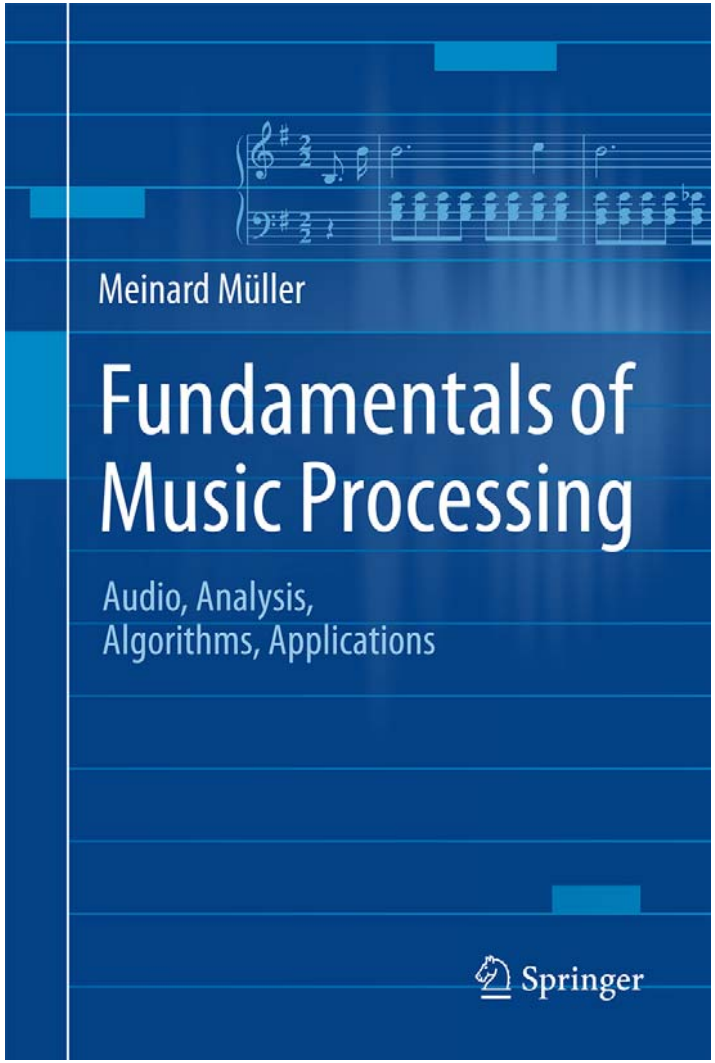
Book: Fundamentals of Music Processing



Meinard Müller
Fundamentals of Music Processing
Audio, Analysis, Algorithms, Applications
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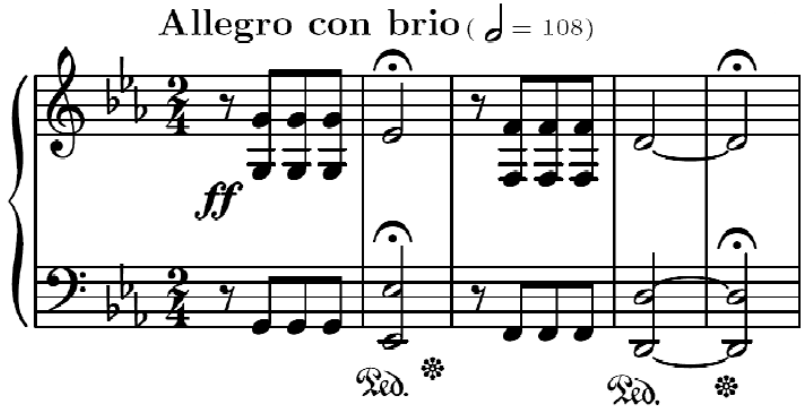
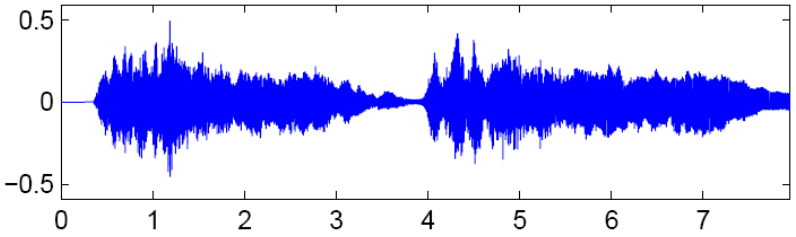
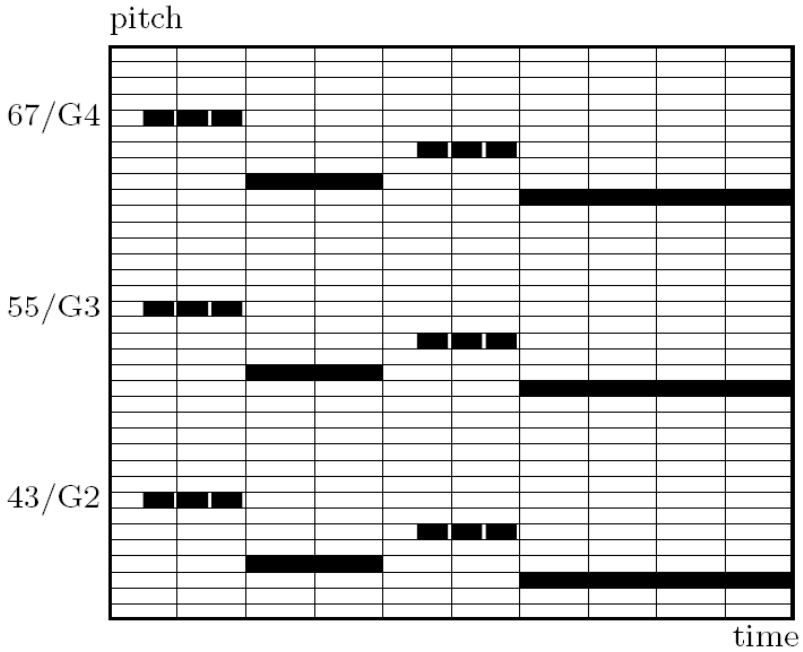
Accompanying website:
www.music-processing.de

Music Representations







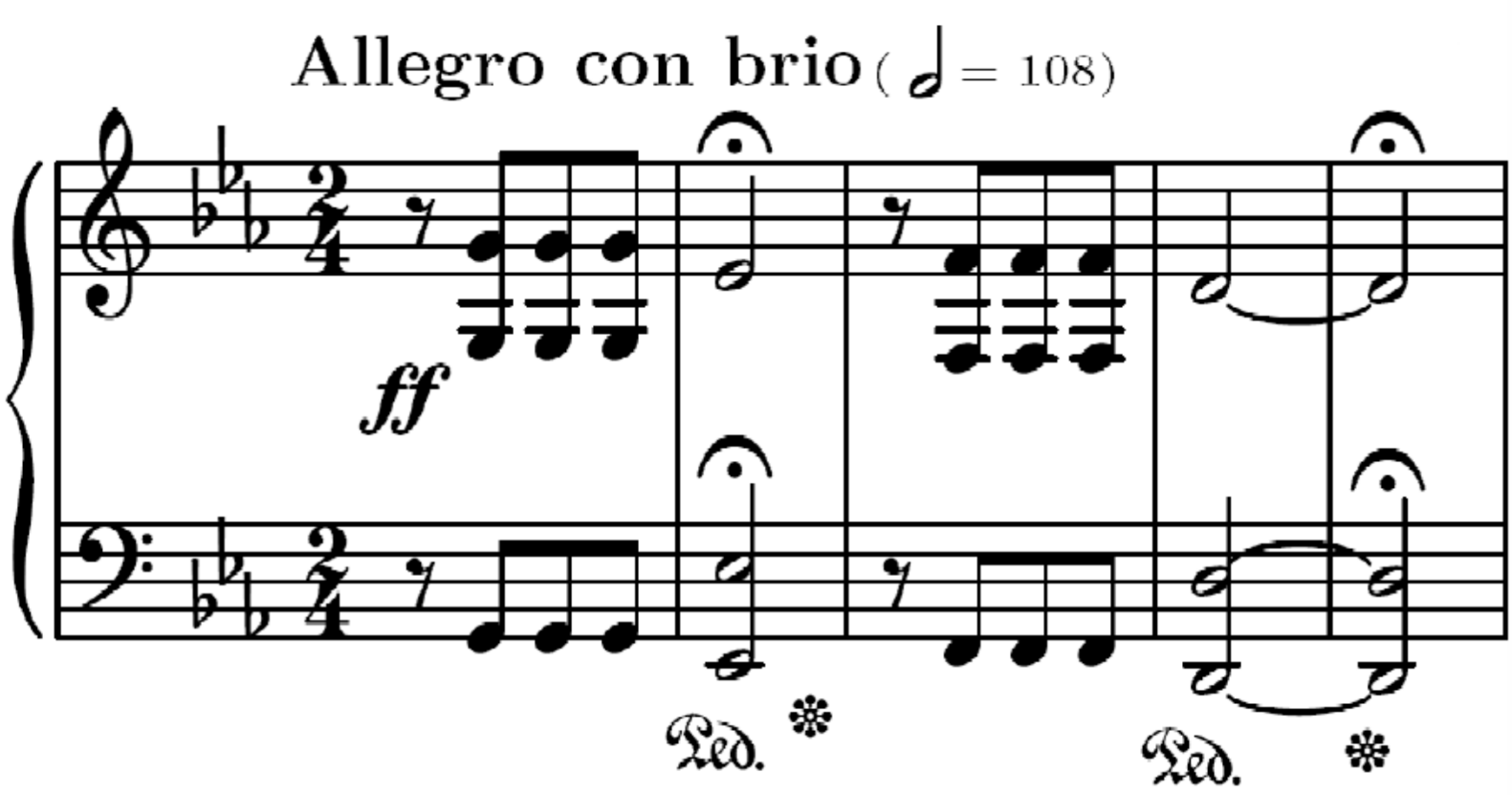
Music Representations

- Sheet music representation
  - visual description of a musical score
  - image format (printed or scanned)
- Symbolic representations
  - description based on entities with explicit musical meaning
  - given in digital format that can be parsed by a computer
- Audio representation
  - physical description
  - encoding of sound wave

