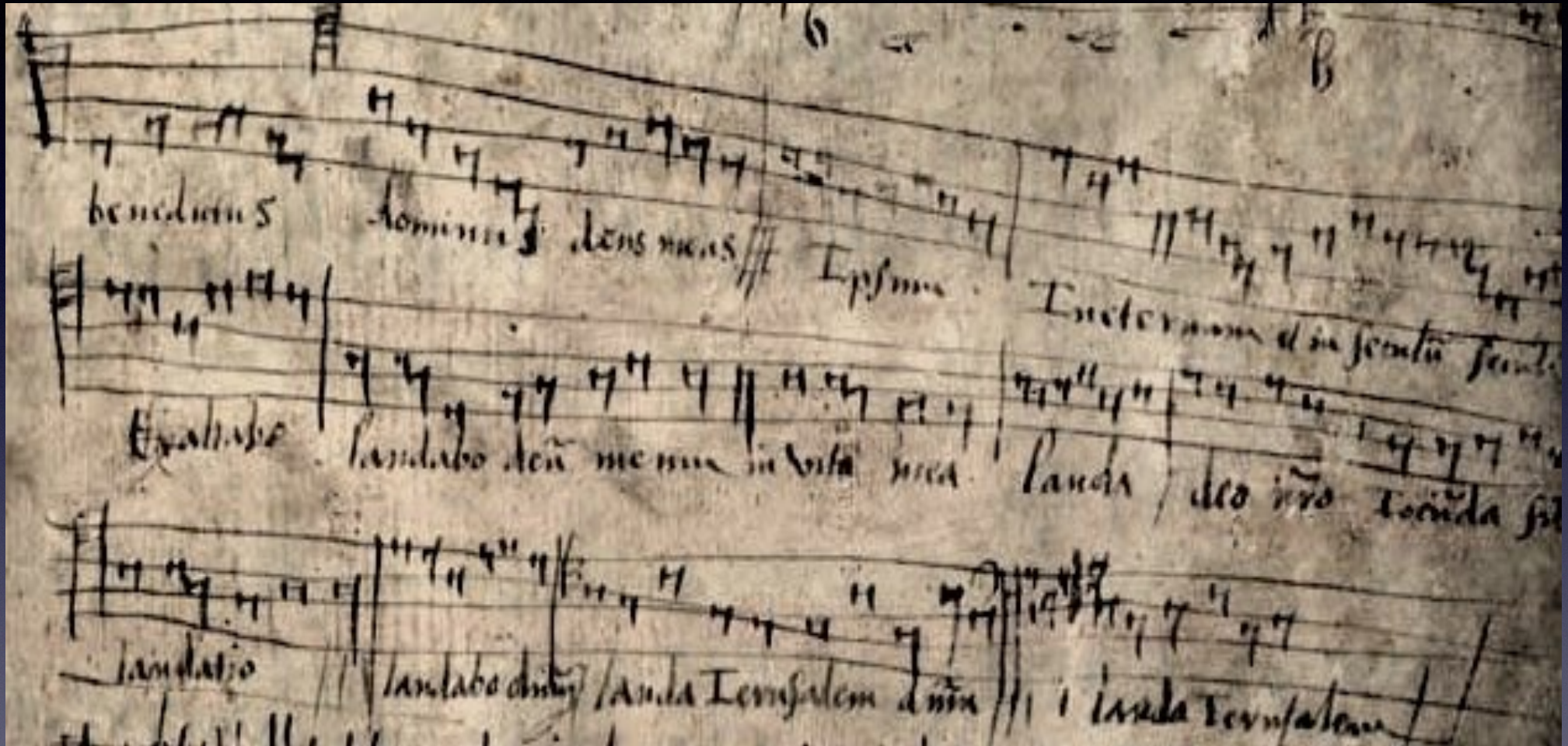


Staffline Removal



Four-line hand-drawn staff example

Staffline Removal



Difficult

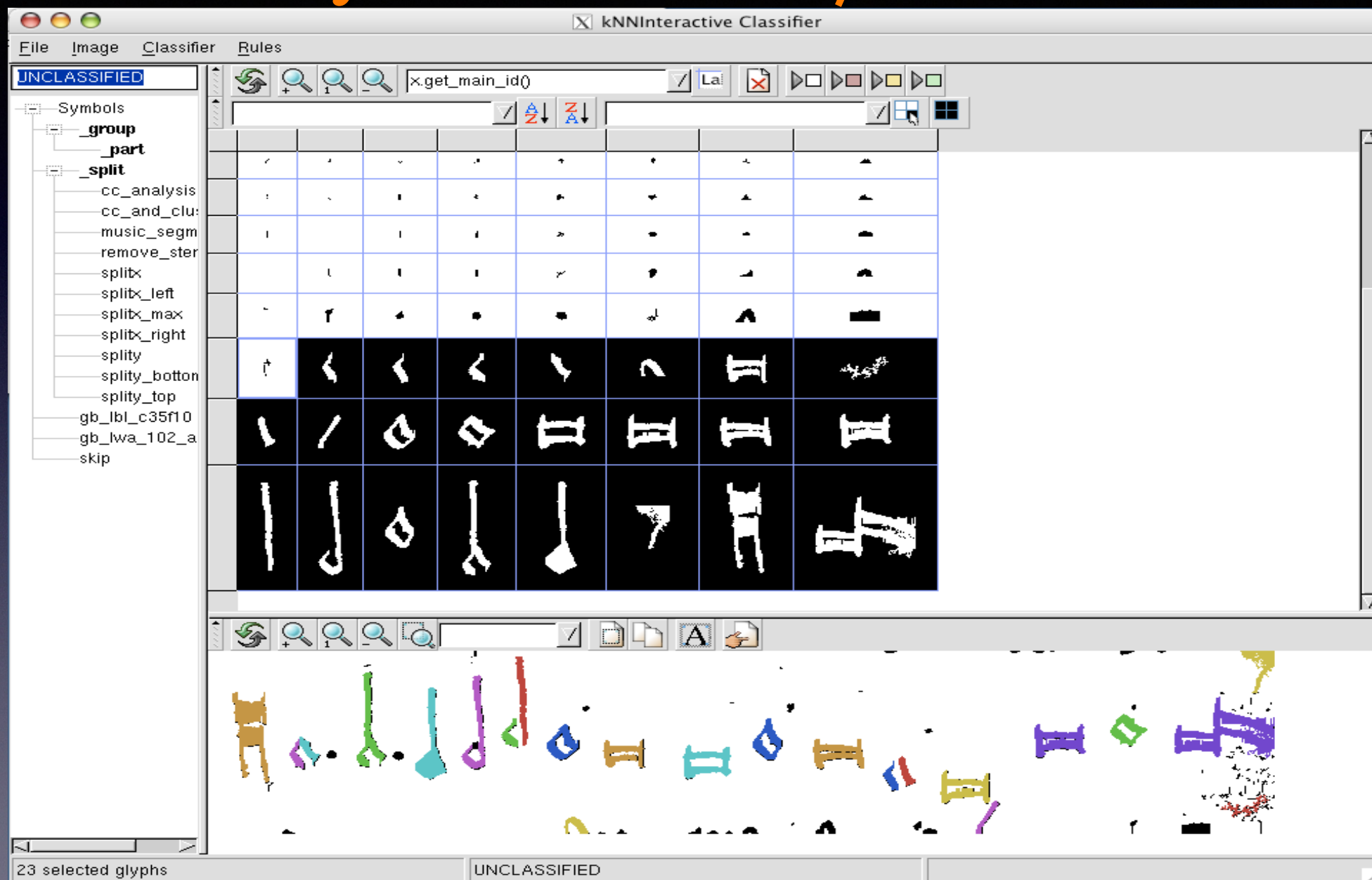
Staffline Removal

Ræludium Laurencini.

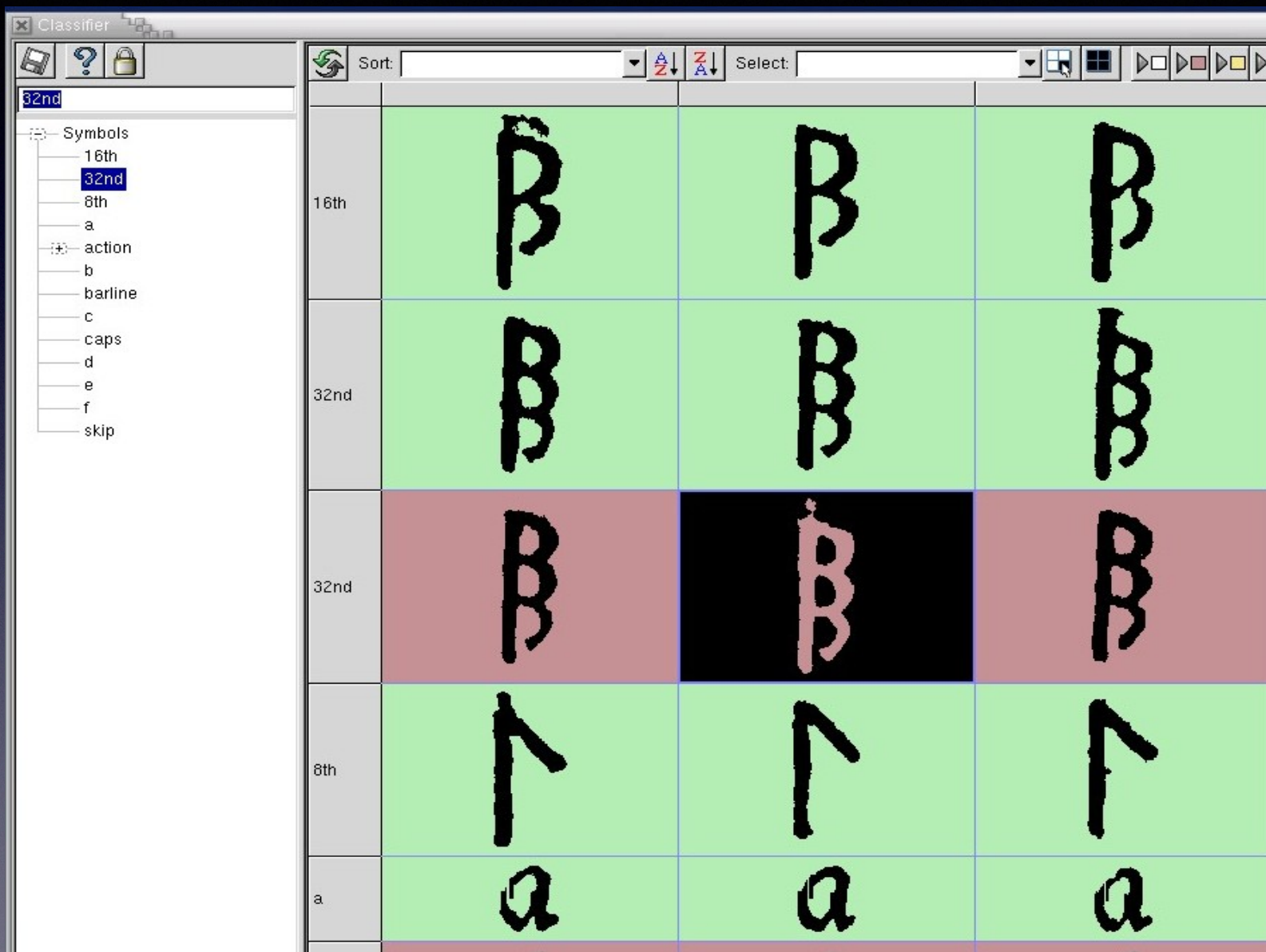
The image displays two versions of a lute tablature score titled 'Ræludium Laurencini.' The top version shows the original notation with staff lines. The bottom version shows the same notation with the staff lines removed, leaving only the letters and numbers on the lines.

