Lecture

Music Processing

Music Representations

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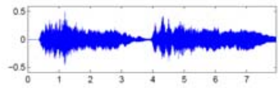
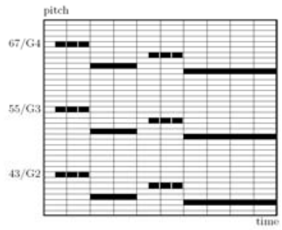
Music Representations





Music Representations

- Score representation: symbolic description
- MIDI representation: hybrid description (models note events explicitely but may also encode agogic and dynamic subtleties)
- Audio representation: physical description (encodes a sound wave)

Score Representation

Musical score / sheet music:

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

Score Representation

Score Representation

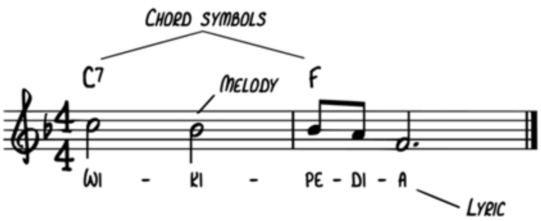
Types of score:

- Full score: shows music for all instruments and voices; used by conductors
- Piano (reduction) score: transcription for piano Example: Liszt transcription of Beethoven symphonies
- Short score: reduction of a work for many instruments to just a fews staves
- Lead sheet: specifies only melody, lyrics and harmonies (chord symbols); used for popular music to capture essential elements of a song

Score Representation

Score Representation

Score Representation



Score Representation

- Scanned image
- Various symbolic data formats
  - Lilypond
  - MusicXML
- Optical Music Recognition (OMR)
- Music notation software
  - Finale
  - Sibelius

Score Representation

MusicXML

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

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

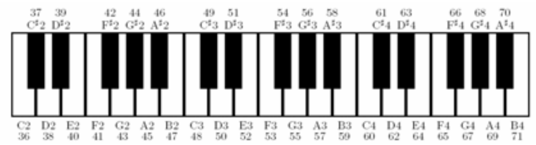
MIDI Representation

MIDI parameters:

- MIDI note number (pitch) $[0:127]$
  - p = 21, …, 108 ≙ „piano keys“
  - p = 69 ≙ concert pitch A ($440Hz$)
- Key velocity $[0:127]$ ≙ intensity
- MIDI channel $[0:15]$ ≙ 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)

MIDI Representation

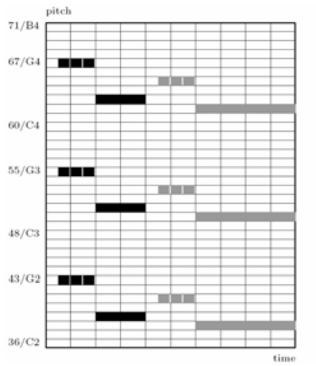
MIDI note numbers (MNN) ≙ piano keys



MIDI Representation

Ticks	Message	Ch.	MNN	Vel
60	NOTE ON	1	67	100
0	NOTE ON	2	55	100
0	NOTE ON	2	43	100
55	NOTE OFF	1	67	0
0	NOTE OFF	2	55	0
0	NOTE OFF	2	43	0
5	NOTE ON	1	67	100
0	NOTE ON	2	55	100
0	NOTE ON	2	43	100
55	NOTE OFF	1	67	0
0	NOTE OFF	2	55	0
0	NOTE OFF	2	43	0
5	NOTE ON	1	67	100
0	NOTE ON	2	55	100
0	NOTE ON	2	43	100
55	NOTE OFF	1	67	0
0	NOTE OFF	2	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

MIDI Representation

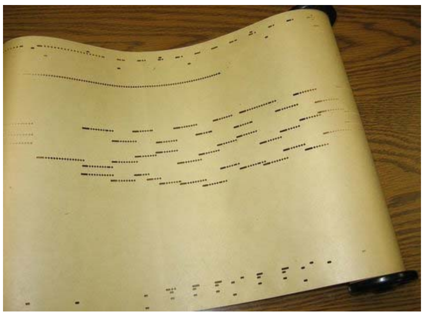


MIDI Representation

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

MIDI Representation



MIDI Representation

Audio Representation

Various interpretations – Beethoven's Fifth

Bernstein	▶
Karajan	▶
Scherbakov (piano)	▶
MIDI (piano)	▶

Audio Representation

- 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

Pure tone (harmonic sound):

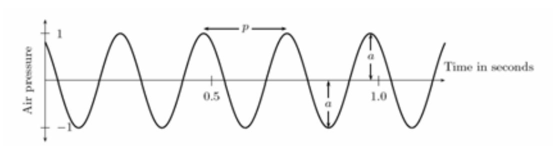
- Sinusoidal wavefrom
- Prototype of an acoustic realization of a musical note

Parameters:

