Utrecht University

DISTINGUISHED LECTURE SERIES IN MUSIC AND DIGITAL HUMANITIES

Musicology and computing

A very short history

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Abstract

I have spent most of my professional life working in the exciting interdisciplinary area between musicology and computing known (among others) as computing in musicology, computational musicology, digital musicology, or music information computing. Each of these terms suggests a different focus, but they also indicate that the field hasn't quite settled, despite its over 70 years of existence. Musicological computing (to use yet another expression) has much in common with other forms of humanities computing, except for one thing: the processing of musical information, in the form of music notation and musical audio. This will be also be the main focus of my talk.

The first, promising experiments in music processing date from the 1950s. The 1960s and 1970s witnessed a period of grand ambitions for computer-supported inventorying, publication, and analysis of musical heritage. In practice, however, the need for technological groundwork was so strong that these ambitions could only be realised to a limited extent, if at all. Furthermore, both computer science and musicology experienced a paradigm shift in 1980s. Consequently, computational musicology, with its ‘scientific’ nature, became largely separated from mainstream musicology.

Soon, however, new connections were formed, first with cognitive science and linguistics, and, then from the late 1990s onwards, with the emerging field of music information retrieval (MIR). While computational musicology initially played a strong role in MIR, attention soon shifted towards applications for the music industry and consumers. The good news was that finally, due to such commercial interests, solutions came within reach that could address the complexities of musical content that computational musicologists had long struggled with. In practice, however, numerous technologies were proposed that were rarely evaluated in terms of their utility for music research, even when they were supposedly designed for musicological clients. Often, such technologies had only little impact on musicology.

Since around 2015, this landscape has changed again for a variety of reasons, including the ready availability of digital resources, access to (free or cheap) software, mobile internet, online communication, and finally the pandemic. Doing musicology in the digital environment has become commonplace. Nevertheless, considerable problems remain with the acceptance of specialised, more advanced technology. Key issues include the match with musicological research problems, the costs of mastering technologies, and the availability of resources. Creating more powerful, technologies is not always the answer: the focus should instead be on making them useful, accessible, and acceptable.

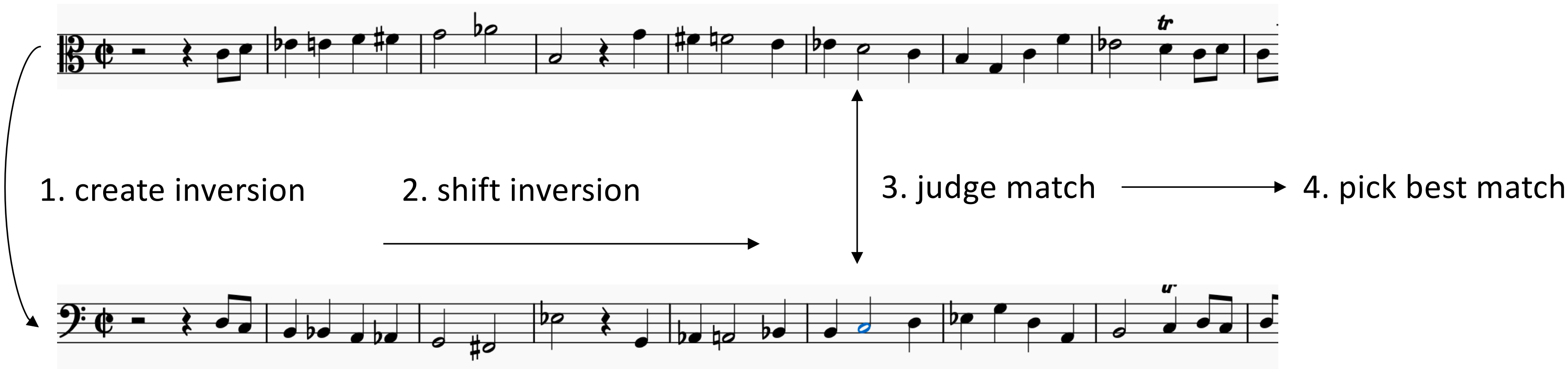
Prologue: a voice from the past, Logemann (1967)

- problem: finding solutions for the canons from Bach's *Musikalisches Opfer* (1747)
- illustrative of many of the characteristics of musicological computing over time

- very detailed discussion of the canon *Quaerendo invenietis*:

- inversion is given (upside down F-clef)
- task is to find its entry point

Human process



Logemann’s (plausible) modelling decisions:

- use quarter notes (crotchets) as basic units
- judge match by *harmonicity*, effectively (3rds + 6ths) – (2nds + 7ths)

Getting the notes into the computer

create reduction

encode on punch cards

D′- D′ E′ E′+ F′ F′ G′- G′- A A R F′
E′+ E′ E′ D′ D′- C′ C′ B A F B E′ D′- D′- C′ B
B A′- F′ D′- E′ E′ C′ E′ D′- G E+ F A C′ E′ D′-
D′- B C′ B B C′ F F E E R E+ R A R B $

convert to numeric representation

3	4	5	6
7	7	8	8
−1	−1	300	7
6	5	5	4
3	2	2	0
−1	−5	0	5
3	3	2	0
0	10	7	3
5	5	2	5
3	−3	−6	−5
−1	2	5	3
3	0	2	0
0	2	−5	−5
−7	−7	300	−6
300	−1	300	0

encoding and representation

- encoding for data entry and storage
- internal representation for processing
- representation by chromatic pitch numbers, 0 = middle C
- 300 = rest

Creating inversion and calculating intervals between voices

3	4	5	6
7	7	8	8
-1	-1	300	7
6	5	5	4
3	2	2	0
-1	-5	0	5
3	3	2	0
0	10	7	3
5	5	2	5
3	-3	-6	-5
-1	2	5	3
3	0	2	0
0	2	-5	-5
-7	-7	300	-6
300	-1	300	0

inversion = –1 * pitch – 10

interval = | pitch1 – pitch2 |

interval = | 0 – (–10) | = 10 = minor 7th

-13	-14	-15	-16
-17	-17	-18	-18
-9	-9	300	-17
-16	-15	-15	-14
-13	-12	-12	-10
-9	-5	-10	-15
-13	-13	-12	-10
-10	-20	-17	-13
-15	-15	-12	-15
-13	-7	-4	-5
-9	-12	-15	-13
-13	-10	-12	-10
-10	-12	-5	-5
-3	-3	300	-4
300	-9	300	-10

intervals folded within the octave

Calculating harmonicity (Excel simulation)

timeshift:	0	total harmonicity	0
melody	canonvoice	interval	harmonicity
3	-13	4	1
4	-14	6	-1
5	-15	8	1
6	-16	10	-1
7	-17	0	0
7	-17	0	0
8	-18	2	-1
8	-18	2	-1
-1	-9	8	1
-1	-9	8	1
300	300	0	0
7	-17	0	0
6	-16	10	-1
5	-15	8	1
5	-15	8	1
4	-14	6	-1
3	-13	4	1
2	-12	2	-1
2	-12	2	-1
0	-10	10	-1
-1	-9	8	1
-5	-5	0	0
0	-10	10	-1
5	-15	8	1
3	-13	4	1
3	-13	4	1
2	-12	2	-1
0	-10	10	-1
0	-10	10	-1
10	-20	6	-1
7	-17	0	0
3	-13	4	1

timeshift:	1	total harmonicity	-1
melody	canonvoice	interval	harmonicity
3	-10	1	-1
4	-13	5	0
5	-14	7	0
6	-15	9	1
7	-16	11	-1
7	-17	0	0
8	-17	1	-1
8	-18	2	-1
-1	-18	5	0
-1	-9	8	1
300	-9	0	0
7	300	0	0
6	-17	11	-1
5	-16	9	1
5	-15	8	1
4	-15	7	0
3	-14	5	0
2	-13	3	1
2	-12	2	-1
0	-12	0	0
-1	-10	9	1
-5	-9	4	1
0	-5	5	0
5	-10	3	1
3	-15	6	-1
3	-13	4	1
2	-13	3	1
0	-12	0	0
0	-10	10	-1
10	-10	8	1
7	-20	3	1
3	-17	8	1

timeshift:	2	total harmonicity	-7
melody	canonvoice	interval	harmonicity
3	300	0	0
4	-10	2	-1
5	-13	6	-1
6	-14	8	1
7	-15	10	-1
7	-16	11	-1
8	-17	1	-1
8	-17	1	-1
-1	-18	5	0
-1	-18	5	0
300	-9	0	0
7	-9	4	1
6	300	0	0
5	-17	10	-1
5	-16	9	1
4	-15	7	0
3	-15	6	-1
2	-14	4	1
2	-13	3	1
0	-12	0	0
-1	-12	11	-1
-5	-10	5	0
0	-9	9	1
5	-5	10	-1
3	-10	1	-1
3	-15	6	-1
2	-13	3	1
0	-13	1	-1
0	-12	0	0
10	-10	8	1
7	-10	5	0
3	-20	11	-1

timeshift:	10	total harmonicity	28
melody	canonvoice	interval	harmonicity
3	-5	8	1
4	-5	9	1
5	-3	8	1
6	-3	9	1
7	300	0	0
7	-4	11	-1
8	300	0	0
8	-9	5	0
-1	300	0	0
-1	-10	9	1
300	-13	0	0
7	-14	9	1
6	-15	9	1
5	-16	9	1
5	-17	10	-1
4	-17	9	1
3	-18	9	1
2	-18	8	1
2	-9	11	-1
0	-9	9	1
-1	300	0	0
-5	-17	0	0
0	-16	4	1
5	-15	8	1
3	-15	6	-1
3	-14	5	0
2	-13	3	1
0	-12	0	0
0	-12	0	0
10	-10	8	1
7	-9	4	1
3	-5	8	1

shift inversion by quarter note

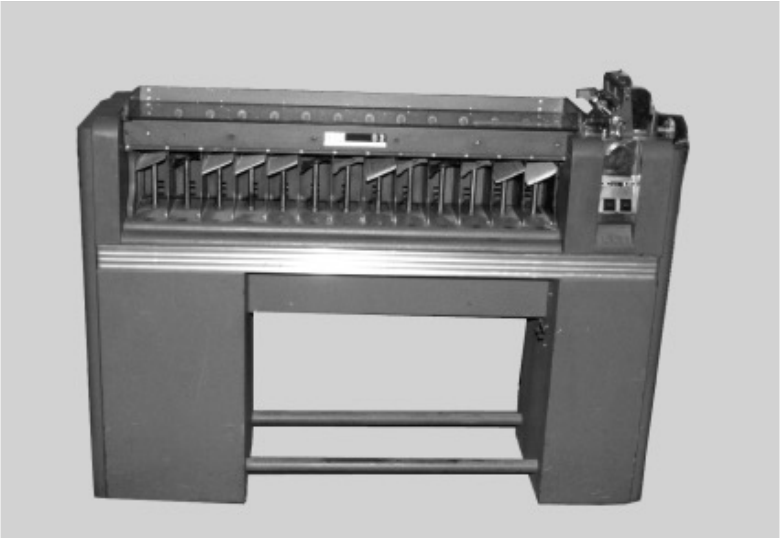
Outcomes

timeshift	harmonicity
0	0
1	-1
2	-7
3	-6
4	-1
5	2
6	-2
7	0
8	-12
9	-7
10	28
11	7
12	-8
13	-1
14	-3
15	3
16	-12
17	-11
18	4
19	14
20	14
21	3
22	-8
23	-13
24	6
25	10
26	-6
27	-3
28	-10
29	-4
30	20
31	-4
32	-10

sorting

timeshift	harmonicity
10	28
50	28
30	20
19	14
20	14
40	14
41	14
25	10
35	10
11	7
49	7
24	6
36	6
18	4
42	4
15	3
21	3
39	3
45	3
5	2
55	2
0	0
7	0
53	0
1	-1
4	-1
13	-1
47	-1
56	-1
59	-1
6	-2
54	-2
14	-3

- 2 best matches (10, 50)
- interesting, unknown match at 30
- similar findings for other canons



IBM card sorter model 082 (built c. 1966)

https://ub.fnwi.uva.nl/computermuseum/cardsorter.html

Next-to-maximal harmonicity

What makes this publication interesting (besides its age)?

clear description of the general process, in four main steps:

1. *representing* musical information, i.e. pitch by number
2. basic *processing*, e.g. calculating the match between 2 melodies
3. *integrating* results, i.e. sorting the matches
4. musicological *interpretation* of the outcomes, i.e. solving the canon

these steps represent fundamental aspects of (the history of) musicological computing, the last one arguably being the toughest

What else makes this publication interesting?

- illustrates focus on *processing of musical information*, specifically *music notation*
  - emphasises the importance of abstraction and formalisation
  - stepwise reduction to essential information only (i.e. pitch numbers)
- harmonicity defined such that it can be *calculated*
- reflects on the *limitations* of the method
  - on-the-beat notes only
  - harmonicity has no notion of harmonic progressions
- *generalises* to whole class of musicological problems
  - requires large number of encoded compositions
  - limited number of operations

What is this article best remembered for

The Canons in the Musical Offering of J. S. Bach:
An Example of Computational Musicology