Lute tablature

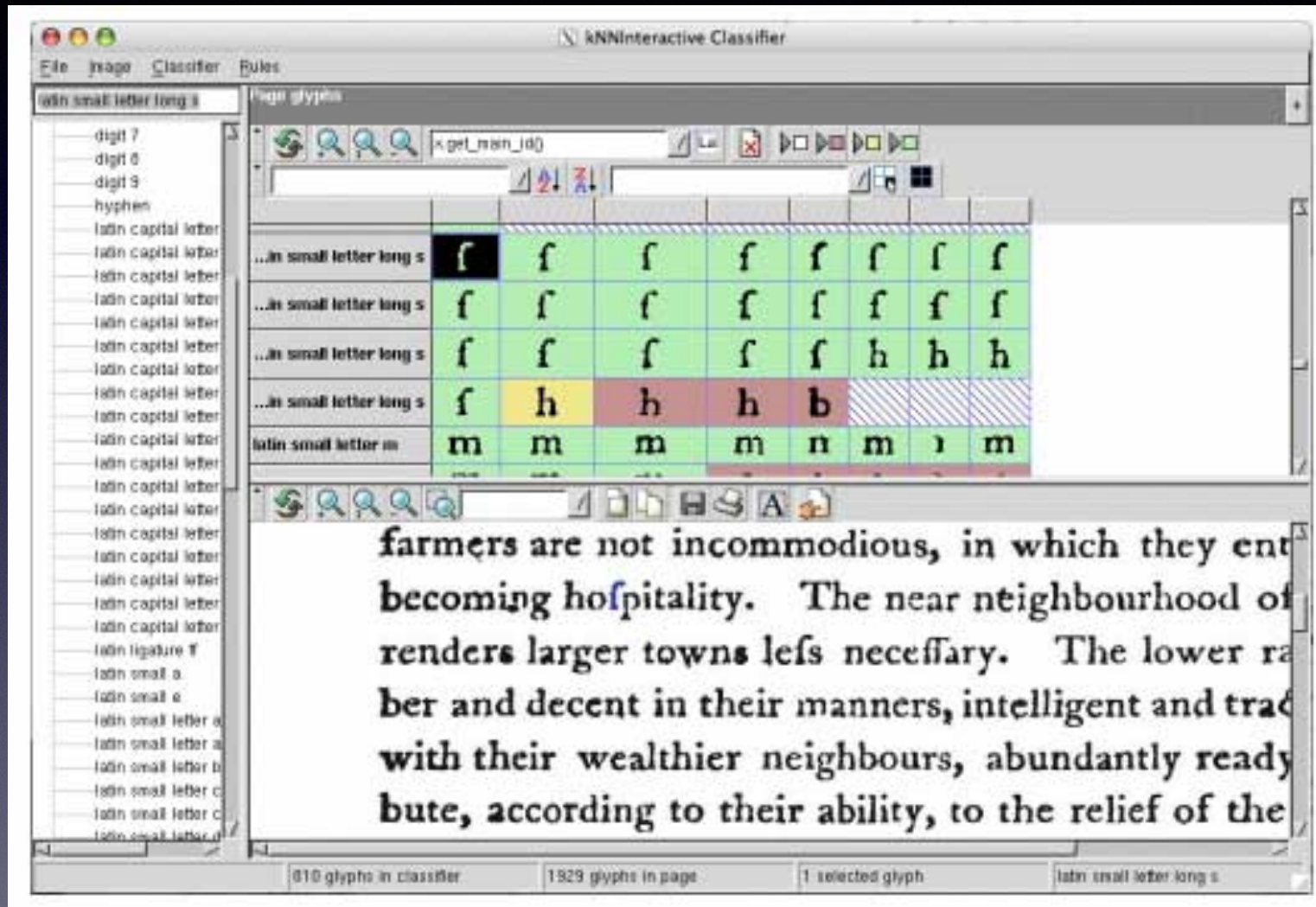
Symbol classifier / Gamera



Lute tablature symbol recognition

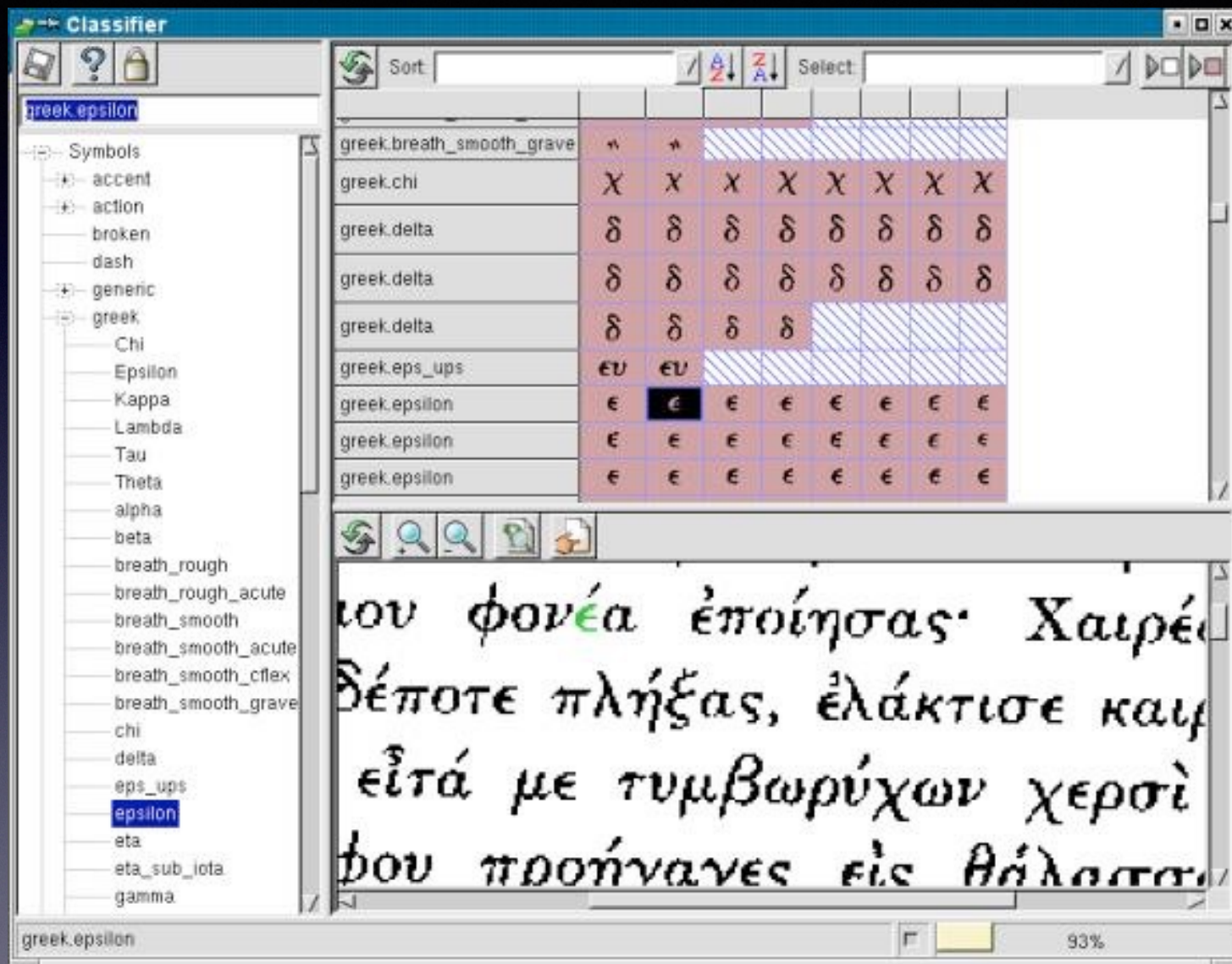


Other Applications



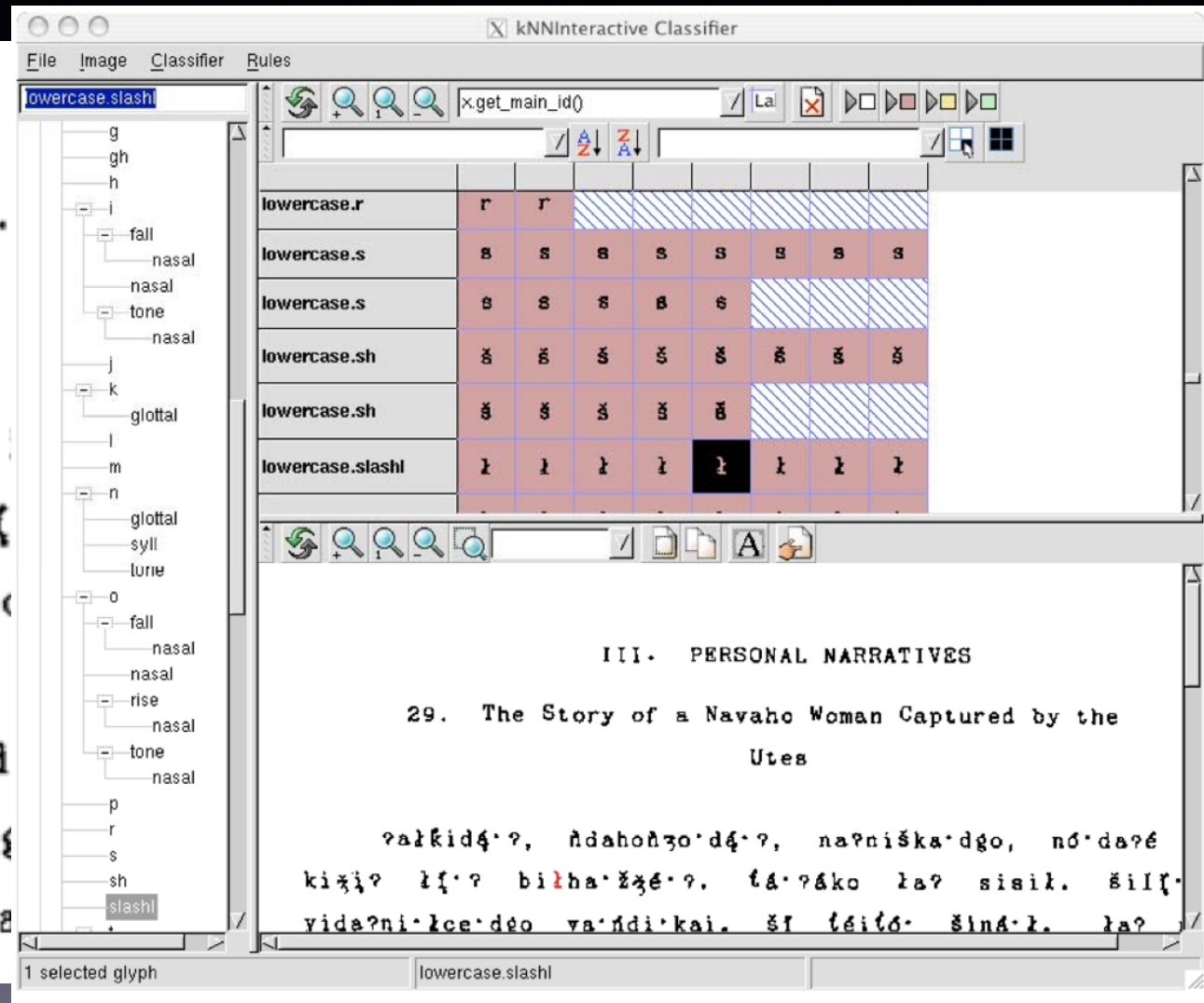
Early Modern English

Other Applications



Greek

Other Applications



lowercase.slash

g
gh
h
i
fall
nasal
nasal
tone
nasal
j
k
glottal
l
m
n
glottal
syll
lurie
o
fall
nasal
nasal
rise
nasal
tone
nasal
p
r
s
sh
slash

lowercase.r	r	r						
lowercase.s	s	s	s	s	s	s	s	s
lowercase.s	s	s	s	s	s			
lowercase.sh	š	š	š	š	š	š	š	š
lowercase.sh	š	š	š	š	š			
lowercase.slashl	ł	ł	ł	ł	ł	ł	ł	ł

III. PERSONAL NARRATIVES

29. The Story of a Navaho Woman Captured by the Utes

ʔałkidʔ, ʔdaħoħʔo·dʔ, naʔniška·dgo, nʔ·daʔé
kiʔiʔ iʔ·ʔ biłha·ʔʔé·ʔ. ʔa·ʔa·ko ʔaʔ sisil. šilʔ·
yidaʔni·lce·dgo va·ndi·kai. šl ʔeitʔ· šlnA·ł. ʔaʔ

1 selected glyph lowercase.slashl

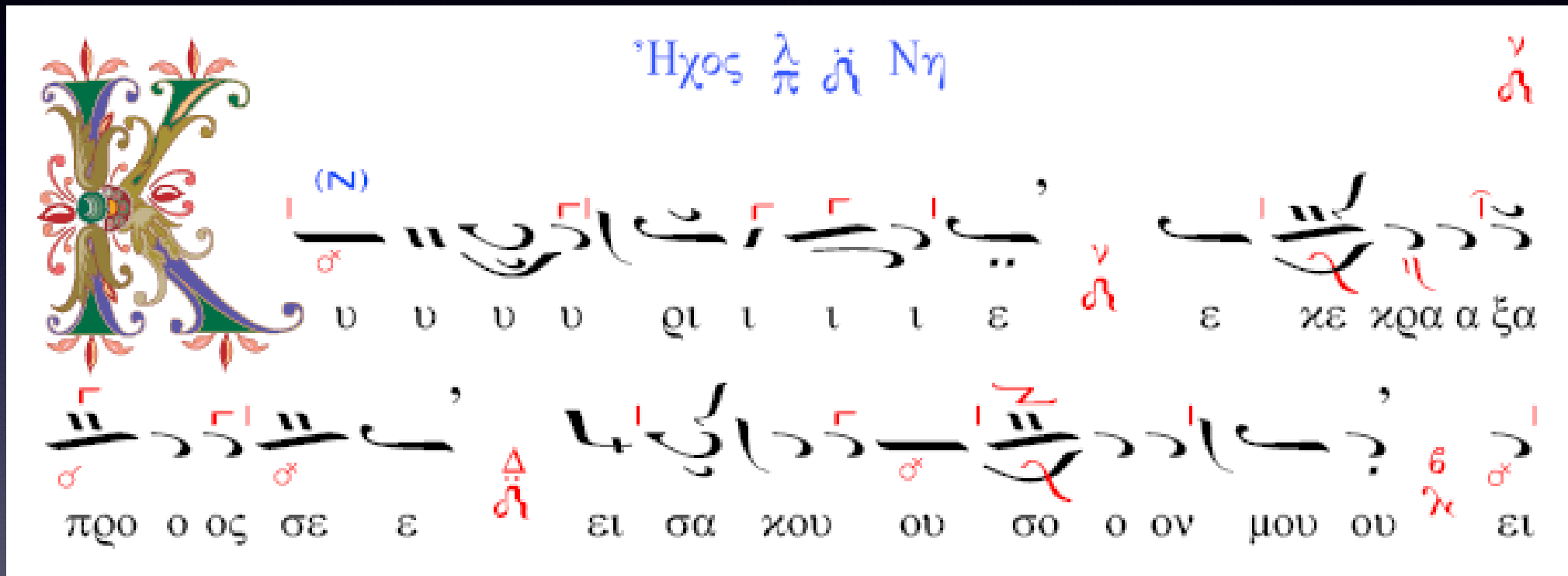
Navajo language recognition

Other Applications



Roman de la Rose (Bodelian MS Douce 195, 90v, 15th C.)

2008: Other Applications



Optical Recognition of Psaltic Byzantine Chant Notation

Christoph Dalitz · Georgios K. Michalakis · Christine Pranzas

2009: Other Applications

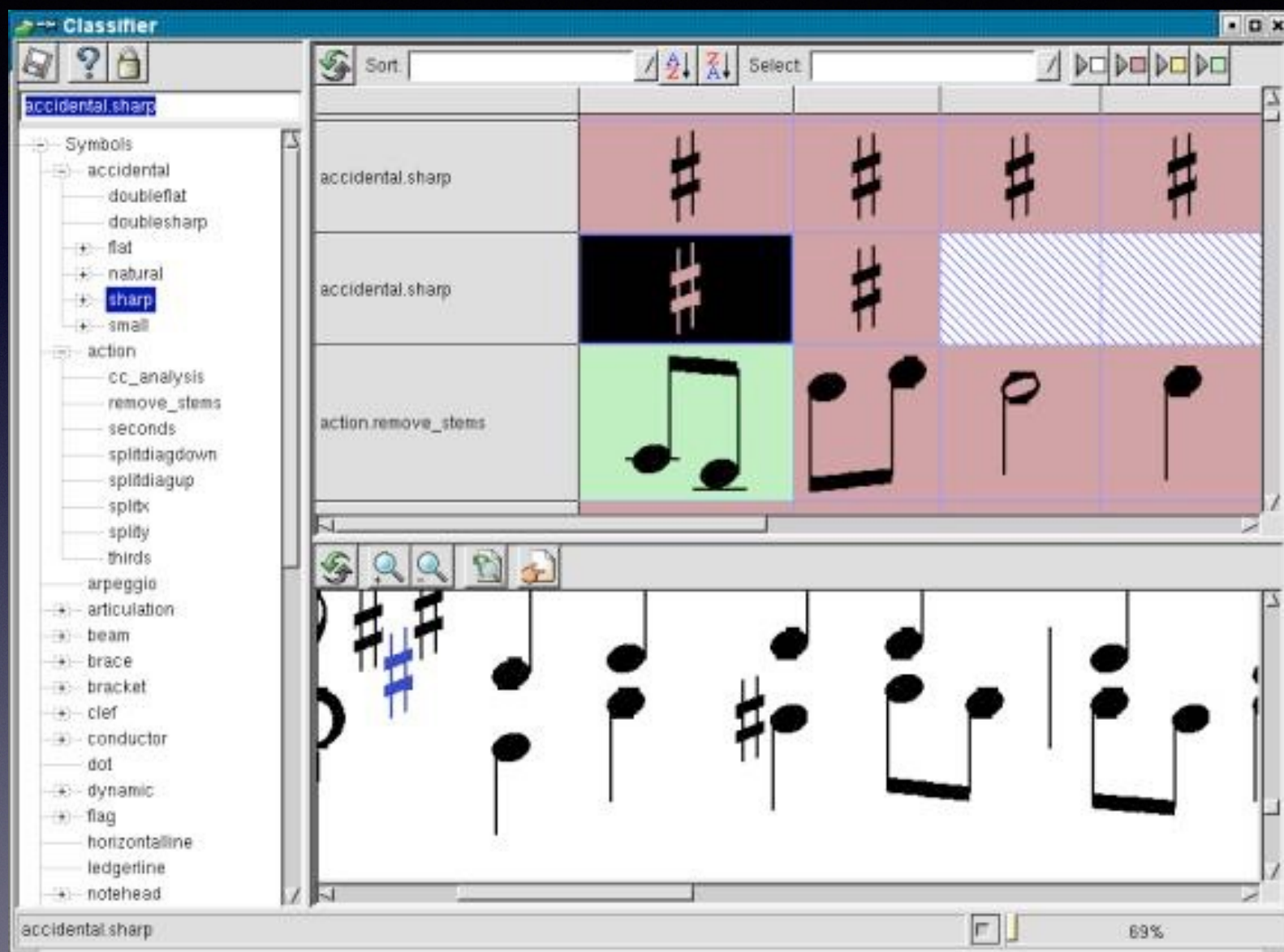
	♯	♯	♯	♯	♯	
a	a	b	a	b	a	b
a	a	b	a	b	a	b
a	a	a	c	.	.	.
c	c	c	a	b	c	b



