

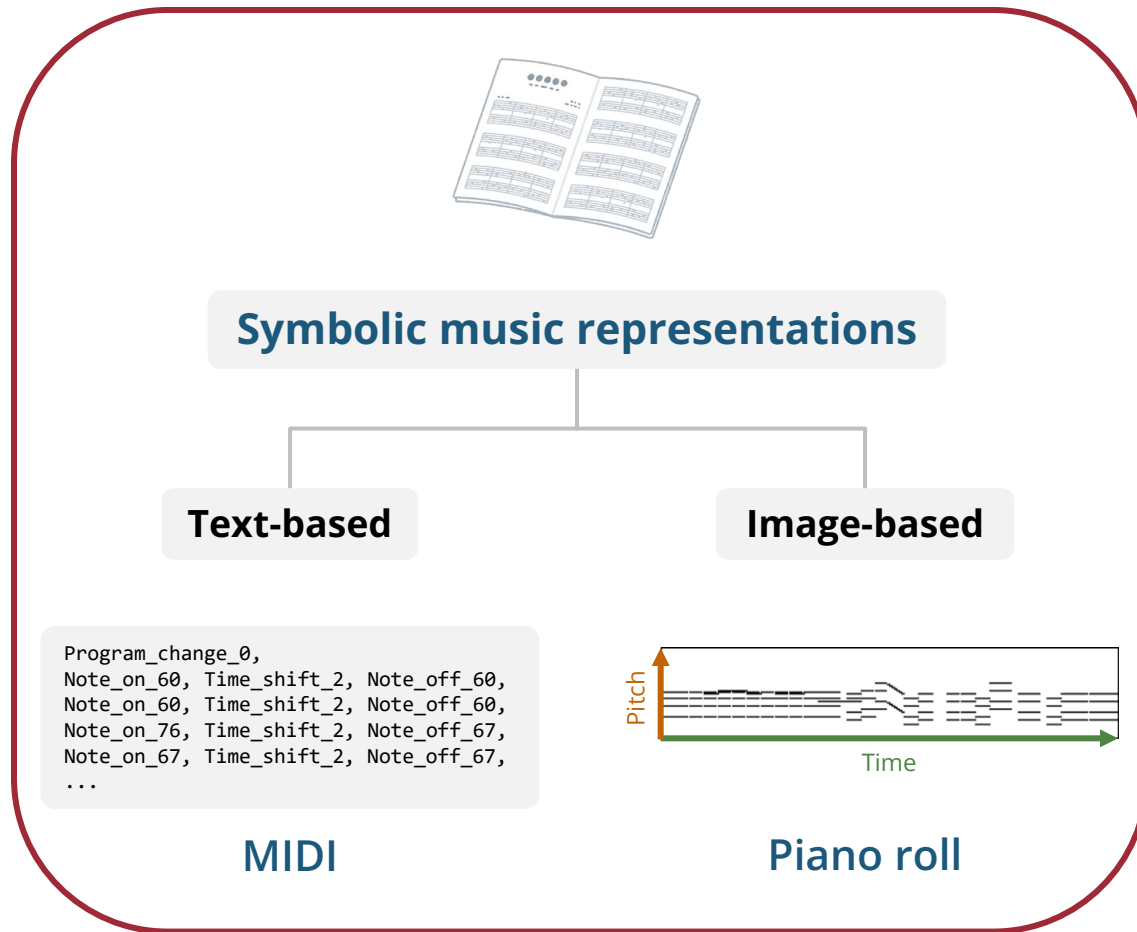
PAT 463/563 (Fall 2026)

Music & AI

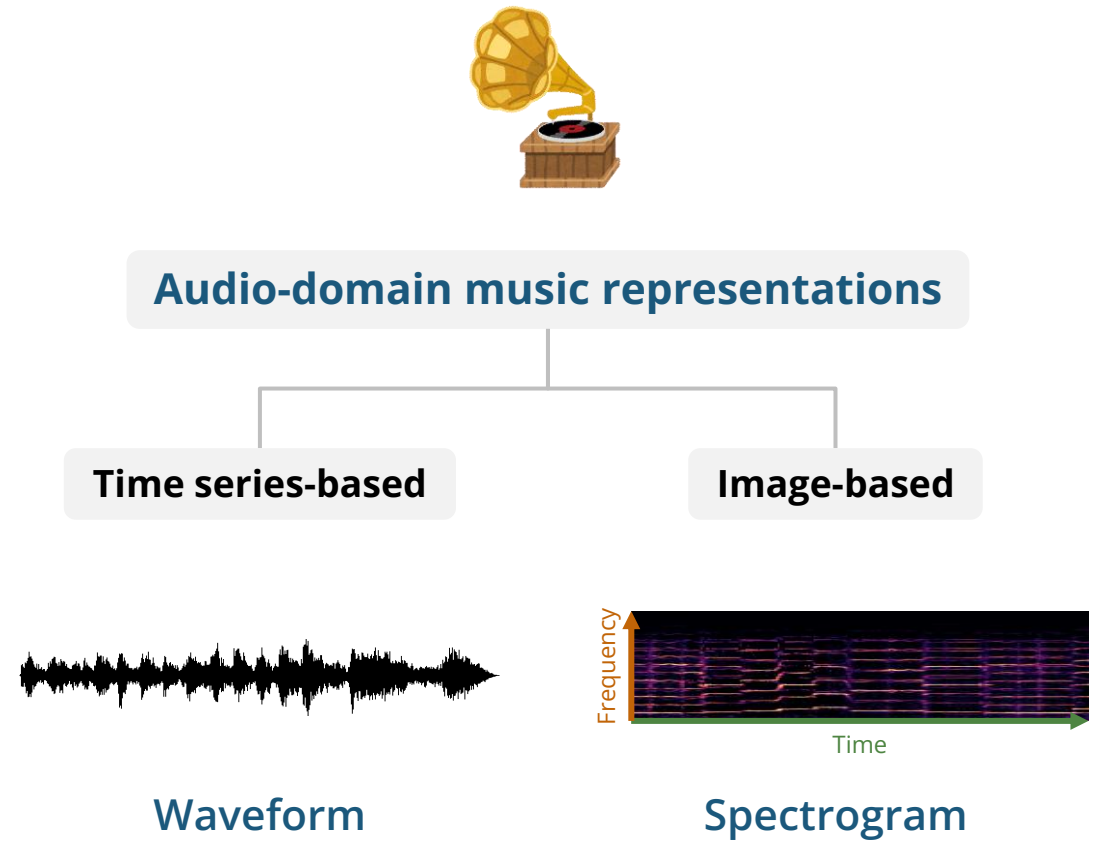
Lecture 4: Symbolic Music Processing

Instructor: Hao-Wen (Herman) Dong

Music Representations



Today's topic!



Machine-readable Music Language

Designing a Machine-readable Music Language

- How can we “represent” music in a way that machines understand?



- A simple text-based notation
- Use **letters** to denote **pitches**
 - Lower octave (A–G), higher octave (a–g)
- Use **prefix** to denote **accidentals**
 - Sharp (^), flat (_), natural (=)



| 🤔 What's this song?

CCGG | AAG2 | FFEE | DDC2 : |
| : GGFF | EED2 | GGFF | EED2 |
CCGG | AAG2 | FFEE | DDC2 : |

Twinkle, twinkle, little star!

An Example of ABC Notation

Ah! vous dirai-je, maman
(Twinkle, twinkle, little star)

anon. (France)

♩ = 120

The image shows a musical score for the song 'Ah! vous dirai-je, maman' (Twinkle, twinkle, little star). The score is written in three staves. The first staff has a tempo marking of ♩ = 120. The first four notes (C4, D4, E4, F4) are enclosed in an orange box, and the next four notes (G4, A4, B4, C5) are enclosed in a green box. A red circle highlights the C5 note. Colored lines connect these boxes to the corresponding ABC notation in the right panel: orange to 'CCGG', green to 'AAG2', and red to '2'.

Metadata

```
X:571
T:Ah! vous dirai-je, maman
T:(Twinkle, twinkle, little star)
C:anon.
O:France
R:Nursery song
M:C Meter
L:1/4 Unit note length (temporal resolution)
Q:120 Tempo
K:C Key
CCGG AAG2 F FEE | DDC2 : |
| : GGFF | EED2 | GGFF | EED2 |
CCGG AAG2 F FEE | DDC2 : |
```

ChatGPT can Compose Songs in ABC Notation!

SA You

Write a cheerful folk song using ABC notation



ChatGPT

Certainly! Here's a cheerful folk song in ABC notation:

vbnet

Copy code

```
X:1
T:Sunshine on the Meadow
M:4/4
K:C
G2 G2 E2 E2 | F2 F2 D4 | E2 E2 G2 G2 | A4 G4 |
G2 G2 E2 E2 | F2 F2 D4 | E2 E2 G2 G2 | C4 E4 |
G2 G2 E2 E2 | F2 F2 D4 | E2 E2 G2 G2 | A4 G4 |
G2 G2 E2 E2 | F2 F2 D4 | G4 F4 | E4 D4 | C4 z4 |
G2 G2 E2 E2 | F2 F2 D4 | E2 E2 G2 G2 | A4 G4 |
G2 G2 E2 E2 | F2 F2 D4 | E2 E2 G2 G2 | C4 E4 |
G2 G2 E2 E2 | F2 F2 D4 | E2 E2 G2 G2 | A4 G4 |
G2 G2 E2 E2 | F2 F2 D4 | G4 F4 | E4 D4 | C4 z4 |
```

Feel free to play around with the tempo and instrumentation to give it your own unique style!

chat.openai.com

Sunshine on the Meadow

The sheet music is rendered with abc.rectanglered.com.



Large Language Models (LLMs)

- The models behind ChatGPT!