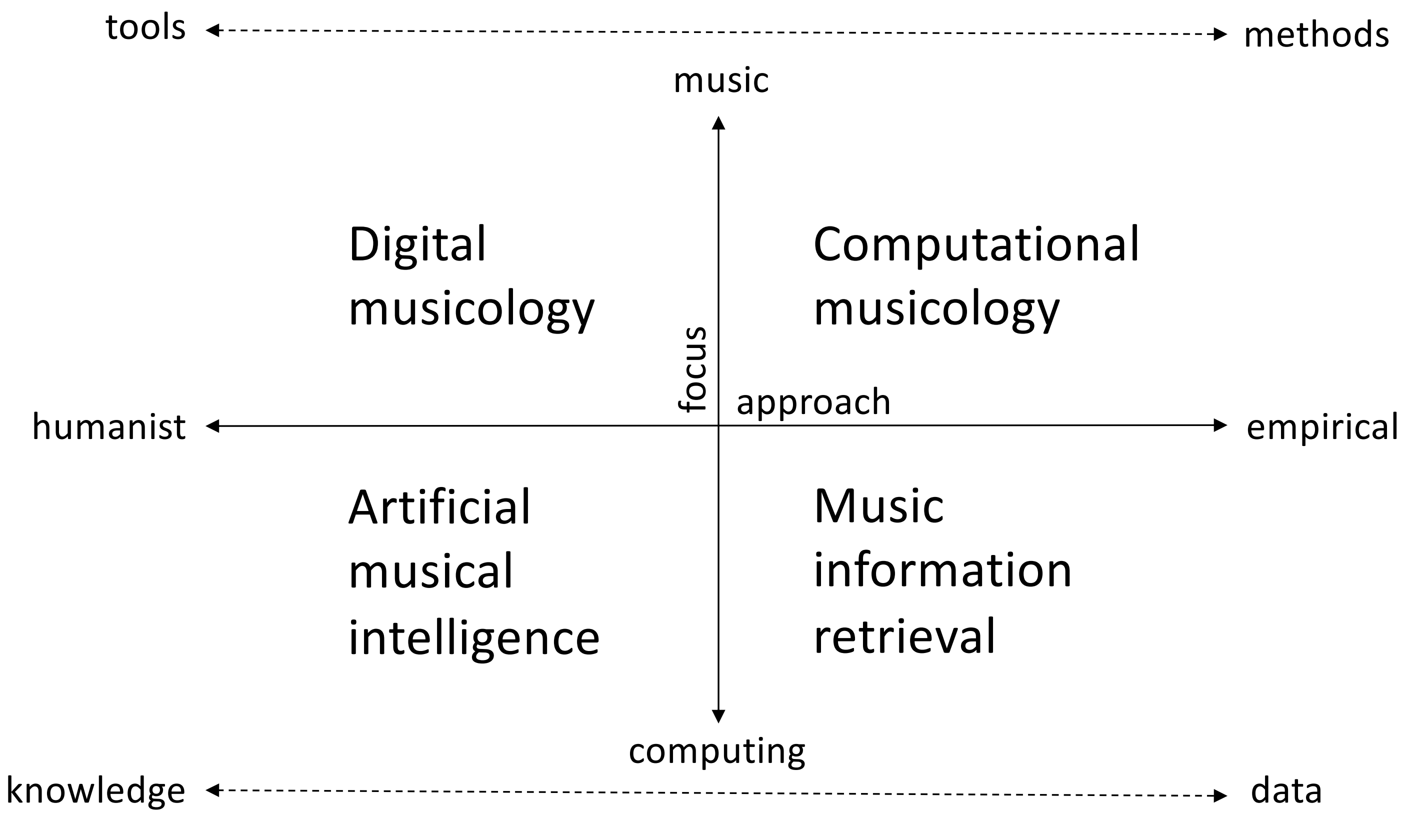
- first documented occurrence of the term ‘computational musicology’
- double irony:
  - Logemann was a computer scientist, not a musicologist
  - term only occurs in the title and remains undefined

implicit meaning:
study musicological problems by means of computational methods

Different names for musicology and computing

- *computational musicology:* study musicological problems by means of computational methods (Logemann 1967)
- *digital musicology:* do musicological work in the digital environment (c. 2005)
- *music information retrieval:* develop technologies for processing musical information (Kassler 1964)
- *artificial (musical) intelligence*: develop computational methods that emulate human (musical) intelligence (Roads 1980)
  - (will be less in evidence in my talk)

A (very!) tentative map of the musicology and computing area



Outline: historical development of musicological computing

1. prehistory (1949-1960)
2. heroic period (1960-1980)
3. crisis and recovery (1980-1995)
4. Internet and MIR (1995-2015)
5. musicology goes digital (2015-present)

strongest break between 2 and 3

Prehistory (1949-1960): scattered initiatives

cataloguing and metadata

- ‘mechanical help’ in folksong research: Bronson (1949)

automatic composition

- Illiac Suite, in 4 experiments (Hiller & Isaacson 1957)
- sometimes considered the first AI application in music

audio generation

- national anthems of UK and Netherlands were played on a Ferranti Mark 1 computer in the early 1950s (Ariza 2011)

https://www.youtube.com/watch?v=fojKZ1ymZlo

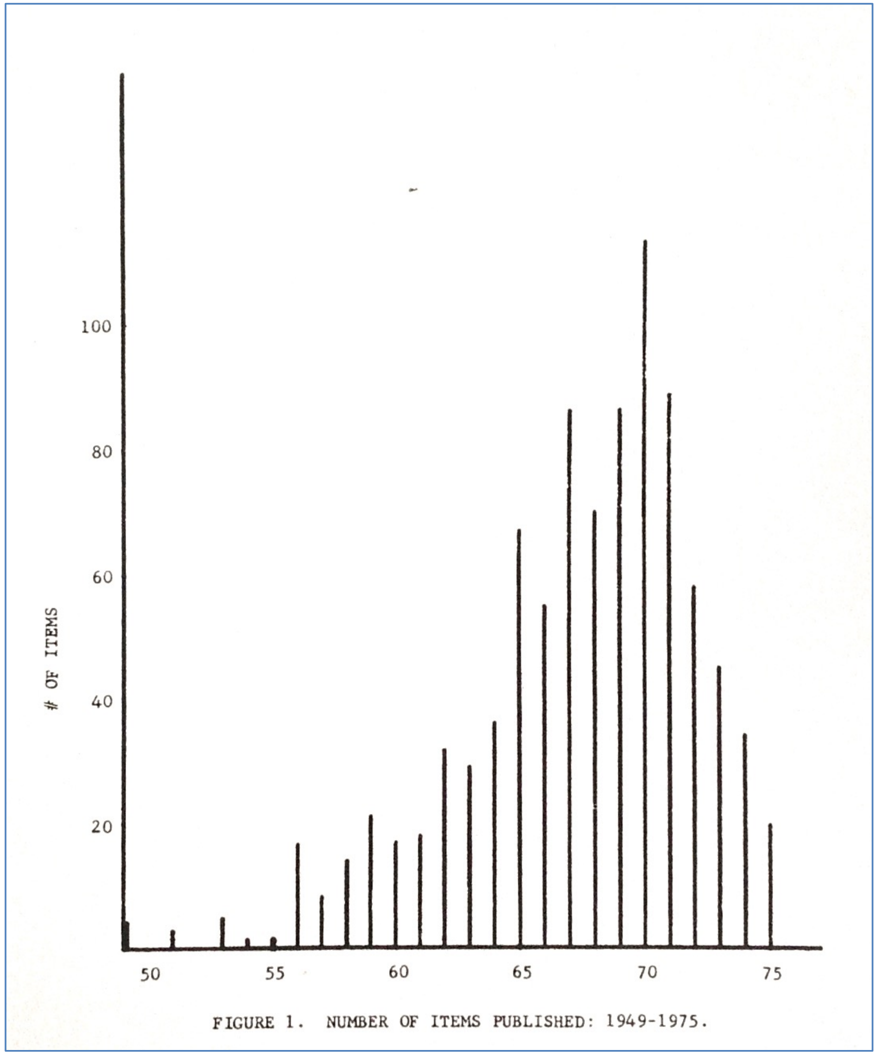
operating Mark 1 (Ariza 2011)

Heroic period (1960-1980)

from c. 1960 strong increase in publications, often displaying great ambitions

near-perfect match with musicological focus
- Western art music
- music notation
- source studies, editing, analysis

'algorithmic' approach to computing (cf. Logemann)
- formalisation, automatic processing
- central role of music encoding



bibliometric study by Pao (1982)

Arthur Mendel (1905-1979) a key figure of the heroic period

https://www.bach-cantatas.com/Bio/Mendel-Arthur.htm

- professor of music, Princeton University
- editorial boards of Neue Bachausgabe and New Josquin Edition
- views on on musicological method influenced by
  - revision of chronology of Bach's cantatas
  - the logical empiricism of Carl Hempel
- IMS keynote in 1961 outlines his positivist programme for musicology

the nature of historical inquiry is scientific (Mendel 1962, p. 13)

Nothing I have read in any of the attempts to prove the "historian's judgment" exempt from analysis by deductive reasoning seems to me any more successful than such attempts would be on behalf of the physician's art of diagnosis (p. 10)

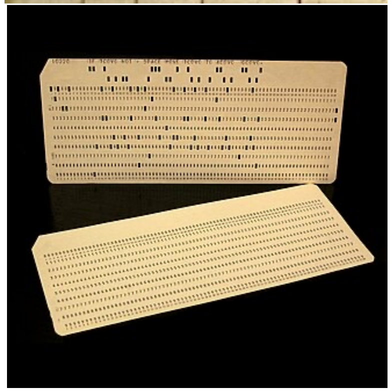
Princeton Josquin Project

Josquin Desprez (c. 1450-1521) was the first composer to be subjected to large-scale computational research

- maybe part of a (successful) attempt to turn him into a Renaissance genius (Higgins 2004)

project directed by Arthur Mendel and Lewis Lockwood

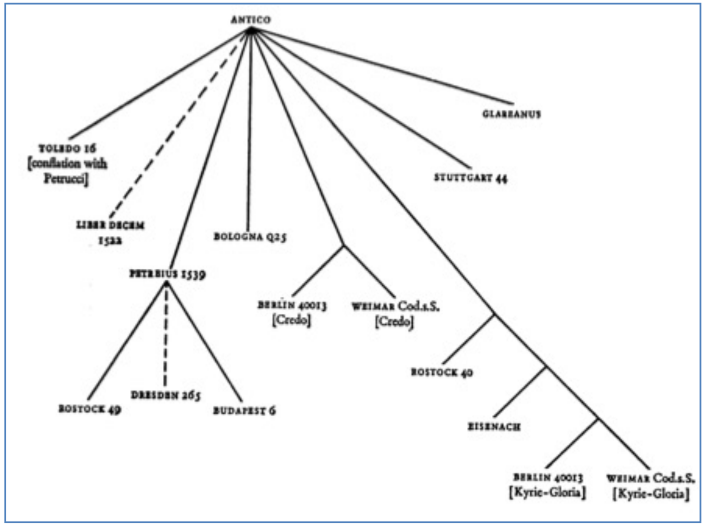
- most technical work probably done by Michael Kassler
- all (?) Josquin's works encoded in 1960s-70s
- punch cards, encoded in IML (Intermediate Music Language), later Fastcode



https://en.wikipedia.org/wiki/Punched_card#/media/File:2punchCards-square.jpg

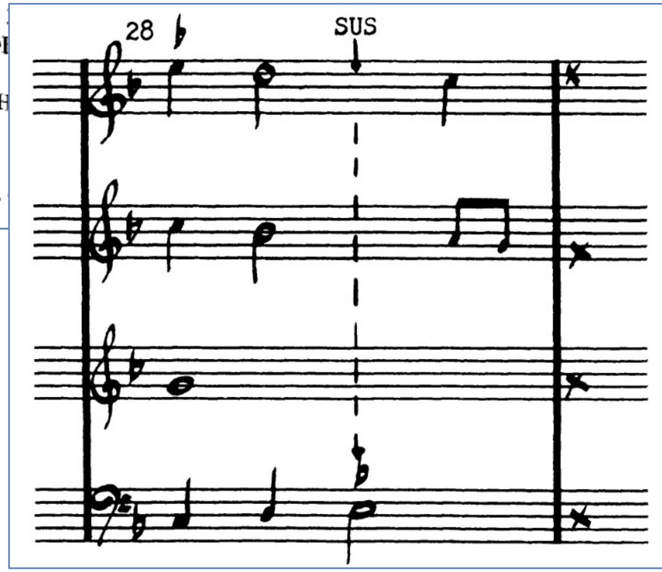
Some ambitions

- composer attribution (Mendel 1969)
- computational analysis of counterpoint (Patrick 1974)
- stemmatics (Hall 1975)
- computer-supported New Josquin Edition



MOVEMENT	A:3&6 &4&5	B:TRIADS & INVERSIONS	A/B
Kyrie 1	13	68	0.19
Christe	17	70	0.24
Kyrie 2	12	61	0.20
KYRIE	15	67	0.22
Gloria	24	56	0.43
Qui tollis	14	61	0.23
GLORIA	19	56	0.34
Credo	16	59	0.27
Et incarnatus	14	79	0.18
Et in spiritum	8	75	0.11
Confiteor	25	45	0.55
CREDO	15	66	0.23
Sanctus	31	49	0.63
Hosanna	14	60	0.23
SANCTUS	24	54	0.44
Agnus Dei 1	21	60	0.35
Agnus Dei			0.17
AGNUS DE			0.18
MISSA L'H			0.24

Fig.



The end...

personal matters

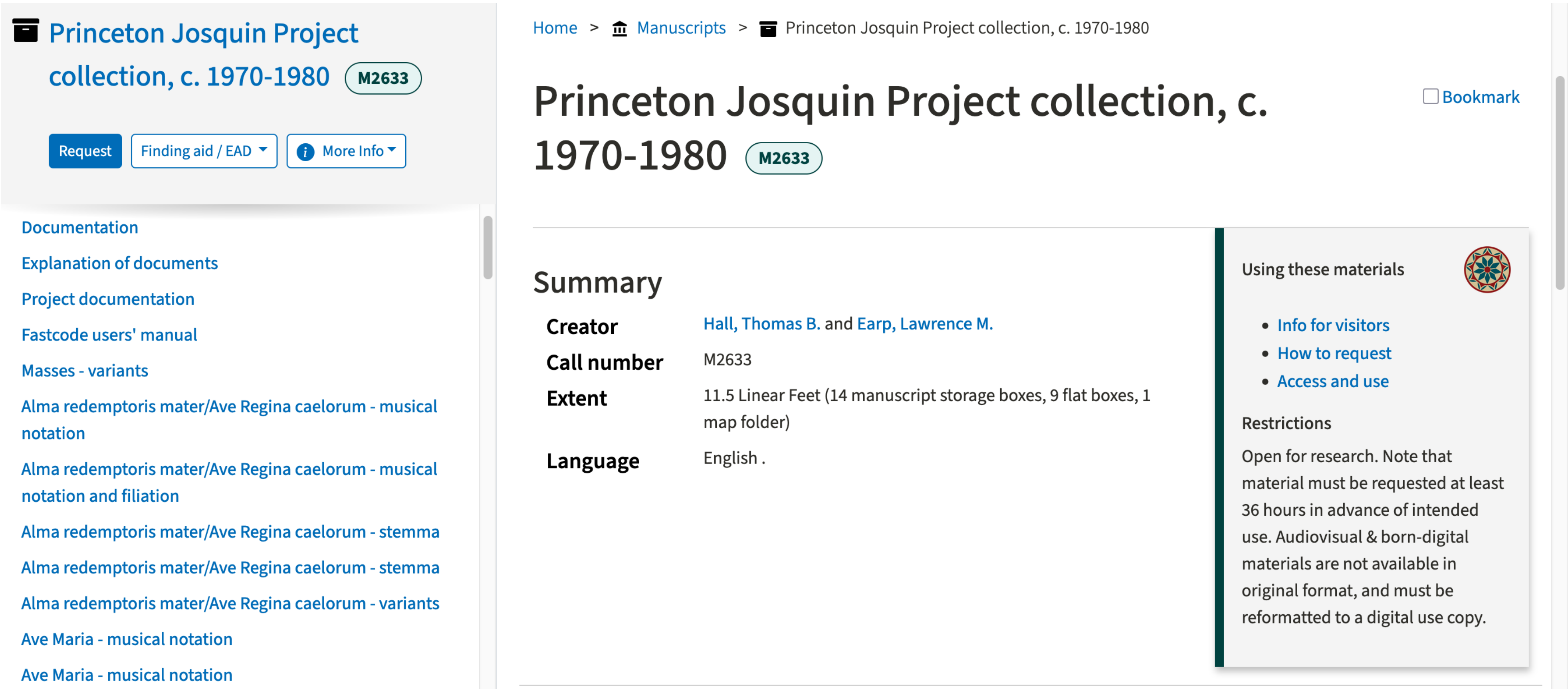
- Kassler 'in goverment service' already in 1969, migrated to Australia 1974
- Arthur Mendel retired in 1973, died in 1979
- Lewis Lockwood left Princeton in 1980 (where he researched Beethoven)

technical matters

- already in the late 1960s, there were migration issues
- hardware platform became obsolete around 1980
- most encodings have disappeared

computer-supported New Josquin Edition never happened

Some stuff has survived



much work archived at Stanford University: https://archives.stanford.edu/catalog/m2633

What else happened during the heroic period?