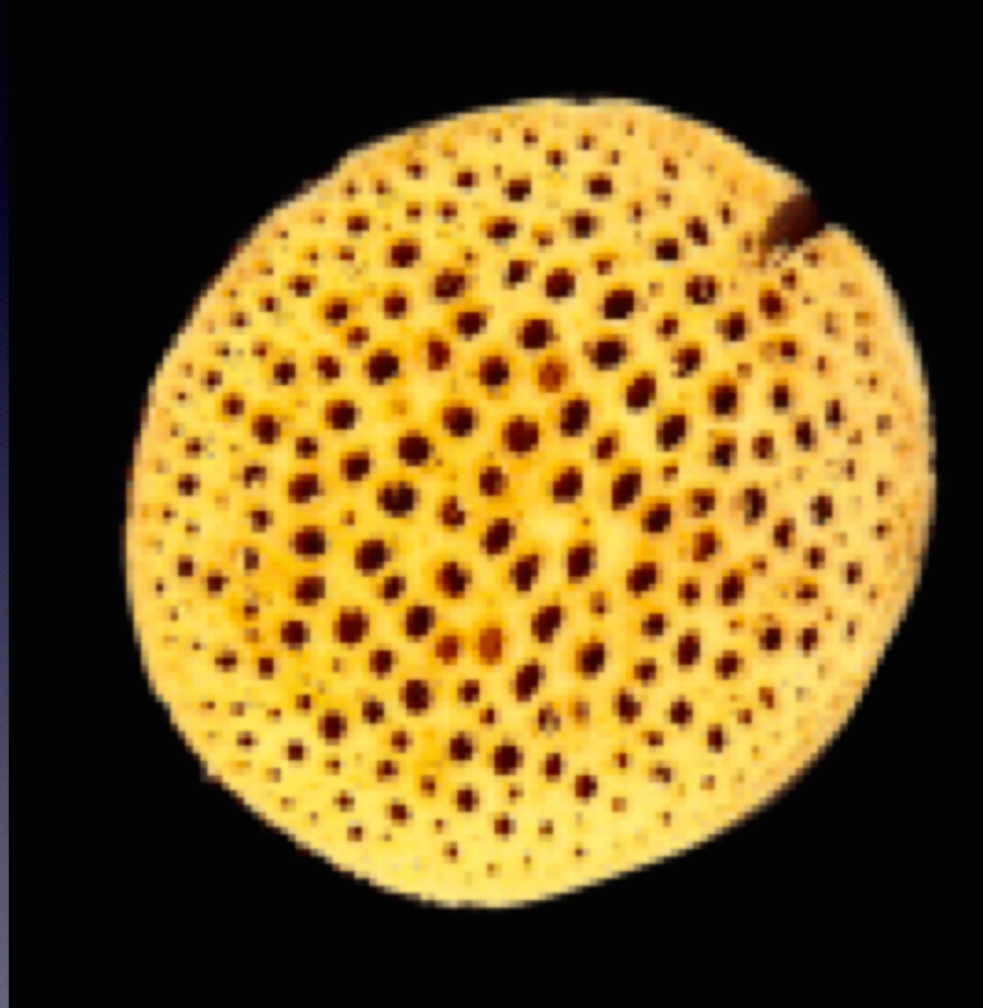
Optical Recognition of Lute Tablature

Christoph Dalitz · Thomas Karsten

Other Applications

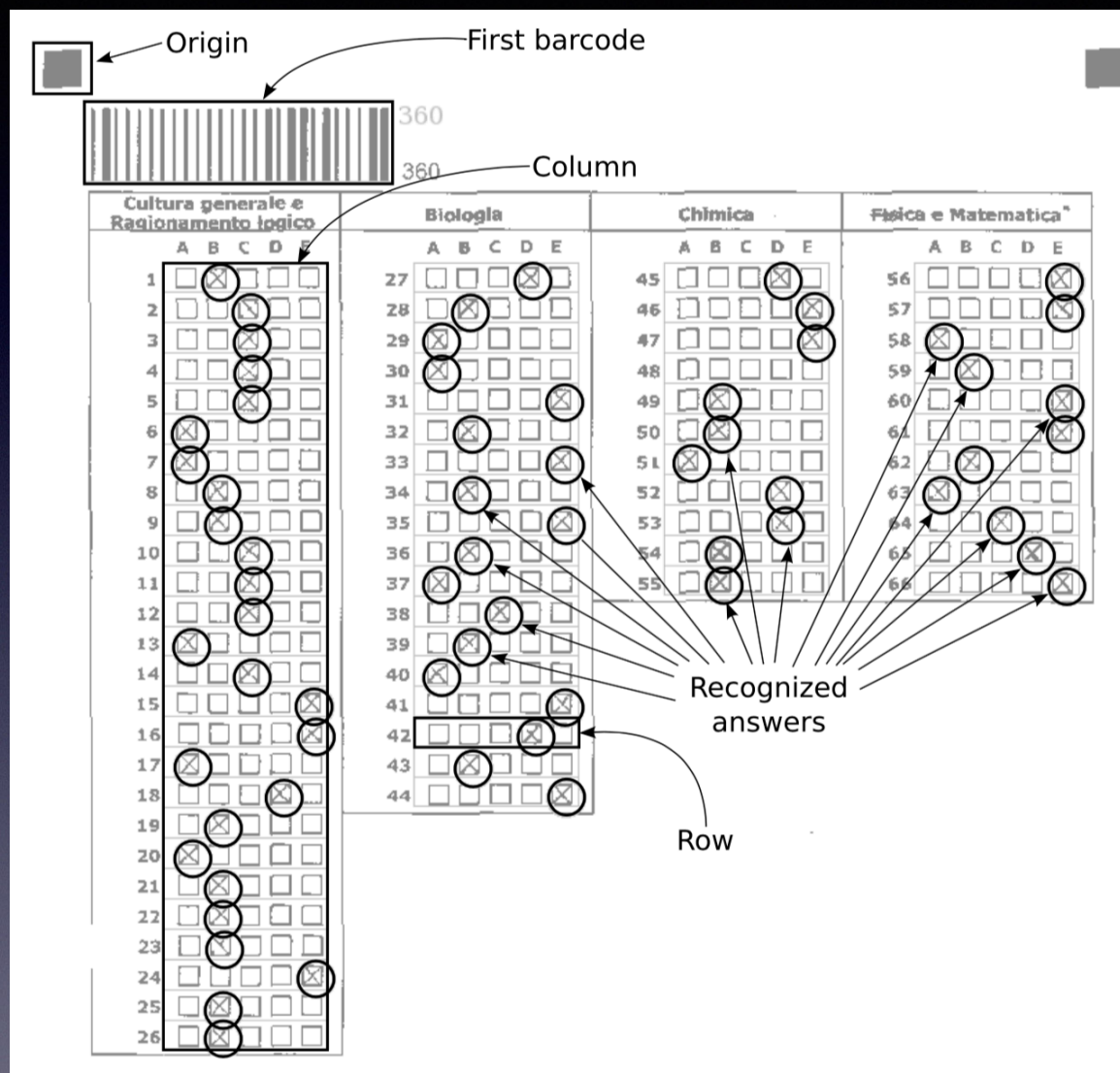


2005: Other Applications



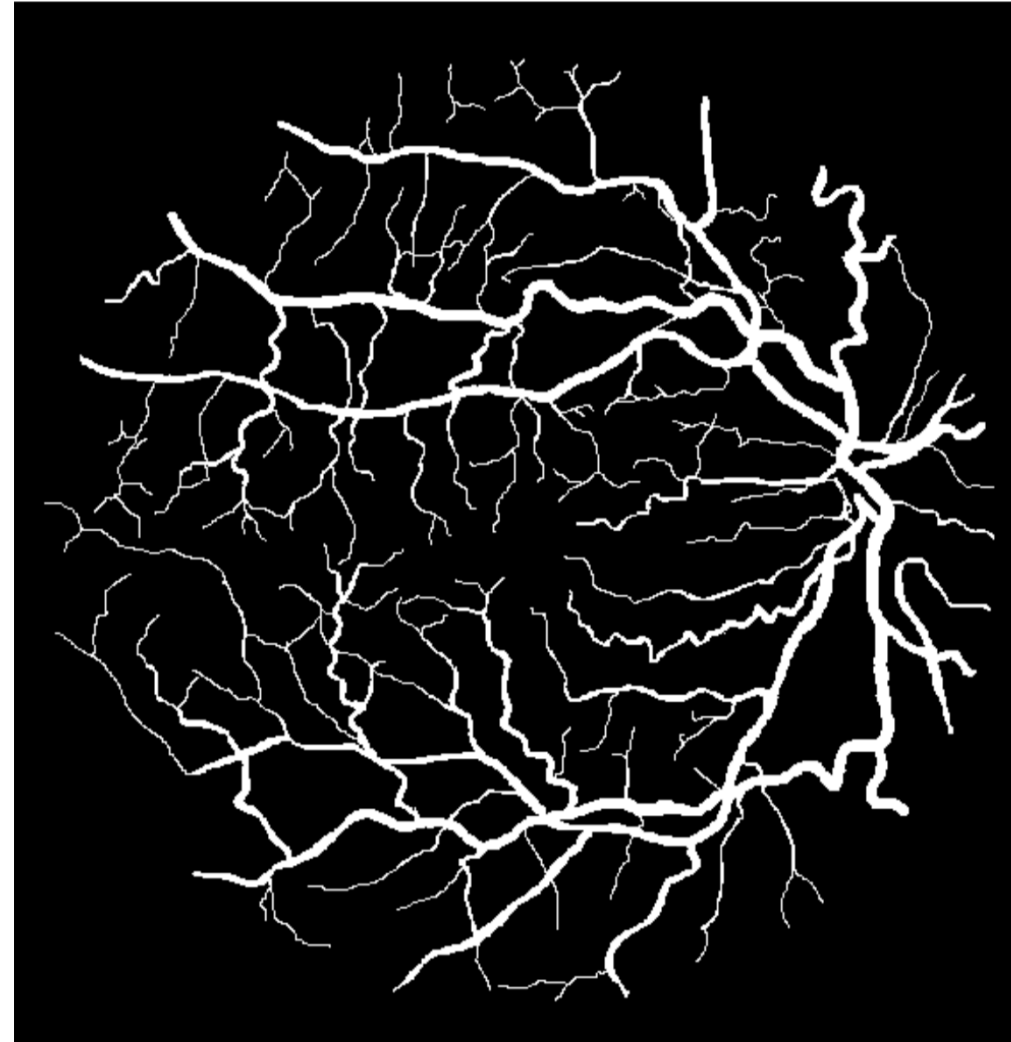
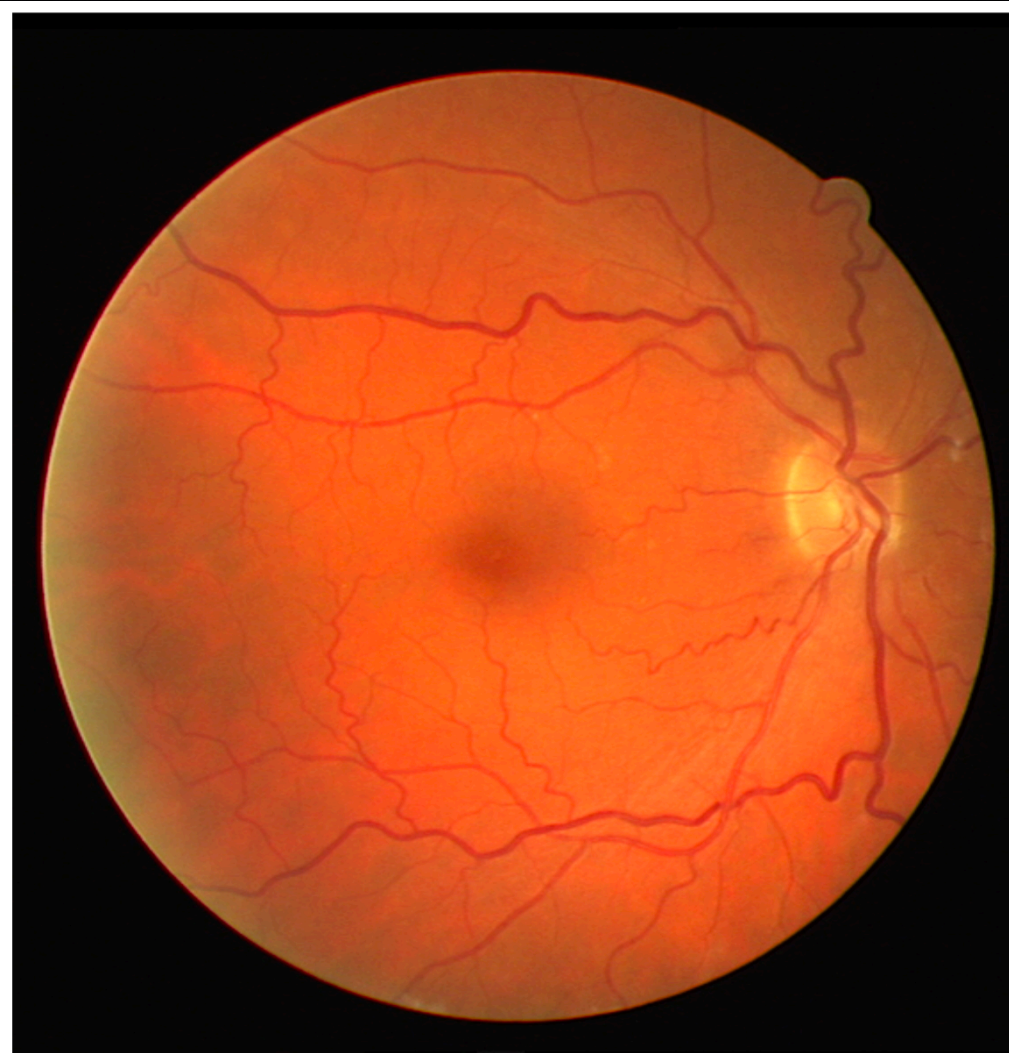
Vascular Anatomy of Plants (Alex Cobb, Harvard)

2009: Other Applications



Multiple-choice Test Recognition System (Spadaccini & Rizzo)

2015: Other Applications



Blood vessel extraction (Dalitz et al.)

2005–2016: VIPs



- ❖ 2005–2012 Ashley Burgoyne (PhD)
- ❖ 2006–2008 Laurent Pugin (Postdoc)
- ❖ 2007–2016 Andrew Hankinson (PhD/Postdoc)
- ❖ 23 publications on OMR between 2007–2016
- ❖ 18 publications on OMR between 2007–2012 (3 per year)

2002: Aruspix

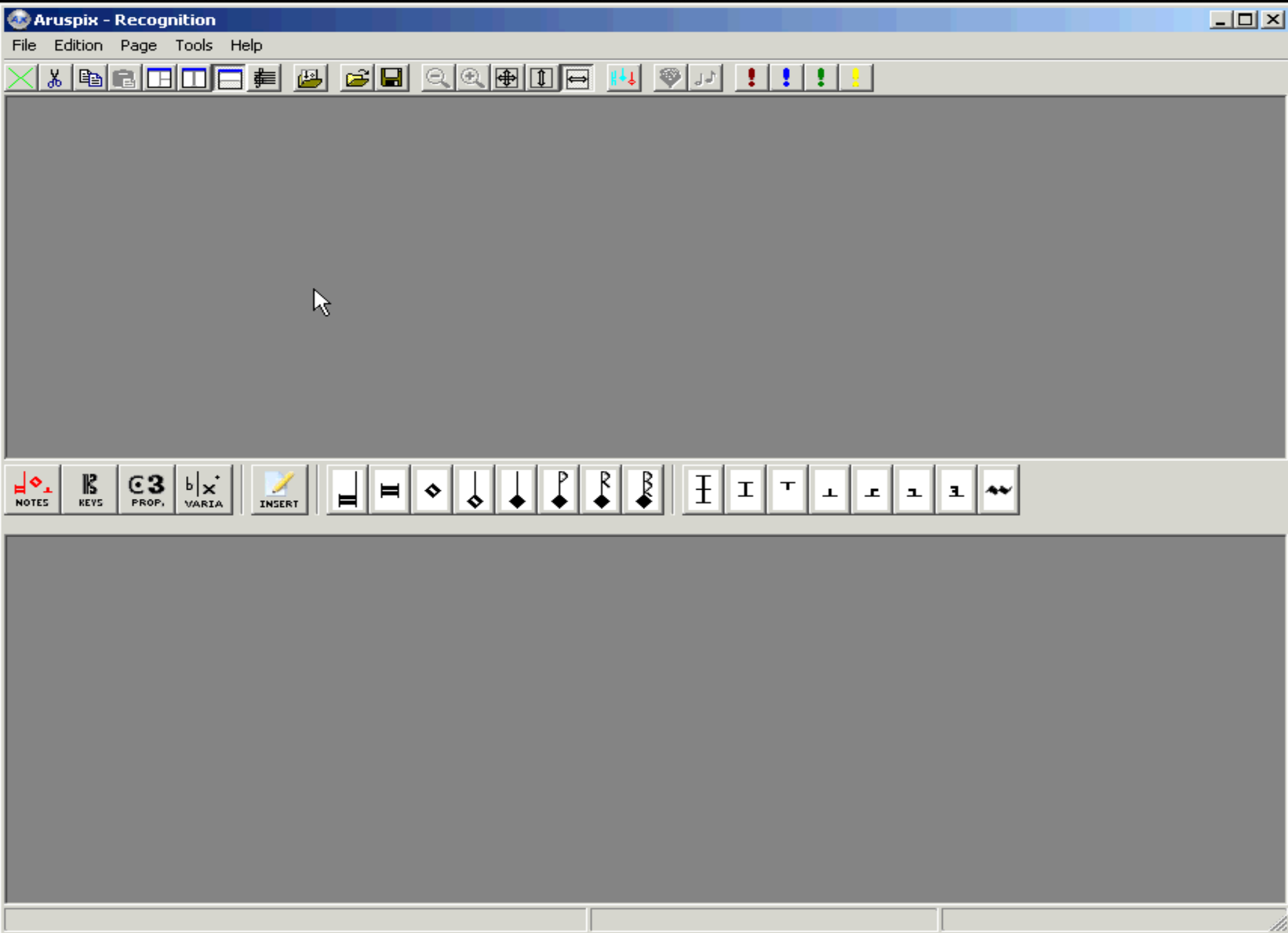


Typographic Music: music set with type (single-impression)

2002: Aruspix

- ❖ Developed by Laurent Pugin
- ❖ Specialized for typographic music
- ❖ Uses HMM (Hidden Markov Model)
- ❖ Does not remove staff lines





SIMSSA | Single Interface for Music | Score Searching and Analysis

- ❖ Similar to “Google Books” minus Google
 - ❖ OMR (optical music recognition) to enable full-text search
 - ❖ Sophisticated music analysis and query
- ❖ Access to digitized scores world-wide from a single website
- ❖ SSHRC-funded 11-year project: 2011–2021: \$4.4M

What would SIMSSA provide?

- ❖ Web-based OMR system with score editors
 - ❖ Rodan (Remote Online Document Analysis Network)
 - ❖ Gamera + Aruspix (a combination of existing OMR software)
 - ❖ Verovio (open-source music engraver) by Laurent Pugin
 - ❖ “Gradsourcing” to correct errors
 - ❖ Early music
- ❖ Web-based user interface to view, search, annotate, and analyze scores
 - ❖ MEI (Music Encoding Initiative) by Perry Roland and others
 - ❖ Diva.js (web-based IIIF-compatible document delivery system)
 - ❖ Humdrum / music21 (analytical tools)

The Vision: Global Music Library

Tools



Music Encoding Initiative

Humdrum

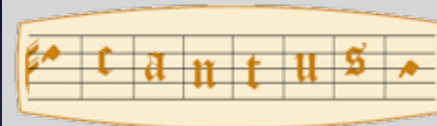
music21



Early Music Online

Music Treasures Consortium

Metadata & Text



SIMSSA Team

- ❖ Musicologists (20)
- ❖ Music Librarians (8)
- ❖ Music Technologists (11)
- ❖ Partners (23) including:
 - ❖ Bavarian State Library
 - ❖ Bibliothèque nationale de France
 - ❖ British Library
 - ❖ Harvard University Music Library
 - ❖ HathiTrust Research Center
 - ❖ New York Philharmonic Archives

Optical Music Recognition (OMR)

A process of converting images of music scores into a symbolic computer representation, such as MIDI, MusicXML, or MEI (Music Encoding Initiative).



OMR



```
<section xml:id="section-0000001229415468">
  <measure xml:id="measure-L6" n="1">
    <staff xml:id="staff-L6F2N1" n="1">
      <layer xml:id="layer-L6F2N1" n="1">
        <rest xml:id="rest-L7F2" dur="2" fermata="above" />
        <note xml:id="note-L11F2" dur="2" oct="4" pname="g" accid.ges="n" />
      </layer>
    </staff>
    <staff xml:id="staff-L6F1N1" n="2">
      <layer xml:id="layer-L6F1N1" n="1">
        <note xml:id="note-L7F1" dots="1" dur="4" oct="3" pname="c" accid.ges="n" />
        <tuplet xml:id="tuplet-L8F1-L10F1" num="3" numbase="2" num.format="count">
          <beam xml:id="beam-L8F1-L10F1">
            <note xml:id="note-L8F1" dur="16" oct="3" pname="d" accid.ges="n" />
            <note xml:id="note-L9F1" dur="16" oct="3" pname="e" accid.ges="n" />
            <note xml:id="note-L10F1" dur="16" oct="3" pname="f" accid.ges="n" />
          </beam>
        </tuplet>
        <note xml:id="note-L11F1" dur="4" oct="3" pname="a" accid.ges="n" />
        <note xml:id="note-L12F1" dur="4" oct="3" pname="a" accid.ges="n" />
      </layer>
    </staff>
    <fermata xml:id="fermata-L10F1" staff="2" startid="#note-L10F1" place="above" />
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    <tie xml:id="tie-L12F1-L15F1" startid="#note-L12F1" endid="#note-L15F1" />
  </measure>
  <measure xml:id="measure-L13" n="2">
    <staff xml:id="staff-L13F2N1" n="1">
      <layer xml:id="layer-L13F2N1" n="1">
        <note xml:id="note-L13F3" dur="2" oct="4" pname="b" accid.ges="n" />
        <note xml:id="note-L16F3" dur="2" oct="5" pname="d" accid.ges="n" />
      </layer>
    </staff>
    <staff xml:id="staff-L13F1N1" n="2">
      <layer xml:id="layer-L13F1N1" n="1">
        <note xml:id="note-L15F1" dur="1" oct="3" pname="a" accid.ges="n" />
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      <layer xml:id="layer-L15F2N2" n="2">
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        <note xml:id="note-L16F2" dur="2" oct="2" pname="a" accid.ges="n" />
      </layer>
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  </measure>
  <measure xml:id="measure-L18" n="3">
    <staff xml:id="staff-L18F2N1" n="1">
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      </layer>
      <layer xml:id="layer-L20F2" n="2">
        <note xml:id="note-L20F2" dur="4" oct="5" pname="d" accid.ges="n" />
      </layer>
    </staff>
  </measure>
</section>
```


Steps Involved in OMR

Digitized Score



Image Preprocessing

Binarization

Noise Removal

Structural Analysis

Image Segmentation

Music Symbol Recognition

Staves Processing

Symbol Segmentation

Symbol Classification

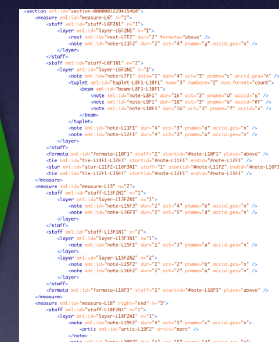
Music Notation Reconstruction

Symbol Combination

Semantic Assignment (pitch, value)

Musical Structure Reconstruction

Final Output



2011: *Liber Usualis* Project




FEAST OF THE BLESSED SACRAMENT.
CORPUS CHRISTI.
Double of the First Class with Octave.
AT FIRST VESPERS.
All as at second Vespers, p. 956, except the following :
At Magn. Ant. 6. F
O quam su-á-vis est, * Dó-mi-ne, spí-ri-tus tú-us! qui ut dulcédí-nem tú-am in ff-li-os de-monstrá-res, pá-ne su-a-vís-sí-mo de caélo praesti-to, esu-ri-éntes réples bónis, fa-stí-dí-ós-sos dí-vi-tes dí-mít-tens in-á-nes. Eu o u a e.
Cant. Magnificat. 6. F. p. 211 or p. 213. Prayer. Deus, qui nobis. p. 943.
At Compline and the Little Hours, the psalms of Sunday are said; the Hymn, today and throughout the Octave, is sung in the tone of Christmas, p. 367, with the doxology Jesu tibi sit glória, Qui natus es de Virgine. All hymns of the same metre end with this doxology throughout the Octave, even on the feasts of Saints, unless the contrary be indicated.
AT MATINS. *
Pater. Ave María. Credo.
D Omí-ne, lá-bi-a mé-a apé-ri-es. R. Et os mé-um an-
* The Chant for Matins is taken from the publications of Solesmes.