SA

You

What's so cool about **AI for music**? Give me a brief answer



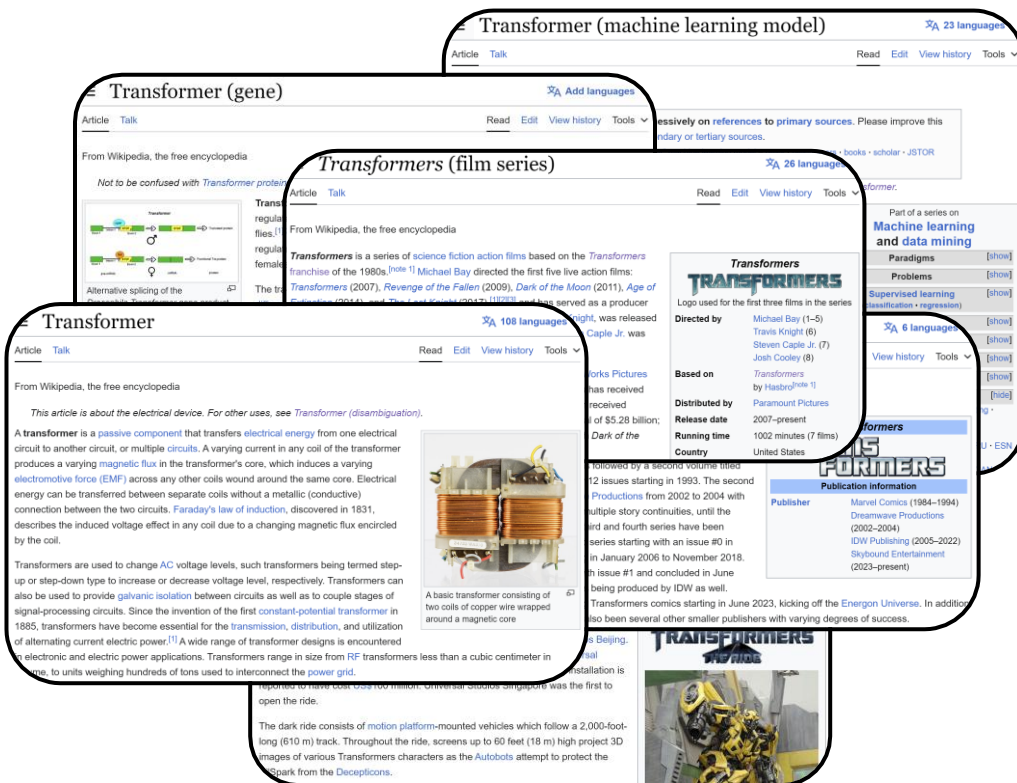
ChatGPT

Word-by-word generation

AI in music is cool because it can compose original pieces, provide personalized recommendations, automate music production tasks, enhance creativity for artists, enable interactive performances, analyze music trends, and even create virtual artists or bands, expanding the possibilities in music creation and enjoyment.

Language Models

- Predicting the next word given the past sequence of words



A transformer is a _____

electrical device ↑

fiction character ↑

deep learning model ↑

family of genes ↑

type of food ↓

musical instrument ↓

| Language Models (Mathematically)

- A class of machine learning models that **learn** the next word probability

$$P(\underset{\substack{\text{Next word}}}{x_i} \mid \underbrace{x_1, x_2, \dots, x_{i-1}}_{\substack{\text{Previous words}}})$$

$P(\text{electrical} \mid \text{A transformer is a})$ ↑

$P(\text{character} \mid \text{A transformer is a})$ ↑

$P(\text{gene} \mid \text{A transformer is a})$ ↑

$P(\text{model} \mid \text{A transformer is a})$ ↑

$P(\text{food} \mid \text{A transformer is a})$ ↓

$P(\text{musical} \mid \text{A transformer is a})$ ↓

Music Language Models (Mathematically)

- A class of machine learning models that learn the next note probability

$$P(\underset{\substack{\text{Next note}}}{x_i} \mid \underbrace{x_1, x_2, \dots, x_{i-1}}_{\substack{\text{Previous notes}}})$$

$$\begin{array}{l} P(\text{G} \mid C C G G A A) \uparrow \\ P(\text{A} \mid C C G G A A) \uparrow \\ P(\text{C} \mid C C G G A A) \uparrow \\ P(\text{F} \mid C C G G A A) \uparrow \\ P(\text{Ab} \mid C C G G A A) \downarrow \\ P(\text{A\#} \mid C C G G A A) \downarrow \end{array}$$

| Language Models: Generation

- How do we **generate** a new sentence using a trained language model?

A transformer is a

→ Model → deep

A transformer is a deep

→ Model → learning

A transformer is a deep learning

→ Model → model

A transformer is a deep learning model

→ Model → introduced

A transformer is a deep learning model introduced

→ Model → in

A transformer is a deep learning model introduced in

→ Model → 2017

| Limitations of ABC Notations

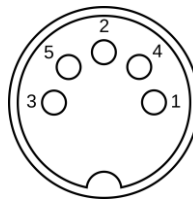
- Limited expressiveness
- Monophonic tunes only

MIDI-like Representation

MIDI (Musical Instrument Digital Interface)



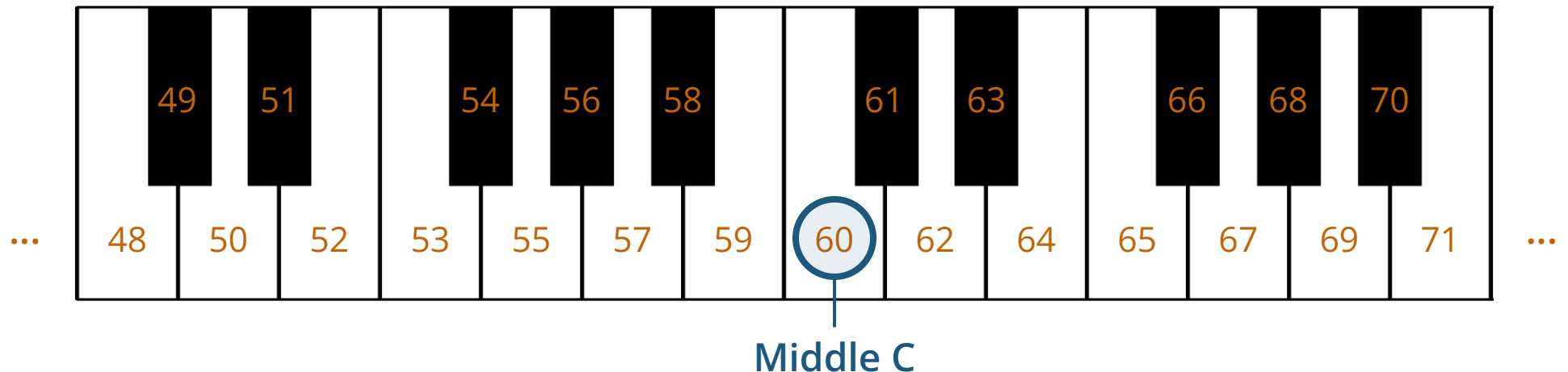
- A communication **protocol** between devices
- MIDI Messages
 - Note on
 - Note off
 - Delta time
 - Program change
 - Control change
 - Pitch bend change



MIDI I/O

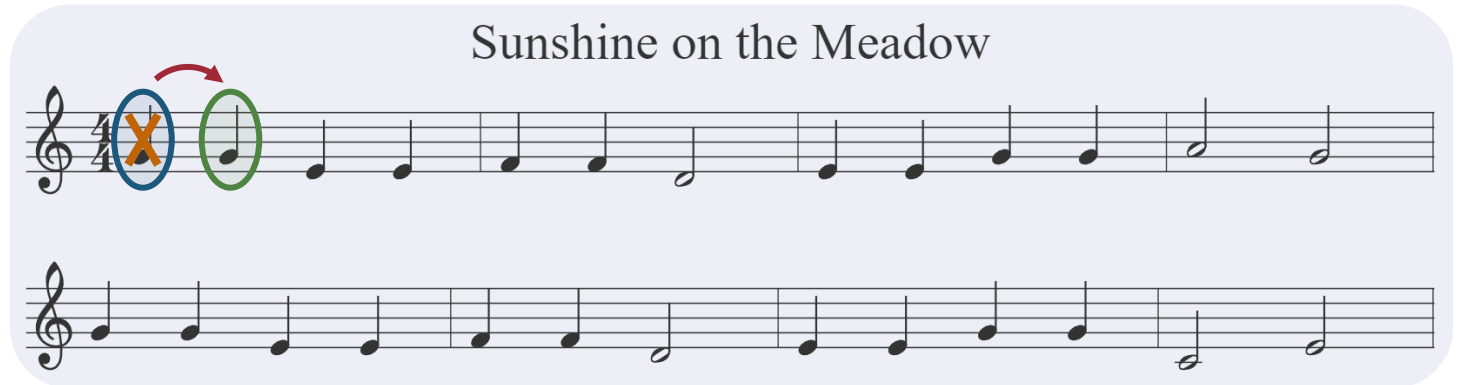
MIDI Note Numbers

- Ranging from 0 to 127
 - Middle C is 60
 - Wider than standard piano's pitch range
- Widely used in various software, keyboards and algorithms



Representing Music using MIDI Messages

- Three main MIDI messages
 - Note on
 - Note off
 - Time Shift



Note_on_67	Time_shift_quarter_note	Note_off_67
Note_on_67	Time_shift_quarter_note	Note_off_67,
Note_on_64,	Time_shift_quarter_note,	Note_off_64,
Note_on_64,	Time_shift_quarter_note,	Note_off_64,
...		

🤔 What about Polyphony?

Clair de Lune

from “Suite Bergamasque” L. 75
3rd Movement

Claude Debussy
(1862–1918)

Andante très expressif

Piano

pp *con sordina*

The musical score for the 3rd movement of 'Clair de Lune' by Claude Debussy is presented for piano. The time signature is 9/8. The score begins with a piano (p) dynamic and a 'con sordina' (with sostenuto) instruction. The music is characterized by its 'Andante très expressif' tempo. The notation shows a complex polyphonic texture with multiple voices and sustained chords. The score includes various musical notations such as notes, rests, and dynamic markings.

Representing Polyphonic Music

- We can now handle music with multi-pitch at the same time
 - In the literature, “polyphonic” & “multi-pitch” are often used interchangeably

Clair de Lune

from "Suite Bergamasque" L. 75

Claude Debussy (1862–1918)

3rd Movement

Andante très expressif

Piano

pp *con sordina*

2 2

Note_on_65, Note_on_68, Time_shift_eighth_note, Note_on_77, Note_on_80,
Time_shift_half_note, Note_off_77, Note_off_80, Note_on_73, Note_on_77,
Time_shift_dotted_quarter_note, Note_off_65, Note_off_68, ...