Panel *Current Advances in Computer Methods* (IMS Congress, Berkeley 1977)

- chaired by Stefan Bauer-Mengelberg
  - initiator of DARMS project (computational music publishing system)
- Thomas Hall on stemmatics
- Norbert Böker-Heil on melody classification as *‘Musikverstehen’*
- Hélène Charnassé on transcription of German lute tablature
- Warren E. Hultberg on transcribing vihuela tablatures, using DARMS
- Michael Kassler on ‘transferring tonal theory to a computer’
  - interactive, rule-based system, replicating the generation of a composition
  - resembles work in musical AI of the time (surveyed in Roads 1980)

full session in Bauer-Mengelberg et al. (1979)

DARMS project (1964 – 1980s)

- Digital Alternate Representation of Musical Scores
- encoding system created by
  - Stefan Bauer-Mengelberg (1927-1996): mathematician, lawyer, conductor
  - Melvin Ferentz (1928-2022): physicist, CUNY
  - (later) Raymond Erickson: music, CUNY
- ambitions
  - completeness (Erickson 1975)
  - formalisation
  - universality
- applications
  - high-quality music printing
  - music analysis

Raymond Erickson in 2025

https://www.bard.edu/conservatory/events/faculty-lecture-recital-raymond-erickson-piano

DARMS code

designed for musically untrained data typists

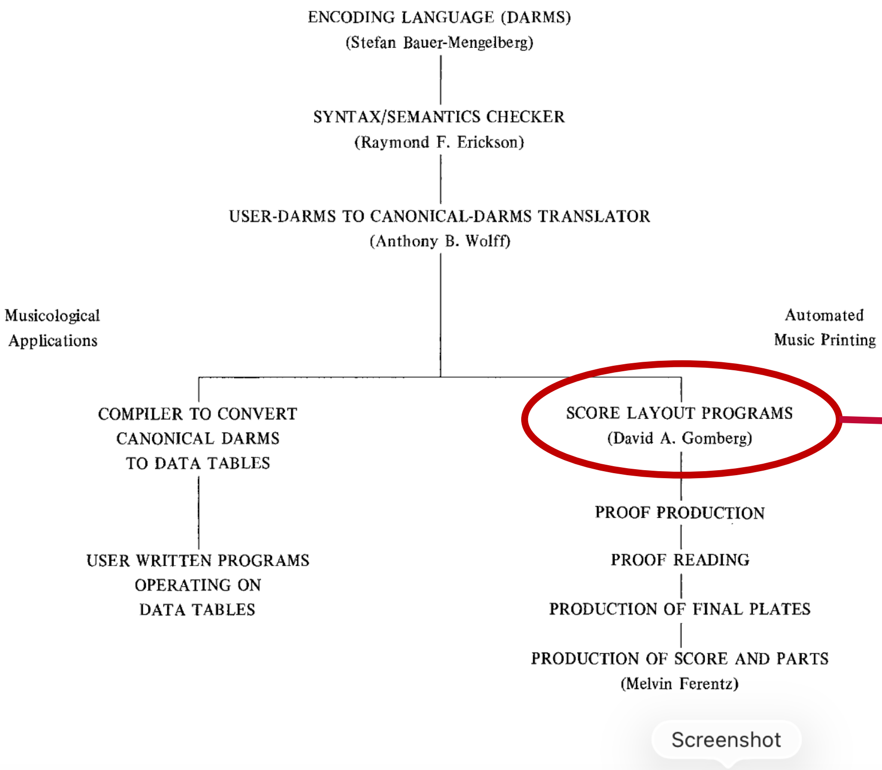
(4. (5)) ((3 0)) (8 (5 2)) (4 2 (5 (6 7 8)) 9)

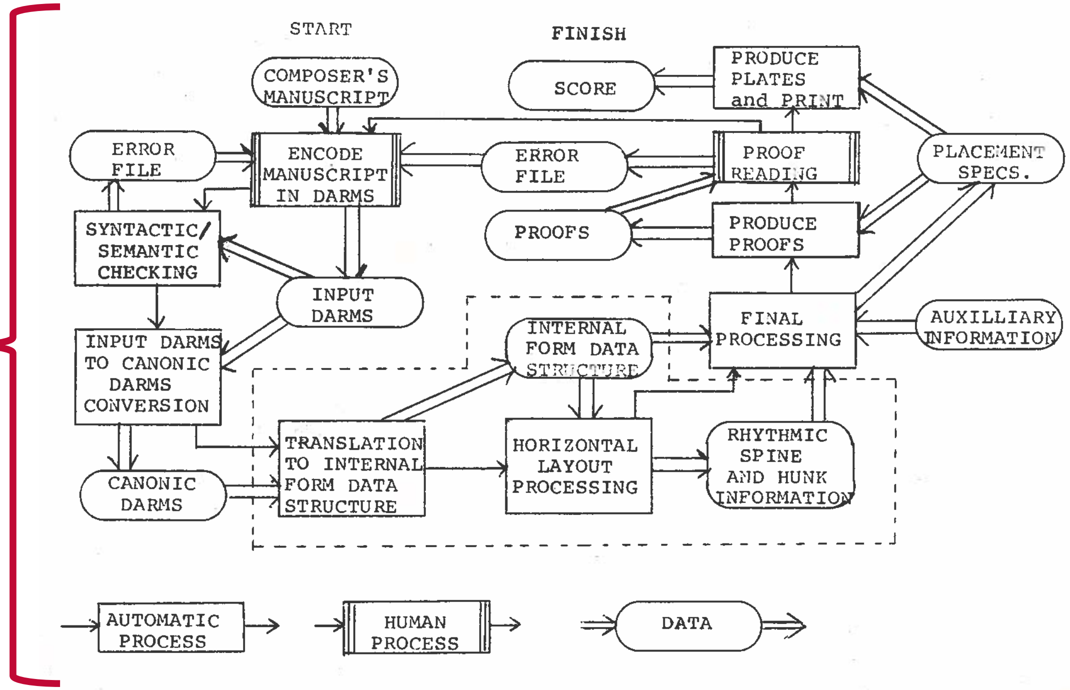
- simple codes are really simple
- codes can become *very* complex, for example for Bartók's String Quartet No. 4
- examples from Brinkman (1990)


```
I0  00@Allegro, QU = 110$
I1  !G  !M4:4  RQ  RE  9E_?V,VF  9#Q._  7#E_  /
I2  !G  !M4:4  1HJ,VF  E  1–E_  2QJ  /
I3  !C  !M4:4  RW  /  RW  /
I4  !F  !M4:4  RQ  17H_,VF  2Q_  /
I1  (8_  7*L  6)  (3L  1–)  REQ  /
I2  (2  1–_)  20–QL  18–E  REQ  /
I4  7#Q_  27!C  8Q_  33E_  REQ  /
I1  19Q._  18–E_  19#H  /  (19*L5,V<1  20  21–L6,V<2)  REH  /
      RH  ((2#L3  1#))  20#Q.J  /  EL4  1Q_  20#E_  1Q._  20E_  /
I2  RE  17E_  18*HJ  E  (18–JL5  /  18–,V<1)  18*QL6,V<2  REH  /
      RQE  ((2L1  1))  20HJ  /  EL2  Q.  19#E_  20Q.J  /
I3  RHE  3–E_,VF  (4–_  3*JL7,V<3)  /  3Q  18EL8,V<4  REH  /
      RE  (7*L1  6#  5#J)  HJ  /  EL2  5*EJ  H  6–E_  5EJ  /
I4  RW  /  RHQE  (9–L1  /  8  7J)  H.J  /  EL2  6–Q.J  E  7–_  6QJ  /
```


25

DARMS ambitions





High-level overview showing the relationship between the two ambitions (Erickson 1975)

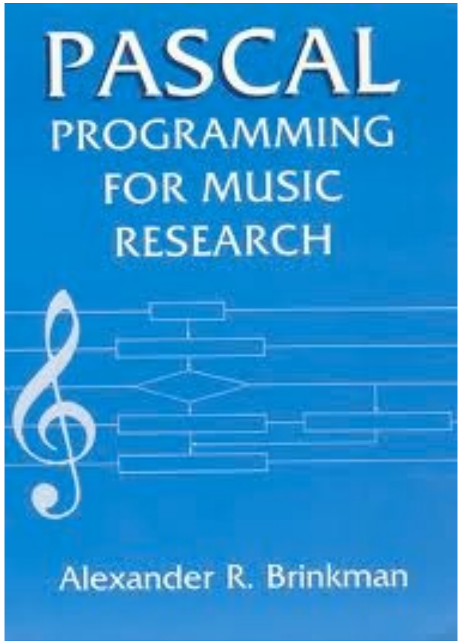
Workflow for music printing (Gomberg 1975). Note that only two human tasks are foreseen, data entry and proofreading

Fadeout, around 1990

code never finished, envisioned complete systems not realized

- complexity too high

- The Note Processor: music printing based on simplified DARMS dialect (mid 1980s, by Stephen Dydo)
- musicological applications
  - indexing 16th c. madrigal and motet prints (Lincoln 1988, 1993)
  - Pascal programs by Brinkman (1990): powerful internal representation, mainframe oriented



The heroic legacy

many projects met a similar fate to the Princeton Josquin Project

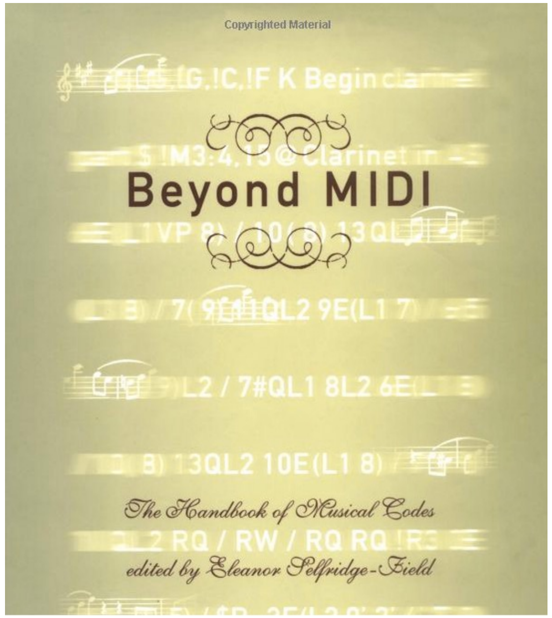
- in terms of data and software, nearly everything has disappeared

what has remained

- 'algorithmic' ethos of computational musicology
- focus on analysis of musical content
- numerous encoding systems (Selfridge-Field 1997)

some lessons from this period

- vulnerability of technology
- danger of being over-ambitious
- role of human circumstances



wonderful documentation of early encoding endeavours

But did all technology disappear?

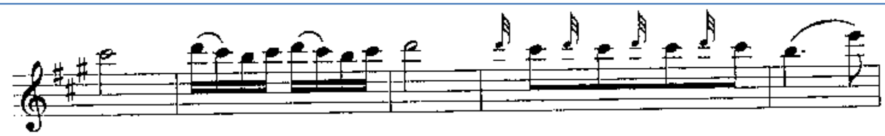
Plaine and Easie Code remains

- created for encoding music using a typewriter (!) in early 1960s (Brook et al. 1964)
- initially, extremely crappy

secret: part of a useful, realistic and acceptable scenario: source cataloguing

- encoding incipits for RISM A/II (manuscript sources)

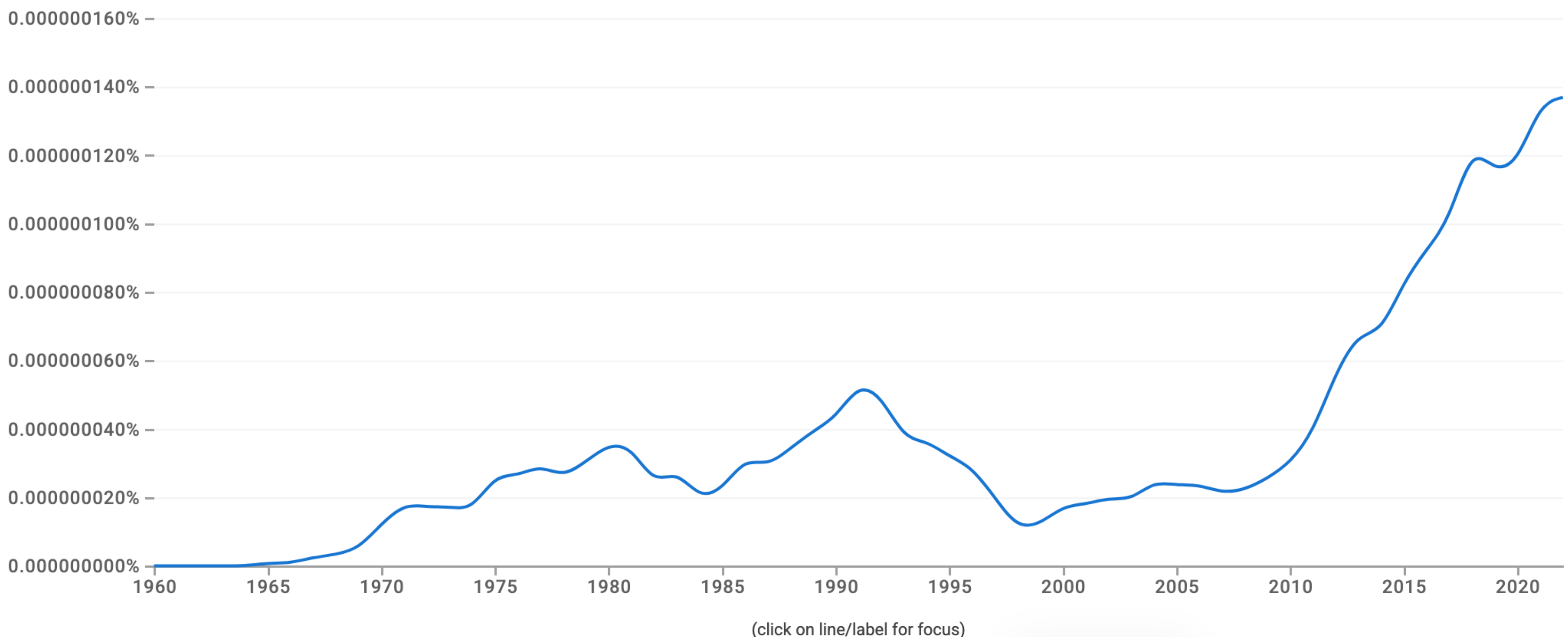
here is a lesson too!



```
112A     1.1.1
112B     pf.
112C     G-2
112D     xFCG
112E     2/4
112F     '''2C/!{y6DCz''B'''C}!f/2D/q3D{8Cq3D8Cq3D8Cq3D8C}/y'
         '4.B'''8Ez/
```

create stuff that people want to use

Crisis and recovery (1980-1995)



Google Books Ngram Viewer (computational musicology)

- dip in the early 1980s
- note the dip around 1998

Revolution in musicology

Joseph Kerman, *Contemplating music: Challenges to musicology* (1985)

