computers and music (1)
representing music digitally

learning goals:
- knowledge of (some) musical activities that can be supported by computers
- familiarity with the basic method for encoding a sound signal digitally, including the guideline for sampling frequency
- knowledge of different levels of music representation and their uses, in particular acoustic and score level
- basic familiarity with musical parameters and their representation in GUIDO Music Notation

Lady Ada’s Vision

[The Analytical Engine] might act upon other things besides number, [...] the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent.

Augusta Ada King, Countess of Lovelace (1815–1852)

Musical objects / data:
- instruments
- scores (written notes, rests, other symbols)
- recordings
as well as less tangible “objects”, such as:
- works (symphonies, songs, sonatas, …)
- melodies, rhythms, voices
- interpretations, performances

Any language begins as music and ends up being an algebra.

André-Marie Ampère, French mathematician and physicist (1775–1836)

Working With Music

(Some) musical activities / processes:
- creating (composition, improvisation)
- playing (performance)
- listening (perception)
but also:
- building instruments
- analysing
- notating / copying / publishing / distributing
( even analysing and designing acoustics of instruments and concert halls)

~ computers can support all these activities
Music Representation

To work with music algorithmically, we need a formal music representation.

But what should we represent?

- Sound? (like on a record, tape, or CD?)
- Score? (like in sheet music)
- Structure? (musical form, “architecture”)
- Properties? (statistical features, number of notes, etc.)

And how?

- a sound wave is *continuous* (analog) and *periodic*
- the *frequency* of a sound wave, measured in Hertz (Hz), is the number of periods per second
- audible sound waves have frequencies ranging between 20Hz and 20 000 Hz (20 kHz)

- *sampling* is used to digitize analog sound waves
- a *sample* is a measurement of the pressure at a point in time

- sample sequence: -110, -010, 101, 001, -110, …
- in this example, 4 bits per sample (1 for the +/- sign)

- sampling rate here is 8 samples/sec
digitised sound quality

• for a given sound wave, the quality of the digitised sound data is determined by
  – the sampling rate
  – the number of bits per sample
  
  **guideline:** for good quality, the sampling rate should be at least twice the maximal frequency

  *Example:* Want to capture frequencies up to 20,000 Hz => need a sampling rate of at least 40,000 samples/sec

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exercise

What is the digitised sound representation for this sound wave, when the sampling rate is 4 and the number of bits per sample is 4?

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exercise

A sound wave that extends for 1 minute is sampled at a rate of 44,000 samples per second. Each sample is 16 bits.

What is the total number of bits needed to represent the sample sequence for that sound wave?

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advantages of digitised sound

• can be copied without loss of quality

• can be edited in complex ways, *e.g.*, remove coughing from live recording
  – speed up or slow down the speed of the music without changes in pitch

• can be compressed to save storage space, *e.g.*, by removing non-audible aspects of sounds (this provides the basis for MP3 coding)

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Levels of music representation:

• *acoustic / physical (level 0)*
  music as sound, represented as waveform
  (*e.g.*, CD recording, WAV file, MP3 file, ...)
  This is what instruments produce and what we hear.

• *score / notation (level 1)*
  explicitly represents musical parameters,
  such as pitch, duration, loudness, instrument
  This is (mostly) what composers write and musicians play from.

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Levels of music representation (continued):

• *structure (level 2)*
  explicitly represents musical structure,
  including movements, repeats, recurring material
  *Example:* A C B C A C, where A, B, C are pieces of music, *e.g.*, the verses and chorus of a song.

• *metastructure (level 3)*
  explicitly represents algorithms for composition and analysis,
  automata, grammars, functions, generators
  *Example:* A program that uses a random number generator to create musical fragments and combines them into a piece.
Sound recording, editing, mixing, playback typically happen at the acoustic level (=level 0).

~ Musical parameters not represented explicitly (very difficult to access and manipulate).

But: Many creative musical activities (including most forms of composition) use musical parameters explicitly.

~ Need score (= level 1) or higher level representation.

Conventional music notation
- complex, expressive graphical language
- historically evolved system, originated ca. AD 1000
- optimised for performance, but equally used for composition, analysis, ...

Elements of music notation: Primary musical parameters
- pitch (related to physical frequency) specified by
  - pitch class (note name):
    - c c-sharp d d-sharp e f f-sharp g g-sharp a a-sharp
      = d-flat e-flat f-flat g-flat a-flat b-flat b
  - register (octave number):
    - 3, 2, 1, 0, 1, 2, 3, ..., 8

  *pitch classes repeat in each register:*
    c1 d1 e1 f1 g1 a1 b1 c2 d2 ...

Elements of music notation: Primary musical parameters (continued)
- note values (related to physical duration)
  - specified as fractions: 1/1, 1/2, 1/4, 1/8, 1/16, ...

Additional elements of music notation: Secondary musical parameters
- tempo (speed)
- intensity (loudness)
- timbre (instrument / style of playing)

GUIDO Music Notation [Hoos et al., 1996–2001]
- represents music notation (level 1)
- plain text, human-readable
- representationally adequate:
  simple things have simple representations
GUIDO Music Notation: Notes and Rests

- Notes: \( \langle \text{pitch} \rangle \langle \text{duration} \rangle \)
  e.g.: \( c_{1/4} \ a_{2/8} \ f_{#1/1} \ b_{6/16} \)

- Rests: \( \langle \text{duration} \rangle \)
  e.g.: \( \_/4 \_/2 \_/8 \)

GUIDO Music Notation: Sequences and Segments

Sequence:
Series of notes (or rests) that are played sequentially (one after the other)
In GUIDO: \([\langle \text{note/rest} \rangle \langle \text{note/rest} \rangle \ldots \langle \text{note/rest} \rangle]\)
E.g.: \([c_{1/4} \ d_{1/4} \ e_{1/4} \ f_{1/4} \ g_{1/2}]\)

Segment:
A set of sequences (voices) that are played concurrently (at the same time)
In GUIDO: \(\{\langle \text{sequence} \rangle, \langle \text{sequence} \rangle, \ldots, \langle \text{sequence} \rangle\}\)
E.g.: \(\{[c_{1/4} \ d_{1/4} \ e_{1/4}], \ [e_{1/4} \ f_{1/4} \ g_{1/2}]\}\)