Full-text search of 2,000 pages of Latin text and square notation

Search the Liber usualis

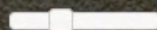
What is this? [Find out more about what we are trying to do.](#)

Strict pitch sequence 

previous

Enter a search query

next



Go to page


Current page: 1 of 2340

THE LIBER USUALIS 1961

This online publication is
provided by the

Preprocessing: Aruspix

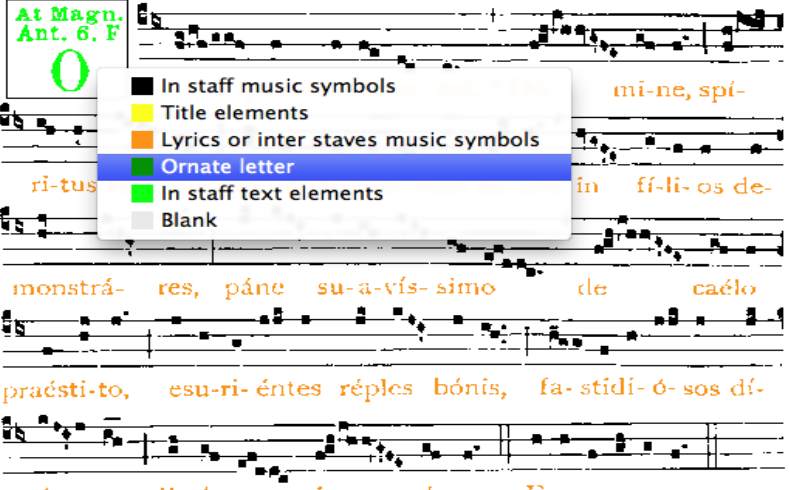
FEAST OF THE BLESSED SACRAMENT.
CORPUS CHRISTI.
Double of the First Class with Octave.
AT FIRST VESPERS.
All as at second Vespers, p. 956, except the following :
At Magn.
Ant. 6. F



vi-tes dimít-tens in-á-nes. E u o u a e.
Cant. Magnificat. 6. F. p. 211 or p. 213. Prayer. Deus, qui nobis. p. 943.
At Compline and the Little Hours, the psalms of Sunday are said, the Hymn, today and throughout the Octave, is sung in the tone of Christmas, p. 367, with the doxology Jesu tibi sit glória, Qui natus es de Virgine. All hymns of the same metre end with this doxology throughout the Octave, even on the feasts of Saints, unless the contrary be indicated.
AT MATINS. †
Pater. Ave María. Credo.

† The Chant for Matins is taken from the publications of Solesmes.

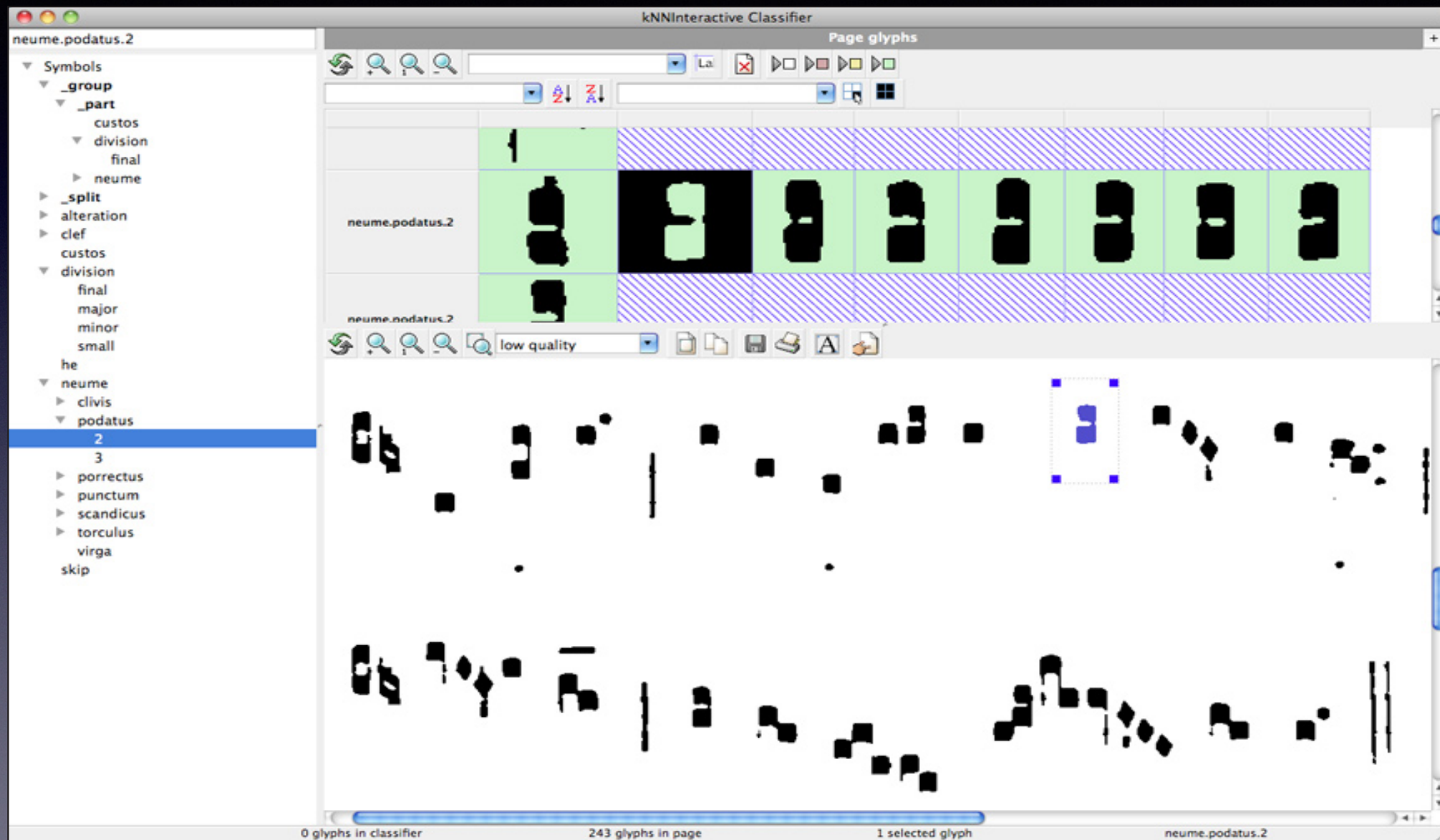
FEAST OF THE BLESSED SACRAMENT.
CORPUS CHRISTI.
Double of the First Class with Octave.
AT FIRST VESPERS.
All as at second Vespers, p. 956, except the following :
At Magn.
Ant. 6. F



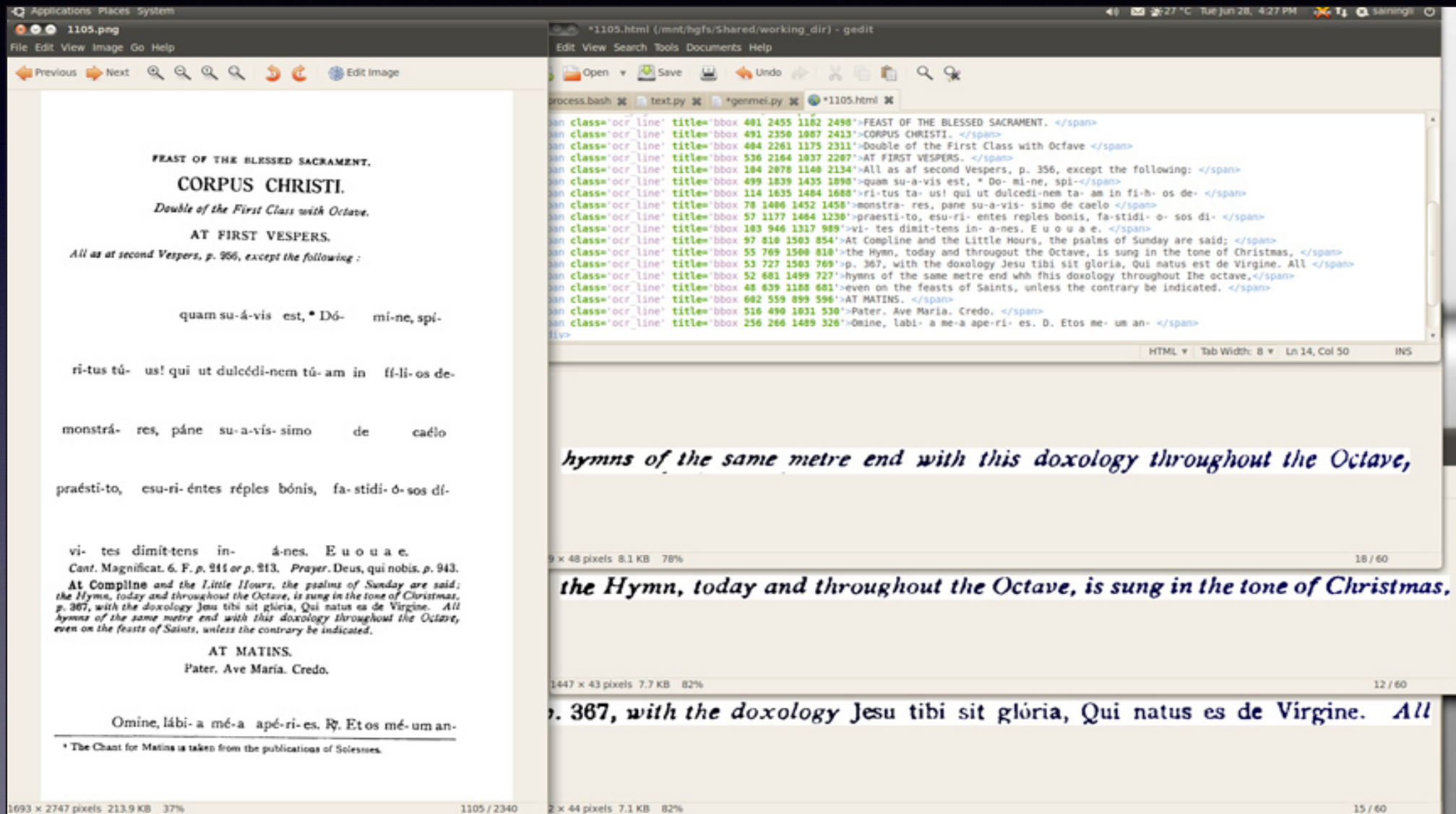
mi-ne, spí-ri-tus in fí-li-os de-monstrá-res, páne su-a-vís-simo de caélo praésti-to, esu-ri-éntes réples bónis, fa-stidi-ó-sos dí-vi-tes dimít-tens in-á-nes. E u o u a e.
Cant. Magnificat. 6. F. p. 211 or p. 213. Prayer. Deus, qui nobis. p. 943.
At Compline and the Little Hours, the psalms of Sunday are said, the Hymn, today and throughout the Octave, is sung in the tone of Christmas, p. 367, with the doxology Jesu tibi sit glória, Qui natus es de Virgine. All hymns of the same metre end with this doxology throughout the Octave, even on the feasts of Saints, unless the contrary be indicated.
AT MATINS. †
Pater. Ave María. Credo.

† The Chant for Matins is taken from the publications of Solesmes.

Music recognition: *Gamera*



Text recognition: Ocropus



The image displays the Ocropus text recognition interface. On the left, a scanned image of a liturgical text is shown. On the right, the corresponding HTML output is displayed, with each line of text wrapped in a `` tag containing bounding box information (bboxes) and the recognized text.

Scanned Image Text:

FEAST OF THE BLESSED SACRAMENT.
CORPUS CHRISTI.
Double of the First Class with Octave.
AT FIRST VESPERS.
All as at second Vespers, p. 956, except the following :

quam su-á-vis est, * Dó- mi-ne, spí-
ri-tus tú- us! qui ut dulcédi-nem tú- am in ff-li- os de-
monstrá- res, páne su-a-vis- simo de caelo
praesti-to, esu-ri-éntes réples bónis, fa- stidi- ó- sos dí-
vi- tes dimittens in- á-nes. E u o u a e.
Cant. Magnificat. 6. F. p. 211 or p. 213. Prayer. Deus, qui nobis. p. 943.
At Compline and the Little Hours, the psalms of Sunday are said; the Hymn, today and throughout the Octave, is sung in the tone of Christmas, p. 367, with the doxology Jesu tibi sit gloria, Qui natus es de Virgine. All hymns of the same metre end with this doxology throughout the Octave, even on the feasts of Saints, unless the contrary be indicated.
AT MATINS.
Pater, Ave Maria. Credo.
Omine, lábi- a mé-a apé-ri-es. R. Et os mé- um an-
* The Chant for Matins is taken from the publications of Solesmes.

HTML Output (OCR):

```

<span class="ocr_line" title="bbox 481 245 911 258">FEAST OF THE BLESSED SACRAMENT. </span>
<span class="ocr_line" title="bbox 481 258 878 271">CORPUS CHRISTI. </span>
<span class="ocr_line" title="bbox 481 271 766 284">Double of the First Class with Octave </span>
<span class="ocr_line" title="bbox 481 284 686 297">AT FIRST VESPERS. </span>
<span class="ocr_line" title="bbox 481 297 836 310">All as at second Vespers, p. 356, except the following: </span>
<span class="ocr_line" title="bbox 481 310 856 323">quam su-a-vis est, * Do- mi-ne, spi- </span>
<span class="ocr_line" title="bbox 481 323 836 336">ri-tus ta- us! qui ut dulcedi-nem ta- am in fi-h- os de- </span>
<span class="ocr_line" title="bbox 481 336 781 349">monstra- res, pane su-a-vis- simo de caelo </span>
<span class="ocr_line" title="bbox 481 349 851 362">praesti-to, esu-ri- entes reples bonis, fa-stidi- o- sos di- </span>
<span class="ocr_line" title="bbox 481 362 776 375">vi- tes dimit-tens in- a-nes, E u o u a e. </span>
<span class="ocr_line" title="bbox 481 375 906 388">At Compline and the Little Hours, the psalms of Sunday are said; </span>
<span class="ocr_line" title="bbox 481 388 906 401">the Hymn, today and throughout the Octave, is sung in the tone of Christmas, </span>
<span class="ocr_line" title="bbox 481 401 906 414">p. 367, with the doxology Jesu tibi sit gloria, Qui natus est de Virgine. All </span>
<span class="ocr_line" title="bbox 481 414 871 427">hymns of the same metre end with this doxology throughout the Octave, </span>
<span class="ocr_line" title="bbox 481 427 856 440">even on the feasts of Saints, unless the contrary be indicated. </span>
<span class="ocr_line" title="bbox 481 440 646 453">AT MATINS. </span>
<span class="ocr_line" title="bbox 481 453 706 466">Pater. Ave Maria. Credo. </span>
<span class="ocr_line" title="bbox 481 466 806 479">Omine, labi- a me-a ape-ri- es. D. Etos me- um an- </span>

```


Highlighted Text in HTML Output:

hymns of the same metre end with this doxology throughout the Octave,

the Hymn, today and throughout the Octave, is sung in the tone of Christmas,

p. 367, with the doxology Jesu tibi sit gloria, Qui natus es de Virgine. All

Pitch correction: *Aruspix*



The screenshot displays the Aruspix software interface, titled "Aruspix - Recognition - untitled (91%)". The interface features a menu bar with options: New, Open, New, Open, Import MEI, Save, Save MEI, Cut, Copy, Paste, Undo, Redo, Zoom out, Zoom in, Fit, and Run. The main workspace shows three staves of musical notation. The lyrics are: "quam su-á-vis est, * Dó- mi-ne, spí- ri-tus tú- us! qui ut dulcédi-nem tú- am in fí-li- os de- monstrá- res, páne su-a-vís- simo de caélo". The notation includes various musical symbols such as notes, rests, and bar lines. A red cursor is visible on the third staff, indicating a specific point in the music. The bottom of the interface has a toolbar with icons for Neumes and Symbols.

Web interface: *Diva.js*

FEAST OF THE BLESSED SACRAMENT.
CORPUS CHRISTI.
Double of the First Class with Octave.
 AT FIRST VESPERS.
All as at second Vespers, p. 956, except the following :

At Magn.
 Ant. 6. F

O quam su-á-vis est, * Dó- mi-ne, spí-
 ri-tus tú- us! qui ut dulcédi-nem tú- am in ff-li- os de-
 monstrá- res, páne su-a-vís- simo de caélo

FGACA Strict pitch sequence Search Clear

previous Found 77 results for FGACA next

Cantus Ultimus

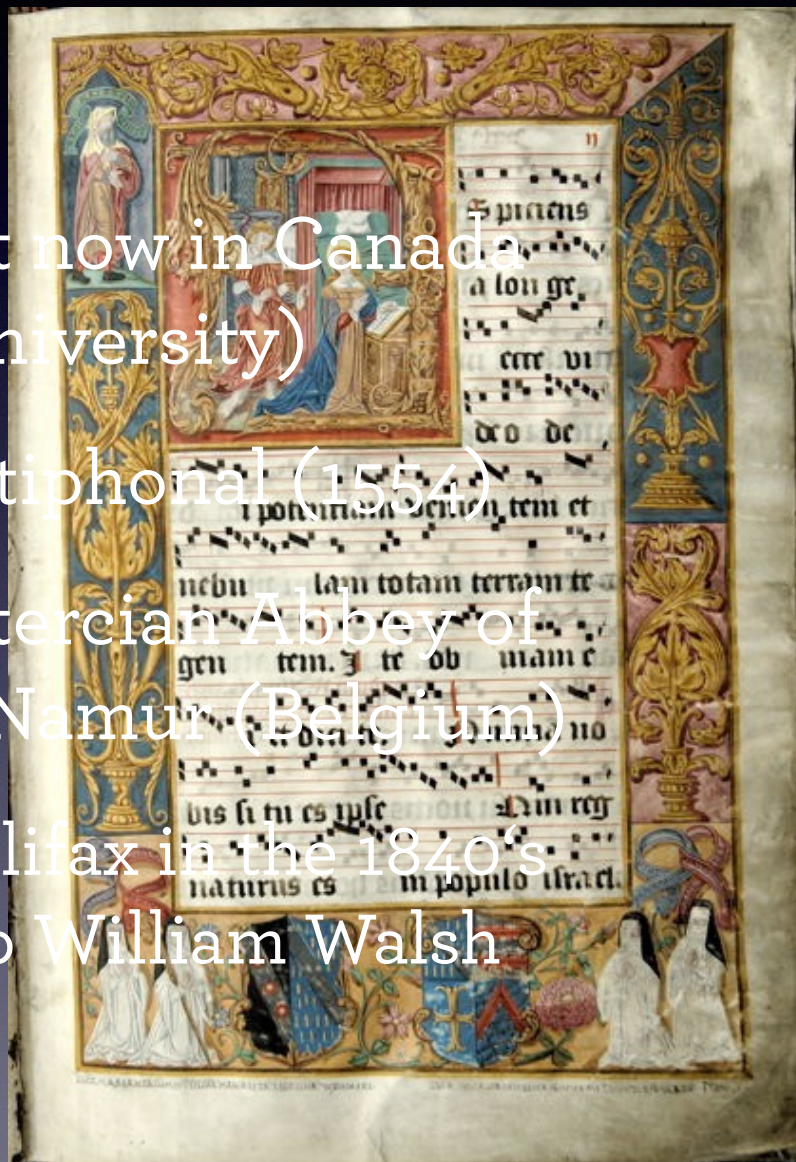
Main Goals of Cantus Ultimus



JRoman?
Take a look thr
presentation sl

2012: Salzinnes Project

- ❖ A manuscript now in Canada (St. Mary's University)
- ❖ Salzinnes Antiphonal (1554)
- ❖ From the Cistercian Abbey of Salzinnes in Namur (Belgium)
- ❖ Brought to Halifax in the 1840's by Archbishop William Walsh



2012: Rodan

Andrew Hankinson

❖ Remote Online Document Analysis Network

❖ Web reco



Rodan: OMR Workflow Management System

Rodan

Project Workflow Window Help

Status

Users

Pages

Designer

Jobs

Results

Workflows

Crop, greyscale, Niblack, despeckle
try again: Crop, greyscale Niblack, de...
Testing: crop, greyscale, BERNSEN, ...