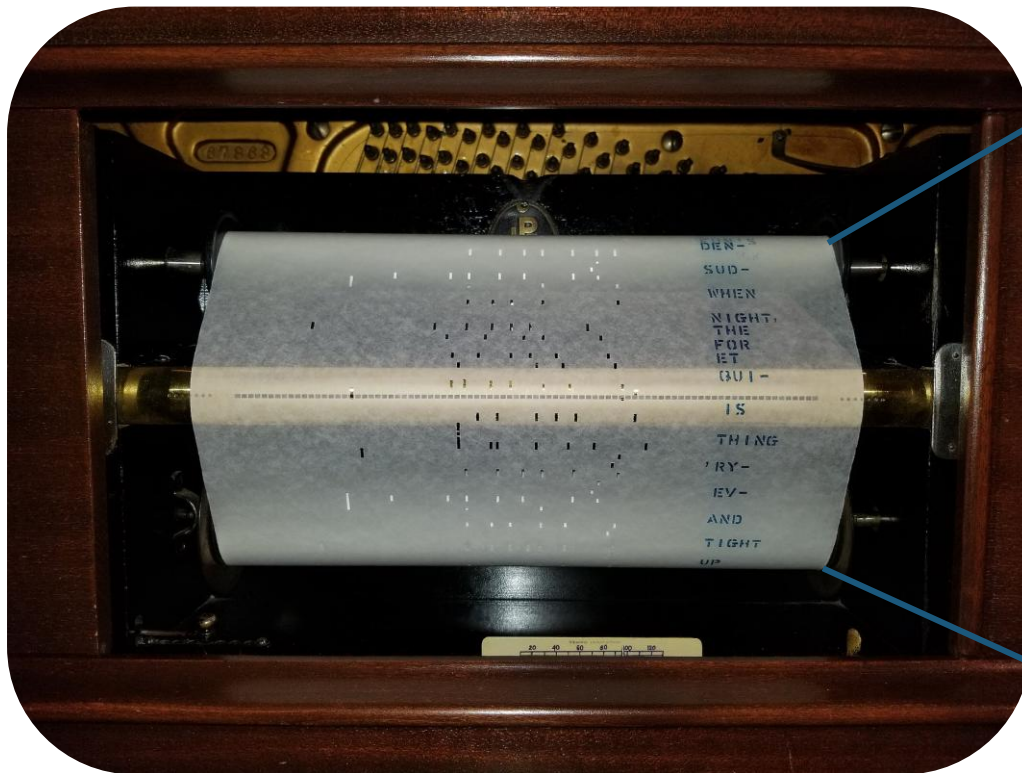
| A.I. Duet (Mann et al, 2016)



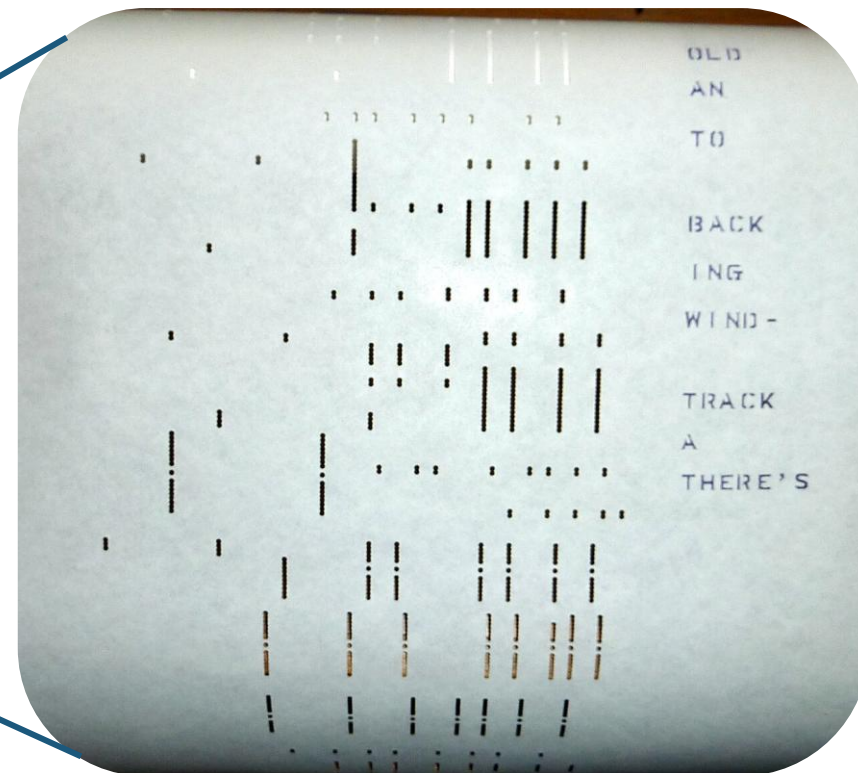
youtu.be/0ZE1bfPtvZo
experiments.withgoogle.com/ai/ai-duet/view

Piano Roll Representation

Piano Rolls



(Source: Draconichiaro)



(Source: Tangerineduel)

| Player Pianos



youtu.be/07krQ661fok

Piano Rolls at the Stearns Collection



M | STEARNS COLLECTION OF
MUSICAL INSTRUMENTS

Photos taken on April 3, 2025.

Stearns Collection of Musical Instruments

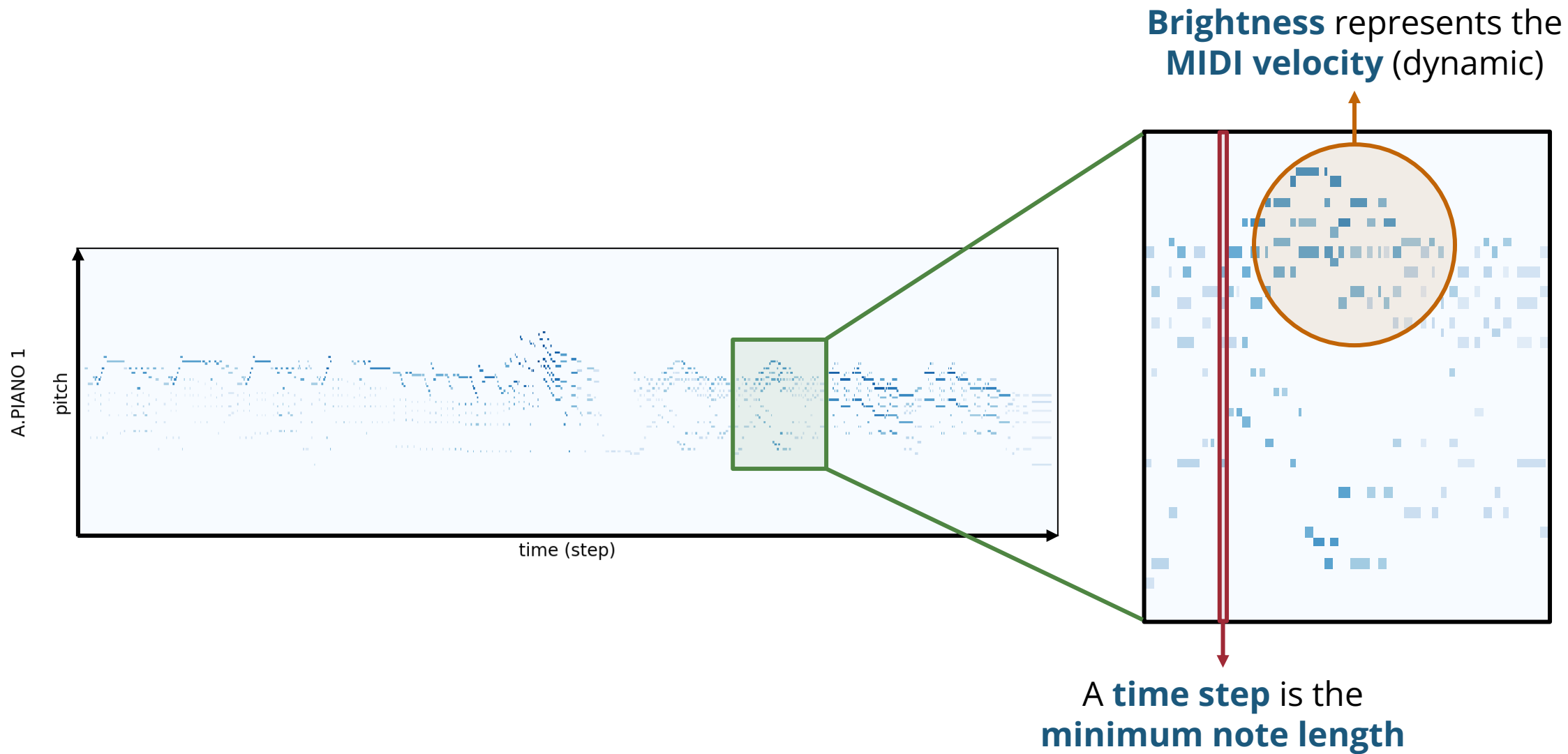


M | STEARNS COLLECTION OF
MUSICAL INSTRUMENTS

smt.d.umich.edu/stearns-collection

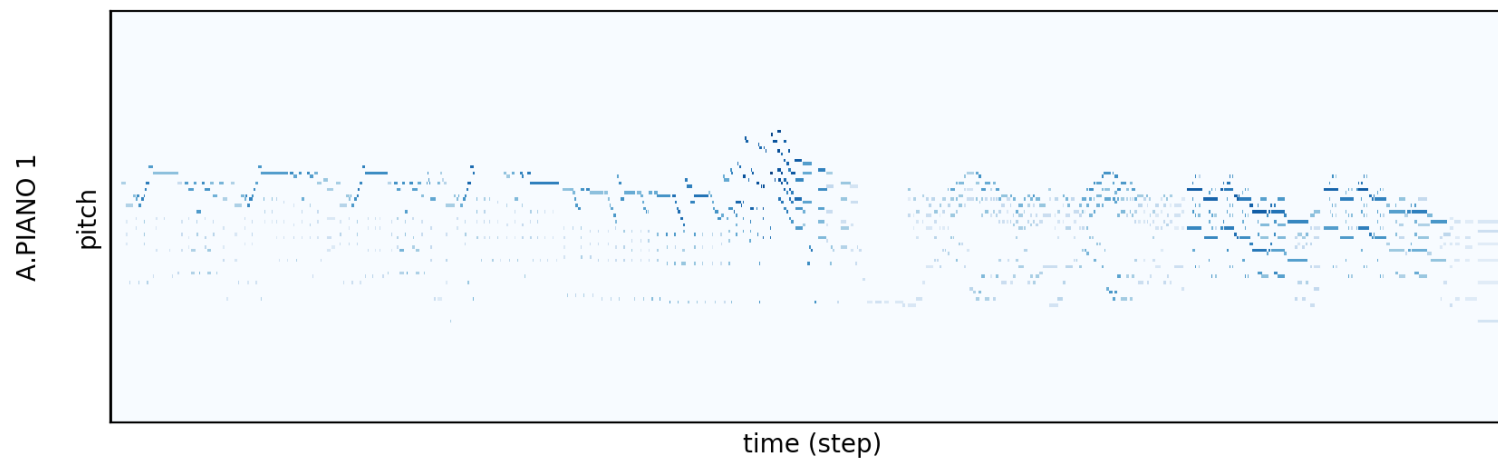
Photos taken on April 3, 2025.