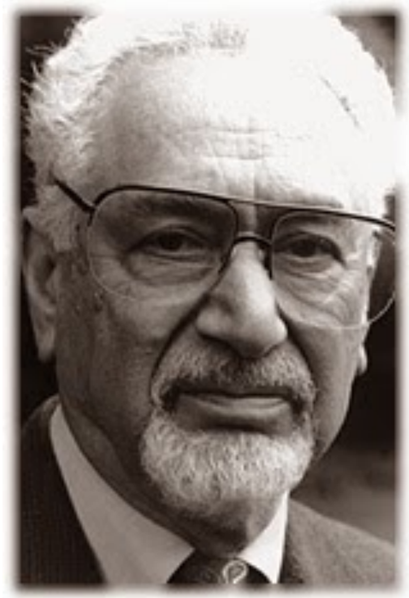
- demands central place for music criticism and aesthetics
- criticises musicological positivism

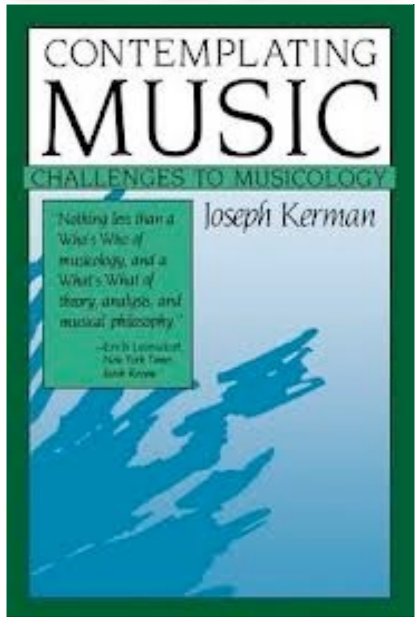
Kerman about Arthur Mendel's positivism:

> **The unhealthy influence of this doctrine, which puts quasi-scientific methodology first and assumes a methodological continuum in the treatment of all kinds of low- and high-level phenomena, can well be imagined (p. 58)**

one of the starting points of new / critical / cultural musicology

- little sympathy for work-centred approaches
- very bad news for computational musicology



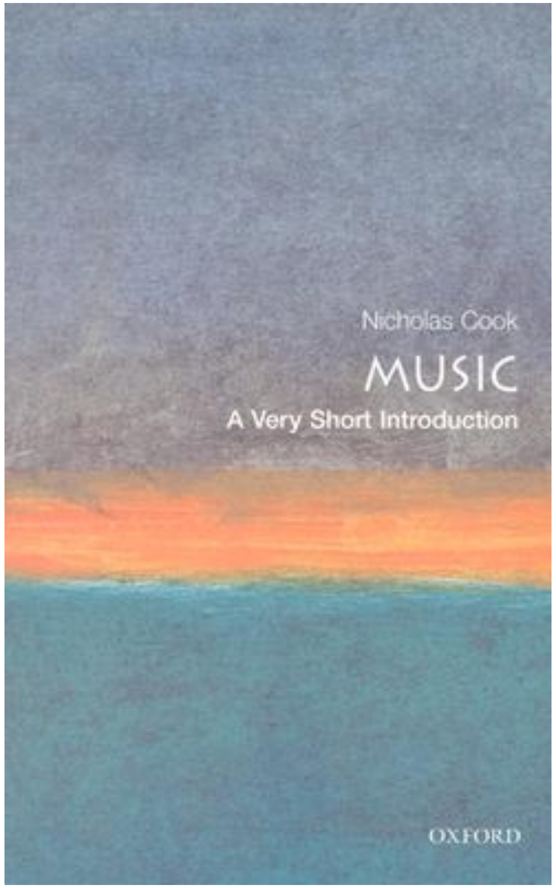


https://musicologynow.org/in-memoriam-joseph-kerman/

Musicology after Kerman

- Kerman's book was one of the starting points of new / critical / cultural musicology
- just a few important aspects
  - musical works not considered as autonomous objects
  - centrality of musical meaning and subjectivity
  - cricism of underlying ideologies
  - musal canon called into question

- it all happened for understandable reasons
  - see Nicholas Cook, *Music: A very short introduction* (1998)
    - second edition (2021) is *very* different
- but very bad news for computational musicology



Personal computers and consumer software

early 1980s witnessed a revolution in computing as well, the introduction of the personal computer

- mainframe-based systems quickly became a niche
- *interactive computing* emerged as a new paradigm

first interactive music printing prototype: Mockingbird

- Maxwell & Ornstein (1984)
- demo: https://www.youtube.com/watch?v=_Xu3r5lZds0

many commercial music printing programmes emerged

- very little attention to musicological needs
- emerging cottage industry of music encoding and editing

Mockingbird setup

Humdrum toolkit

created by David Huron (1954-2025)

- first music-analytical toolkit for end users (1986-89)
  - versatile encoding language
  - simple tools, chained for complex tasks
- systematic musicology important application area
- available at https://www.humdrum.org/

rather special ecosystem

- Unix flavour, command line processing
- significant amounts of data (https://kern.ccarh.org/)
- active community of users (in 2026)

https://en.wikipedia.org/wiki/David_Huron

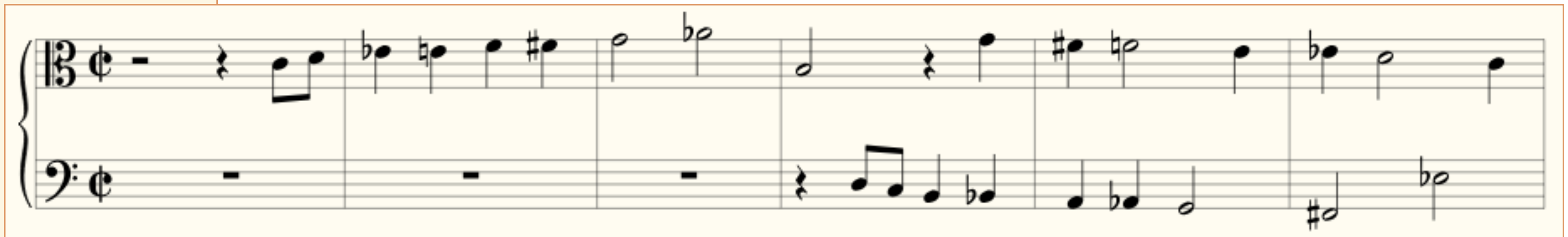
complete pipeline from data to research outcome

Humdrum encoding

```
!!!COM: Bach, Johann Sebastian
!!!OTL: Canon a 2 Quaerendo invenietis.
!!!SCT: BWV 1079
!!!filter: autobeam
**kern	**kern
*staff2	*staff1
*clefF4	*clefC3
*k[]	*k[]
*M4/4	*M4/4
*met(c|)	*met(c|)
=1-	=1-
1r	2r
.	4r
.	8c
.	8d
=2	=2
1r	4e-
.	4e
.	4f
.	4f#
=3	=3
1r	2g
.	2a-
=4	=4
4r	2B
8D	.
8C	.
4BB	4r
4BB-	4g
=5	=5
4AA	4f#
4AA-	2f
2GG	.
.	4e
=6	=6
2FF#	4e-
.	2d
2E-	.
.	4c
=7	=7
*-	*-
```

```
*staff2	*staff1
*clefF4	*clefC3
*k[]	*k[]
*M4/4	*M4/4
*met(c|)	*met(c|)
=1-	=1-
1r	2r
.	4r
.	8c
.	8d
=2	=2
1r	4e-
.	4e
.	4f
.	4f#
=3	=3
```

- tabular format, voices are columns
- **kern is the format for Common western notation
- columns can represent any timeseries
  - tablature
  - analytical information
  - everything else you need
- seamless connection with tools



https://verovio.humdrum.org/

Seamless connection of encoding system and tools

=4	=4
4r	2B
8D	.
8C	.
4BB	4r
4BB-	4g
=5	=5
4AA	4f#
4AA-	2f
2GG	.
.	4e
=6	=6
2FF#	4e-
.	2d
2E-	.
.	4c

=4	=4
4r	4B
4D	4B
4BB	4r
4BB-	4g
=5	=5
4AA	4f#
4AA-	4f
4GG	4f
4GG	4e
=6	=6
4FF#	4e-
4FF#	4d
4E-	4d
4E-	4c

=4
-
M6
-
M13
=5
M13
M13
m14
M13
=6
d14
m13
M7
M6

=4	=4	=4
4r	4B	-
4D	4B	M6
4BB	4r	-
4BB-	4g	M13
=5	=5	=5
4AA	4f#	M13
4AA-	4f	M13
4GG	4f	m14
4GG	4e	M13
=6	=6	=6
4FF#	4e-	d14
4FF#	4d	m13
4E-	4d	M7
4E-	4c	M6

sample (by quarter note) hint (harmonic intervals) assemble (score and analysis)

Humdrum's 15 minutes of fame (2007)

Mazurka project: analysis of piano performance, timing in particular

- Humdrum tools to generate *timescapes* (Sapp 2007)
- analyse multiple performances of same piece (e.g. Chopin)
- trace performance traditions or piano 'schools'

Strange patterns found for enigmatic pianist Joyce Hatto (1928-2006)

- close resemblances with multiple other pianists
- scam was detected, mainly through timescapes
- Hatto's husband William Barrington-Coupe partly confessed

see also: https://www.newyorker.com/magazine/2007/09/17/fantasia-for-piano

Ashkenazy, Vladimir
Aspaas, Tor Espen
Babayan, Sergei
Banowetz, Joseph
Baselga, Miguel
Bellucci, Giovanni
Benoit, Prisca
Biret, Idil
Bloch, Boris
Bronfman, Yefim
Browning, John
Brownridge, Angela
Budiardjo, Esther

some Hatto ghost performers

Musical grammars

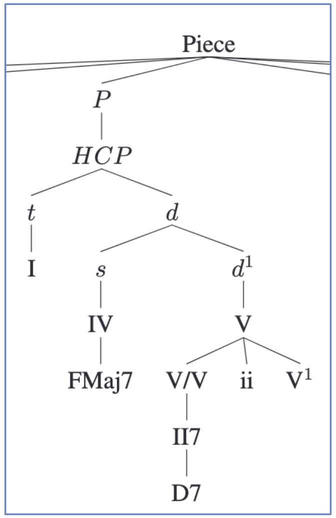
influenced by linguistics, Chomsky's work in particular

- generative grammars: production rules that produce grammatical utterances
- seminal text: Lerdahl and Jackendoff, *Generative theory of tonal music* (1983)
  - still no full implementation available
- much work in computational grammars of harmony

fundamental reorientation: focus on modelling human competence rather than musical objects

- connection with Artificial Intelligence (of the rule-based variety)

example metrical analysis



computer-generated harmonic analysis (De Haas et al. 2009)

Community building

Center for Computer Assisted Research in the Humanities

- founded in 1984 by Walter B. Hewlett, Stanford University
- staff included Eleanor Selfridge-Field and Craig Sapp
- online resources: https://www.ccarh.org/
- Yearbook Computing in Musicology (1985-2007)
- Visiting Fellowships

IMS Study Group in Musical Data and Computer Applications

- founded by Hewlett and Selfridge-Field in 1986
- currently Digital Musicology Study Group
- https://digital.musicology.org/

https://newsarchive.berkeley.edu/news/media/releases/2007/09/10_hewlett-text.shtml
https://cmems.stanford.edu/people/eleanor-selfridge-field
https://music.stanford.edu/people/craig-sapp-0

Conclusion: late 1990s

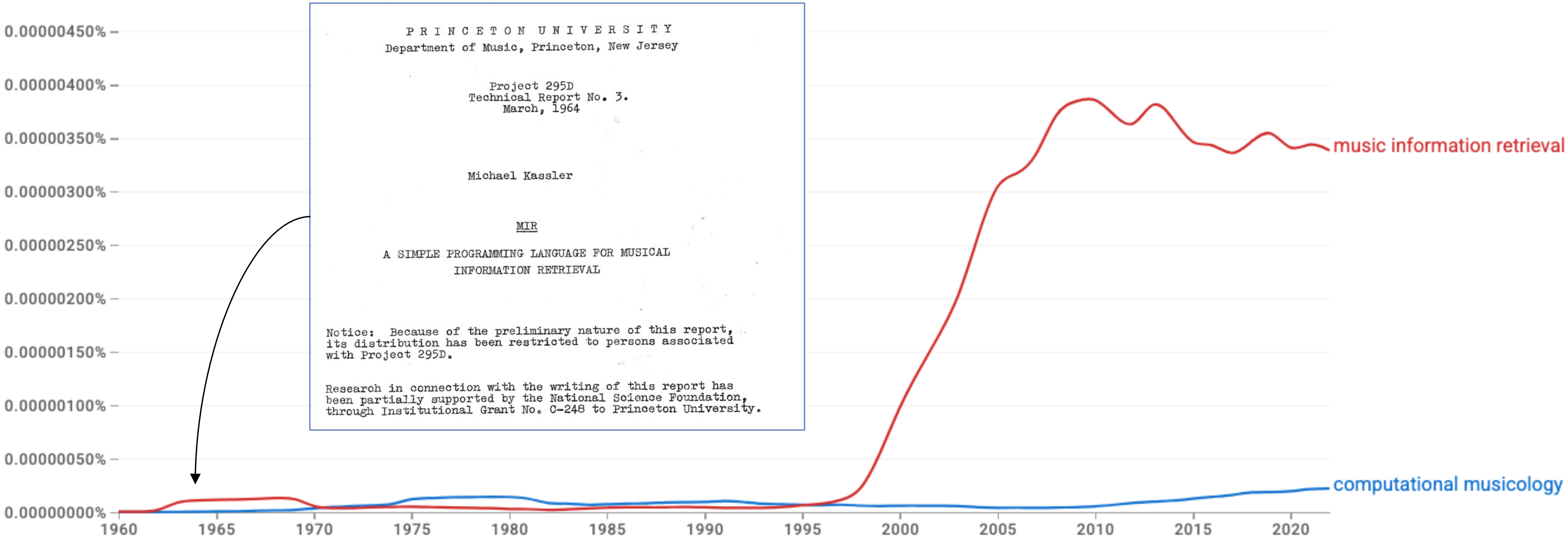
gradual recovery from crisis

- contours of technical infrastructure emerging
- some software and data still available

separation from mainstream musicology

- emerging community (CCARH, IMS Study Group)
- anchoring discipline elsewhere:
  - music psychology: cognition and perception
  - linguistics, AI
  - new friend: Music Information Retrieval

Internet and Music Information Retrieval (1995-2015)



Google Books Ngram Viewer (again)

- term 'Musical Information Retrieval' created by Michael Kassler (1964)
- dormant until c. 1995

MIDI (Musical Instrument Digital Interface)

MIDI specification released in 1983 (https://midi.org/)

- middle ground between sound and notation
- specifies ‘note-on’ and note-‘off’ events (and more…)
- supports interchange between electronic instruments
- allows low-level interchange between music programs and between people

MIDI converted to notation: enharmonic issues

note on/off

time step

pitch number

velocity

```
v360    90 '60 '64       ; note-on C4
v60     80 '60 '64       ; note-off C4
v0      90 '62 '64       ; note-on D4
v60     80 '62 '64       ; note-off D4
v0      90 '63 '64       ; note-on D#4
v120    80 '63 '64       ; note-off D#4
v0      90 '64 '64       ; note-on E4
v120    80 '64 '64       ; note-off E4
v0      90 '65 '64       ; note-on F4
v120    80 '65 '64       ; note-off F4
v0      90 '66 '64       ; note-on F#4
v120    80 '66 '64       ; note-off F#4
v0      90 '67 '64       ; note-on G4
v240    80 '67 '64       ; note-off G4
v0      90 '68 '64       ; note-on G#4
v240    80 '68 '64       ; note-off G#4
```

MIDI is a binary format, here converted to text

Sharing MIDI

MIDI soon took off on the internet

- small files (bandwith was at a premium)
- easy to ceate and use in a variety of applications
- Classical MIDI archives started in 1994
  - currently Classical Archives, 20,799 MIDI files
  - https://www.classicalarchives.com/

Soon superseded by other formats on the web

- MP3 for audio (https://www.iso.org/standard/26797.html)
- MusicXML for notation interchange (https://www.w3.org/2021/06/musicxml40/)

Classical music archives, August 2002

https://web.archive.org/web/20020820073725/https://www.classicalarchives.com/

Searching for music on the Internet

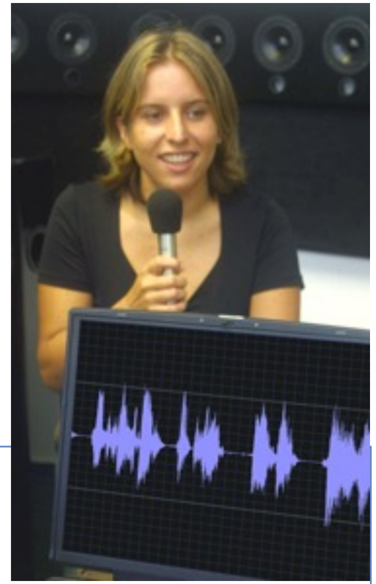
from the early 1990s, substantial music collections emerged on the internet, often as MIDI files, creating new problem:

- how can you find a song that you're looking for
- especially when you don't know artist or title?