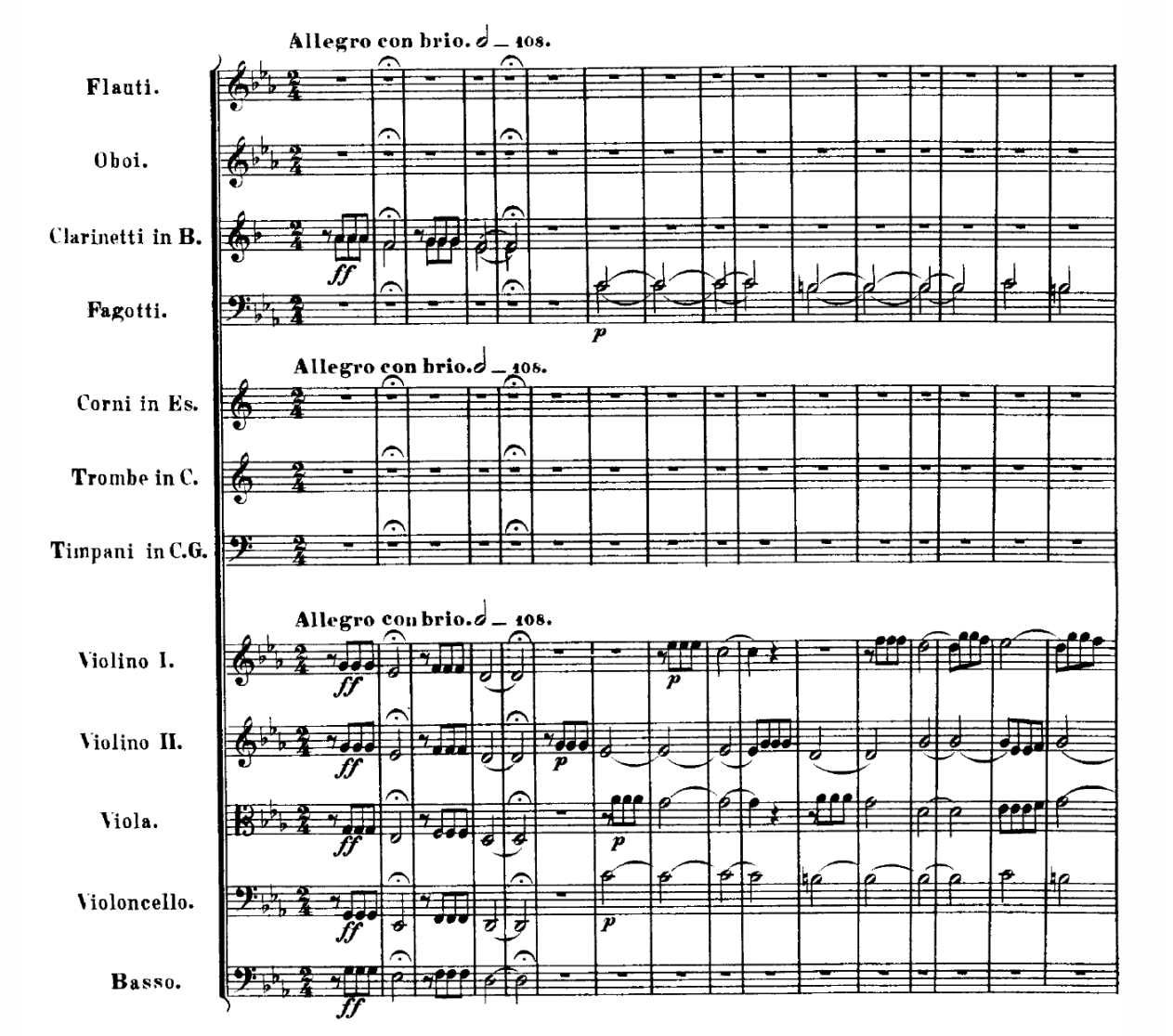
Sheet Music Representation

- Graphical-textual encoding of musical parameters
  - notes (onsets, pitches, durations)
  - tempo, measure, dynamics
  - instrumentation
  - …
- Guide for performing music
- Leaves freedom for various interpretations