Piano Roll Representation

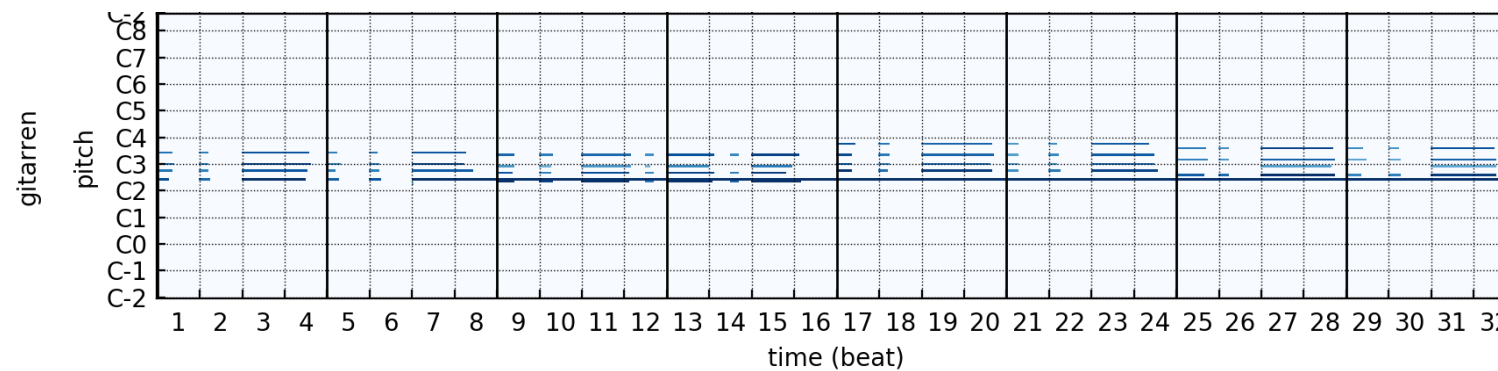


Piano Roll Representation

With expressive timing

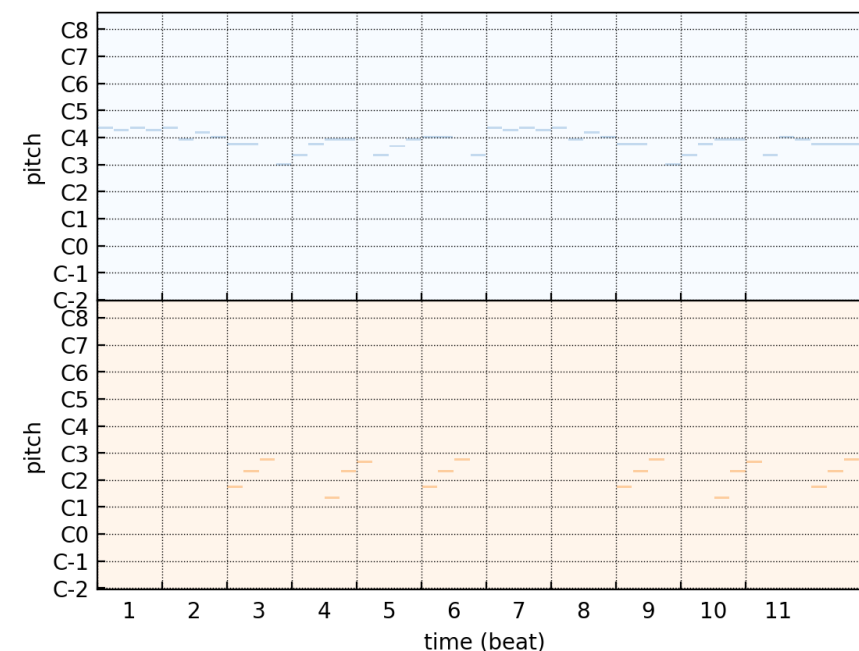


Without expressive timing



🔥 PA 1: Symbolic Music Processing

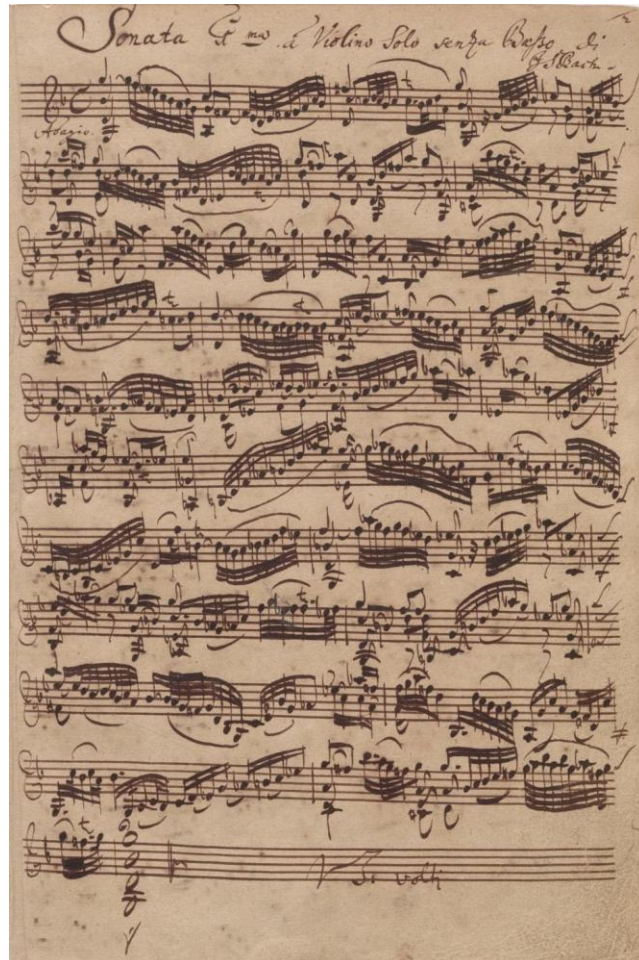
- Instructions will be sent by **emails** and released on the **course website**
- Use **MusPy** to process symbolic music
 - **Read** MIDI and MusicXML files
 - **Manipulate** notes, instruments, and tempos
 - **Show** as piano roll(s)
 - **Write** as MIDI and MusicXML files
 - **Synthesize** into WAV files
- Learn to code in **Jupyter Notebook**
- Learn about **Google Colab**



Digital Musical Scores

Staff Notations

Handwritten



Typeset

Sonata No. 1 in G Minor
for solo violin

Johann Sebastian Bach
BWV 1001

Adagio

A typeset version of the musical score for Johann Sebastian Bach's Violin Sonata No. 1 in G minor, BWV 1001. The score is presented in a clean, modern layout with a single staff and a treble clef. The key signature is one flat (F major/D minor). The tempo is marked 'Adagio'. The score includes a variety of musical notations such as notes, rests, and ornaments, and is numbered from 1 to 20. The typesetting is clear and professional, making it easy to read and play.

MusicXML

```
<?xml version="1.0" encoding="UTF-8"
standalone="no"?>
<!DOCTYPE score-partwise PUBLIC
"-//Recordare//DTD MusicXML 4.0 Partwise//EN"
"http://www.musicxml.org/dtds/partwise.dtd">
<score-partwise version="4.0">
  <part-list>
    <score-part id="P1">
      <part-name>Music</part-name>
    </score-part>
  </part-list>
  <part id="P1">
    <measure number="1">
      <attributes>
        <divisions>1</divisions>
        <key>
          <fifths>0</fifths>
        </key>
        <time>
          <beats>4</beats>
          <beat-type>4</beat-type>
        </time>
        <clef>
          <sign>G</sign>
          <line>2</line>
        </clef>
      </attributes>
      <note>
        <pitch>
          <step>C</step>
          <octave>4</octave>
        </pitch>
        <duration>4</duration>
        <type>whole</type>
      </note>
    </measure>
  </part>
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```

Temporal
resolution

Key signature

Time signature

Clef



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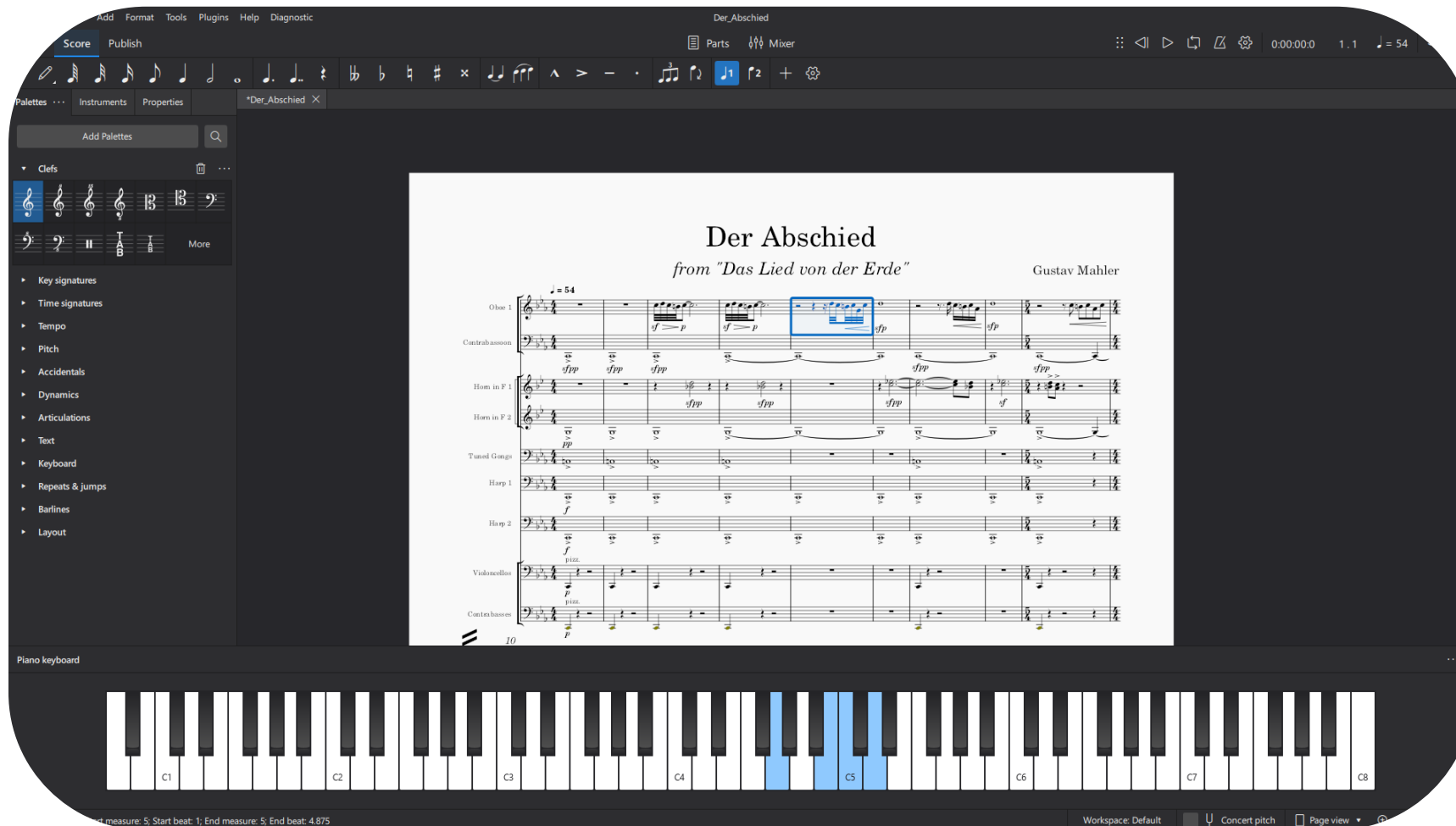


Pitch

Duration (physical)

Duration (symbolic)

Editing MusicXML Files with MuseScore



(Source: MuseScore)

Handling MusicXML Files in Python with music21