Ghias et al. (1995): *Query by Humming*

- hum the melody into the computer
- pitch extraction from audio signal
- match to melodies in MIDI collection

audio pitch extraction and melodic search became core topics in Music Information Retrieval



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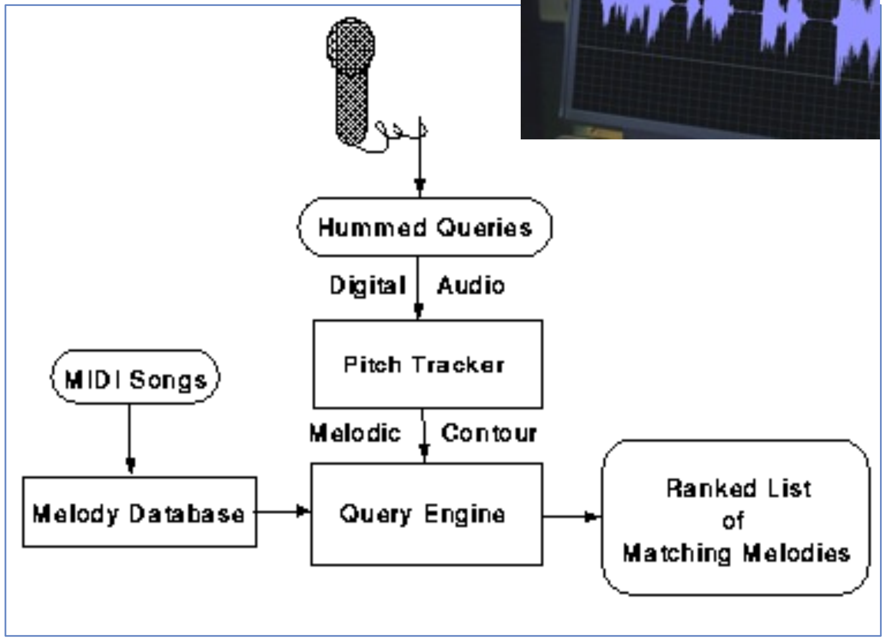


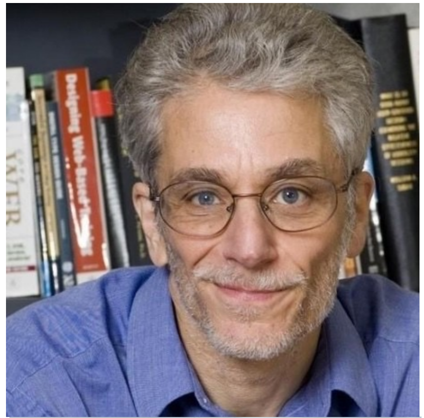
International Symposium on Music Information Retrieval

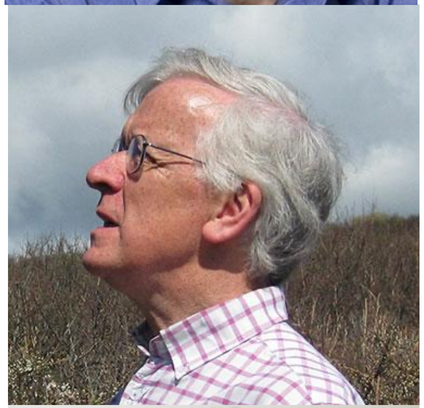
Conference since 2002

ISMIR founded by Donald Byrd, Tim Crawford and J. Stephen Downie (2000)

Interest in music information retrieval (music IR) is exploding. This is not surprising: music IR has the potential for a wide variety of applications in the educational and academic domains as well as for entertainment

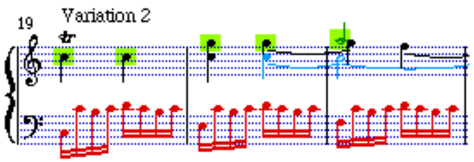
- multidisciplinary event: computational musicology, library science, audio signal processing, computer science
- developed into very successful conference series
  - all papers open access: https://ismir.net/conferences/





https://github.com/donbyrd
https://www.gold.ac.uk/computing/people/t-crawford/
https://ischool.illinois.edu/people/j-stephen-downie

Institutionalising MIR



ISMIR logo from 2000

ISMIR

ISMIR logo from 2015

shared vision (Downie 2003)

- again, heroic ambitions requiring a lot of technology development

development of organisational structures

- ISMIR society (2008)
- TISMIR journal (2018): https://transactions.ismir.net/

growing community

- multidisciplinary; closely-connected but volatile
- homebase for computational musicologists for a period

considerable industrial backing (at least since ISMIR 2005)

- research, funding, *consumer audio applications*
- treating music as commodity

a multidisciplinary research endeavor... to make the world's vast store of music accessible to all (Downie 2003)

Audio pitch analysis

raw audio is quite unstructured

- extraction of basic musical features (beat, onset, pitch) requires considerable effort
- *very many* audio features have been developed

example feature (or rather, feature family): *chroma*

- amount of energy per pitch class per timespan
- pitch *class* not pitch: melodic information lost
- chords can be inferred (again, not easy)

many applications, including

- harmonic analysis (Fujishima 1999)
- identify cover songs (Serrà et al. 2008)

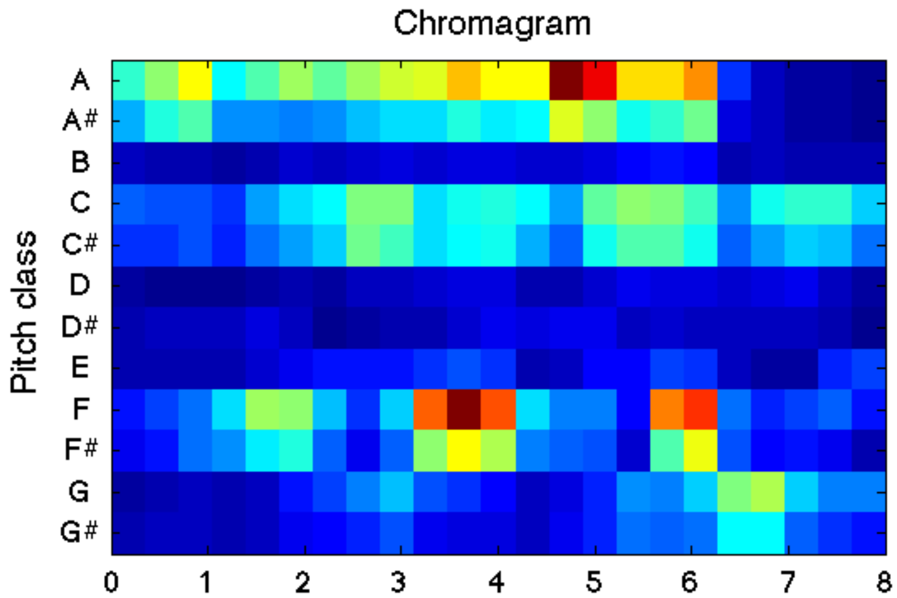


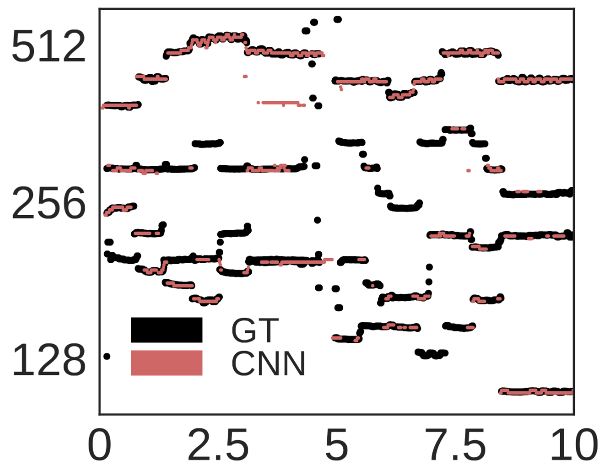
image: https://www.mattprockup.com/livenote

What about melody transcription?

solved for monophony (YIN, De Cheveigné & Kitahara 2002)
- good news for Query By Humming paradigm

polyphony (aka multiple F0 extraction) researched since at least 2004 (Anssi Klapuri), but hard

Percussion, overlapping harmonics, high degrees of polyphony, and masking make these tasks notoriously difficult (Bittner et al. 2017)



automatic transcription of Bach chorale recording, superimposed on human ground truth

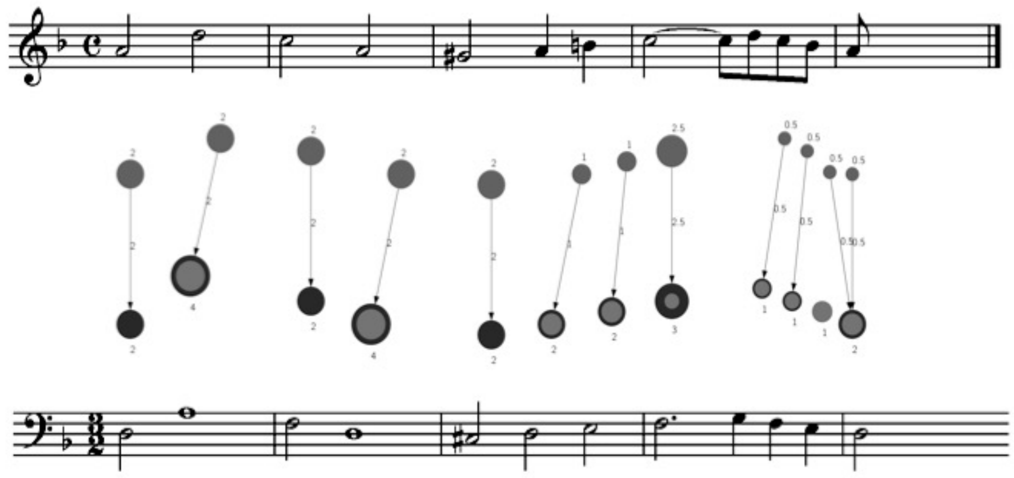
generic deep learning model proposed by Bittner et al. (2017)
- evaluated by comparing output to human F0 annotations
- outperformed state-of-the art models (though not for Bach…)

Studying music similarity

basic task: find melodies that are similar to a given melody, e.g. in:

- query by humming
- finding sources by musical incipit
- tracing transmission of melodies

nearly always relevant items are similar but not identical due to 'accidental' variation

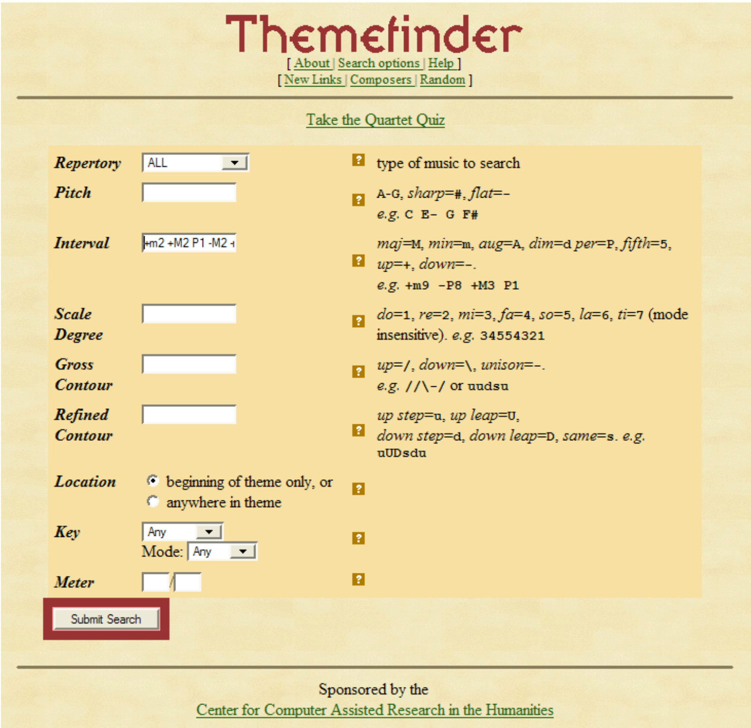


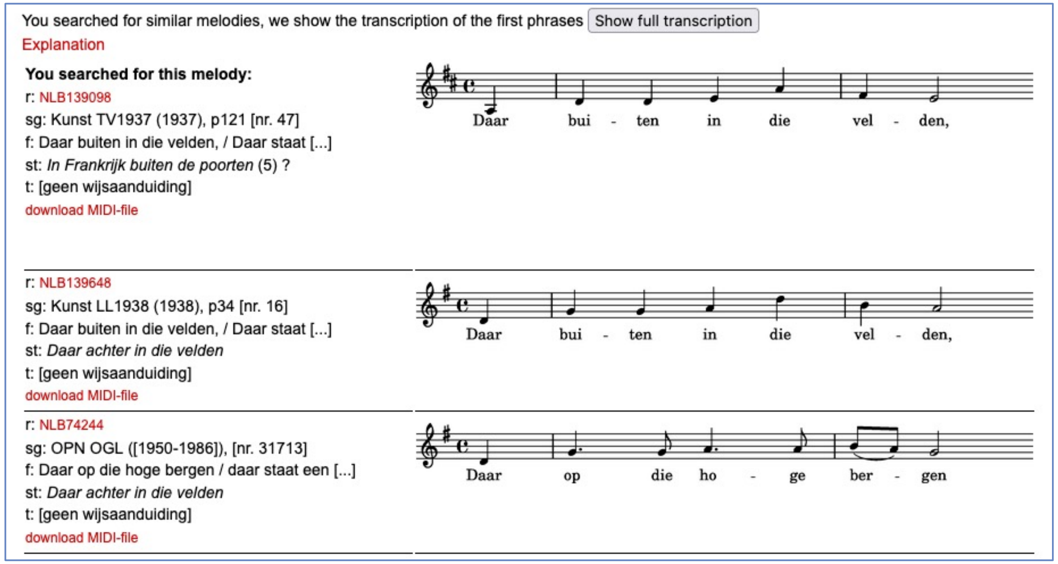
Earth Mover's Distance performs approximate melody matching, taking both pitch and duration into account (Typke 2007)