Runs

Mon Jun 16 2014 10:33:39 G...

Pages

csg-0390_017.jpg
csg-0390_110.jpg

Workflow Run

URL: Mon Jun 16 2014 11:50:41 GMT-0400 (EDT)
Created on: Mon Jun 16 2014 10:33:39 GMT-0400 (EDT)
Updated on: <http://rodan.simssa.ca/workflowrun/139ed692304d4402a34e8059c820f129/>

Results Packages

Cancel Workflow Run

Run Jobs

Start Job

View Error Details

View Run Job Settings

Sequence	Job Name	Status	Error	UUID	Page Name
1	Crop Bord...	Has finished		9d65fc9012fe4...	csg-0390_110.jpg
2	To Greysc...	Has finished		30179f3e4e504...	csg-0390_110.jpg
3	Bernsen T...	Has finished		01ebd132cb88...	csg-0390_110.jpg
4	Rdn Desp...	Has finished		bf17ef9e78524...	csg-0390_110.jpg
6	Pixel Seg...	Has finished		478ba796135d...	csg-0390_110.jpg

Results

View Result

Run Job name

Bernsen Threshold

URL:

/data/projects/c50c031df54e4e4a986852e715f06ad8/workflows/837f52c

Created on:

Mon Jun 16 2014 10:43:07 GMT-0400 (EDT)

Updated on:

Mon Jun 16 2014 10:50:01 GMT-0400 (EDT)

View Result

Run Job name

Rdn Despeckle

URL:

/data/projects/c50c031df54e4e4a986852e715f06ad8/workflows/837f52c

Created on:

Mon Jun 16 2014 10:49:52 GMT-0400 (EDT)

Updated on:

Mon Jun 16 2014 10:50:08 GMT-0400 (EDT)

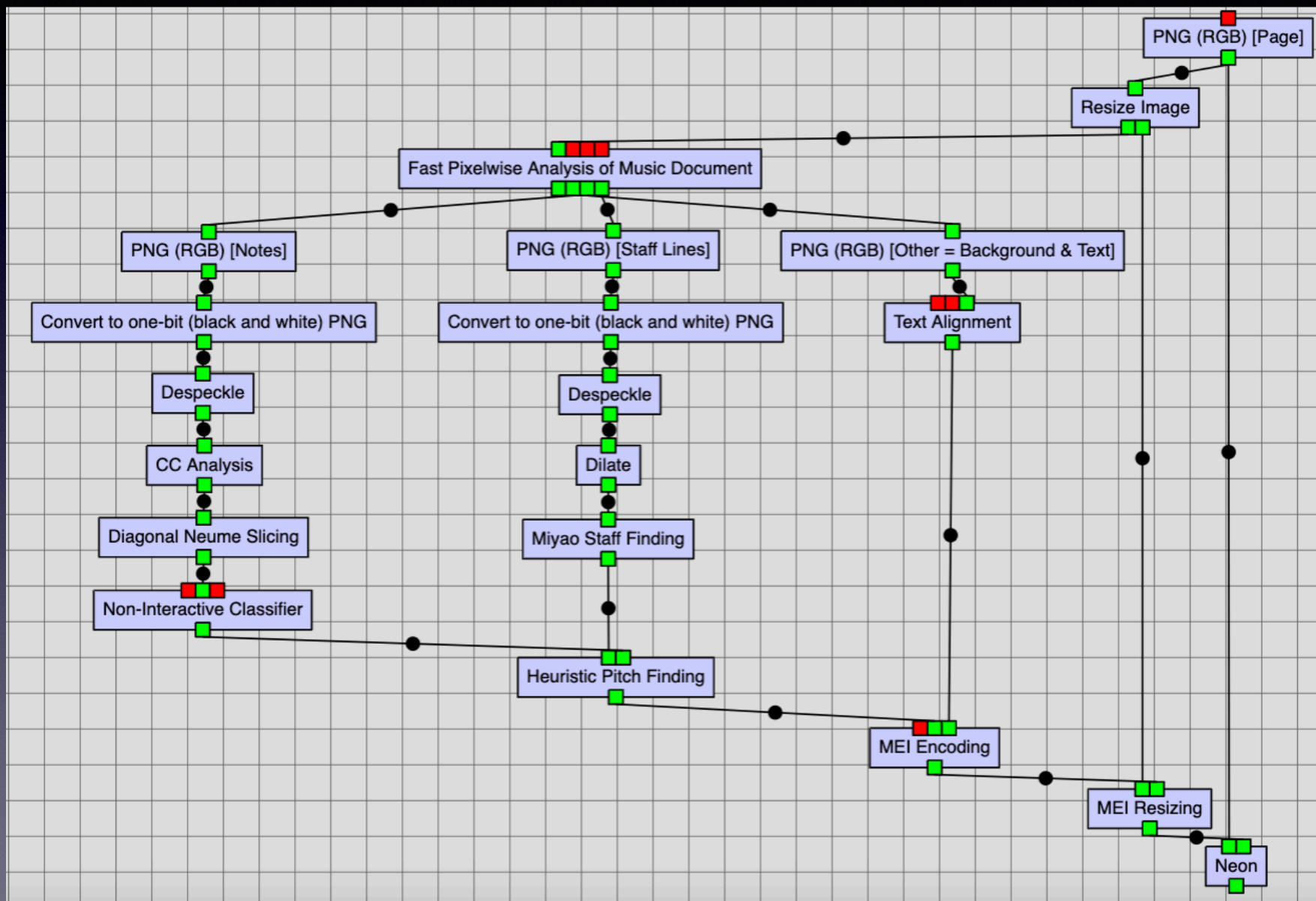
View Result

Page

Page name: csg-0390_110.jpg
URL: <http://rodan.simssa.ca/page/f7603e9fb397461db36777849771e5b/>



Rodan Workflow



2016: Breakthrough in OMR preprocessing!

❖ Pixel-level classification

- ❖ Background

- ❖ Text

- ❖ Staff lines

- ❖ Musical symbols

❖ Convolution Neural Network

❖ Jorge Calvo Zaragoza: “Calvo’s Method”