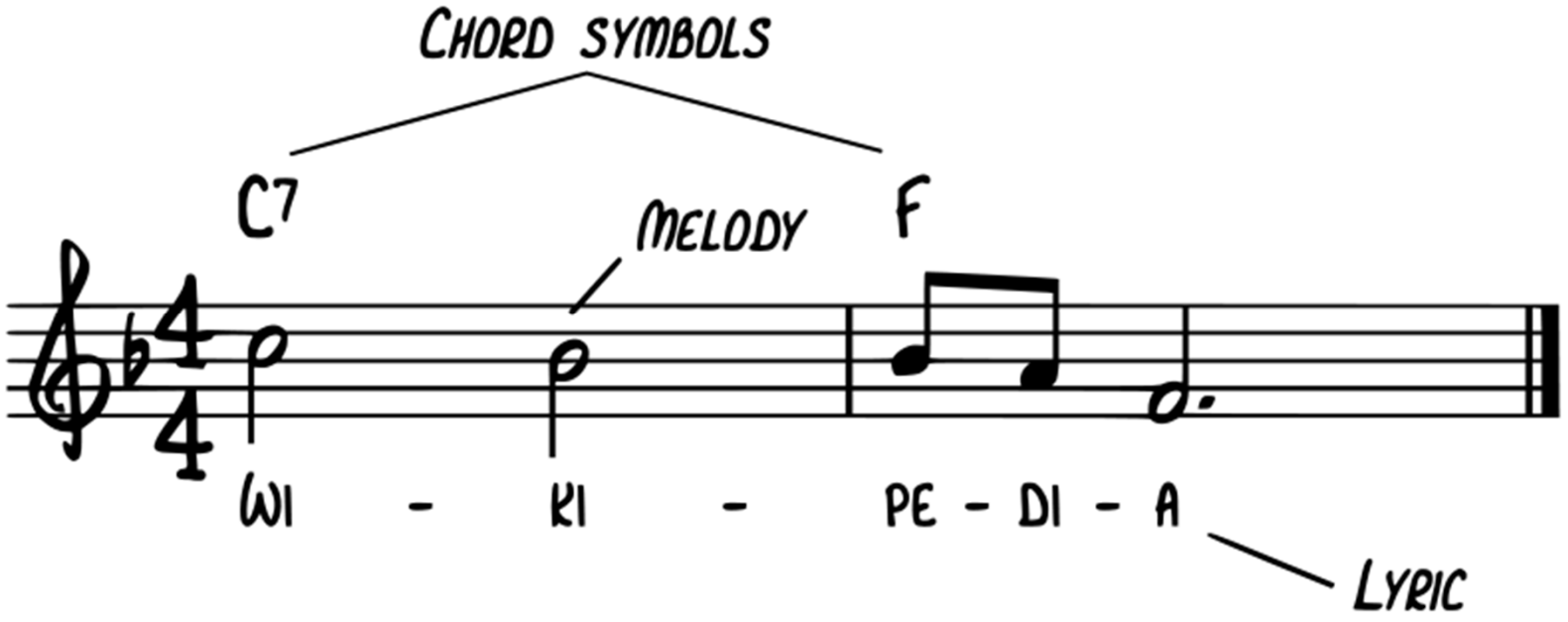
Sheet Music Representation



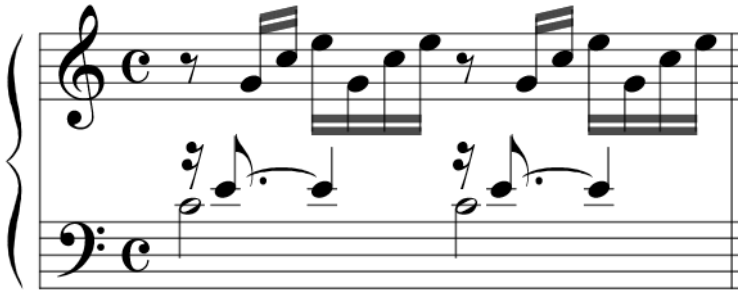
Sheet Music Representation

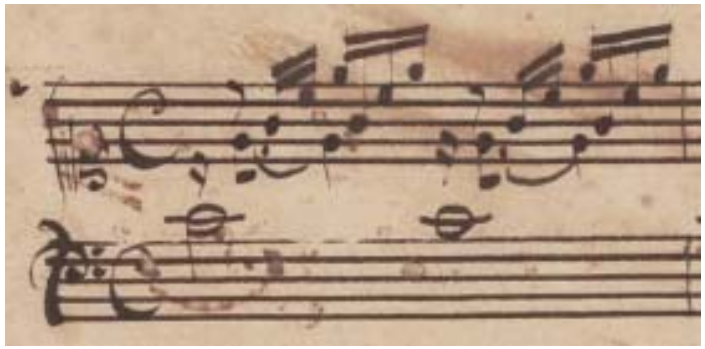


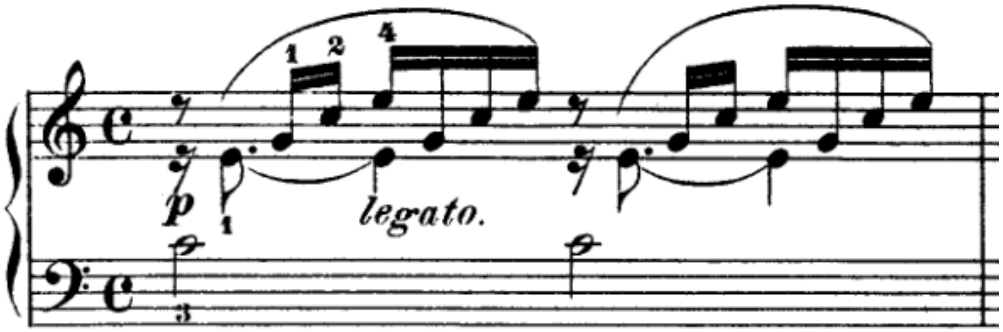
Sheet Music Representation

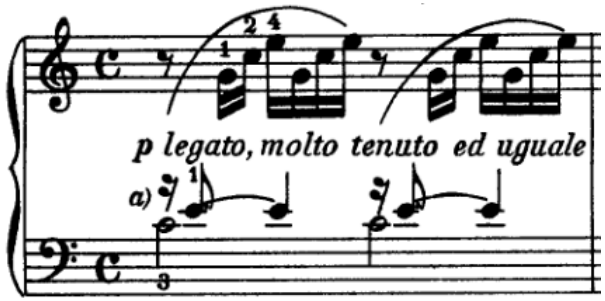


Sheet Music Representation









Symbolic Representation

- Symbolic description of music
  - based on entities that have an explicit musical meaning
  - given in some digital format
  - can be parsed by a computer

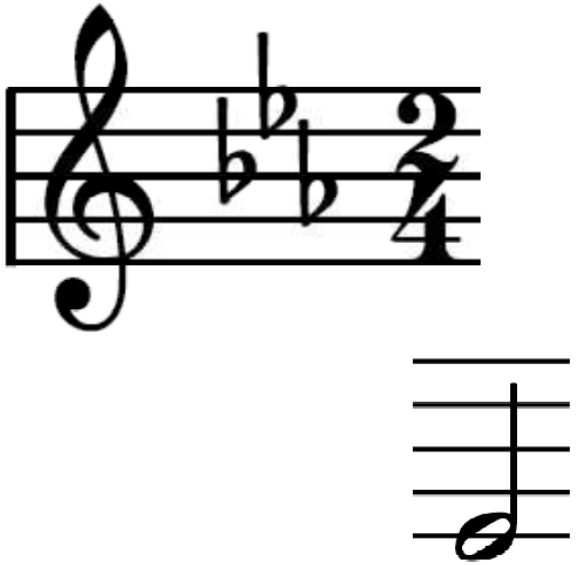
- Note:
  - Scanned sheet music based on pixels
  - Digital audio file based on samples

  are not regarded as being symbolic music formats

Symbolic Representation

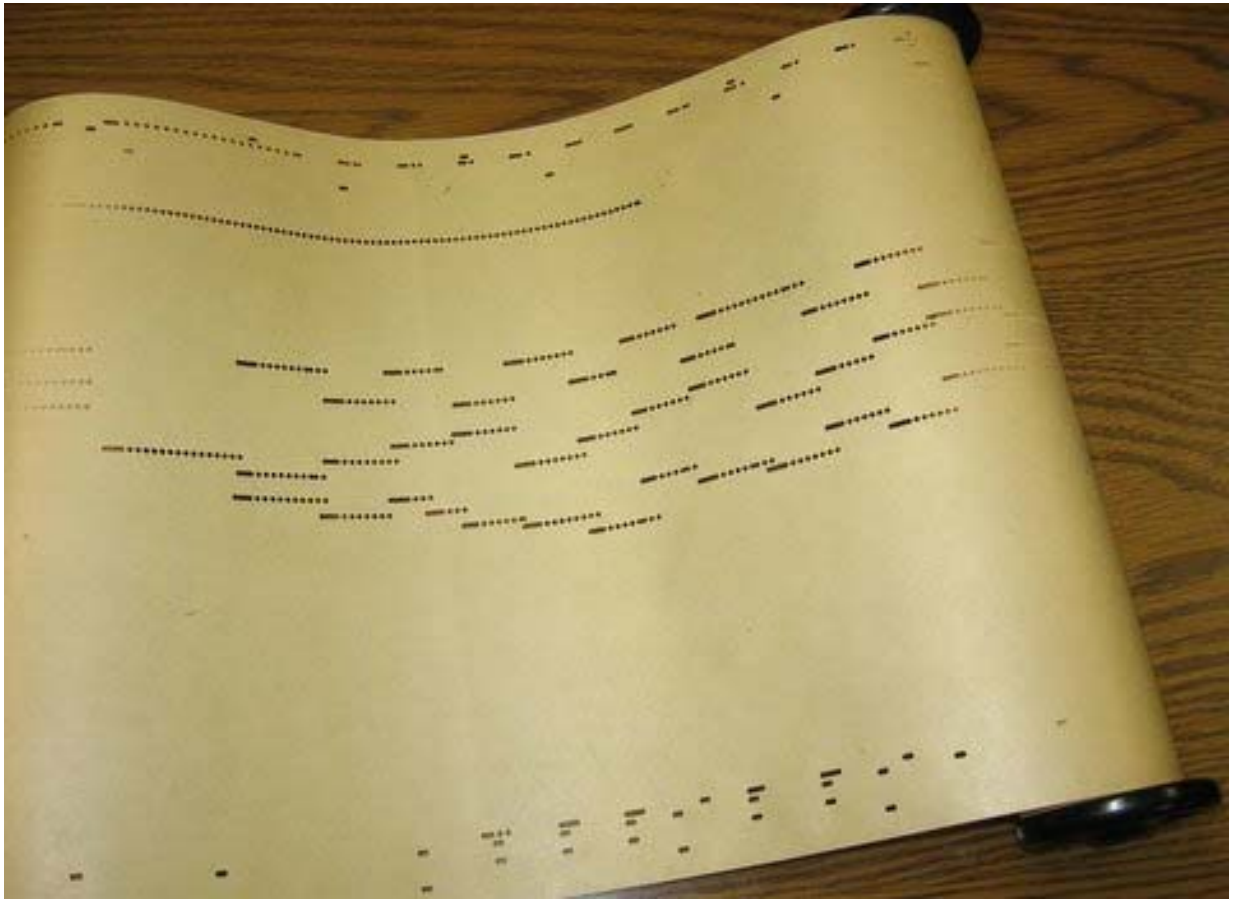
MusicXML

```
<note>
  <pitch>
    <step>E</step>
    <alter>-1</alter>
    <octave>4</octave>
  </pitch>
  <duration>2</duration>
  <type>half</type>
</note>
```



Symbolic Representation

Piano roll representation



Symbolic Representation

Piano roll representation

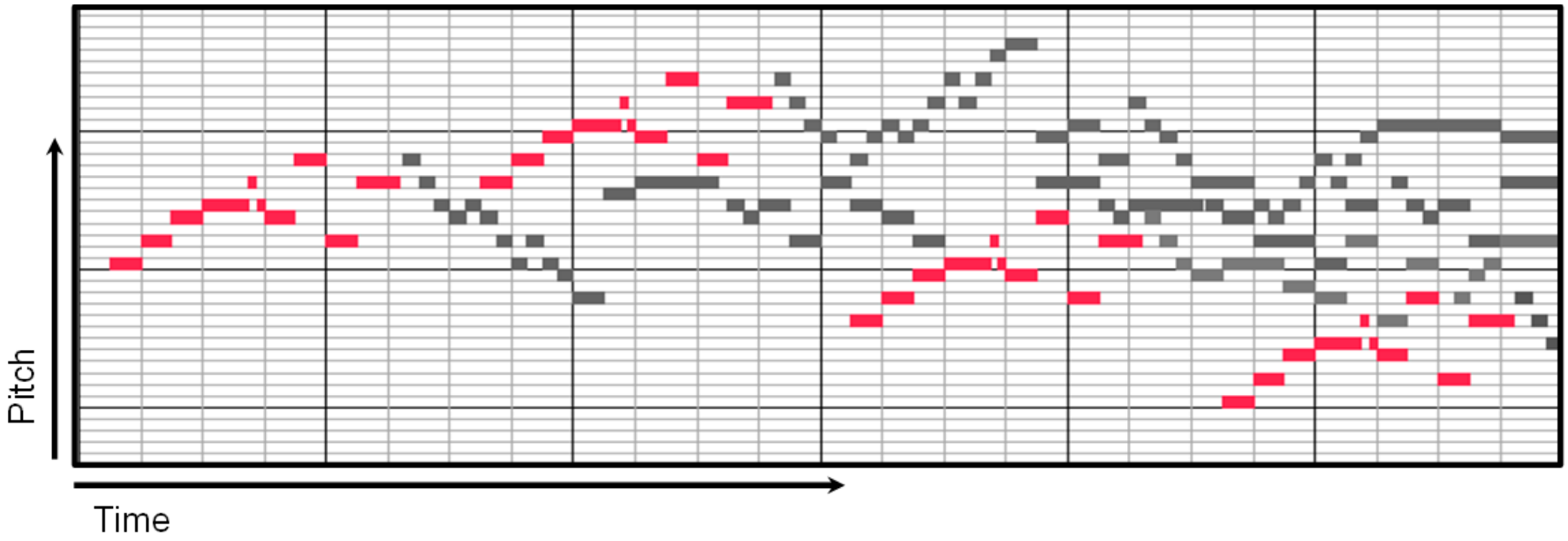
Symbolic Representation

Piano roll representation

- Piano roll: music storage medium used to operate a player piano
- Perforated paper rolls
- Holes in the paper encode the note parameters onset, duration, and pitch
- First pianola: 1895