```
from music21 import *  
  
bwv295 = corpus.parse('bach/bwv295')  
  
for thisNote in bwv295.recurse().notes:  
    thisNote.addLyric(thisNote.pitch.german)  
  
bwv295.show()
```

bwv295.mxl

J.S. Bach

Soprano
Des heil'-gen Gei - stes rei - che Gnad' die Her - zen

Alto
A A D E D A A G Fis G G F F E Es D

Tenor
F G A G A A G F E D D D D A D C C

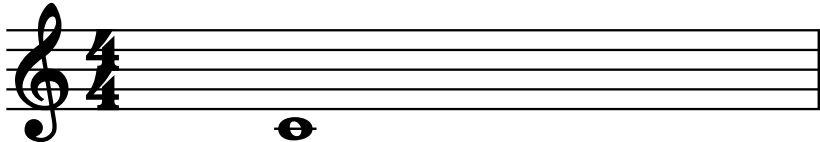
Bass
D E F E F D Cis D Fis G A B G D D E Fis

(Source: music21.org)

Music Encoding Initiative (MEI)

```
<?xml version="1.0" encoding="UTF-8"?>
<mei xmlns="http://www.music-encoding.org/ns/mei" meiversion="5.1">
  <meiHead>
    <fileDesc>
      <titleStmt>
        <title>Hello World</title>
      </titleStmt>
      <pubStmt></pubStmt>
    </fileDesc>
  </meiHead>
  <music>
    <body>
      <mdiv>
        <score>
          <scoreDef>
            <staffGrp>
              <staffDef n="1" lines="5" clef.shape="G" clef.line="2" meter.count="4" meter.unit="4" />
            </staffGrp>
          </scoreDef>
          <section>
            <measure n="1">
              <staff n="1">
                <layer n="1">
                  <note pname="c" oct="4" dur="1" />
                </layer>
              </staff>
            </measure>
          </section>
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Hello World

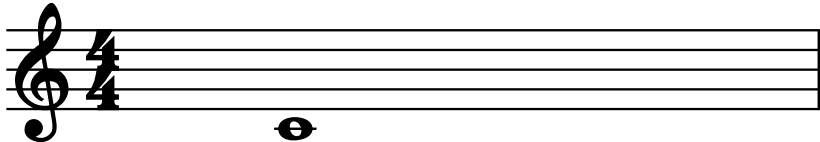


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```

Metadata

Hello World

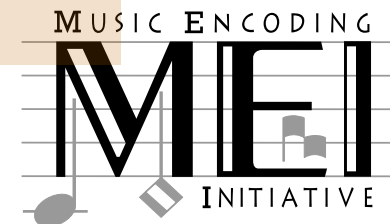
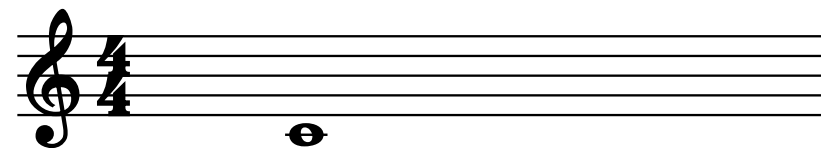


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```

Score

Hello World



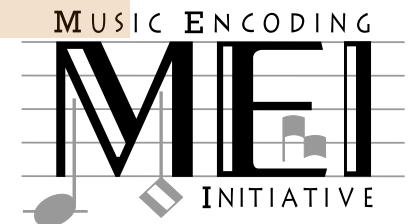
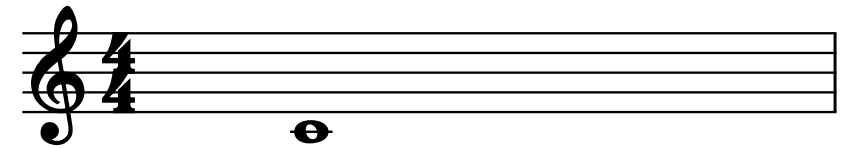
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          <scoreDef>
            <staffGrp>
              <staffDef n="1" lines="5" clef.shape="G" clef.line="2" meter.count="4" meter.unit="4" />
            </staffGrp>
          </scoreDef>
          <section>
            <measure n="1">
              <staff n="1">
                <layer n="1">
                  <note pname="c" oct="4" dur="1" />
                </layer>
              </staff>
            </measure>
          </section>
        </score>
      </mdiv>
    </body>
  </music>
</mei>
```

Score Definition

A section

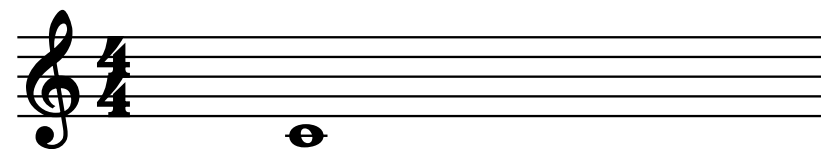
Hello World



Music Encoding Initiative (MEI)

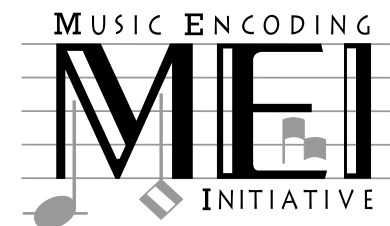
```
<?xml version="1.0" encoding="UTF-8"?>
<mei xmlns="http://www.music-encoding.org/ns/mei" meiversion="5.1">
  <meiHead>
    <fileDesc>
      <titleStmt>
        <title>Hello World</title>
      </titleStmt>
      <pubStmt></pubStmt>
    </fileDesc>
  </meiHead>
  <music>
    <body>
      <mdiv>
        <score>
          <scoreDef>
            <staffGrp>
              <staffDef n="1" lines="5" clef.shape="G" clef.line="2" meter.count="4" meter.unit="4" />
            </staffGrp>
          </scoreDef>
          <section>
            <measure n="1">
              <staff n="1">
                <layer n="1">
                  <note pname="c" oct="4" dur="1" />
                </layer>
              </staff>
            </measure>
          </section>
        </score>
      </mdiv>
    </body>
  </music>
</mei>
```

Hello World



Clef

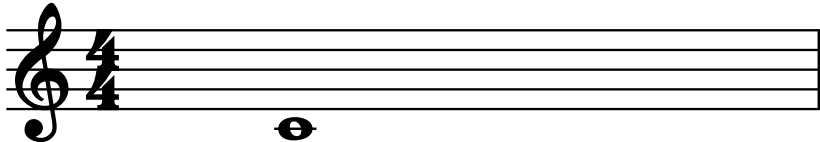
Time signature



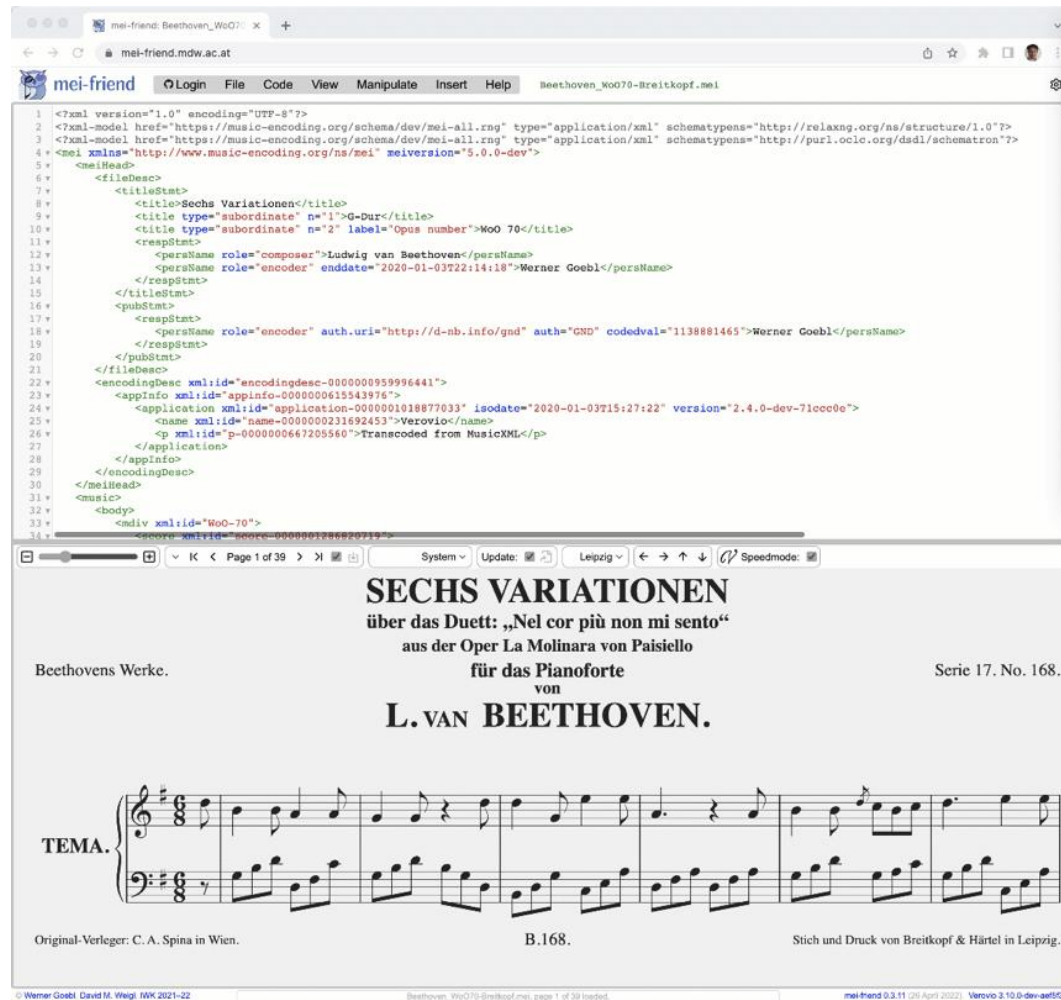
Music Encoding Initiative (MEI)