Greyscale

Binarization

Border Removal

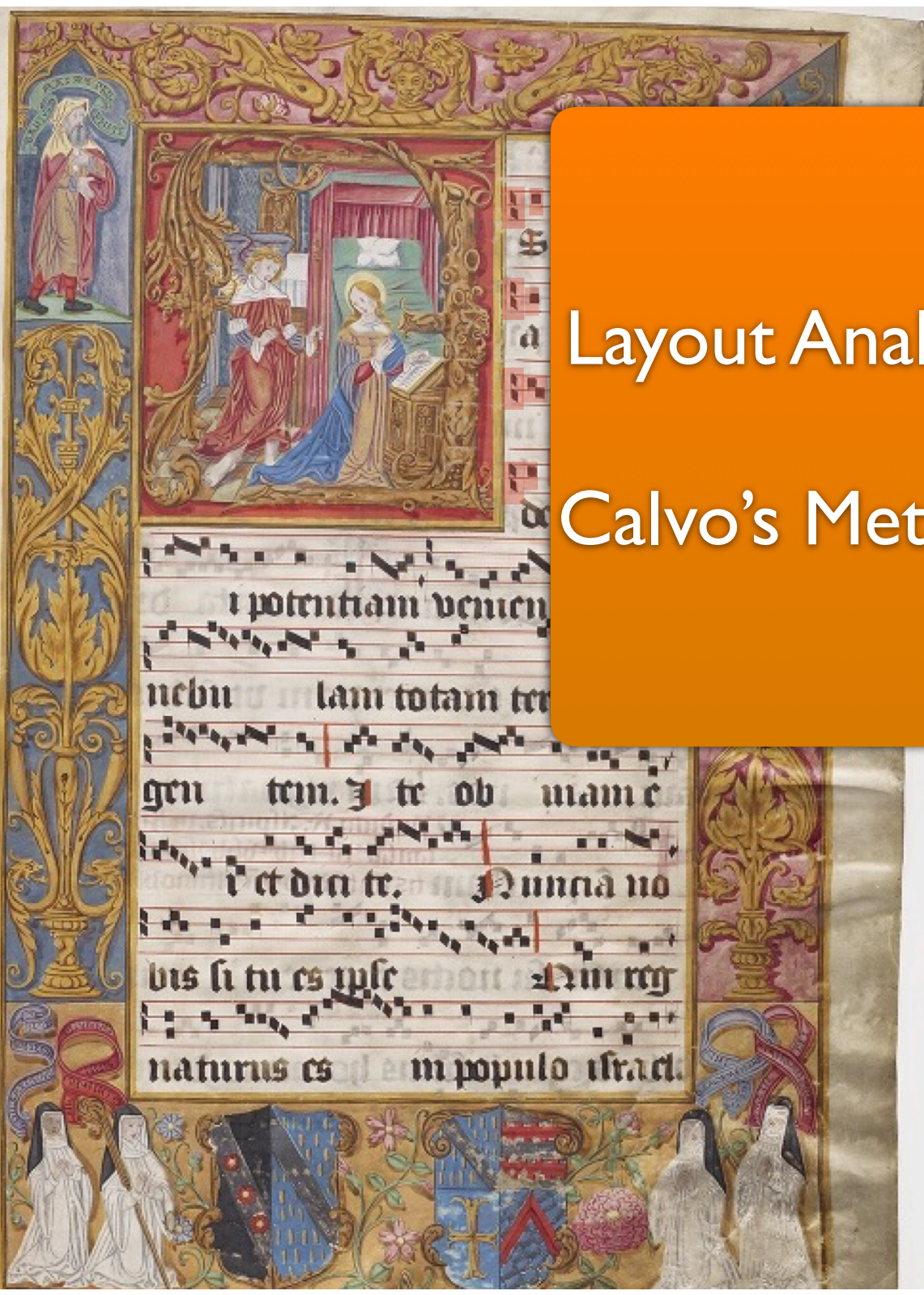
Lyric Removal

Staff Removal

Shape Classification

Music Reconstruction

Shape/Image Alignment



Layout Analysis Calvo's Method

Greyscale

Binarization

Border Removal

Lyric Removal

Staff Removal

Shape Classification

Music Reconstruction

Shape/Image Alignment

Three Different Outputs in One Step! Using Convolutional Neural Networks



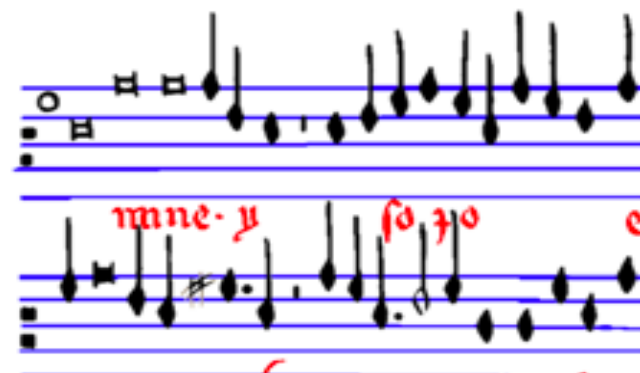
(a) Input image



(b) Binarization



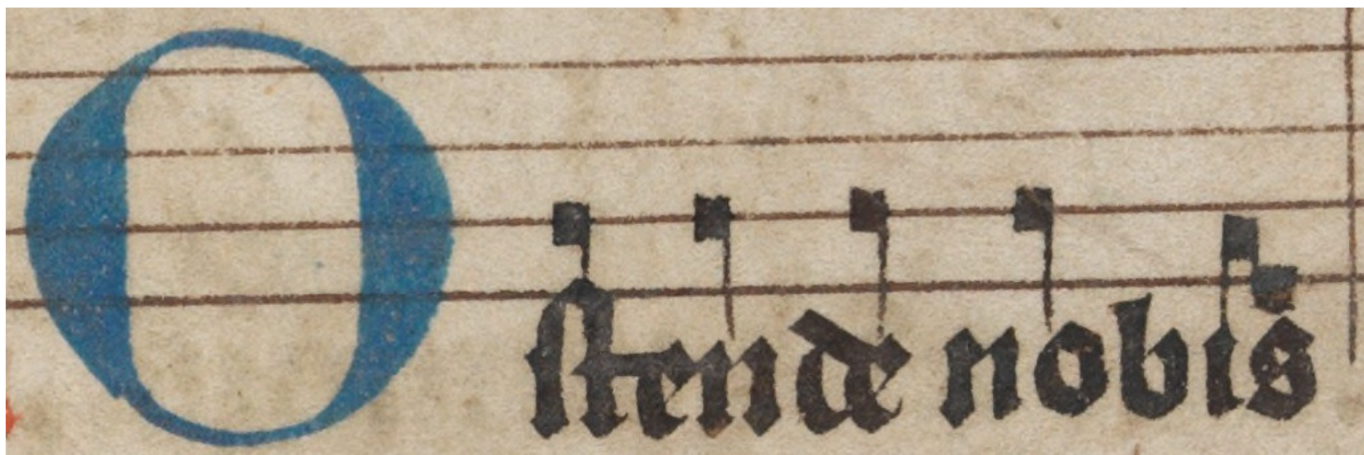
(c) Text detection



(d) Staff-line detection

Calvo's Method

Complete Layout Analysis



(a) Example of input piece of score



(b) Input score after layout analysis

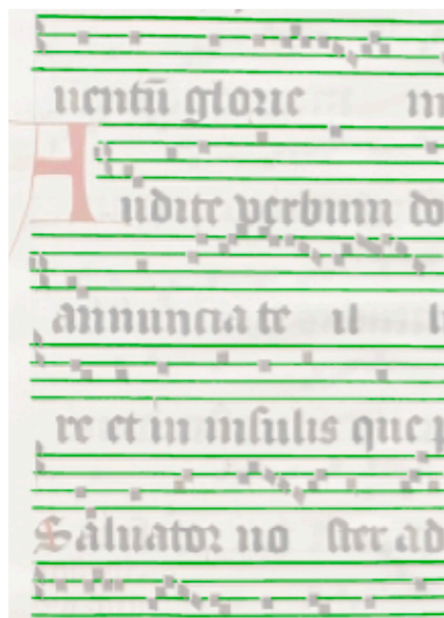
Separation of Staff, Notes, & Text

Jorge Calvo Zaragoza

Actual



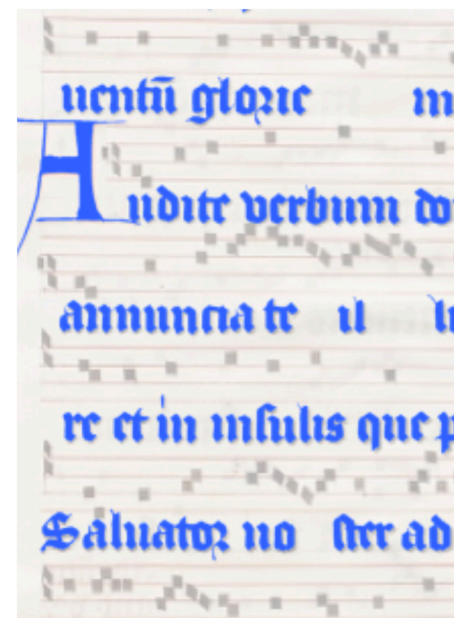
Staff



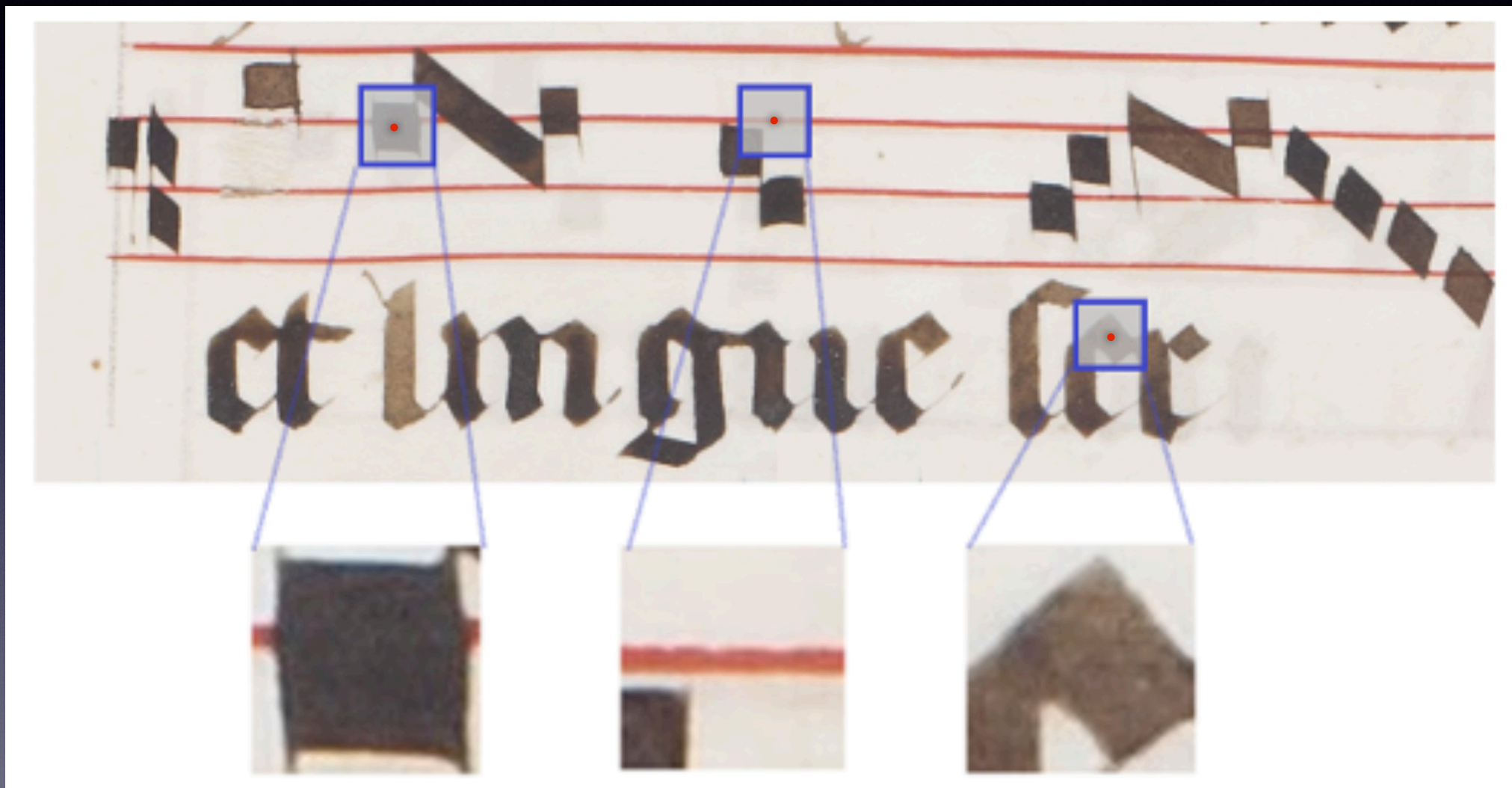
Note



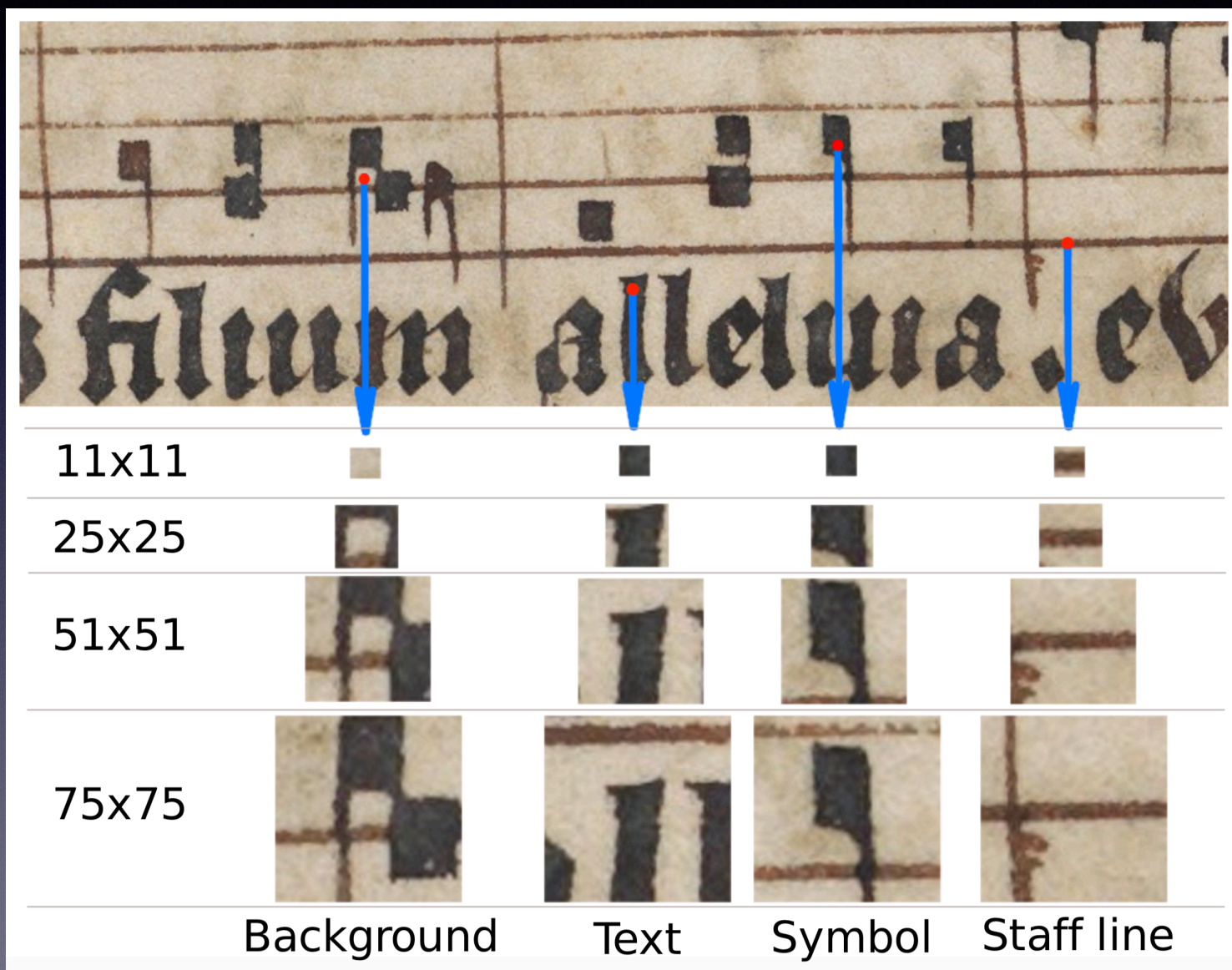
Text



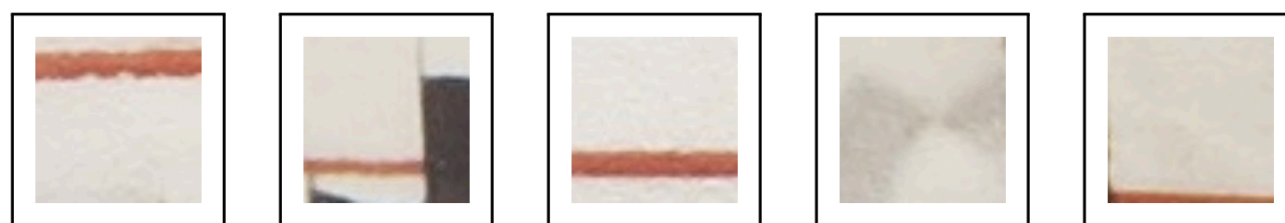
Creating the Ground Truth



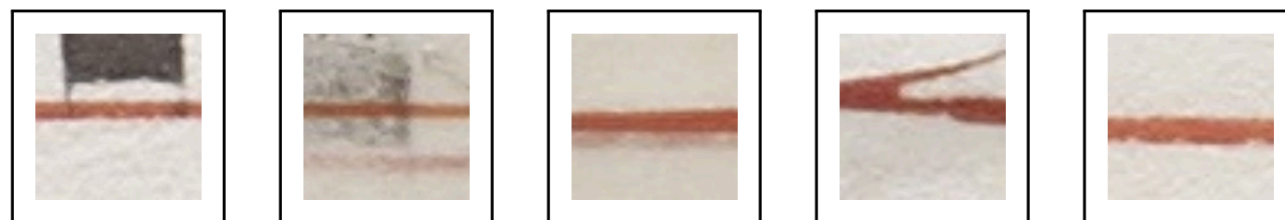
Examples of Different CNN Input Window Size



Samples of different classes



(a) Samples of *background* class



(b) Samples of *staff* class



(c) Samples of *text* class

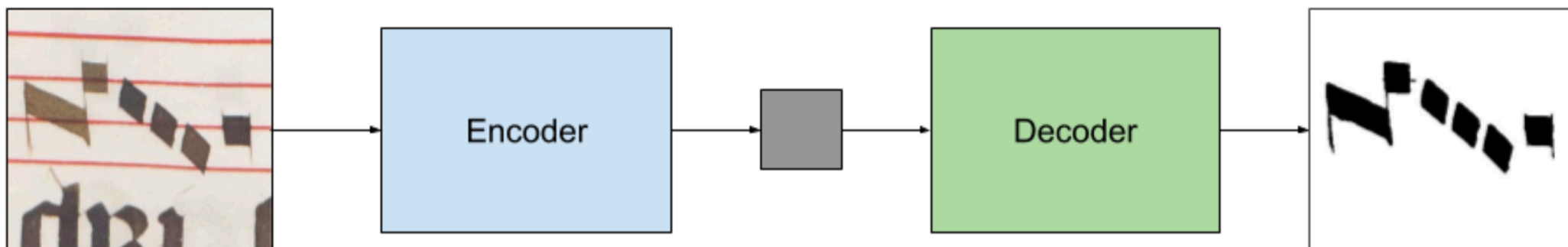
Separation of Staff, Notes, & Text



2018: A Different Neural Network Model

Selective Auto Encoders

Jorge Calvo Zaragoza



Encoding Decoding

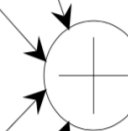
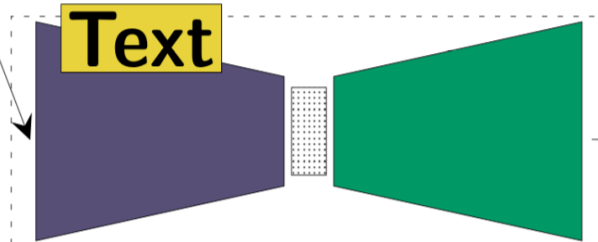
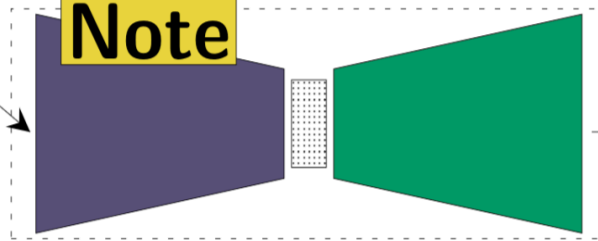
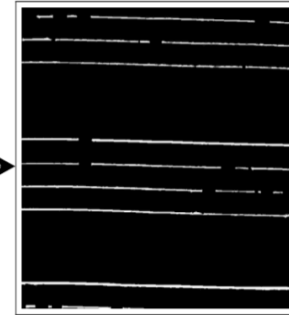
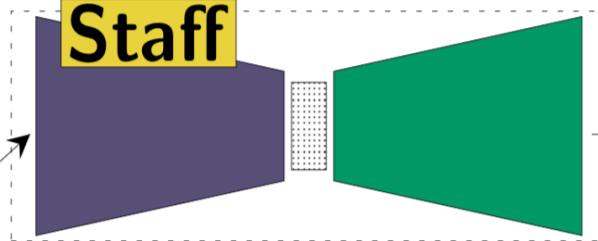
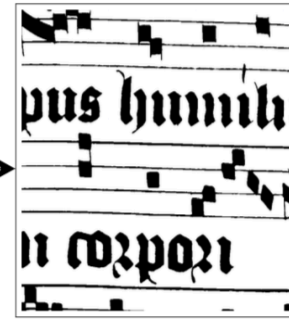
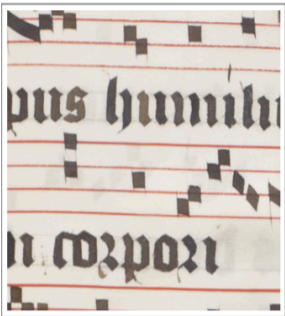
Background

Staff

Note

Text

Combination



Accuracy & Classification Time Comparison

Selective Auto Encoders (SAE) vs Convolutional Neural Nets (CNN)

Two Medieval Manuscripts: Salzinnes & Einsiedeln

Strategy	Macro F_1		Time per page
	Salzinnes	Einsiedeln	
SAE	96.4	89.3	~ 1 minute
CNN	91.3	88.4	~ 6 hours

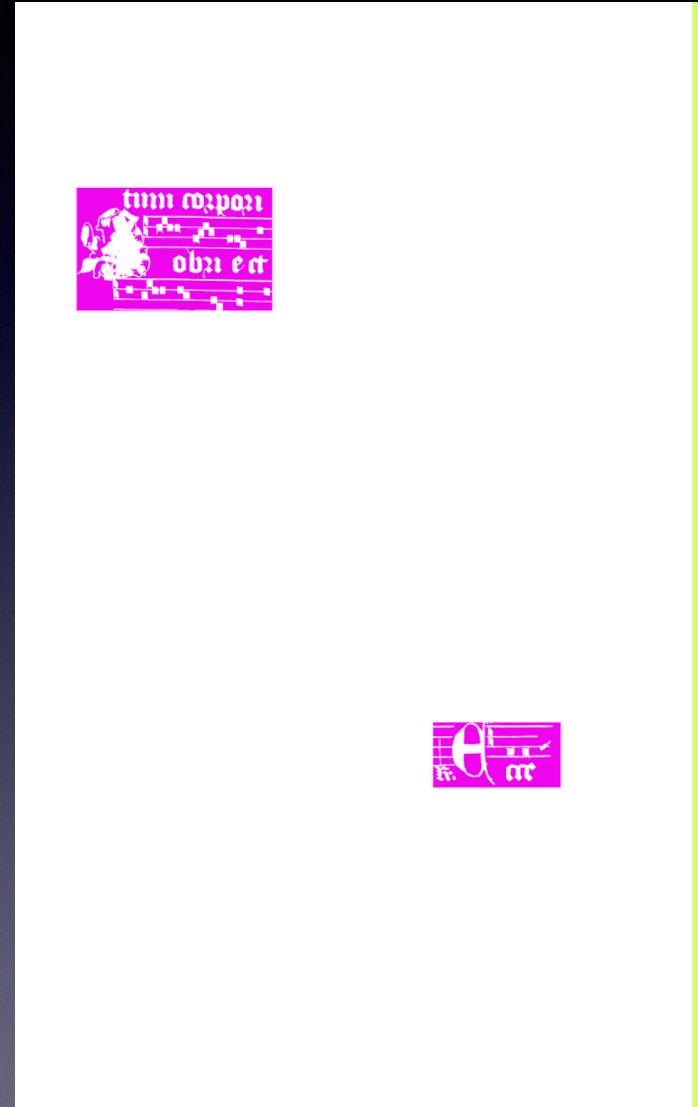
Pixel.js

Zeyad Saleh, Ké Zhang, Eric Liu



To annotate one page of a manuscript containing over 30 million pixels took 24 hours (3 days!)

nū iesum dñi sup. Qui reformabit
 corpus humiliatū no sine configura
 tum corpori clari ta tis su e. *66.*
 obui e et iuste et pie uiuam in hoc
 seculō expectantes beatam spem et ad
 uentū glorie magni de i. *2. 2. 2.*
Audite uerbum domini gentes et
 annuncia te il lud in finibus ter
 re et in insulis que procul sunt dicite
 Saluator no ster ad ueni et. *66.* **A**nnū
 cia te et auditum faci te loquim
 in et et clama te. Sal. *66.* **E**cce



Ground Truth



tmm m2p021

ob21 e ct

Original Image & Ground Truth



Original Image



Ground Truth

Classification of a Page: Notes

VI.

flore quia cito veniet salus tu a. Dil.

In laud. **A**lleluia. ps. Misere mei. R. m.

Anti. **Q**uem ad liberandum nos. Domine

deus virtutum. **E**t ostende faciem

tuam et salvi erimus. Domine. **P**rimo.

Splendor paterne. **Vers.** E mitte agnū domine

dominatorem terre. De petra deserti ad montem

filie syon. **Ad benedictus Antiphona.**

Spiritus sanctus in te descendet ma

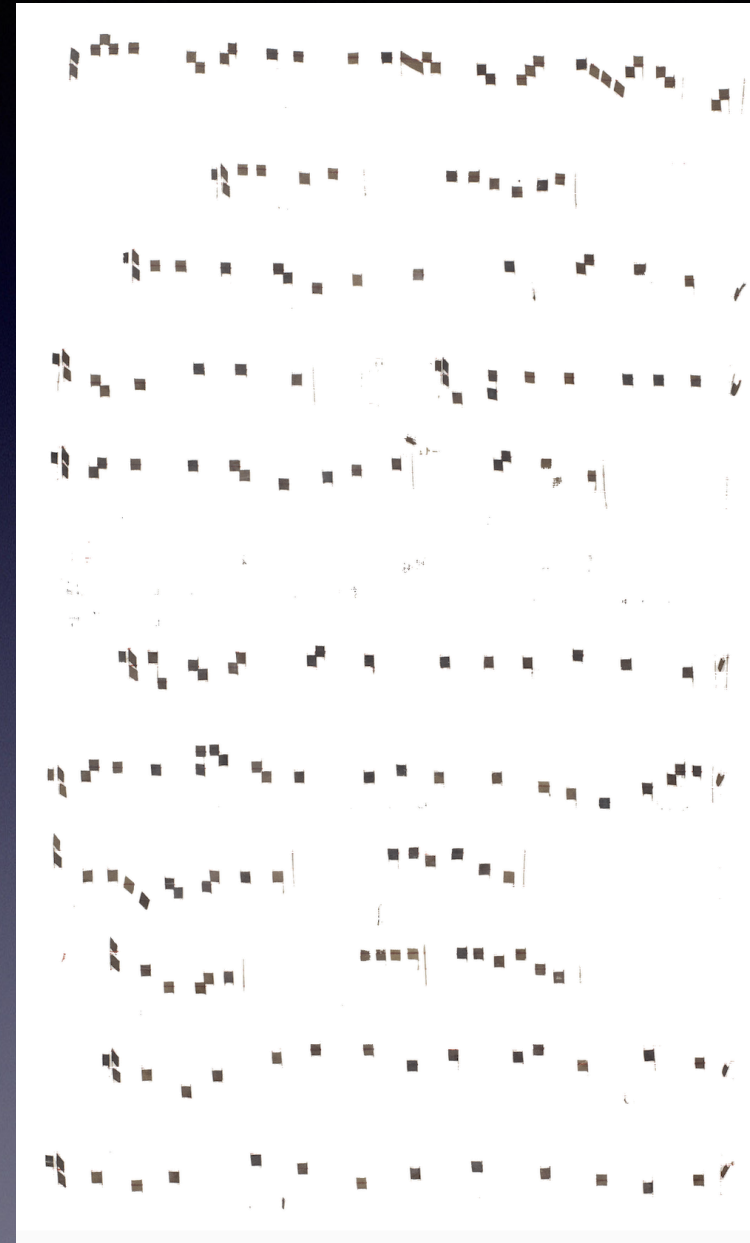
ria ne ti meas habebis in utero filius

dei alleluia. **Benedictus.** **Ad p̄mā. aū**

Alleluia. ps. Beati immaculati. **p̄m.**

Quonditor alme syderum eterna lux cre

dentium christe redemptor omnium ex



Classification of a Page: with Staves

VI.

flore quia cito veniet salus tu a. Dil.