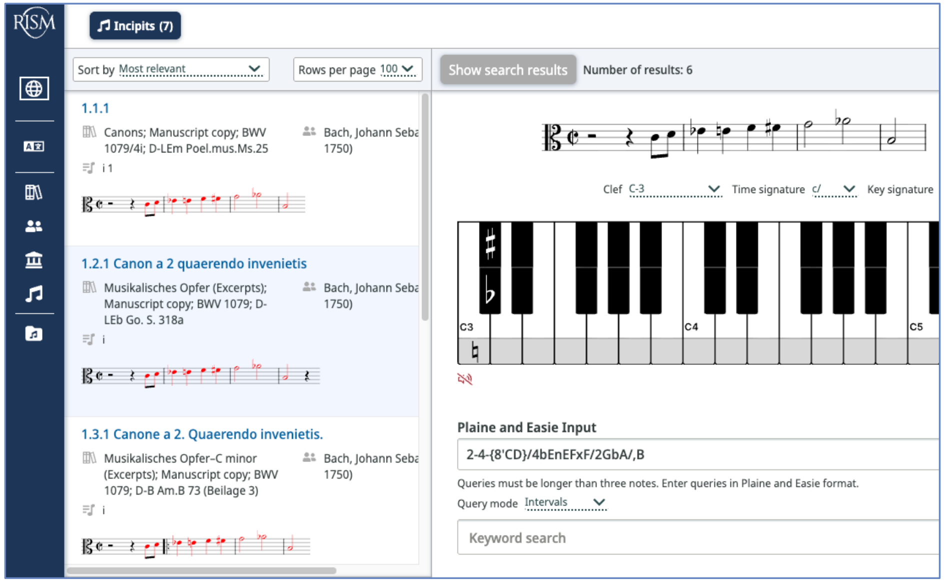
- similarity has many dimensions like pitch, rhythm, phrasing, harmony (Volk et al. 2012)
- important place for music cognition and perception

Three musicological search engines

Themefinder: http://themefinder.org/
Dutch Song Database: https://www.liederenbank.nl/
RISM: https://rism.online/







What has MIR done for musicology?

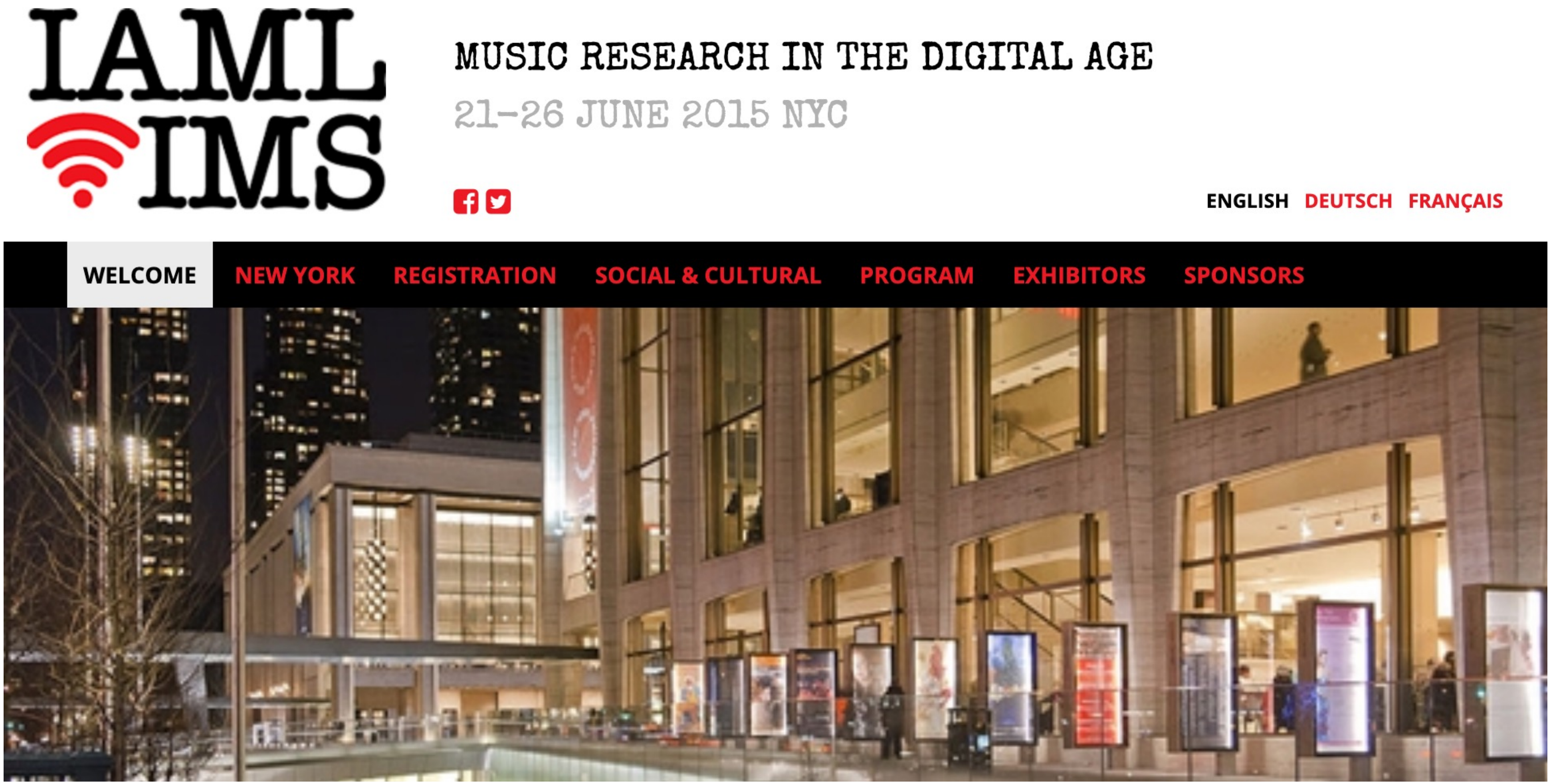
bad news

- dominant engineering approach (whatever it takes to get the best results)
  - lowers explanatory value
- glass ceilings
- many solutions in search of a (musicological) problem

good news

- many complete systems developed (e.g. music search engines)
- lots of computational methods waiting to be exploited
- audio-based research now serious possibility
- ready to deal with data-rich potential of the Internet

Musicology goes digital (2015-present)



https://www.musiclibraryassoc.org/mpage/IAML_IMS_2015

A milestone: first major conference on digital musicology

- backed by two ‘traditional’ societies, IAML and IMS
- 5 days of digital musicology in the wild
- huge variety of topics

The Formalized Fiddle

The empirical research of a Georgian sound scale

Modeling performance traditions in Giacomo Puccini’s *Turandot*

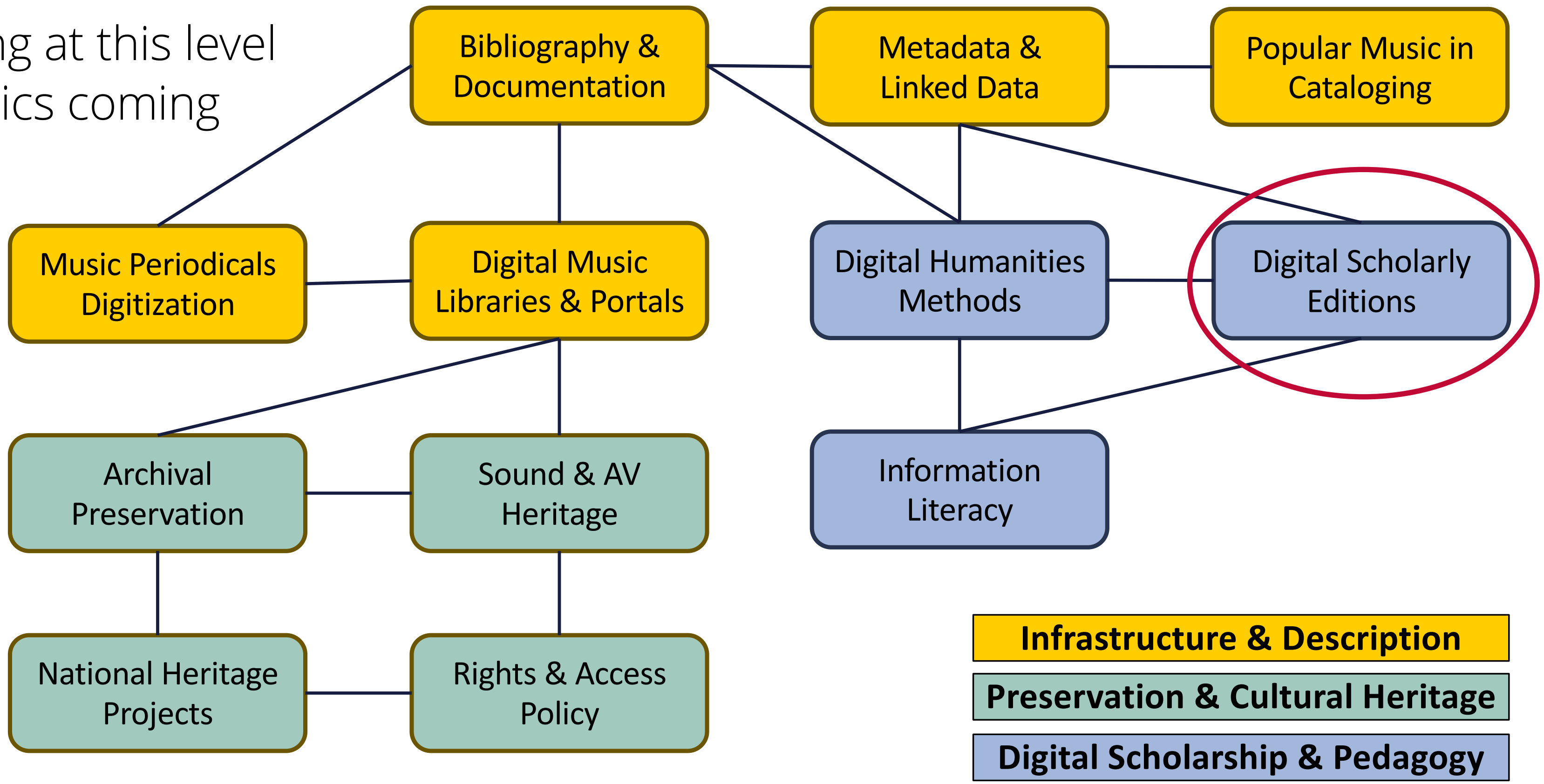
Close and distant reading: Data analysis meets the Renaissance chanson

Localizing Texas-Mexican conjunto music through social network analysis

Re-purposing DNA and protein analysis software to examine improvisation practices in Vietnamese music

Co-occurrence network: twelve main topics

- analysis of the c. 150 abstracts
- hardcore computational and MIR topics missing at this level
- many 'library' topics coming from IAML



This is the only slide for which I used ChatGPT

Digital Scholarly Editions

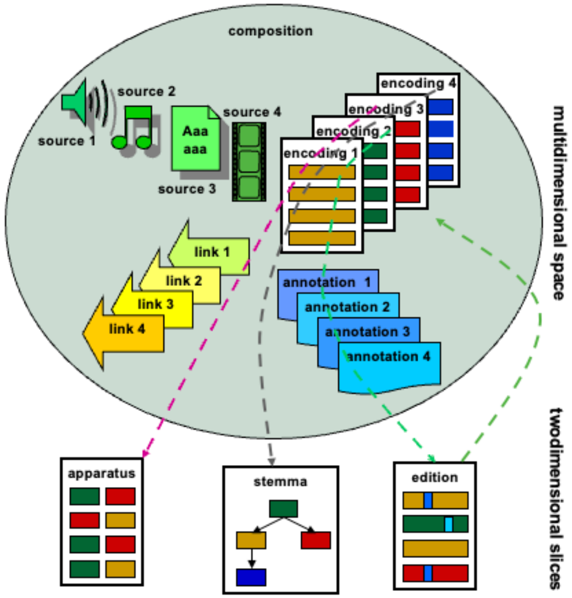
traditional monumental editions of music have limitations

- methodological: encourage strong work concept
- practical: difficult access to source information via critical commentary
- sustainability: static, no way to add new information
- cost: business model for publishers, (too?) expensive

multidimensional model (Wiering 2009)