```
<?xml version="1.0" encoding="UTF-8"?>
<mei xmlns="http://www.music-encoding.org/ns/mei" meiversion="5.1">
  <meiHead>
    <fileDesc>
      <titleStmt>
        <title>Hello World</title>
      </titleStmt>
      <pubStmt></pubStmt>
    </fileDesc>
  </meiHead>
  <music>
    <body>
      <mdiv>
        <score>
          <scoreDef>
            <staffGrp>
              <staffDef n="1" lines="5" clef.shape="G" clef.line="2" meter.count="4" meter.unit="4" />
            </staffGrp>
          </scoreDef>
          <section>
            <measure n="1">
              <staff n="1">
                <layer n="1">
                  <note pname="c" oct="4" dur="1" />
                </layer>
              </staff>
            </measure>
          </section>
        </score>
      </mdiv>
    </body>
  </music>
</mei>
```

Hello World



Editing MEI Files with MEI-Friend & Verovio



mei-friend



(Source: github.com/mei-friend/mei-friend)

Editing MEI Files with MEI-Friend & Verovio

mei-friend Login File Code View Manipulate Insert Help CMN 5.1 Demo encoding: Baumann-Ludwig_Mondnacht-am-Meer.mei

6 Verovio warnings: [Warning] Time spanning element 'tie' with @xml:id 't13v16fz', @startid '#n12e2cy1', and @endid '#n1105wtn' could not be matched. ↓ x

Mondnacht am Meer
nach Mus. Hs. 1324
Ludwig Baumann

p U - ber'm

Full page ☐ Show zone boxes ☒ Edit zones ☐

img/Baumann-Ludwig_Mondnacht-am-Meer/01.jpg

0:01 / 0:04 Speed mode No expansion

Hosted by IWK at mdw, with ♥ from Vienna. Imprint.

Baumann-Ludwig_Mondnacht-am-Meer.mei, page 1 of 15 loaded.

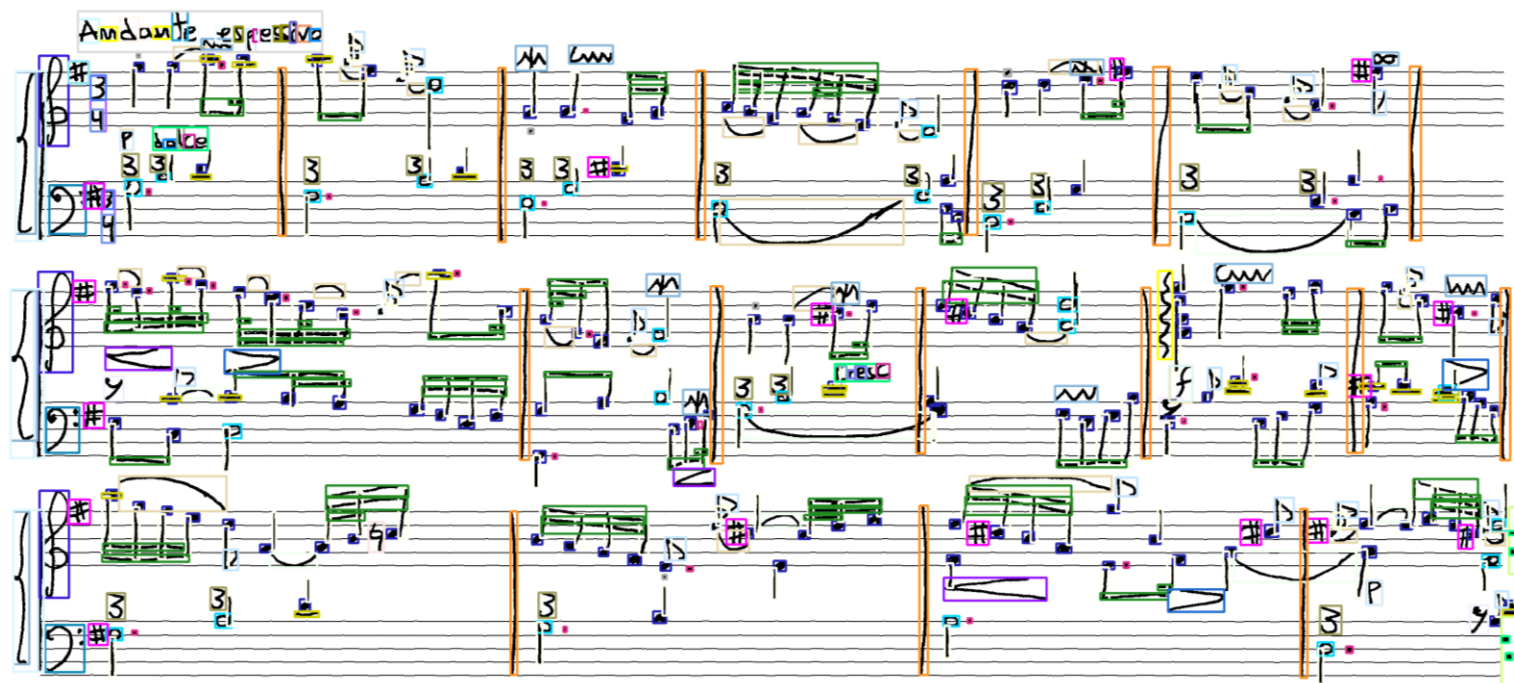
mei-friend 1.4.2 (9 July 2026). Verovio 6.3.0-425dd7b