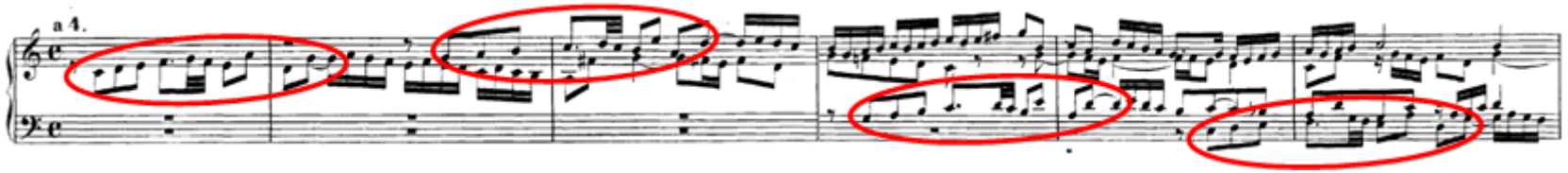
Symbolic Representation

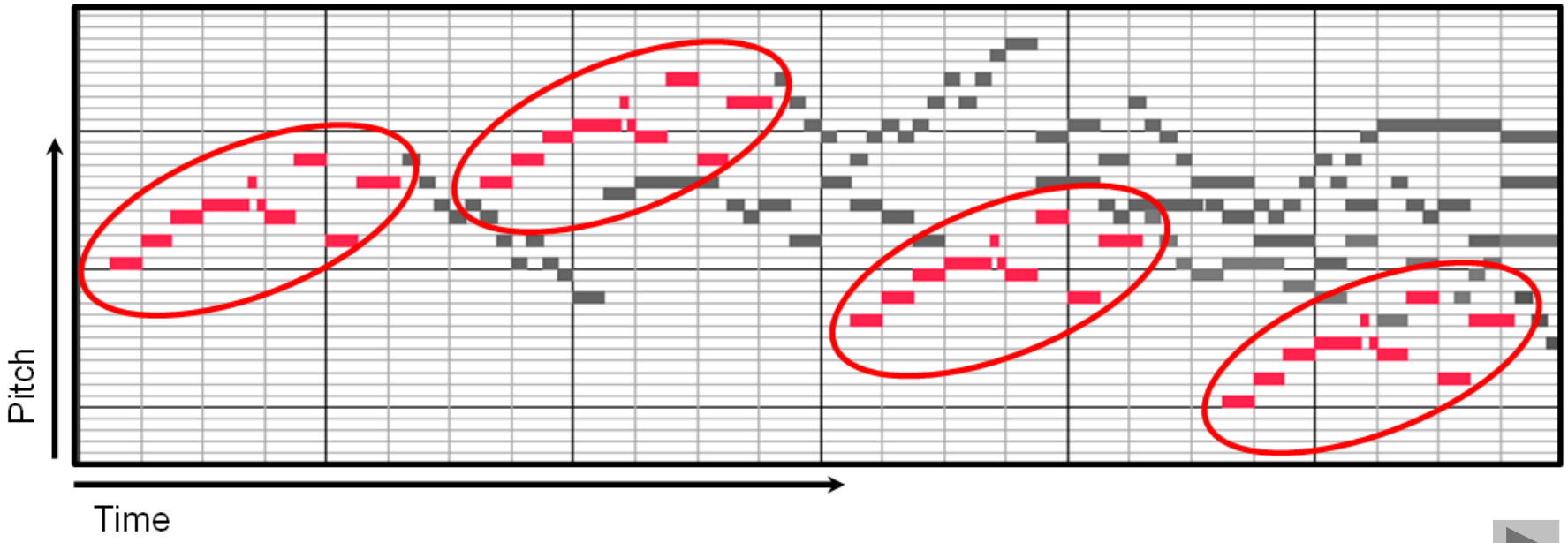
Piano roll representation



Symbolic Representation

Piano roll representation





Symbolic Representation

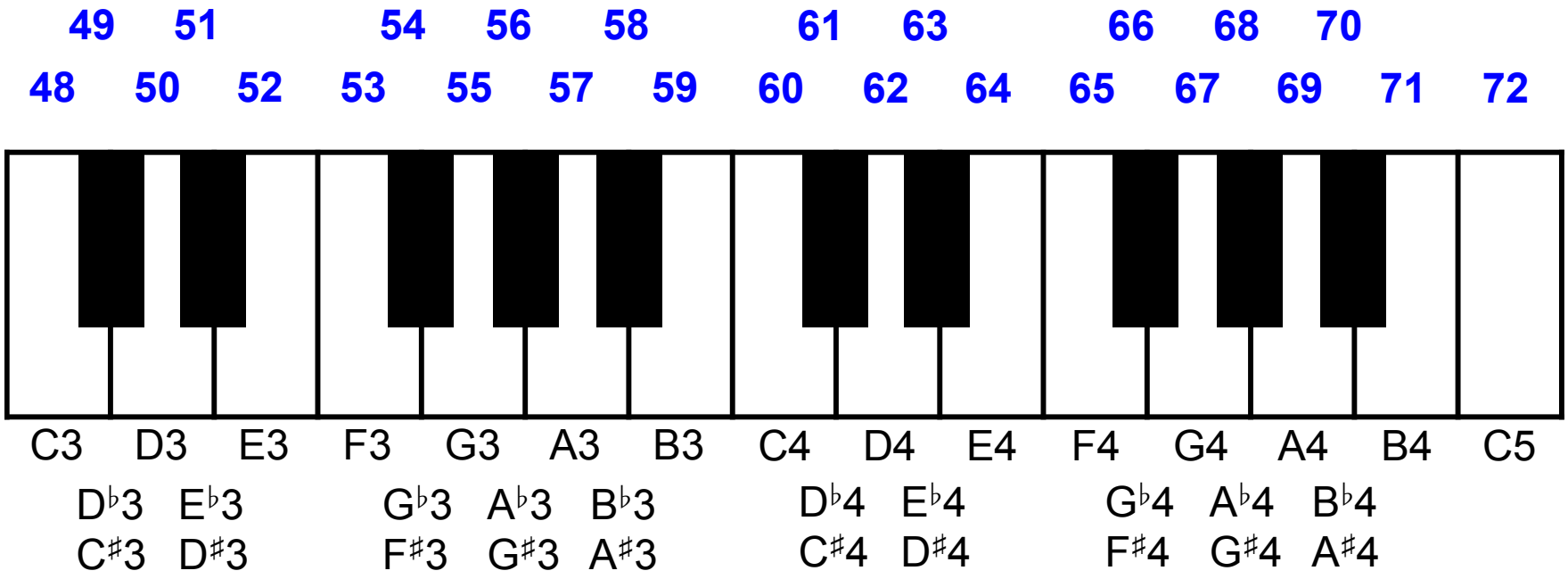
MIDI representation

- Musical Instrument Digital Interface (MIDI)
- Standard protocol for controlling and synchronizing digital instruments
- Standard MIDI File (SMF) is used for collecting and storing MIDI messages
- SMF file is often called MIDI file

Symbolic Representation

MIDI representation

MIDI note numbers (MNN) ≙ piano keys



Symbolic Representation

MIDI representation

- MIDI note number (pitch)

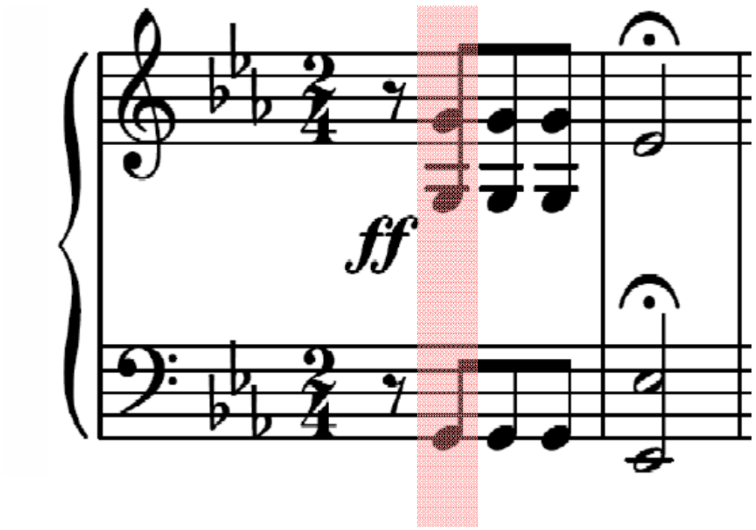
  p = 21, …, 108 ≙ piano keys

  p = 69 ≙ concert pitch A4

- Key velocity ≙ intensity
- MIDI channel ≙ instrument
- Note-on / note-off events ≙ onset time & duration
- Tempo measured in clock pulses or ticks
  (each MIDI event has a timestamp)
- Absolute tempo specified by
  - ticks per quarter note (musical time)
  - micro-seconds per tick (physical time)