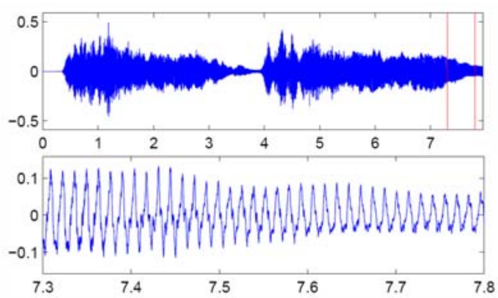
- Period p : time between to successive high pressure points
- Frequency $f = \frac{1}{p}$ (measured in Hz)
- Amplitude a : air pressure at high pressure points

Audio Representation

Waveform

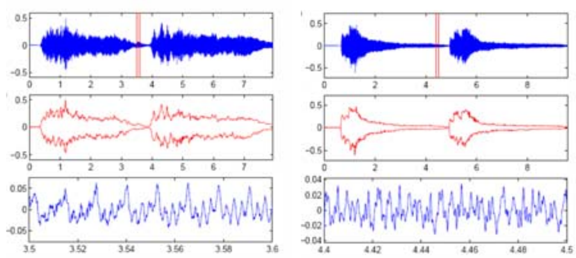


Audio Representation



Audio Representation

Bernstein (orchestra) Glen Gould (piano)



Audio Representation

- 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: middle A or 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

Equal-tempered scale: a system of tuning in which every pair of adjacent notes has an identical frequency ratio

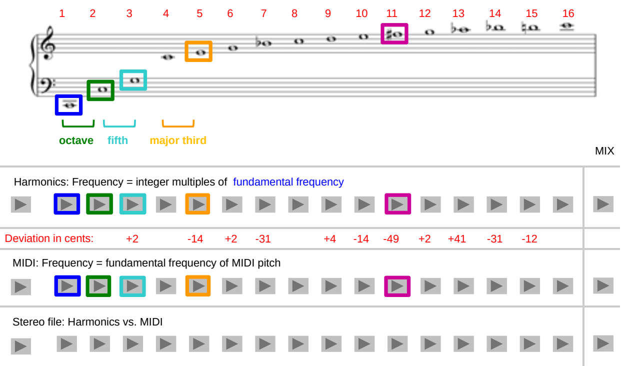
Western music: 12-tone equal-tempered scale

- Each octave is devided up into 12 logarithmically equal parts
- Notes correspond to piano keys $p = 21\ (\mathrm{A0})$ to $p = 108\ (\mathrm{C8})$
- Referenz: standard pitch $p = 69\ (\mathrm{A4}) \triangleq 440\ \mathrm{Hz}$
- Frequency of a note with MIDI pitch p

$$f_{\mathrm{MIDI}}(p) = 2^{\frac{p-69}{12}} \cdot 440$$

Audio Representation

Harmonics



Audio Representation

Timbre

- Quality of musical sound that distinguishes different types of sound production such as voices or instruments
- Tone quality
- Tone color

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

- $intensity = \frac{energy}{time \cdot area} = \frac{power}{area} \quad \left(\frac{W}{m^2}\right)$
- Decibel (dB): logarithmic unit to measure intensity relative to a reference level
- Reference level: threshold of hearing (THO) $P_0 = 1 \cdot 10^{-12} \frac{W}{m^2}$
- Intensity P_1 measured in dB: $dB(P_1) = 10 \cdot \log_{10}\left(\frac{P_1}{P_0}\right)$
- Examples:

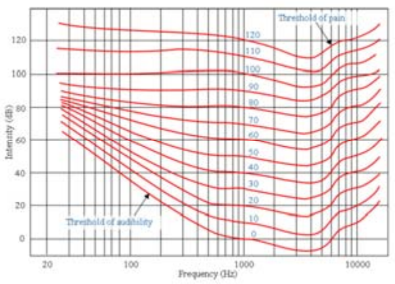
$$P_1 = 10 \cdot P_0 \rightarrow P_1 \text{ has a sound level of } 10\ dB$$
$$P_2 = 100 \cdot P_0 \rightarrow P_2 \text{ has a sound level of } 20\ dB$$

Audio Representation

Source	**Intensity**	**Intensity level**	**# Times TOH**
Threshold of hearing (TOH)	10^{-12}	**0 dB**	0
Whisper	10^{-10}	**20 dB**	10^{2}
Pianissimo	10^{-9}	**30 dB**	10^{3}
Normal conversation	10^{-6}	**60 dB**	10^{6}
Fortissimo	10^{-2}	**100 dB**	10^{10}
Threshold of pain	10	**130 dB**	10^{13}
Jet take-off	10^{2}	**140 dB**	10^{14}
Instant perforation of eardrum	10^{4}	**160 dB**	10^{16}

Audio Representation

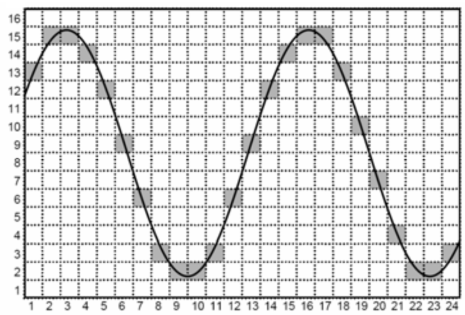
Equal-loudness contours (phone)



(from en.wikibooks.org/wiki/Physics_Study_Guide/Sound)

Audio Representation

Discretization



Audio Representation

Discretization / 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