```
1 <?xml version="1.0" encoding="UTF-8"?>
2 <?xml-model href="https://music-encoding.org/schema/5.1/mei-CMN.rng" type="application/xml" schematypens="i
3 <?xml-model href="https://music-encoding.org/schema/5.1/mei-CMN.rng" type="application/xml" schematypens="i
4 <mei xmlns="http://www.music-encoding.org/ns/mei" meiversion="5.1">
5   <meiHead>
6     <fileDesc>
7       <title>Mondnacht am Meer</title>
8     <respStmt>
9       <persName xml:id="lb" auth="GND" auth.uri="https://d-nb.info/gnd/" codedval="117758817" role="composer">Luc
10      <persName xml:id="ap" auth="GND" auth.uri="https://d-nb.info/gnd/" codedval="1229022201" role="encoder">Ani
11    </respStmt>
12    </title>
13    <pubStmt>
14      <date isodate="2024-08-01T09:59:15"/>
15    </pubStmt>
16    <fileDesc>
17      <encodingDesc xml:id="eh7ebg01">
18        <appInfo xml:id="a3tff0c1">
19          <application xml:id="a03mgbf" enddate="2026-06-02T12:29:31" startdate="2024-08-01T10:49:53" version="1.3.0"
20          <name xml:id="nbtjpo81">mei-friend</name>
21        <p xml:id="p24vfb71">First edit by mei-friend 1.1.5, 14 May 2024.</p>
22      </application>
23    </appInfo>
24    <encodingDesc>
25      <meiHead>
26        <music xml:id="mm9bgqh1">
27          <facsimile xml:id="fgyean2">
28            <surface xml:id="surface_01J46HF9ZHFCAXXKMAJ7X4VW9" lrx="1999" lry="2580" n="1" ulx="0" uly="0">
29              <graphic xml:id="graphic_01J46HF9ZHFCAXXKMAJ7X4VW9" height="2581" target="img/Baumann-Ludwig_
30              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="1036" lry="804" type="measure" ulx="127" u
31              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="1715" lry="803" type="measure" ulx="999" u
32              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="1016" lry="1334" type="measure" ulx="142" u
33              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="1716" lry="1333" type="measure" ulx="983" u
34              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="1003" lry="1867" type="measure" ulx="162" u
35              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="1705" lry="1856" type="measure" ulx="966" u
36              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="987" lry="2375" type="measure" ulx="165" u
37              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="1726" lry="2388" type="measure" ulx="962" u
38            </surface>
39            <surface xml:id="surface_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="1999" lry="2580" n="2" ulx="0" uly="0">
40              <graphic xml:id="graphic_01J46HF9ZJRWGJ7WCNPEY2G62" height="2581" target="img/Baumann-Ludwig_
41              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="1005" lry="790" type="measure" ulx="238" u
42              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="1772" lry="803" type="measure" ulx="966" u
43              <zone xml:id="zone_01J46HF9ZJRWGJ7WCNPEY2G62" lrx="991" lry="1313" type="measure" ulx="934" u
44            </surface>
45          </facsimile>
46        </music>
47      </meiHead>
48    </encodingDesc>
49  </meiHead>
50 </mei>
```

mei-friend.mdw.ac.at

🤔 Can't we use sheet music "scans" directly?

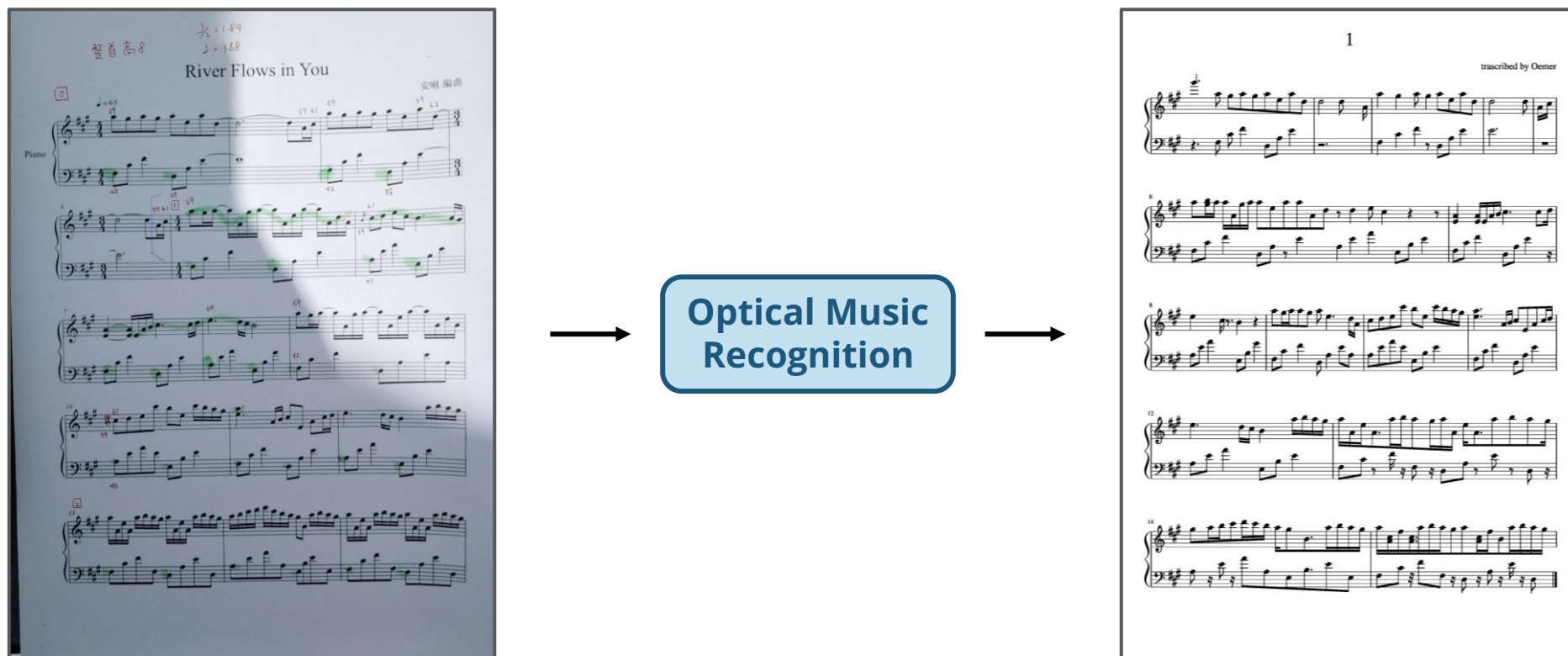
- Machines still have a hard time reading scanned sheet music
- A task known as **optical music recognition (OMR)**



(Source: Pacha et al.)

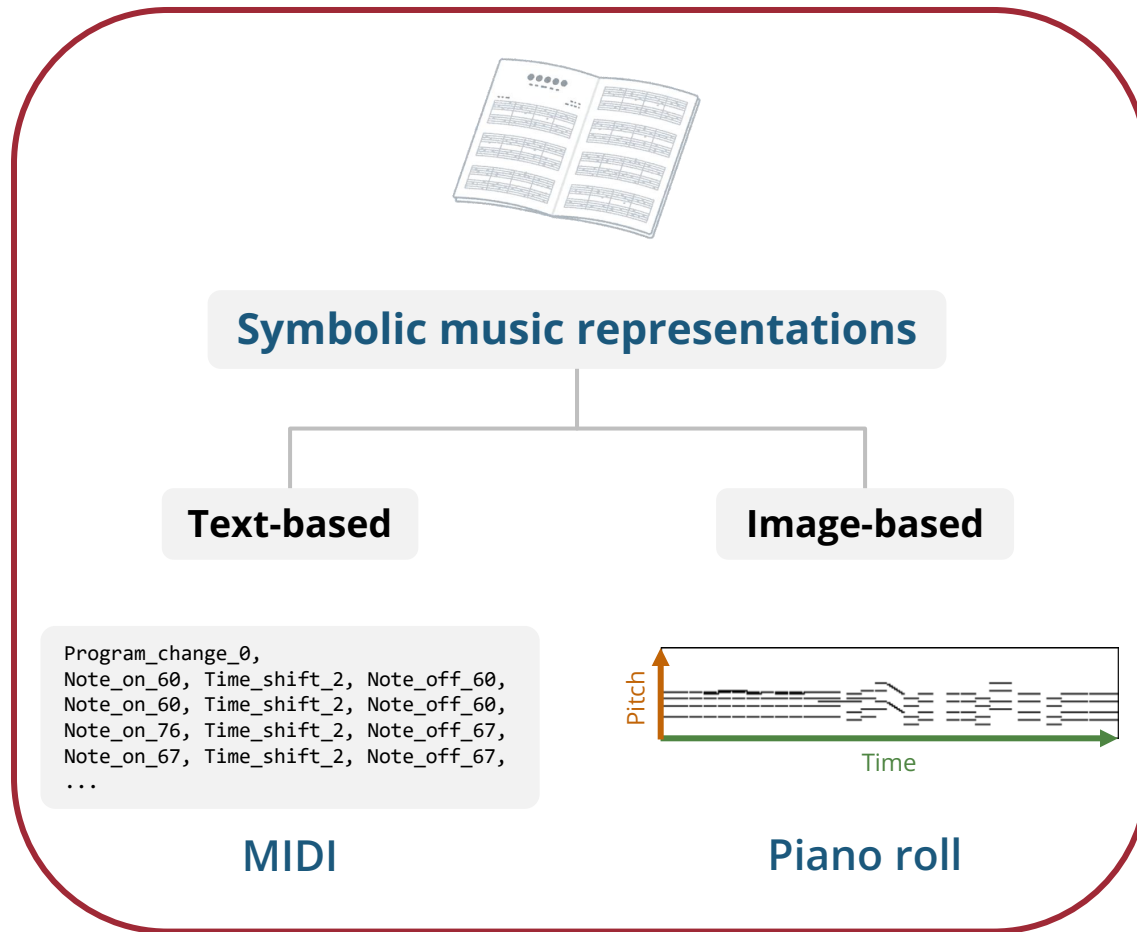
Optical Music Recognition (OMR)

- **Goal:** Convert **scanned sheet music** into **digital musical notation**

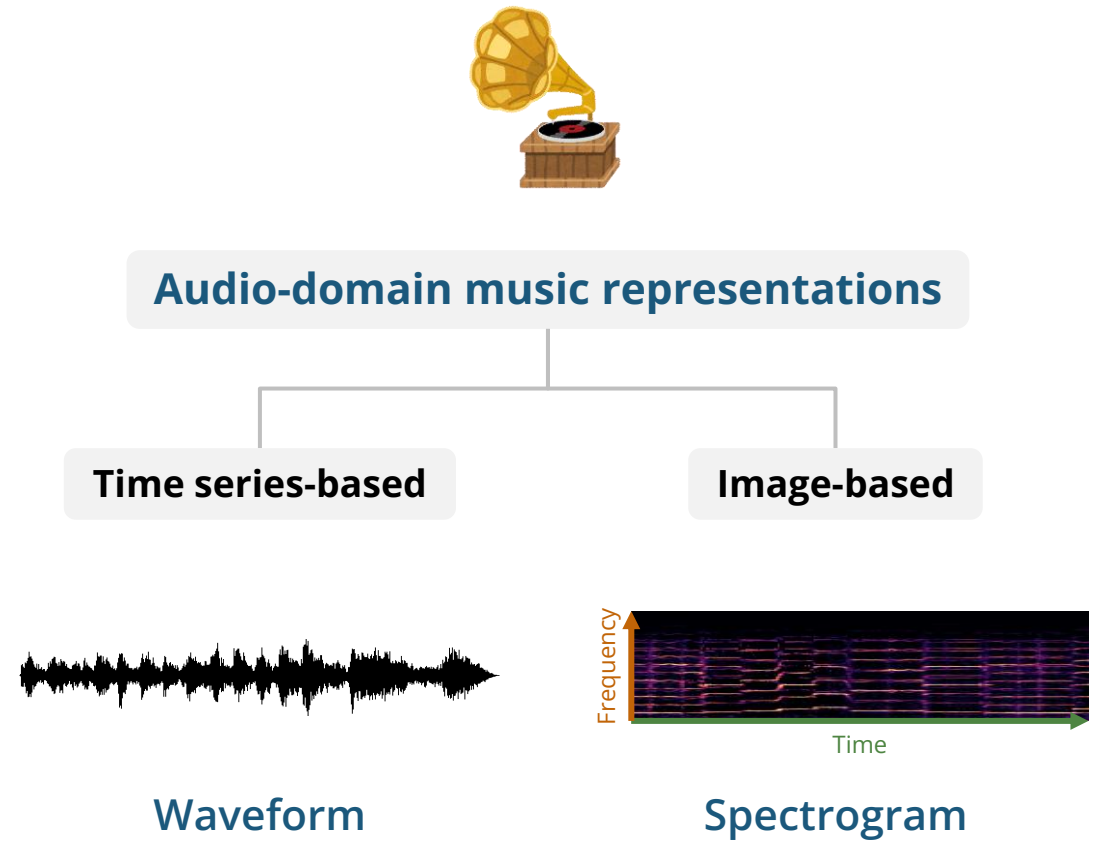


Recap

Music Representations



Today's topic!



An Example of ABC Notation

Ah! vous dirai-je, maman
(Twinkle, twinkle, little star)

anon. (France)

$\text{♩} = 120$

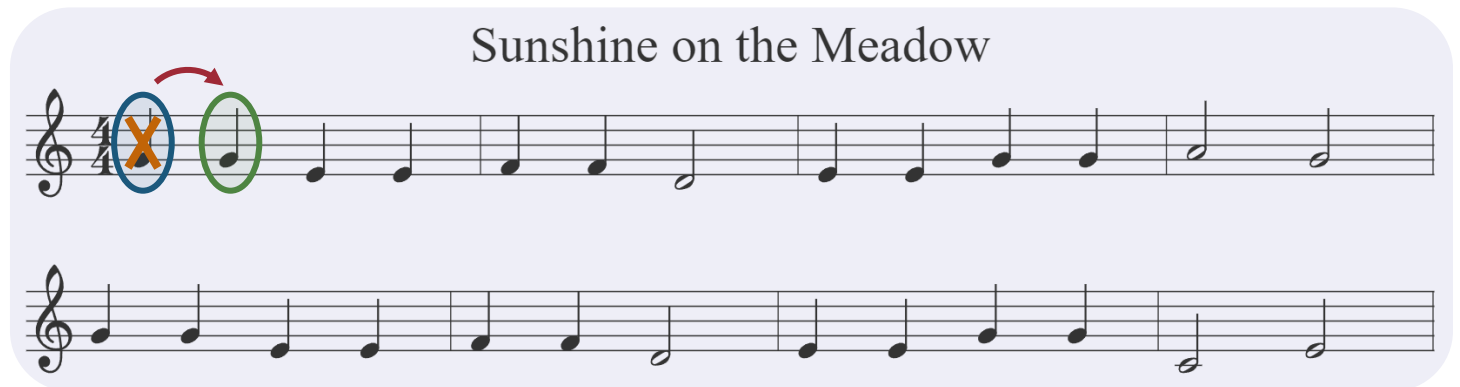
The image shows a musical score for the song 'Ah! vous dirai-je, maman' (Twinkle, twinkle, little star). The score is written in three staves. The first staff has a tempo marking of $\text{♩} = 120$. The first staff has an orange box around the first four notes (C4, D4, E4, F4) and a green box around the next four notes (G4, A4, B4, C5). A red circle highlights the C5 note. Lines connect these boxes to the corresponding ABC notation: CCGG (orange), AAG2 (green), and A (red).

Metadata