Symbolic Representation

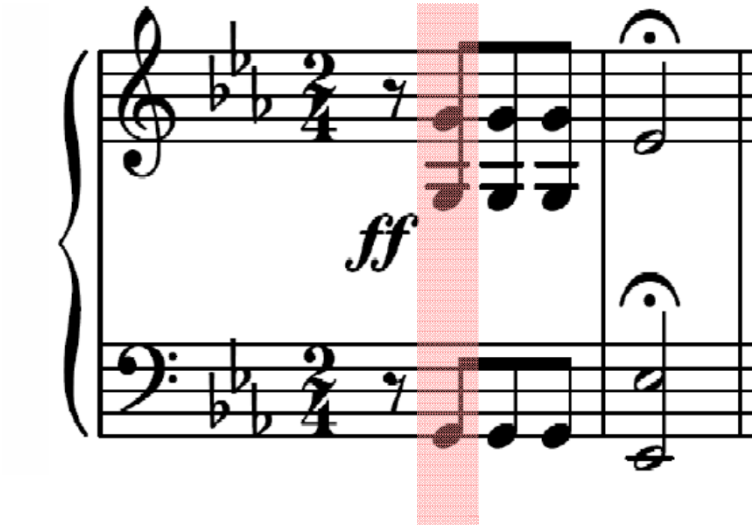
MIDI representation

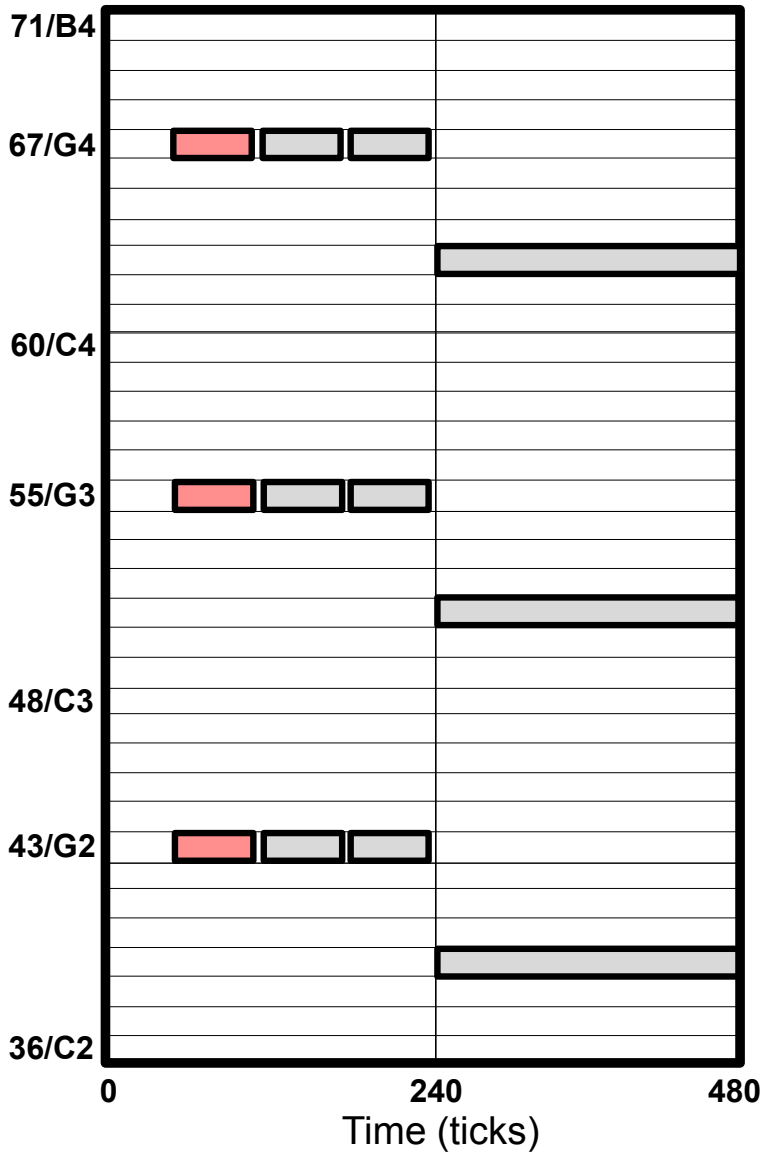


Time (Ticks)	Message	Channel	Note Number	Velocity
60	NOTE ON	1	67	100
0	NOTE ON	1	55	100
0	NOTE ON	2	43	100
55	NOTE OFF	1	67	0
0	NOTE OFF	1	55	0
0	NOTE OFF	2	43	0
5	NOTE ON	1	67	100
0	NOTE ON	1	55	100
0	NOTE ON	2	43	100
55	NOTE OFF	1	67	0
0	NOTE OFF	1	55	0
0	NOTE OFF	2	43	0
5	NOTE ON	1	67	100
0	NOTE ON	1	55	100
0	NOTE ON	2	43	100
55	NOTE OFF	1	67	0
0	NOTE OFF	1	55	0
0	NOTE OFF	2	43	0
5	NOTE ON	1	63	100
0	NOTE ON	2	51	100
0	NOTE ON	2	39	100
240	NOTE OFF	1	63	0
0	NOTE OFF	2	51	0
0	NOTE OFF	2	39	0