- coordinated collection of digitised sources, encodings, annotations and links
- user-defined two-dimensional views
- supports incremental growth

https://www.bach-leipzig.de/de/neutral/die-geschichte-des-bach-archivs-leipzig



Early initiatives

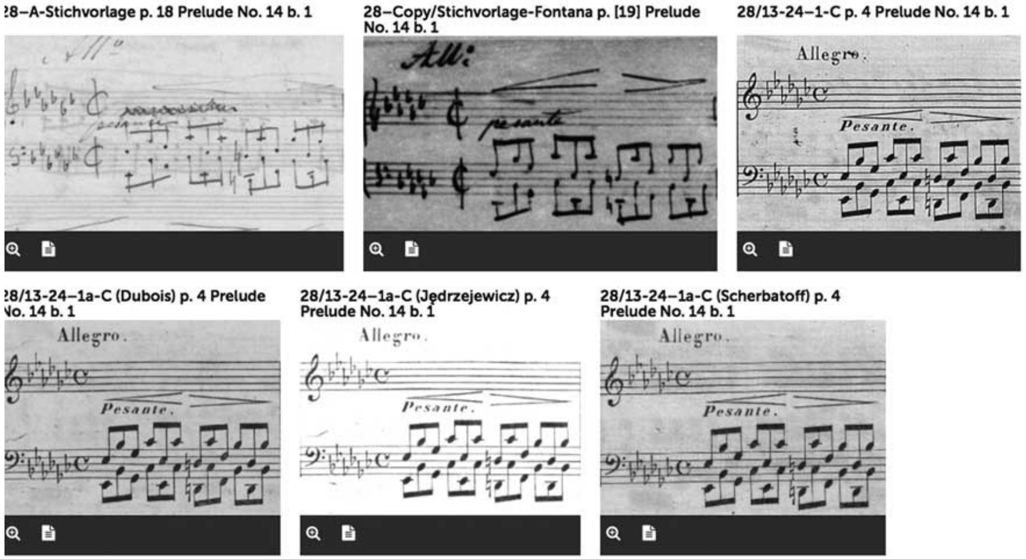
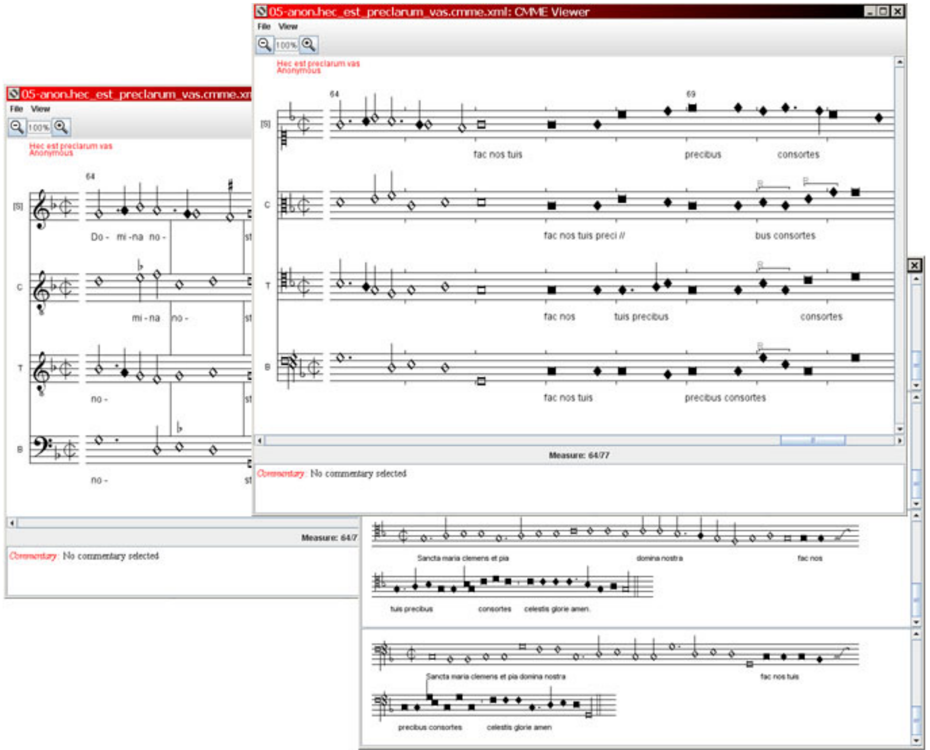


illustration from Hood (2017)



Online Chopin Variorum Edition (created 2003-2017; Rink 2024)

- digital facsimiles
- every edition is different, no definitive version

Computerized Mensural Music Editing (https://cmme.org/; Dumitrescu 2001)

- source and edition visualisations
- generated from underlying XML encoding

Music Encoding Initiative

Originally, XML-based language for encoding CMN *information* (Roland 2000, 2002)

- long gestation period
- initially weak on software

adopted by Edirom project for digital critical editions (https://edirom.de/) around 2009

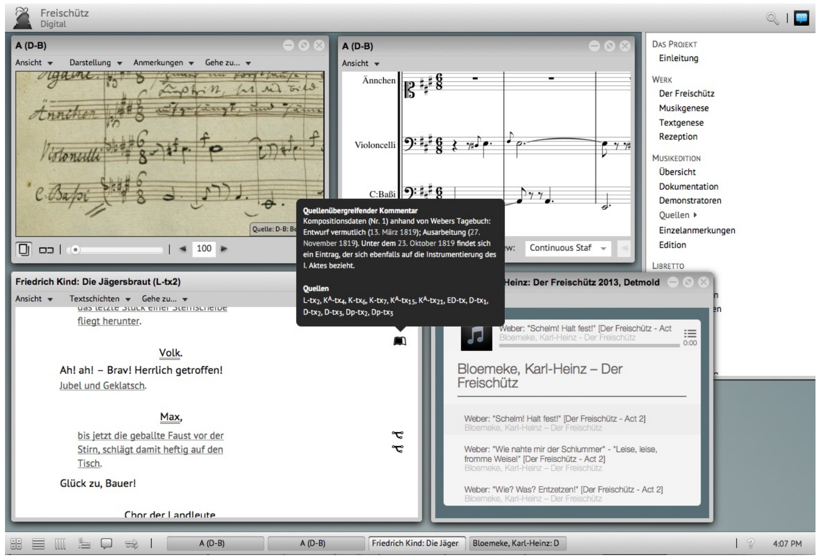
- digital edition of Weber's *Freischütz*

evolved into full ecosystem since 2015, https://music-encoding.org/

- modules for other notations
- software support

MEI study group founders, Dagstuhl 2009 (red circles)

www.dagstuhl.de/storage/media/0001/1067/conversions/09051.01.l.jpg



MEI encoding

```
<measure n="4">
 <staff n="1">
  <layer n="1">
   <note dur="2" oct="3" pname="b"/>
   <rest dur="4" />
   <note dur="4" oct="4" pname="g"/>
  </layer>
 </staff>
 <staff n="2">
  <layer n="5">
   <rest dur.ppq="2" dur="4"/>
   <beam >
    <note dur="8" oct="3" pname="d"/>
    <note dur="8" oct="3" pname="c"/>
   </beam>
   <note dur="4" oct="2" pname="b"/>
   <note dur="4" oct="2" pname="b">
    <accid accid="f"/>
   </note>
  </layer>
 </staff>
</measure>
<measure n="5">
```

MEI is XML-based

- uses markup (elements, attributes) to make information content explicit
- organises information *hierarchically*, in a tree structure
- enables *enrichment*, by adding sub-elements (for example a variant)
- unfortunately, music has multiple hierarchies (e.g. voices and chords)
- processing can become quite complex

Optical Music Recognition

Part of the Aruspix User Interface, https://www.aruspix.net/

human effort has always been a bottleneck in large-scale music encoding

- Optical Music Recognition has been a promise for decades
  - *much* more difficult than Optical Character Recognition (the classical Artificial Intelligence problem)

exception: type-set music from the 16th-18th centuries

- due to very small character set (Pugin 2006)
- still an interactive task

deep learning methods for OMR are booming (surveyed in Castellanos et al. 2025)

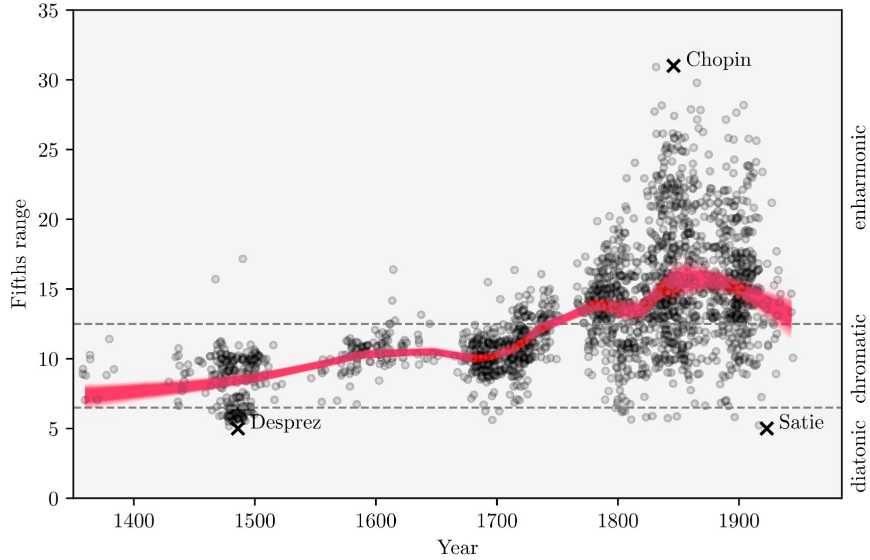
- e.g. MuRET (developed at U. of Alicante)
- tested on sources in Bayerische Staatsbibliothek (Umbreit & Schumann 2024)

Big data history of music

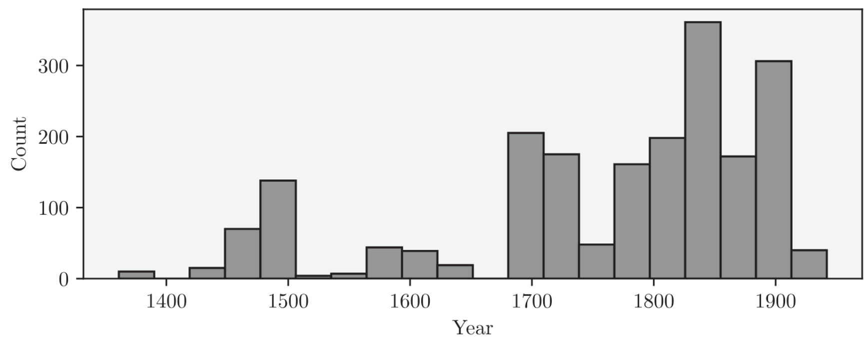
expression coined by Rose and Tuppen (2014) for study of large-scale metadata collections

with enough encodings you can do corpus analysis
- e.g. quantitative approach to stylistic development (Moss et al. 2023)

often there is ony little data, and it comes in many different formats
- especially true for early music
- is audio analysis an alternative? (Visscher & Wiering 2025)



development of fifth range ('chromatic richness')

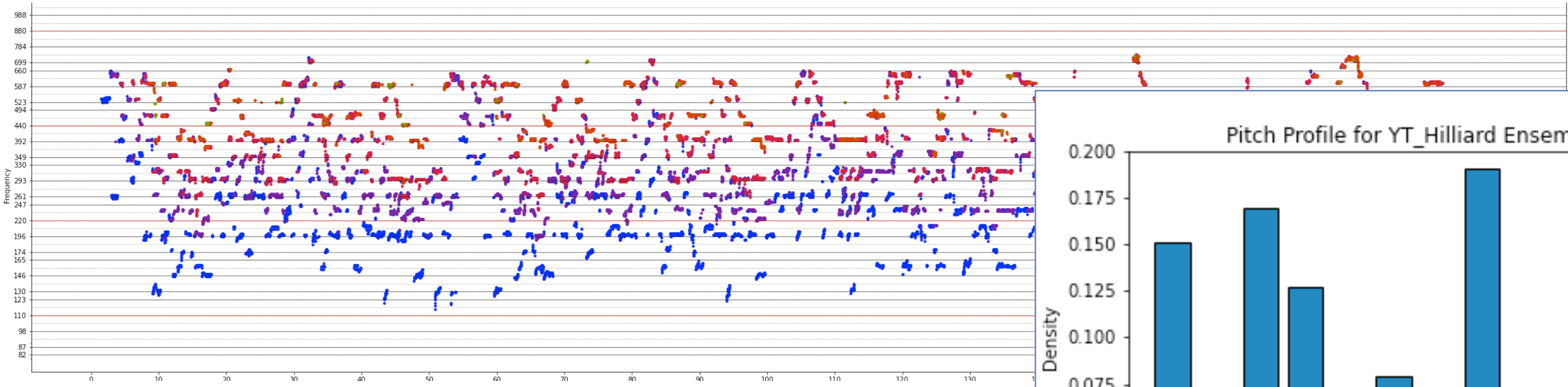


chronological distribution of pieces

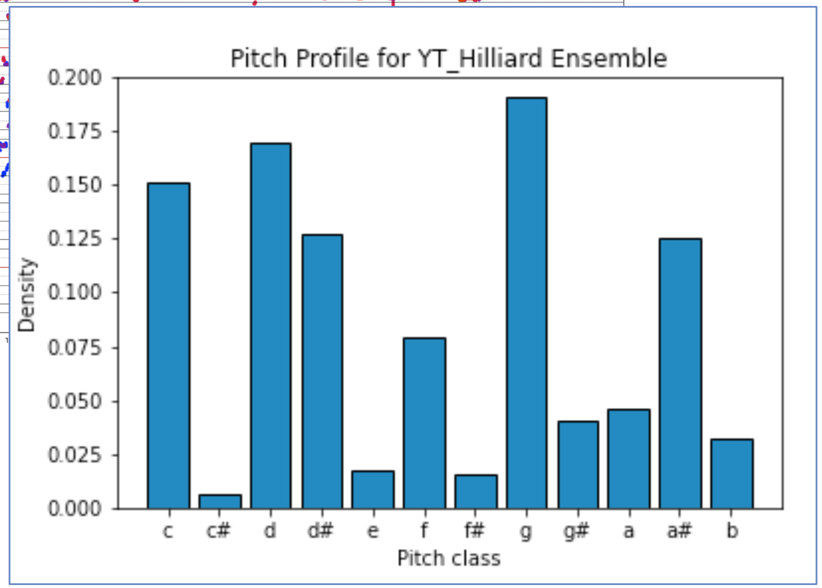
Audio analysis: multiple F0 extraction

context: history of polyphonic modality

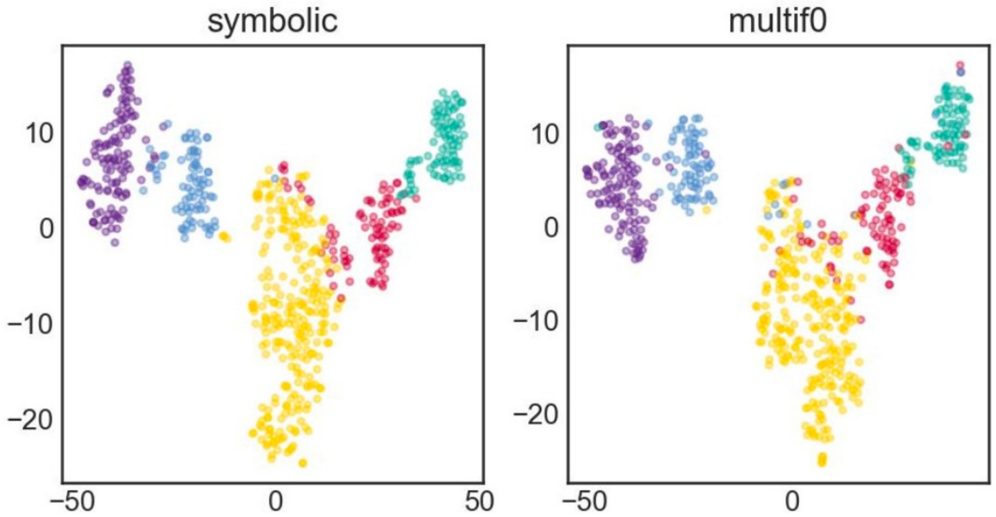
- deep learning method developed by Cuesta et al. (2020) gives best results
- example: Palestrina, *Vergine bella*, performed by Hilliard ensemble
- note: shows pitch events, not voices