```
X:571
T:Ah! vous dirai-je, maman
T:(Twinkle, twinkle, little star)
C:anon.
O:France
R:Nursery song
M:C Meter
L:1/4 Unit note length (temporal resolution)
Q:120 Tempo
K:C Key
CCGG AAG2| FFEE| DDC2:|
|: GGFF| EED2| GGFF| EED2|
CCGG| AAG2| FFEE| DDC2:|
```

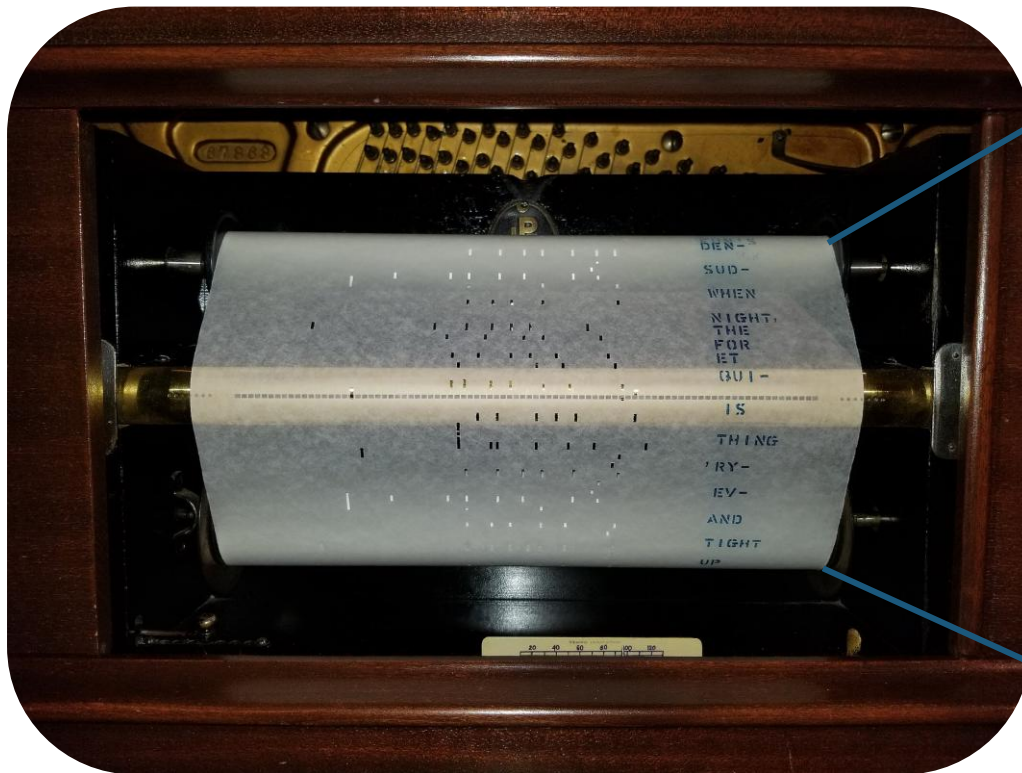
Representing Music using MIDI Messages

- Three main MIDI messages
 - Note on
 - Note off
 - Time Shift

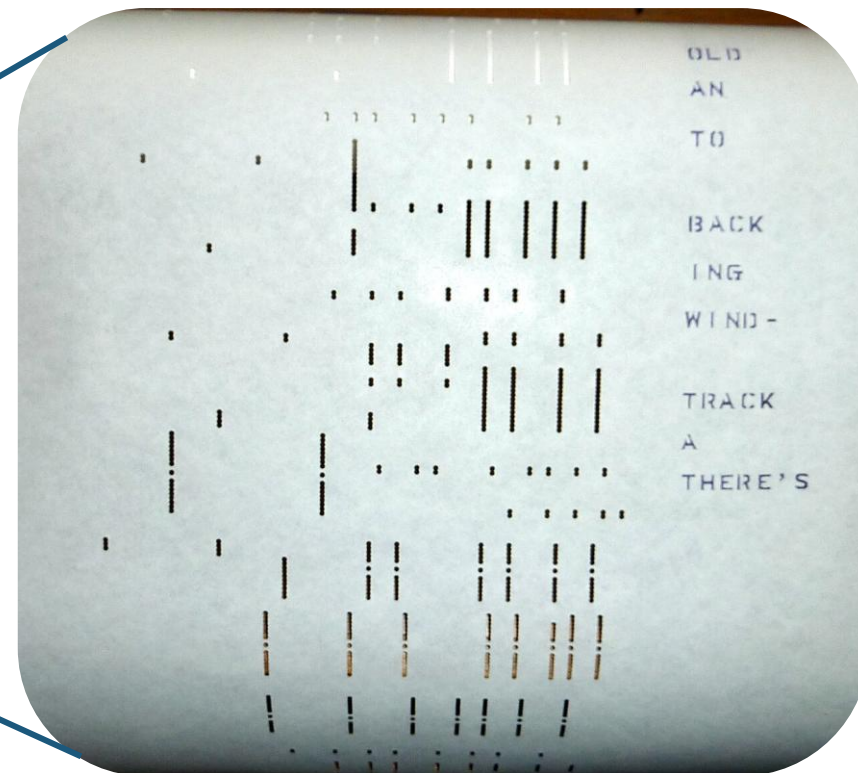


Note_on_67	Time_shift_quarter_note	Note_off_67
Note_on_67	Time_shift_quarter_note	Note_off_67,
Note_on_64,	Time_shift_quarter_note,	Note_off_64,
Note_on_64,	Time_shift_quarter_note,	Note_off_64,
...		

Piano Rolls

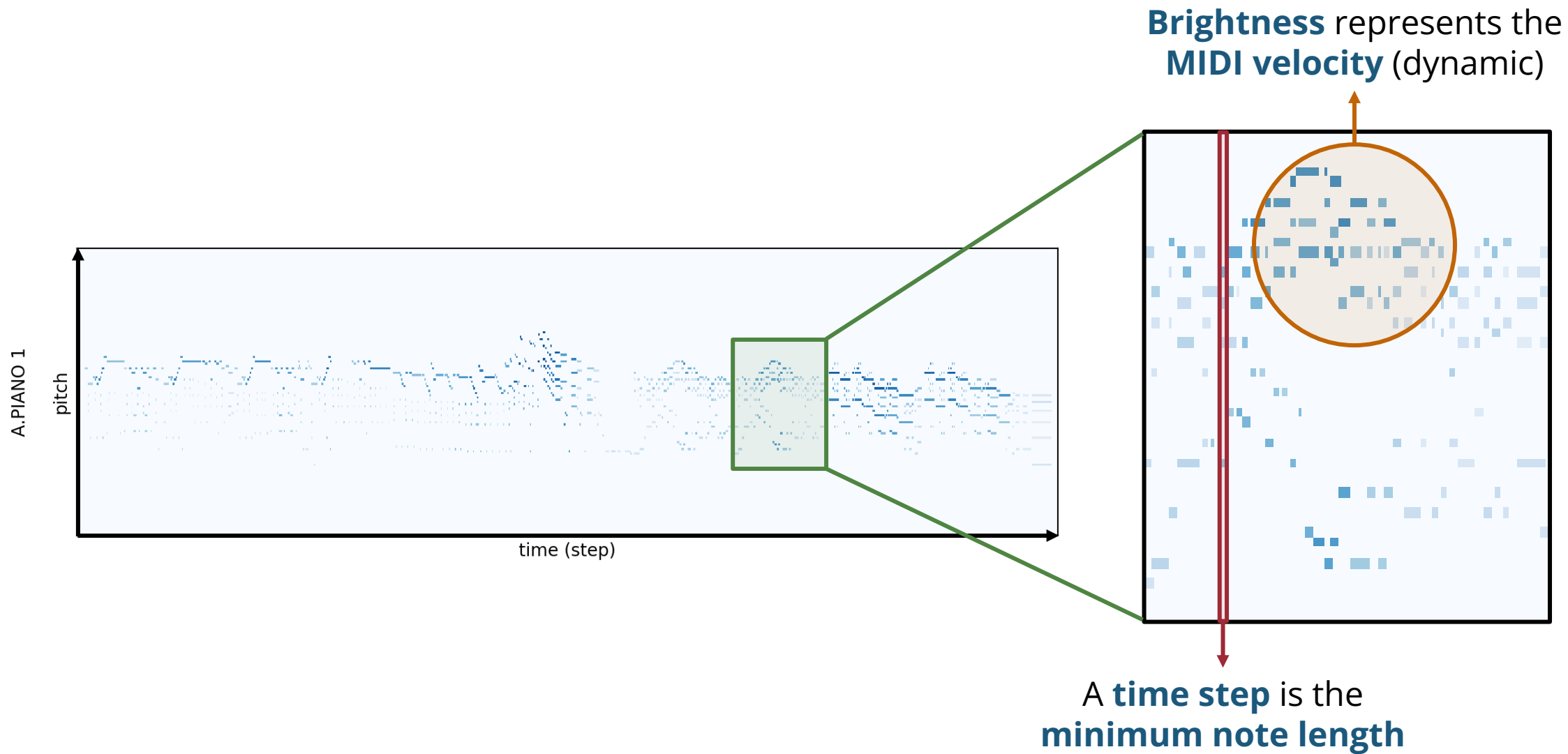


(Source: Draconichiaro)



(Source: Tangerineduel)

Piano Roll Representation



MusicXML

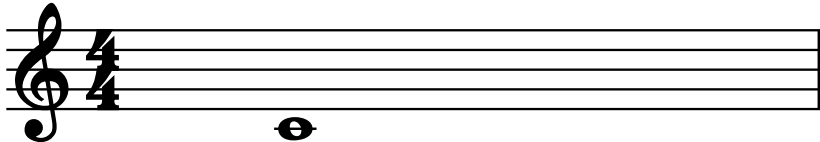
```
<?xml version="1.0" encoding="UTF-8"
standalone="no"?>
<!DOCTYPE score-partwise PUBLIC
"-//Recordare//DTD MusicXML 4.0 Partwise//EN"
"http://www.musicxml.org/dtds/partwise.dtd">
<score-partwise version="4.0">
  <part-list>
    <score-part id="P1">
      <part-name>Music</part-name>
    </score-part>
  </part-list>
  <part id="P1">
    <measure number="1">
      <attributes>
        <divisions>1</divisions>
        <key>
          <fifths>0</fifths>
        </key>
        <time>
          <beats>4</beats>
          <beat-type>4</beat-type>
        </time>
        <clef>
          <sign>G</sign>
          <line>2</line>
        </clef>
      </attributes>
      <note>
        <pitch>
          <step>C</step>
          <octave>4</octave>
        </pitch>
        <duration>4</duration>
        <type>whole</type>
      </note>
    </measure>
  </part>
</score-partwise>
```



Music Encoding Initiative (MEI)

```
<?xml version="1.0" encoding="UTF-8"?>
<mei xmlns="http://www.music-encoding.org/ns/mei" meiversion="5.1">
  <meiHead>
    <fileDesc>
      <titleStmt>
        <title>Hello World</title>
      </titleStmt>
      <pubStmt></pubStmt>
    </fileDesc>
  </meiHead>
  <music>
    <body>
      <mdiv>
        <score>
          <scoreDef>
            <staffGrp>
              <staffDef n="1" lines="5" clef.shape="G" clef.line="2" meter.count="4" meter.unit="4" />
            </staffGrp>
          </scoreDef>
          <section>
            <measure n="1">
              <staff n="1">
                <layer n="1">
                  <note pname="c" oct="4" dur="1" />
                </layer>
              </staff>
            </measure>
          </section>
        </score>
      </mdiv>
    </body>
  </music>
</mei>
```

Hello World



Next Lecture

Digital Audio



1 Second



(Source: van den Oord et al., 2016)