In laud. **A**lleluia. ps. Misere mei. R. m

Quem ad liberandum nos. Domine

deus virtutum. **E**t ostende faciem

tuam et salui erimus. Domine. **P**rimo.

Splendor paterne. **Vers.** E mitte agnū domine

dominatorem terre. De petra deserti ad montem

filie syon. **Ad benedictus Antiphona.**

Spiritus sanctus in te descendet ma

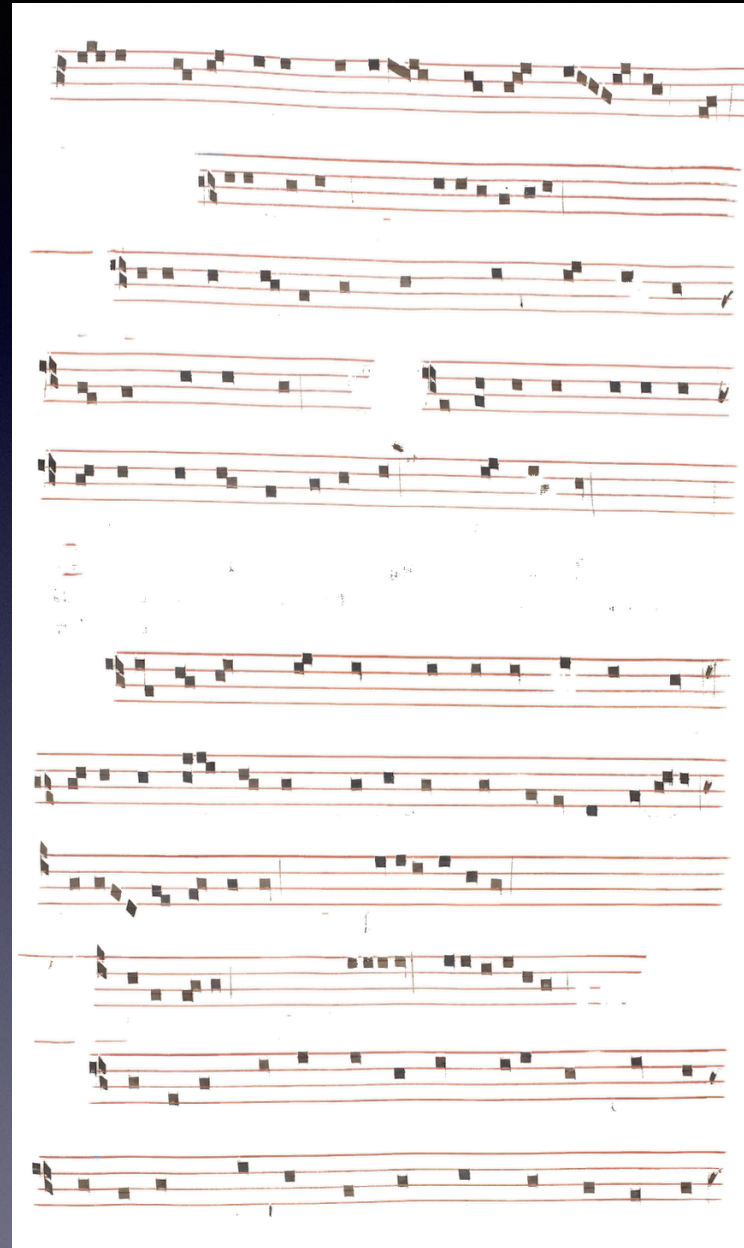
ria ne ti meas habebis in utero filius

dei alleluia. **Benedictus.** **Ad p̄mā. aū**

Alleluia. ps. Beati immaculati. **p̄m.**

Quonditor alme syderum eterna lux cre

dentium christe redemptor omnium ex



Classification of a Page

VI.

flore quia cito veniet salus tu a. Dil.

In laud. Anti. **A**lleluia. ps. Misere mei. R. m.

Quem ad liberandum nos. Domine

deus virtutum. **E**t ostende faciem

tuam et salui erimus. Domine. **V.**

Splendor paterne. **V.** E mitte agnū domine dominatorem terre. De petra deserti ad montem filie syon. **Ad benedictus Antiphona.**

Spiritus sanctus in te descendet ma

ria ne ti meas habebis in utero filius

dei alleluia. **Benedictus.** **Ad p̄mā. aū**

Alleluia. ps. Beati immaculati. **p̄m.**

Quonditor alme syderum eterna lux cre

dentium christe redemptor omnium ex

VI.

flore quia cito veniet salus tu a. Dil.

In laud. Anti. **A**lleluia. ps. Misere mei. R. m.

Quem ad liberandum nos. Domine

deus virtutum. **E**t ostende faciem

tuam et salui erimus. Domine. **V.**

Splendor paterne. **V.** E mitte agnū domine dominatorem terre. De petra deserti ad montem filie syon. **Ad benedictus Antiphona.**

Spiritus sanctus in te descendet ma

ria ne ti meas habebis in utero filius

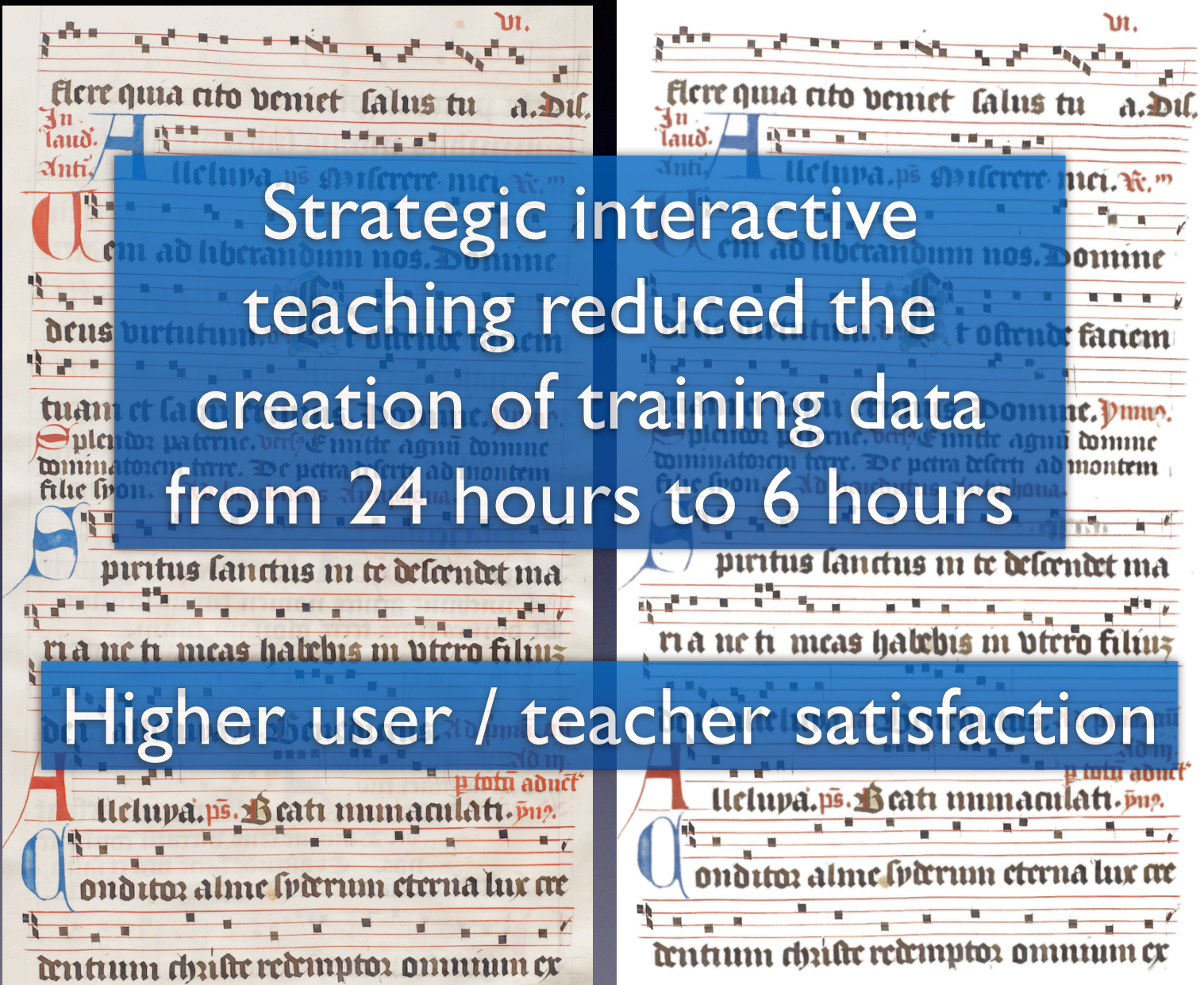
dei alleluia. **Benedictus.** **Ad p̄mā. aū**

Alleluia. ps. Beati immaculati. **p̄m.**

Quonditor alme syderum eterna lux cre

dentium christe redemptor omnium ex

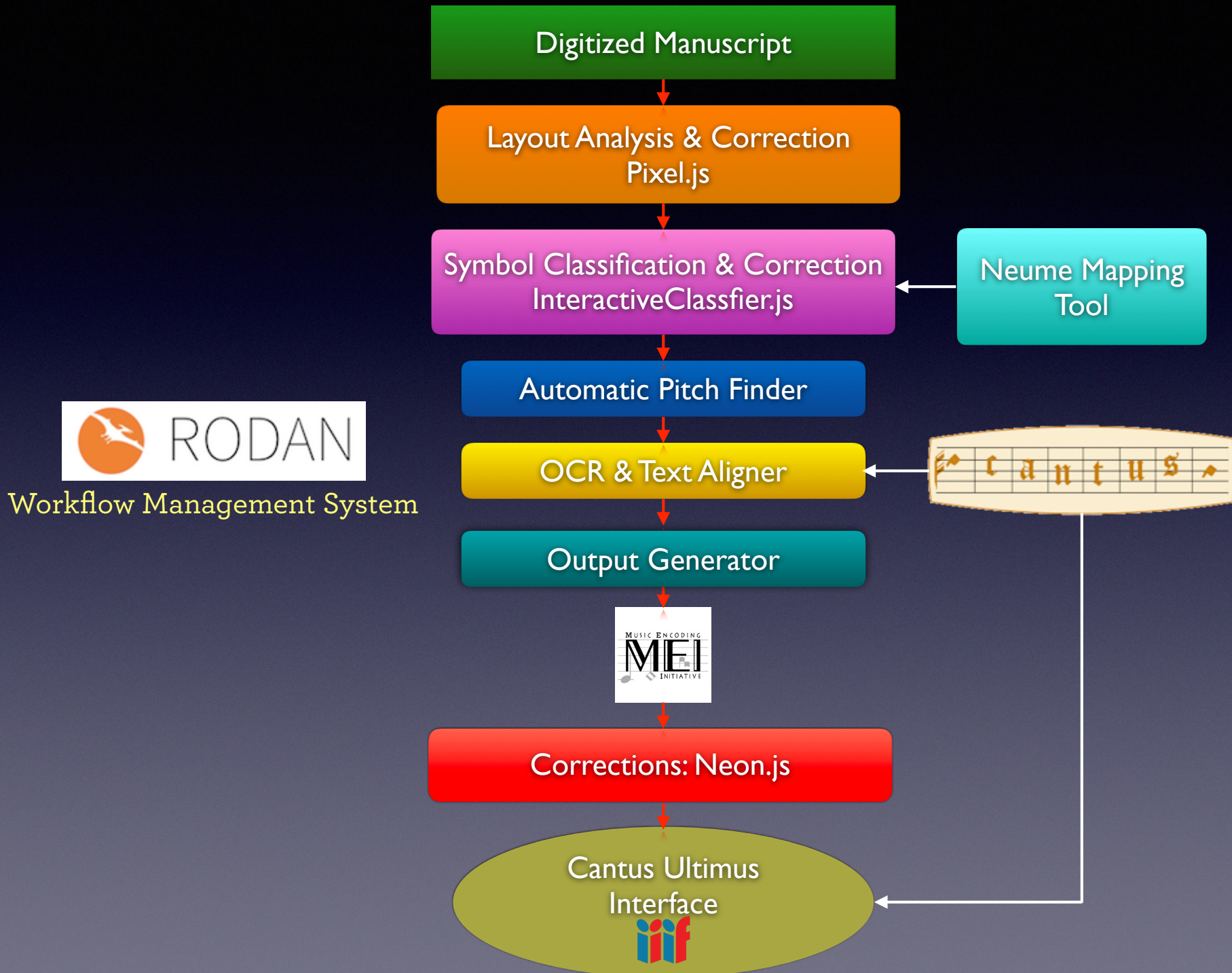
Results with a New Page



Strategic interactive
teaching reduced the
creation of training data
from 24 hours to 6 hours

Higher user / teacher satisfaction

SIMMSA Workflow for Neume Notation






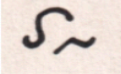
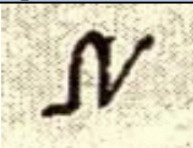
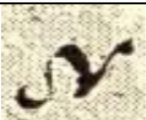
Minh Anh Nguyen





- ❖ The Music Encoding Initiative (MEI) is a community-driven effort to define a system for encoding musical documents in a machine-readable file format (XML).
- ❖ In development since 1999.
- ❖ MEI is based on Text Encoding Initiative (TEI).
- ❖ MEI is an alternative to MusicXML.

Neume Mapping Table to MEI

		Torculus 3		
3 pitches: n-h-l				
	21,5 (10r) plenitudine m	Torculus	neume.torculus	<pre><neume> <nc tilt= "e" /> <nc angled= "true" tilt= "n" intm= "u" /> <nc tilt= "se" intm= "d" /> </neume></pre>
	21,5 (10r) tua	Torculus	neume.torculus	<pre><neume> <nc curve= "a" /> <nc tilt= "nw" intm= "u" /> <nc curve= "c" intm= "d" /> </neume></pre>
	21,5 (10r) et	Torculus melodic	neume.torculus	<pre><neume> <nc tilt= "e" /> <nc angled= "true" tilt= "n" intm= "u" /> <nc tilt= "se" intm= "d" rel_len= "1" /> </neume></pre>
		Torculus	neume.torculus	<pre><neume> <nc curve= "a" /> <nc tilt= "n" intm= "u" curve= "c" /> <nc con= "g" tilt= "ne" angled= true" intm= "d" /> </neume></pre>
		Torculus resupinus 4		
4 pitches: n-h-l-h				
	21,12 (10r) nostrum	Torculus resupinus	neume.torculus_resupinus	<pre><neume> <nc tilt= "e" /> <nc tilt= "n" angled= "true" intm= "u" /> <nc tilt= "s" intm= "d" /> <nc angled= "true" tilt= "ne" intm= "u" /> </neume></pre>
	22,13 (10v) tribuisti	Torculus resupinus	neume.torculus_resupinus	<pre><neume> <nc curve= "a" /> <nc tilt= "n" intm= "u" /> <nc tilt= "se" intm= "d" /> <nc angled= "true" tilt= "ne" intm= "u" /> </neume></pre>

Neume Mapping Tool

Imane Chafi

[Home](#) [New neume](#) [About us](#) [Contact](#) [Help](#) [Log-out](#) [User1](#)

Punctum

Images:



Name:

Punctum

Folio:

1/r9

Description:

Punctum

Classification:

neume.punctum

Update

Delete

Mei Snippet:

```
1 //mei snippet for neume.punctum
2 <neume>
3 <nc>
4 </neume>
```

Pes

Images:



Name:

Pes

Folio:

1r/3, 1r/5

Description:

Classification:

neume.pes.b.3

Update

Delete

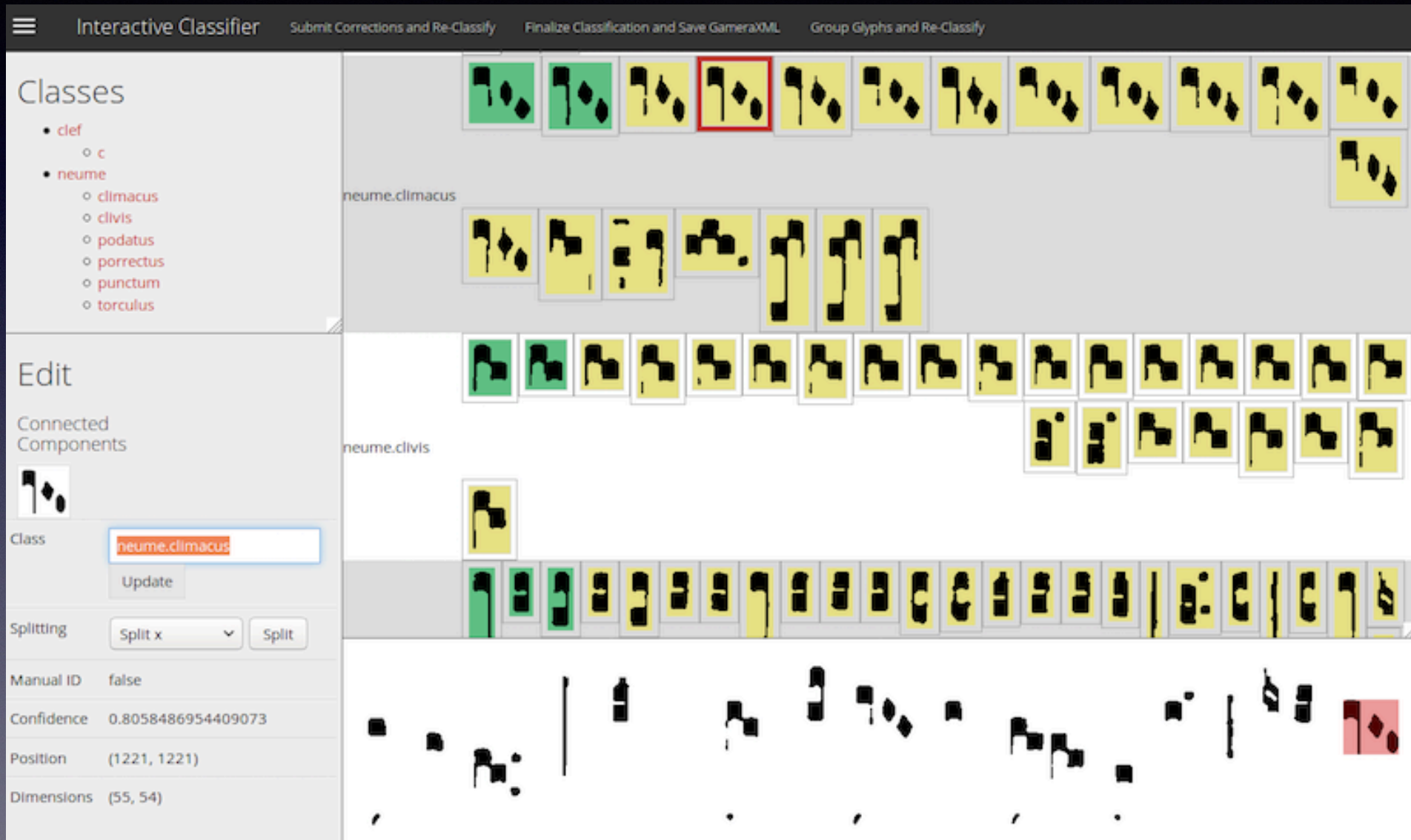
Mei Snippet:

```
1 //mei snippet for neume.pes.b.3
2 <neume>
3 <nc/>
4 <nc intm = "25"/>
5 </neume> <|
6
```

element parse error: Error: invalid tagName:

InteractiveClassifier.js (K-NN)

Minh Anh Nguyen



Interactive Classifier

Submit Corrections and Re-Classify

Finalize Classification and Save GameraXML

Group Glyphs and Re-Classify

Classes

- def
 - c
- neume
 - climacus
 - clivis
 - podatus
 - porrectus
 - punctum
 - torculus

Edit

Connected Components

Class

neume.climacus

Update

Splitting

Split x

Split

Manual ID

false

Confidence

0.8058486954409073

Position

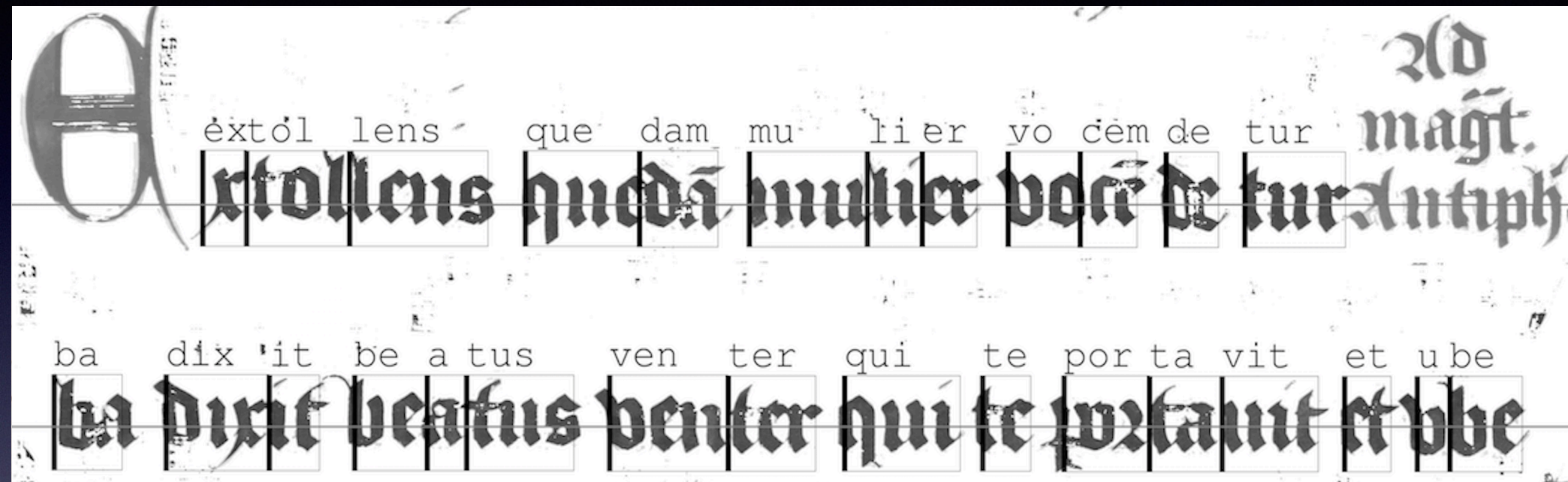
(1221, 1221)

Dimensions

(55, 54)

OCR & Text Aligner

Timothy de Reuse



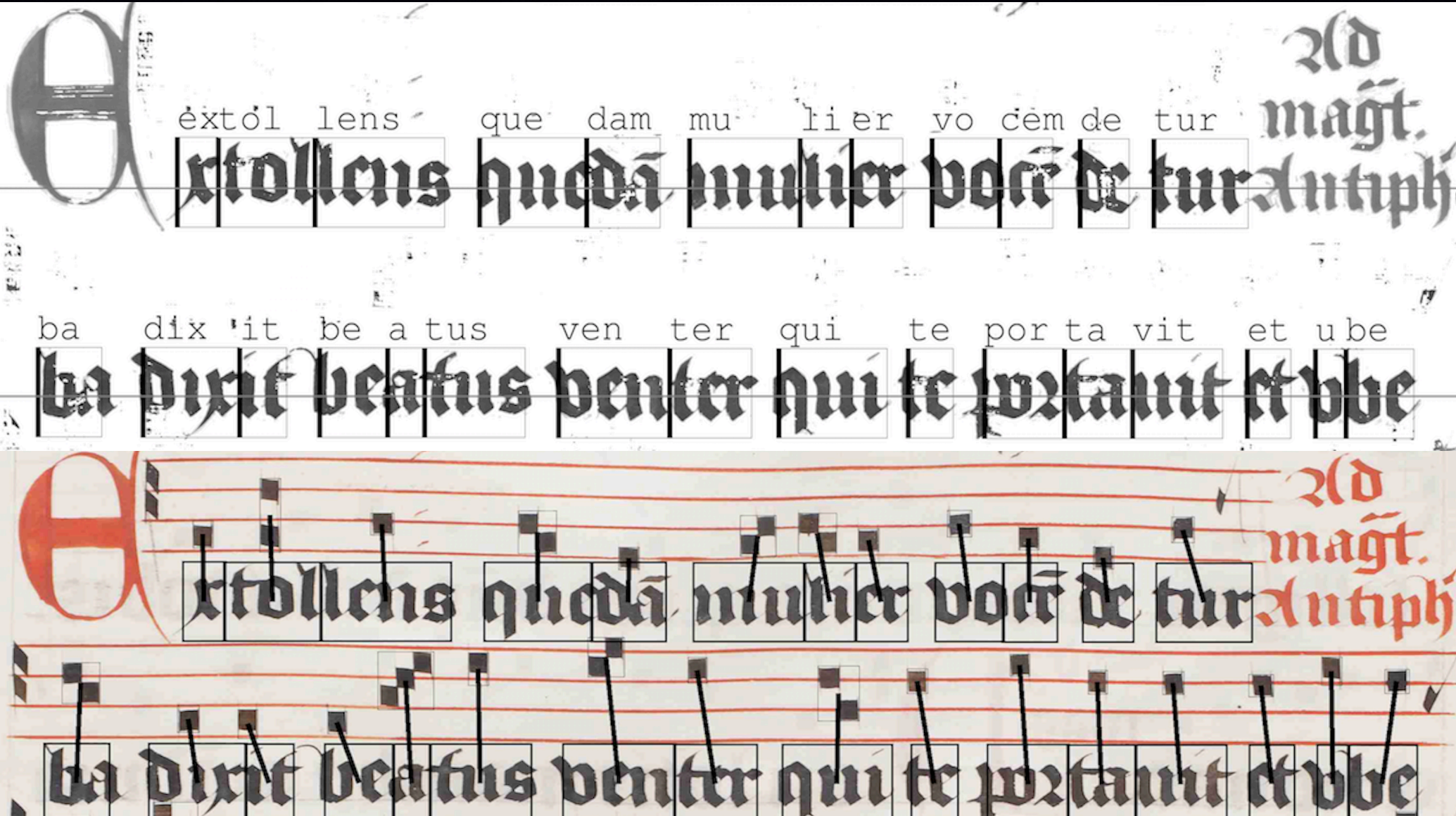
From Cantus Database

Extollens quaedam mulier vocem de tur-
ba dixit beatus venter qui te portavit et ube...

- ❖ OCR used: OCRopus (recurrent neural network: LSTM)
- ❖ Sequence alignment: Needleman-Wunsch algorithm

OCR & Text Aligner

Timothy de Reuse



extollens quendam mulier vocat de tur Antiph

ba dixit beatus venter qui te portavit et ube


Neume Editor ONline: Neon.js

Juliette Regimbal

The screenshot displays the Neon.js Neume Editor interface. The main window shows a manuscript page titled "Salzinnes, CDN-Hsmu M2149.L4" with the text "omnis homo quia et ce" and "et. Et t prepara bi tur in mi". The manuscript is overlaid with a digital neume editor interface. The neumes are represented by colored squares (yellow, blue, red, green, orange, pink) and black lines on a five-line staff. The text is in a Gothic script. The interface includes a menu bar (Neon, File), a search bar, a zoom level (5), and a folio number (011r). On the right, there is a control panel with sections for Display (Glyph Opacity, Image Opacity), Display Text (Display Info, Highlight - Syllable), MEI Status (VALID), Insert (Neume, Grouping, Clef, System), Edit (Select By: Syllable, Neume, Neume Component, Staff), and Undo/Redo buttons.

Neon: Neume Editor ONline

Juliette Regimbal, Caitlin Hutnyk, Gaby Halpin, Yinan Zhou



DISPLAY

Zoom 115

Glyph Opacity 100

Image Opacity 100

Display Options:

Highlight- Neume ▼

Text ☒ BBoxes ☒ Info ☐

INSERT

Primitive Elements Grouping System

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EDIT

Syllables on this page

◊ spi ci ens a lon ge ec ce vi de o dei po ten ti
am ve ni en tem et ne bu lam to tam ter ram gen
tem te ob vi am ei et di ci te nun ci no bis si tu
es ip se qui reg na tu rus es in po pu

Neon.js: Text Editing

Caitlin Hutnyk



Display

Zoom

Glyph Opacity

Image Opacity

Display Text: ☒

Display BBoxes: ☒

Display Info: ☐

Highlight - Syllable

MEI Status: VALID

Insert

Neume

Grouping

Clef

System

■

┐

◆

└

Edit

Select

By:

Syllable

Neume

Neume Component

Staff

Ungroup

Delete

Undo

Redo

Egre di tur do mi nus de sa ma ri a ad por tam qu res pi cit le em ad o ri en ten et ve ni et in beth le em am bu lans su per a quas re dem ptio nis u de tunc sal ce vus e rit Et nis ho mo qui a ec ce ve ni et Et pre pa ra bi tur in mi se ri cor di so li um e i et se de bit su per il

SIMSSA | Single Interface for Music
Score Searching and Analysis

OMR Fujinaga

DDMAL | DISTRIBUTED DIGITAL MUSIC
ARCHIVES & LIBRARIES LAB

90 / 97

Cantus Ultimus Interface

cantus.simssa.ca/manuscript/133/?folio=002r&chant=1

Cantus Ultimus › Salzinnes, CDN-Hsmu M2149.L4

About Activities Team Manuscripts Search

Zoom level: 2

Folio 002r (3 of 479)

Go

Manuscript info

Previous Folio Next Folio

Folio 002r

Search Manuscript


Chants

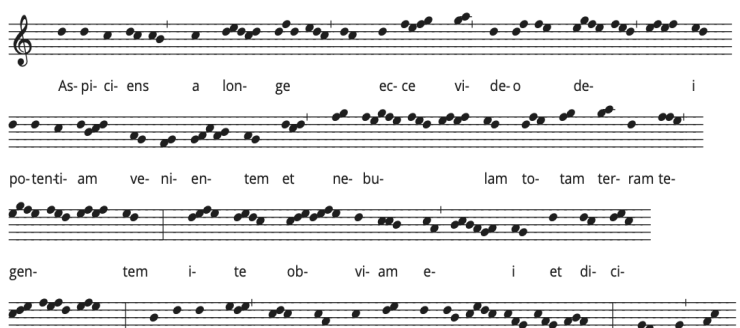
Aspiciens a longe ecce video

Cantus ID: 006129
Sequence: 1
Feast: Dom. 1 Adventus
Office: Matins
Genre: Responsory
Mode: 7

Full Text

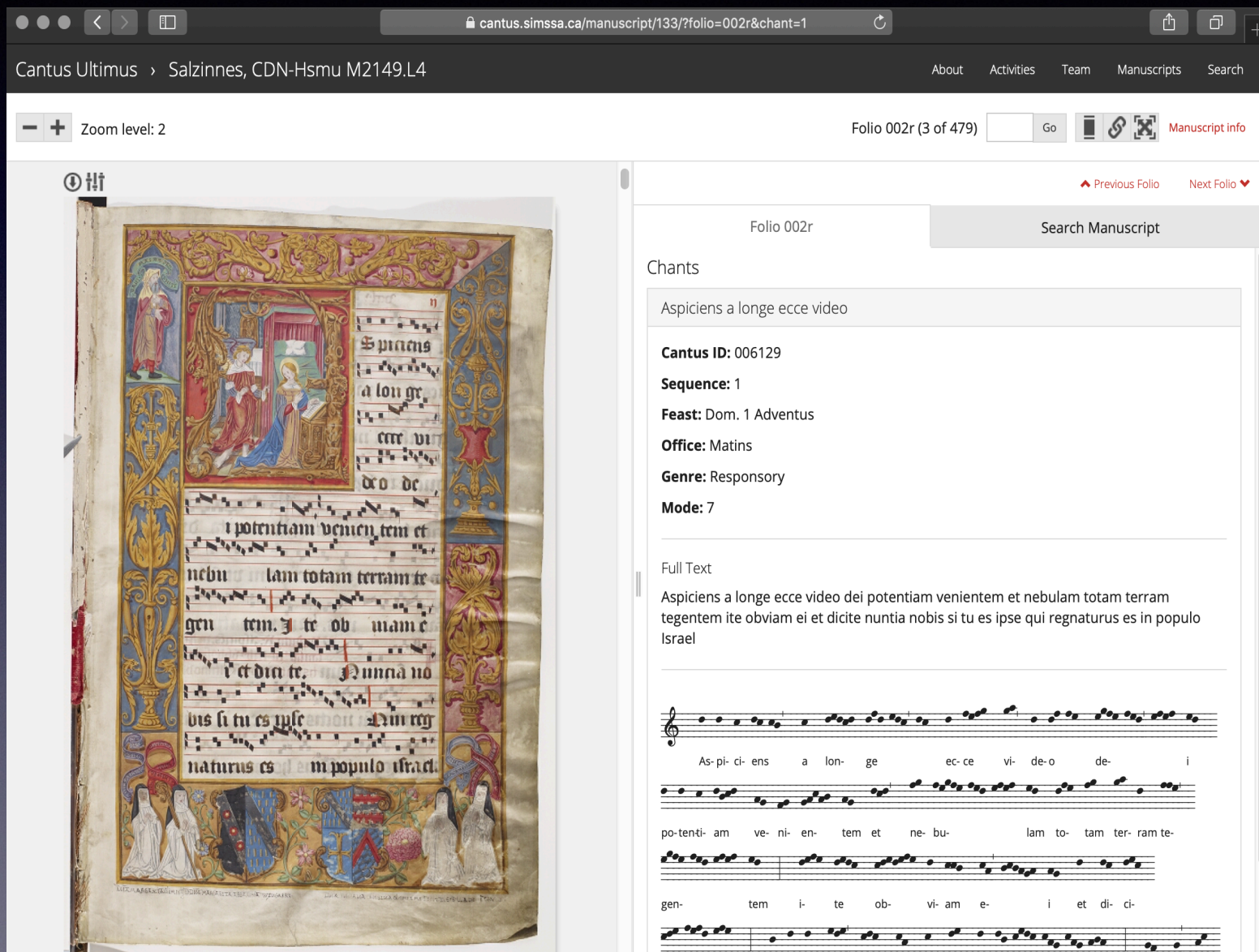
Aspiciens a longe ecce video dei potentiam venientem et nebulam totam terram tegentem ite obviam ei et dicite nuntia nobis si tu es ipse qui regnaturus es in populo Israel





Cantus Ultimus Interface

Andrew Fogarty, William Bain, Néstor Nápoles, Dylan Hillerbrand



The screenshot displays the Cantus Ultimus web interface. The browser address bar shows the URL: cantus.simssa.ca/manuscript/133/?folio=002r&chant=1. The page title is "Cantus Ultimus > Salzinnes, CDN-Hsmu M2149.L4". The interface includes a navigation bar with links: About, Activities, Team, Manuscripts, and Search. Below the navigation bar, there is a zoom control set to "Zoom level: 2" and a folio indicator showing "Folio 002r (3 of 479)".

The main content area is split into two panels. The left panel shows a high-resolution image of a manuscript page (Folio 002r) with a large, ornate initial 'S' and a miniature of a figure in a landscape. The right panel displays the digital transcription of the manuscript page. It includes a search bar labeled "Search Manuscript" and a "Chants" section with the following details:

- Aspiciens a longe ecce video
- Cantus ID: 006129
- Sequence: 1
- Feast: Dom. 1 Adventus
- Office: Matins
- Genre: Responsory
- Mode: 7

Below the chant details, there is a "Full Text" section with the Latin text: "Aspiciens a longe ecce video dei potentiam venientem et nebulam totam terram tegentem ite obviam ei et dicite nuntia nobis si tu es ipse qui regnaturus es in populo Israel". The text is accompanied by a musical score with notes and lyrics.

Neume search in Cantus Ultimus

cantus.archive.simssa.ca/manuscript/133?folio=016r&search%5Btype%5D=ne

≡ Cantus Ultimus > Salzinnes, CDN-Hsmu M2149.L4

− + Zoom level: 3.00
 Folio 016r (31 of 479)
Go
📄 🔗 🖨
Manuscript info

⬆ Previous Folio
Next Folio ⬆

Folio 016r
Search Manuscript

Neume ▾

Search

Neume search

29 results for query "clivis clivis punctum torculus"

Folio	Neumes	Pitches	Contour
016r		a g f e b d e d	
024r		b a g d a c d c	
034v		b a b g c e f e	

Summary

“A Retrospective on Optical Music Recognition Research”

- ❖ Early developments
- ❖ OMR Thesis
- ❖ Gamera
- ❖ SIMSSA (Single Interface for Music Score Searching and Analysis)
- ❖ Cantus Ultimus

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Cantus Ultimus: cantus.simssa.ca/manuscripts

Project page: simssa.ca

Github sources: github.com/DDMAL

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Canada



McGill



Schulich School of Music
École de musique Schulich

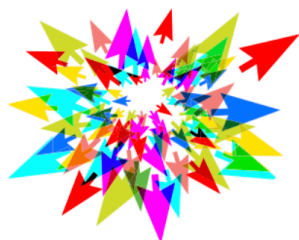


Centre for Interdisciplinary Research
in Music Media and Technology



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