Symbolic Representation

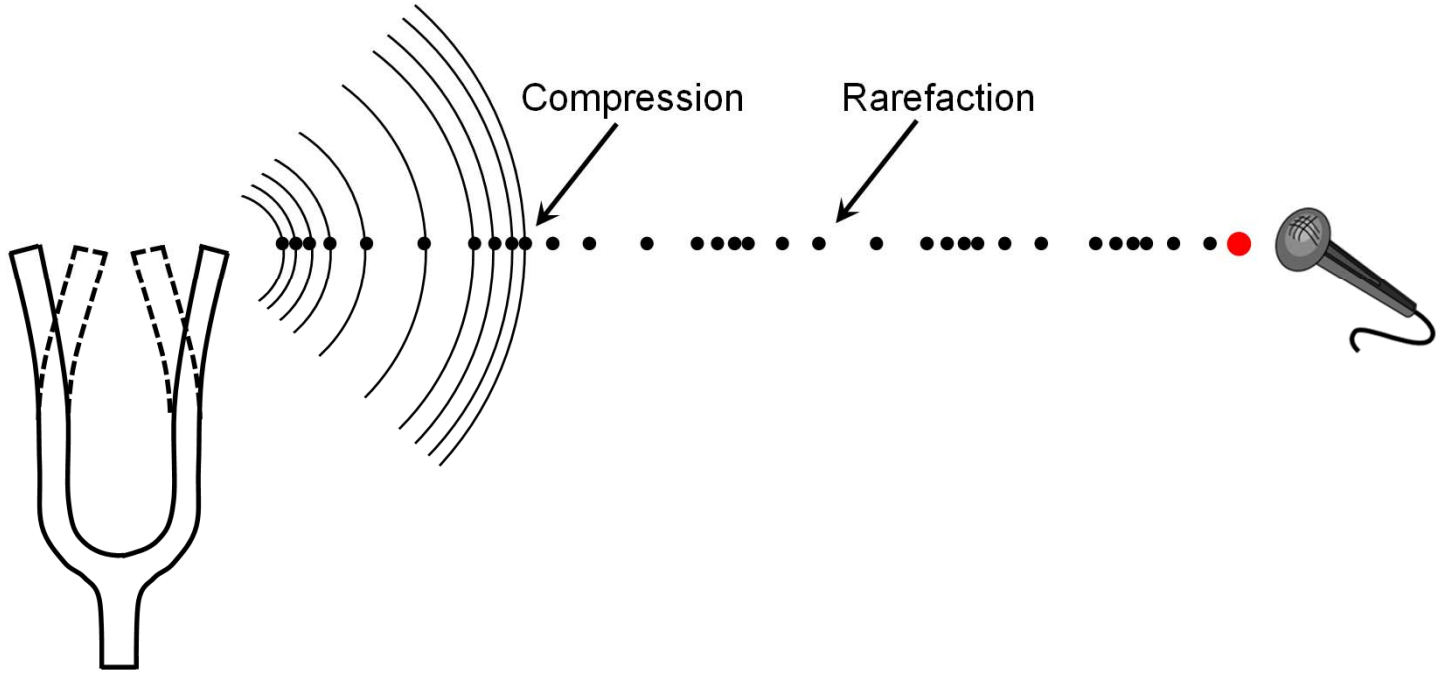
MIDI representation





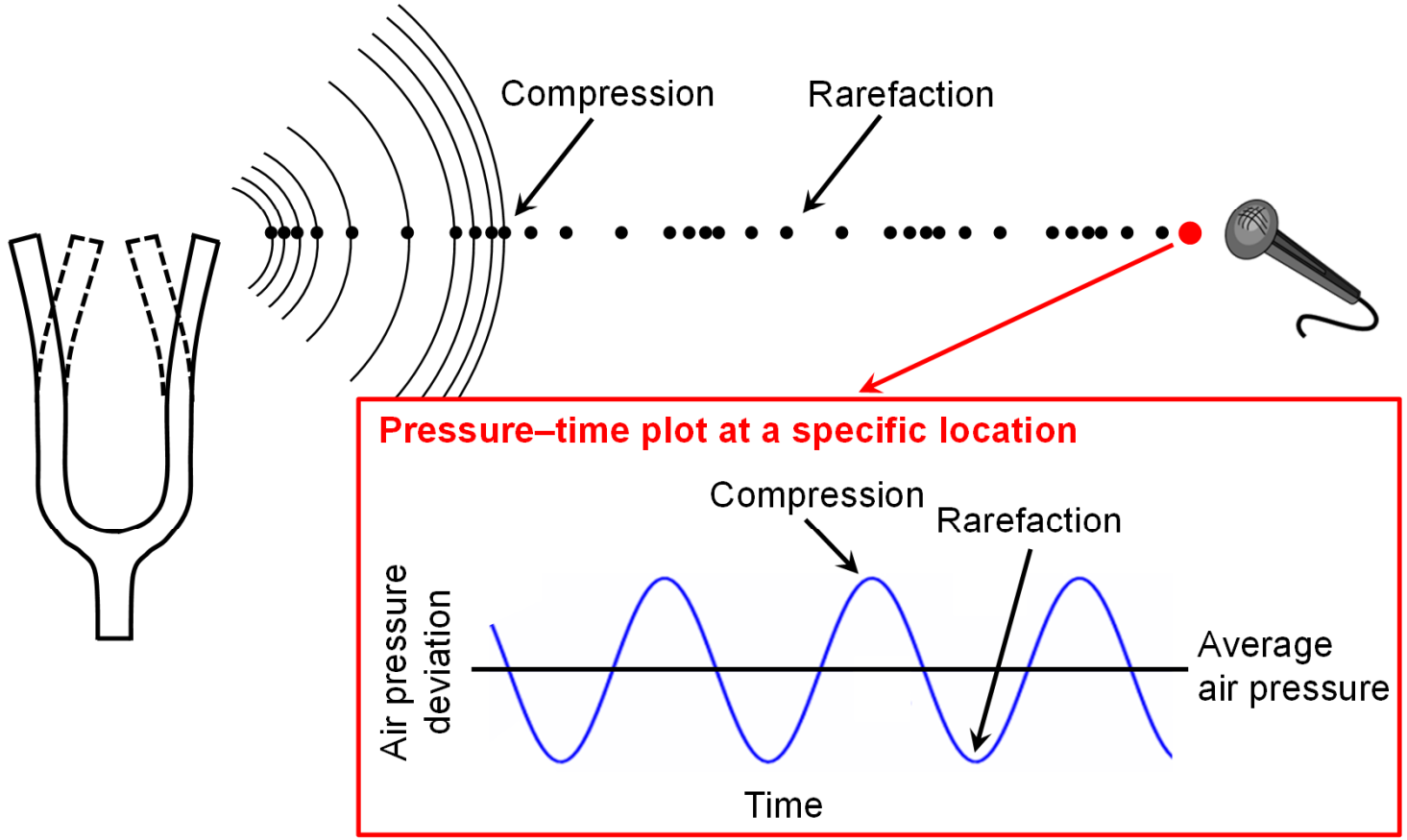
Audio Representation

Waveform



Audio Representation

Waveform



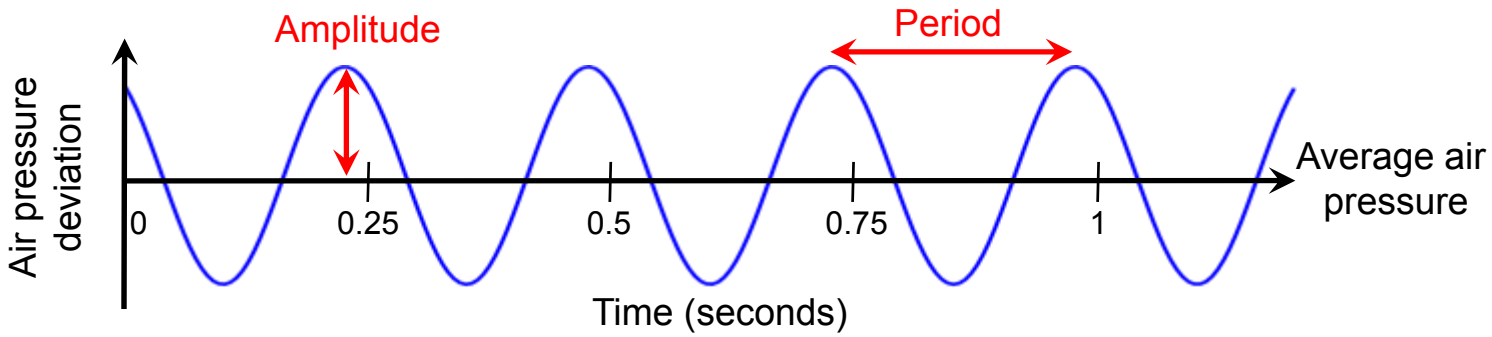
Audio Representation

Waveform

- Audio signal encodes change of air pressure at a certain location generated by a vibrating object (e.g. string, vocal cords, membrane)
- Waveform (pressure-time plot) is graphical representation of audio signal
- Parameters: amplitude, frequency / period

Audio Representation

Waveform



Audio Representation

Waveform

Pure tone (harmonic sound):

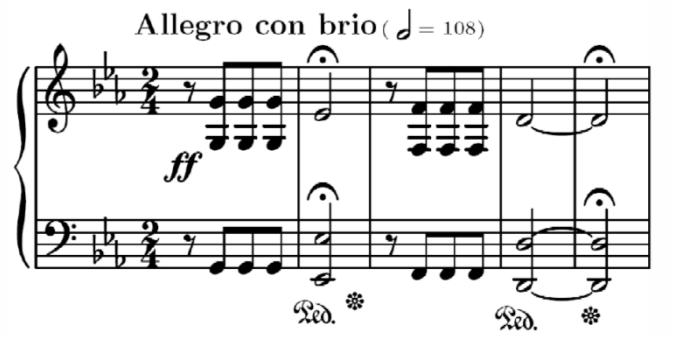
- Sinusoidal waveform
- Prototype of an acoustic realization of a musical note

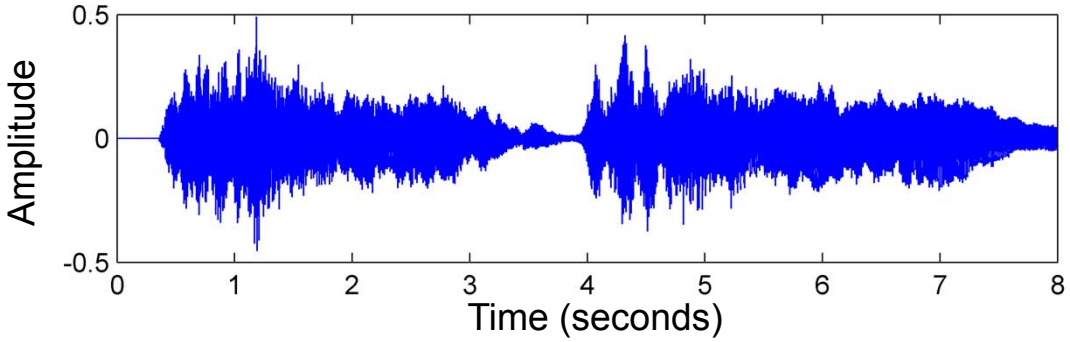
Parameters:

- Period p : time between to successive high pressure points
- Frequency $f = \frac{1}{p}$ (measured in Hz)
- Amplitude a : air pressure at high pressure points