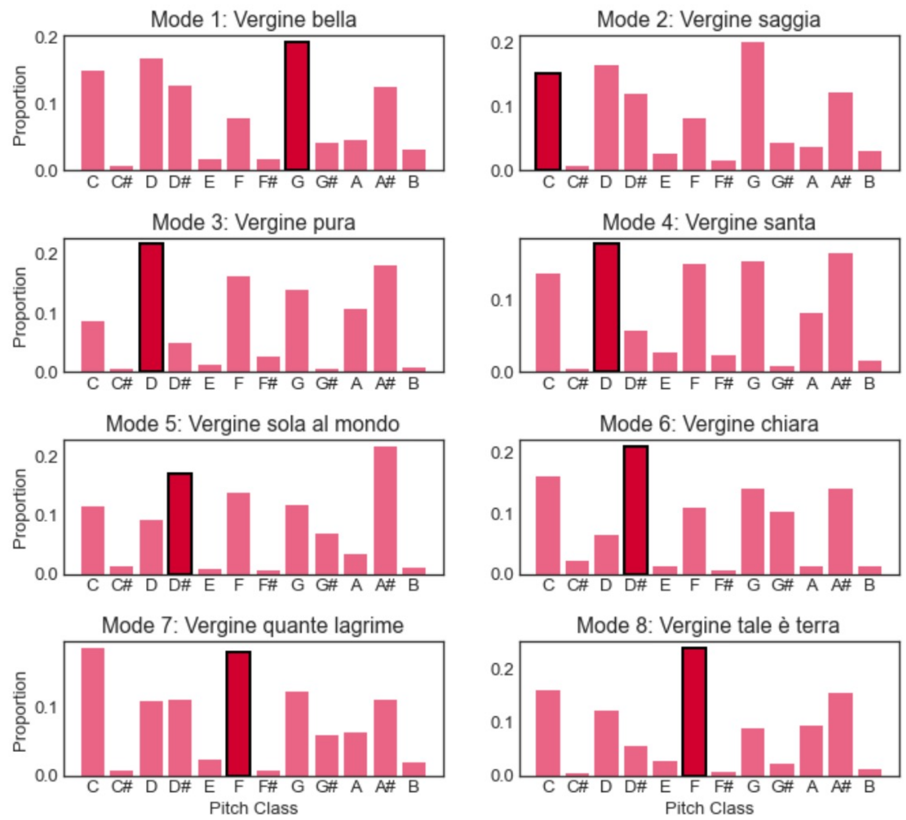
- extractions used to generate pitch class profiles
- closely resemble symbolic profiles (Visscher & Wiering 2025)



Corpus analyis with pitch class profiles (Visscher & Wiering 2025)



unsupervised clustering with t-SNE of audio and symbolic pitch class profiles shows very similar results. Data: encodings from the Stanford Josquin Project and corresponding recordings. Clusters correspond to modal pairs



pitch class profiles of an 8-mode cycle, Palestrina’s *Vergine* cycle

Very interesting, but what about the average musicologist?

What Do Musicologists Do All Day (Inskip & Wiering 2015)

- worldwide survey of technology acceptance in music research, n=625

main outcomes:

- musicologists use technology widely and creatively
- widely-shared feeling this has changed musicology
- access and discovery are very important
- only weak interest in software for processing musical data (music notation programs excepted)

benefits of technology responses: terms related to processing are infrequent

WDMDAD the pandemic edition (2022)

Q18: Which of the [technology-related] changes you have been forced to make are you going to keep after the pandemic is over?

area of change	count
human interaction: teaching, conferences, collaboration,...	130
digital and physical materials	76
remote work, travel	50
hardware, software, services	24
other changes: health, skills and attitudes, ...	21
total	**301**

strongest impacts on social structure of the discipline and on research materials

Pandemic as a catalyst

> perhaps none of them [my changes] huge or transformative on their own, but in sum the changes in habit and standard operating procedure have been huge. [176]

- during the pandemic, technical skills were essential for survival
- many discovered potential of technology for research
- online materials became a major resource
  - matched by concerns about study of physical resources
- perspectives for collaboration and networking were widened
- new research topics and methodological reflections
- many fundamentals of the discipline have been affected
- the digital has become an integral part of the musicological discipline

full analysis in Wiering & Inskip (2025)

Two examples of methodological reflections

Our tools shape the way we think - the increased speed of digitisation allows for more analysis of big data and more research questions based on questions related to quantifications in general

I am concerned about how reliance on digital resources can shape research questions and trends - a topic which to my knowledge no one has looked into.

Community aspects: venues

- several new conferences have emerged, for example:
  - Digital libraries for musicology (since 2014)
  - Music encoding conference (since 2013)
  - International Conference on Computational and Cognitive Musicology (since 2022)
- journals that regularly publish articles on musicological computing include
  - TISMIR (2018)
  - Journal of New Music Research (1972)
  - Music and Science (2018)
  - Journal of Mathematics and Music (2007)
  - Musicae Scientiae (1977)
  - Journal of Interdisciplinary Music Studies (2007)

Community aspects: mingling

- mainstream journals publish articles on digital and computational musicology, for example:
  - Fontes Artis Musicae
  - Early Music
- mainstream conferences have dedicated sessions, but computational work is often part of sessions with a musicological focus, as in:
  - IMS Congress
  - MedRen conference
- many smaller events such as workshops and lecture series

Community aspects: money and infrastructure

- funding for large-scale, often international projects such as:
  - Transforming Musicology
  - Polifonia
  - LinkedMusic
  - Polish Music Heritage in Open Access
  - EarlyMuse (with a strong digital component)
  - E-LAUTE
- importance of digital infrastructures is acknowledged
  - four R's: RISM, RILM, RIPM, RIdIM
  - DIAMM
  - ...

Where are we now?

- digital in musicology has become ubiquitous
- reconnection with computing is clearly happening
- but issues remain when it comes to adiption of more advanced technologies

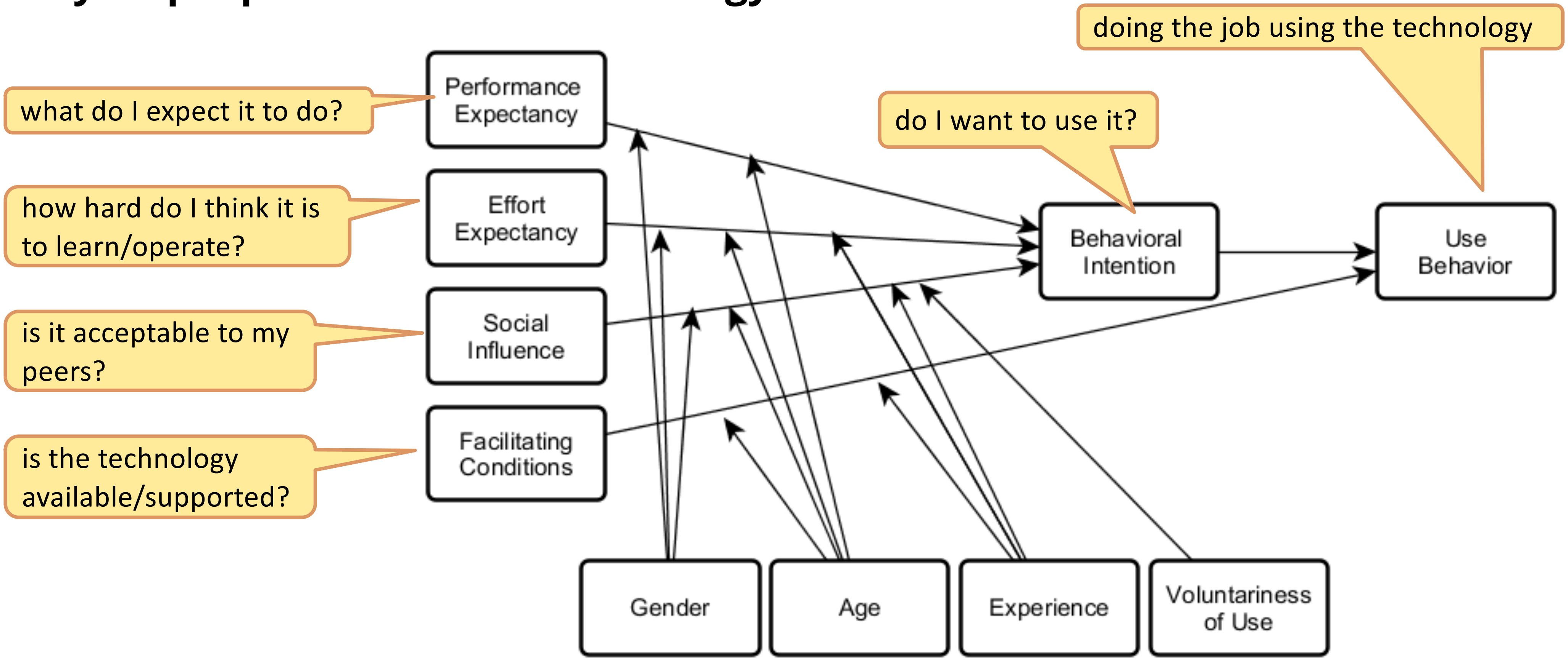
remember the four steps we saw in Logemann (1967):

1. *representing* musical information — **stability**
2. basic *processing* — **very many methods**
3. *integrating* results — **several functioning ecosystems**
4. musicological *interpretation* of the outcomes — **often difficult or problematic**

waterfall method

technology-first approach leads to problems of technology acceptation

Why do people *want* to use technology?



- such questions need to be addressed first
- there are plenty of methods to do so

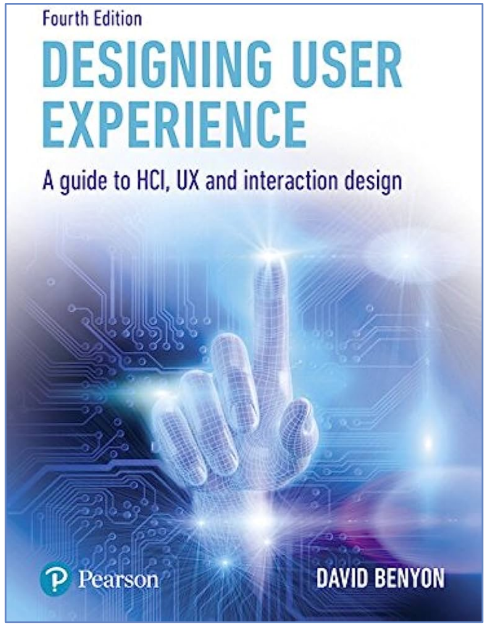
UTAUT model (Unified Theory of Acceptance and Use of Technology, Venkatesh et al. 2003)

Human Centred Design

basic principle: humans first, technology second
- investigate human goals, values and work practices
- choose or create technologies that fit with these
- far beyond ‘making the interface user-friendly’

what methods can you apply in HCD?
- interview, survey
- create personas and scenarios
- prototype
- evaluate…

there is some HCD research in ISMIR, but not a lot
- basic problem is already outlined in Raskin (2001)

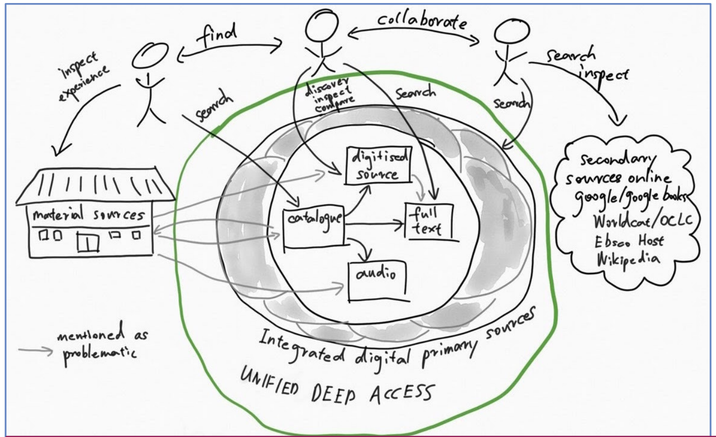


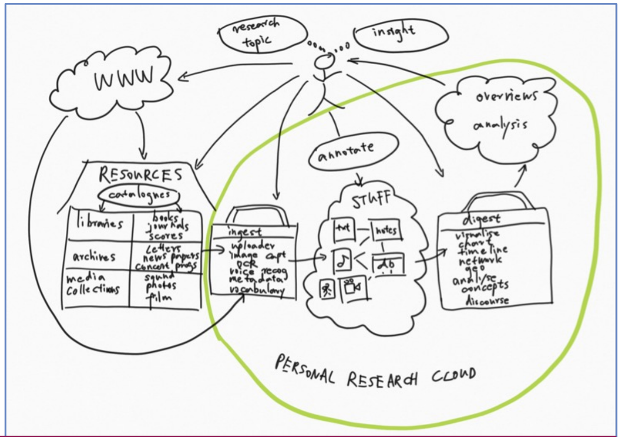
https://www.bol.com/nl/nl/p/designing-user-experience/9200000054815556/

Benyon 2019

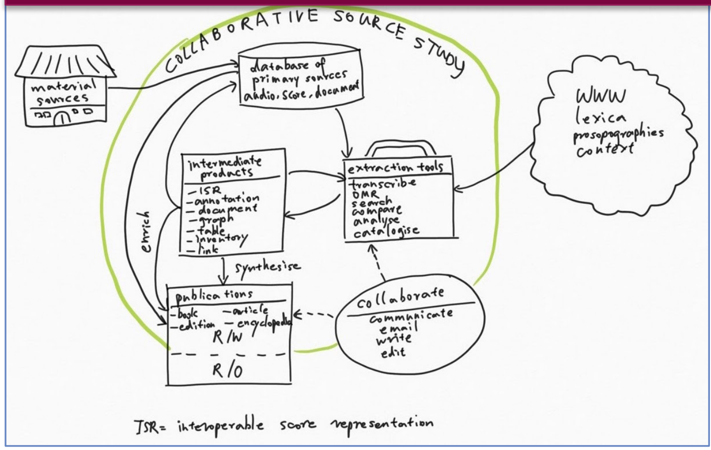
There is a sad truth I wish to bring forcibly to our attention, and surprisingly, it is one that we all know, though you may have put in the back of your mind -- for if you thought about it often, it would either make you mad or drive you mad. And that truth is that our computers and our software are too hard to use. This would not be a primary concern of mine if the difficulty was a necessary consequence of computer technology and the tasks we are trying to accomplish, but most of the difficulties are unnecessary. They can be fixed. Computer software is not beyond our control; unlike the weather, we can do something about it.

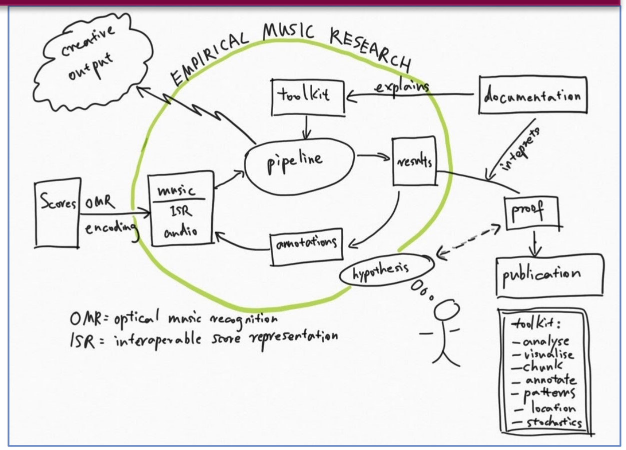
To conclude: some dream systems proposed by musicologists (2017)





take home challenge: help to make such systems a reality





abstractions derived from 15 interviews, see https://tinyurl.com/musicologicaldreams

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