Audio Representation

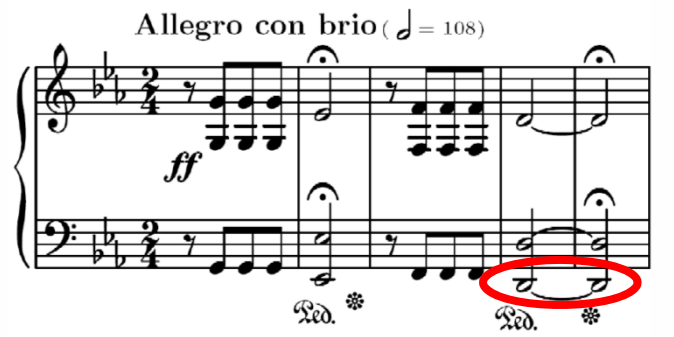
Waveform



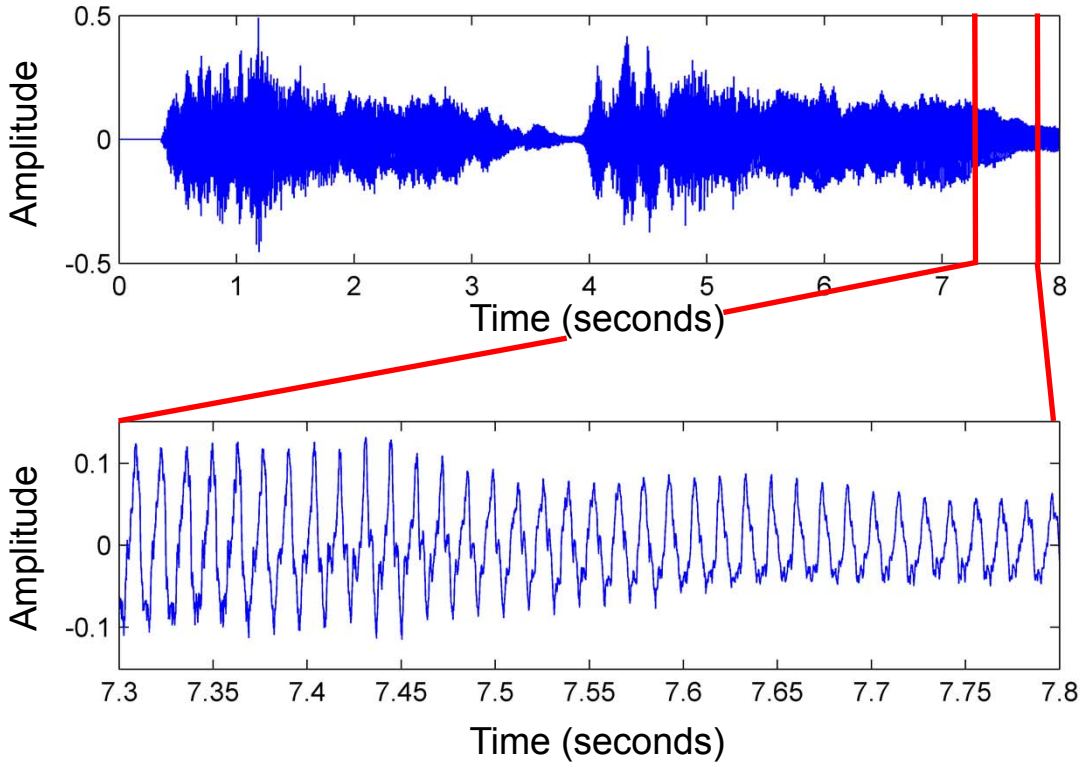


Audio Representation

Waveform

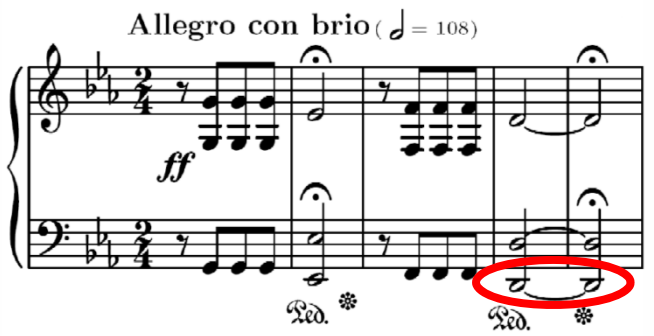


D2 (73.4 Hz)

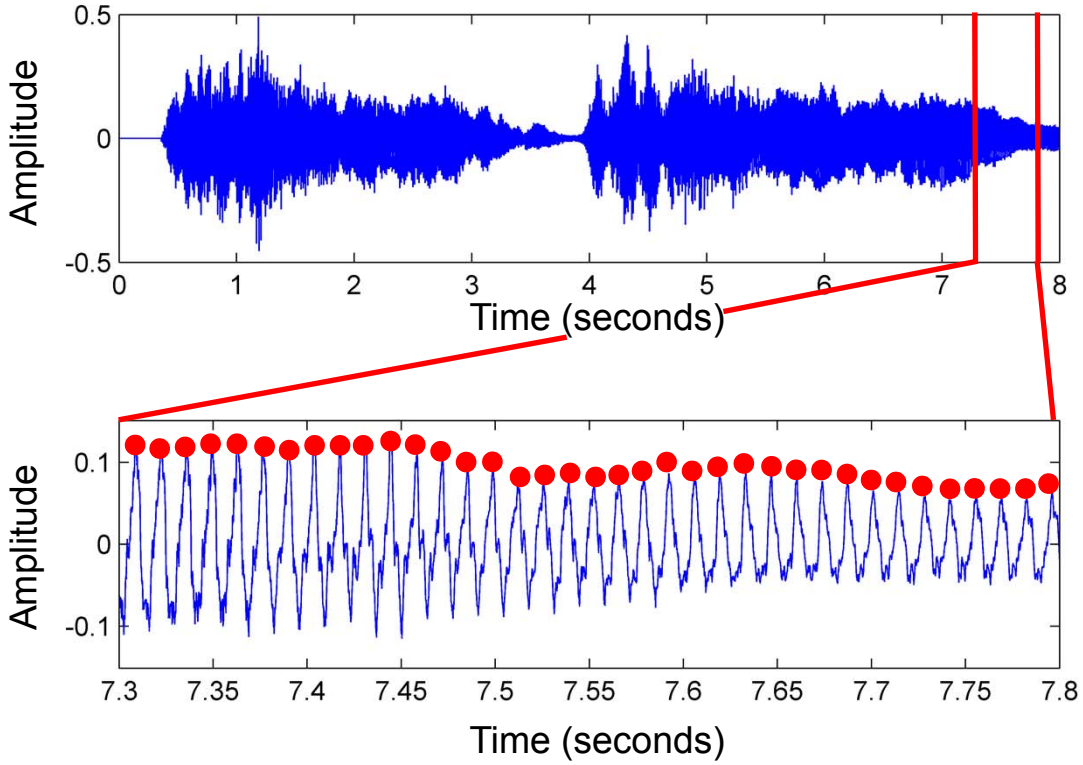


Audio Representation

Waveform



D2 (73.4 Hz)



37 periods within
500 ms section

Audio Representation

Sound

- Sound: superposition of sinusoidals

- When realizing musical notes on an instrument one obtains a complex superposition of pure tones (and other noise-like components)

- Harmonics: integer multiples of fundamental frequency

1. Harmonic	≙ fundamental frequency	(e.g. 440 Hz)
2. Harmonic	≙ first overtone	(e.g. 880 Hz)
3. Harmonic	≙ second overtone	(e.g. 1320 Hz)

Audio Representation

Pitch

- Property that correlates to the perceived frequency (≙ fundamental frequency)
- Example: A4 (also called concert pitch) ≙ 440 Hz
- Slight changes in frequency have no effect on perceived pitch (pitch ≙ entire range of frequencies)
- Pitch perception: logarithmic in frequency

  Example: octave ≙ doubling of frequency

Audio Representation

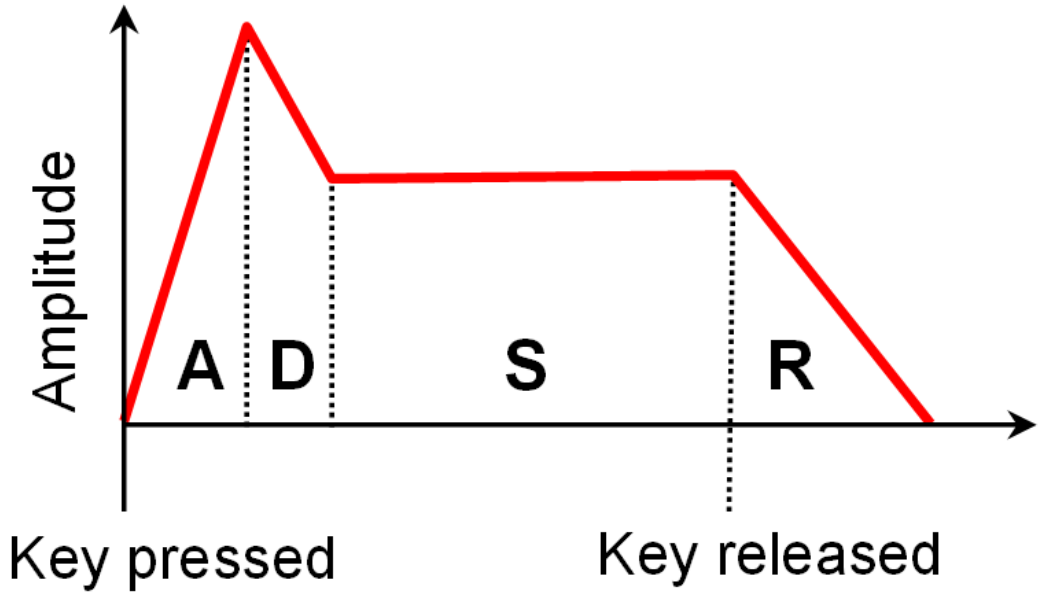
Dynamics

- Intensity of a sound
- Energy of the sound per time and area
- Loudness: subjective (psychoacoustic) perception of intensity (depends on frequency, timbre, duration)

Audio Representation

Dynamics

ADSR model: attack (A), decay (D), sustain (S), and release (R) phase



Audio Representation

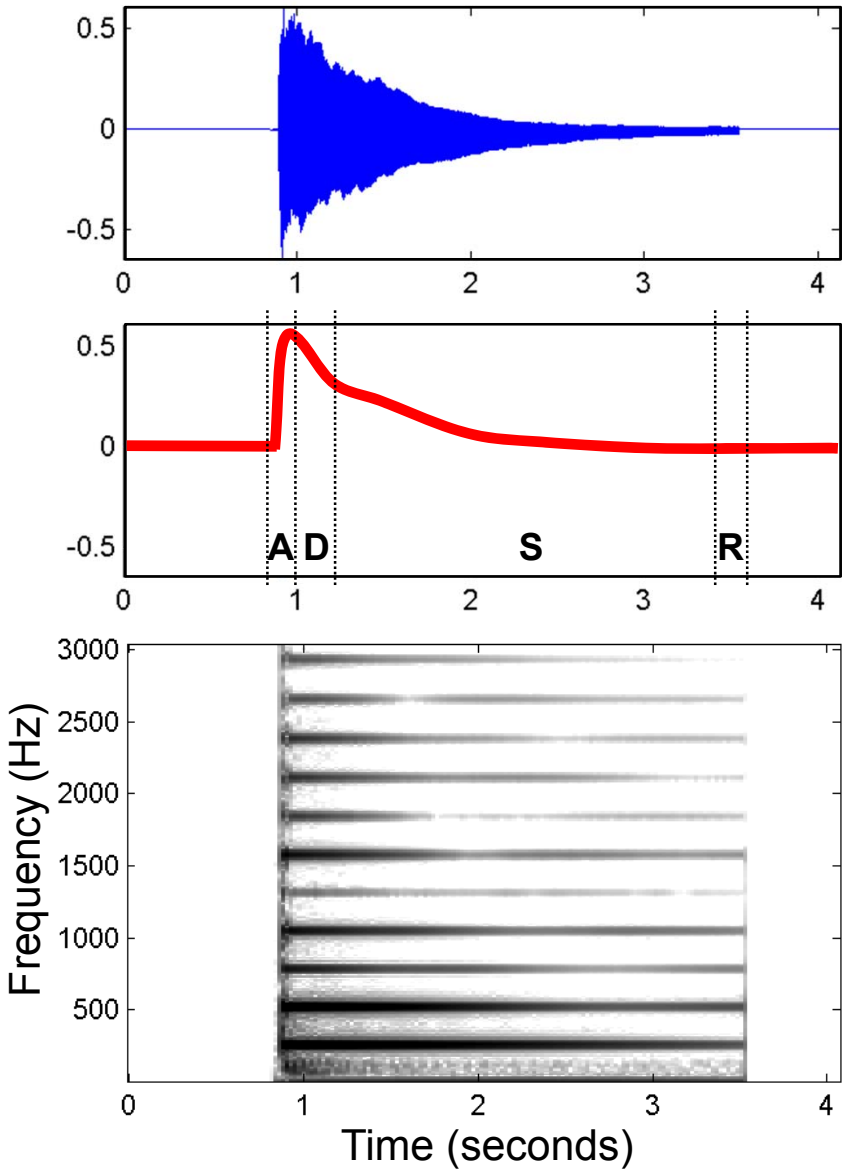
Timbre

- Quality of musical sound that distinguishes different types of sound production such as voices or instruments
- Tone quality
- Tone color
- Depends on energy distribution in harmonics

Audio Representation

Timbre

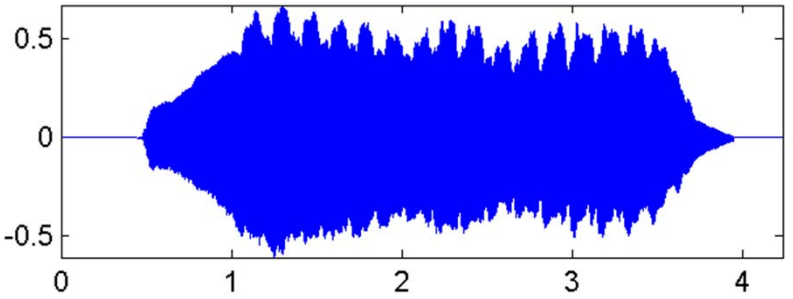
Piano playing
note C4 (261.6 Hz)

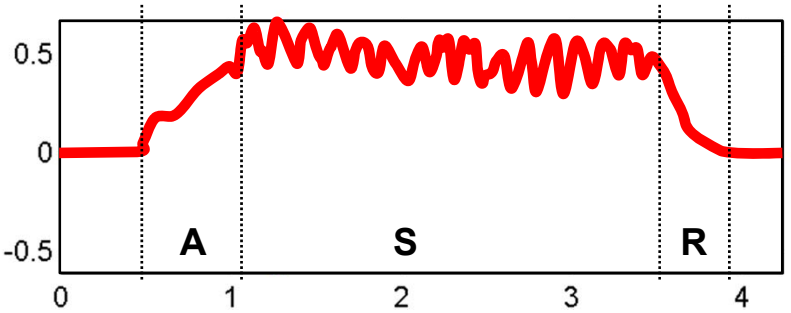


Audio Representation

Timbre

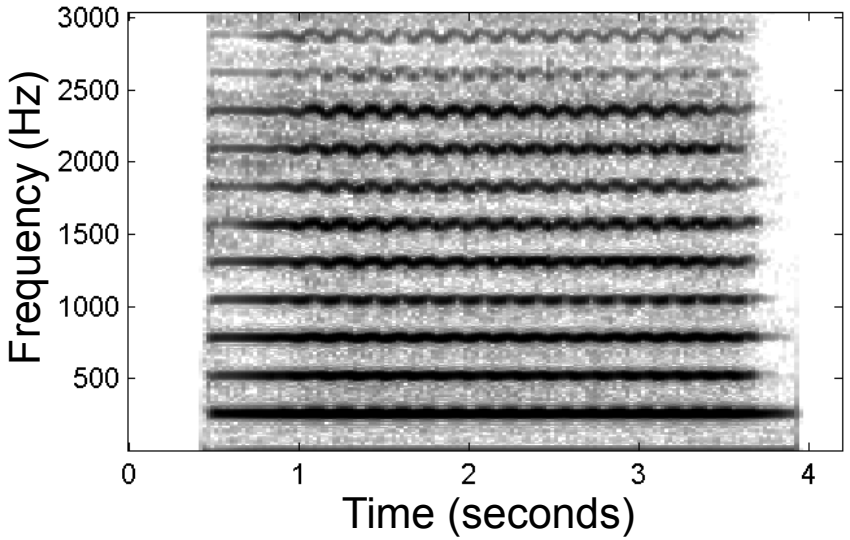
Violine playing
note C4 (261.6 Hz)





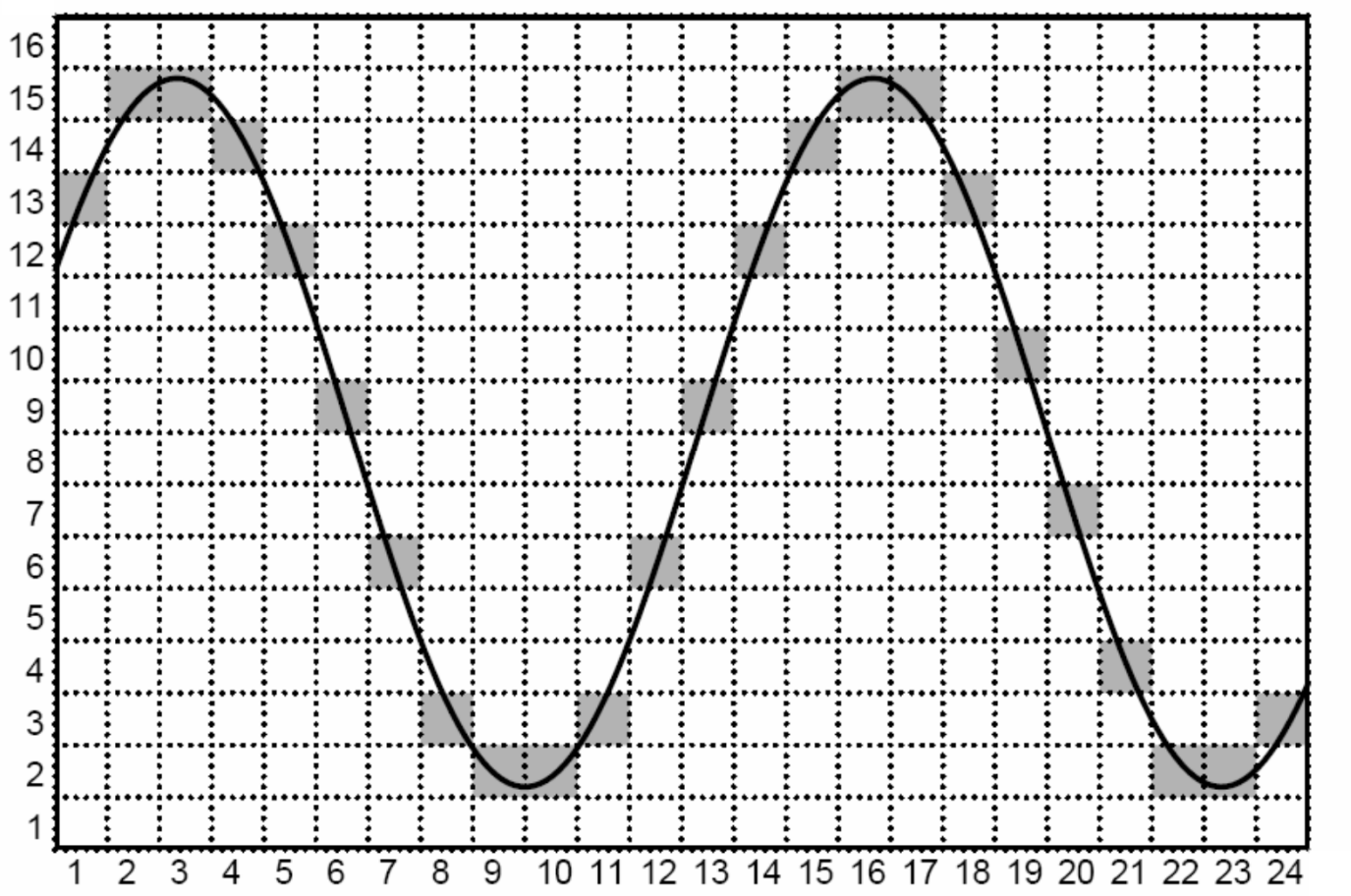
Vibrato:
Frequency modulations

Tremolo:
Amplitude modulations



Audio Representation

Digitization



Audio Representation

Digitization

- Convertion of continuous-time (analog) signal into a discrete signal
- Sampling (discretization of time axis)
- Quantization (discretization of amplitudes)

Examples:

- Audio CD: 44100 Hz sampling rate
  16 bits (65536 values) used for quantization
- Telephone: 8000 Hz sampling rate
  8 bits (256 values) used for quantization