Computing for Musicology (Course code: F104N5) 1. Introduction to the Course

J.N. Oliveira

Dept. Informática,
Universidade do Minho
Braga, Portugal

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Licenciatura em Música + Opção U.Minho
(`http://www.musica.ilch.uminho.pt/`)
Universidade do Minho
Braga

Introduction

Quoted from my machine's native dictionary:

Musicology (noun) the study of music as an academic subject, as distinct from training in performance or composition; **scholarly research** into music.

Computing (noun) the use or operation of computers : *developments in mathematics and computing*

In this course you will learn how to program computers to help you in **musical analysis**.

About this course

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What this course is **not** about:

- music electronics
- computer music
- music typesetting

What this course (implicitly) **is** about:

> **Computational thinking** — *"using abstraction and decomposition when attacking a large complex task or designing a large complex system" (Wing, 2006)*

Our complex task will be to **understand music** and perform **music analysis**.

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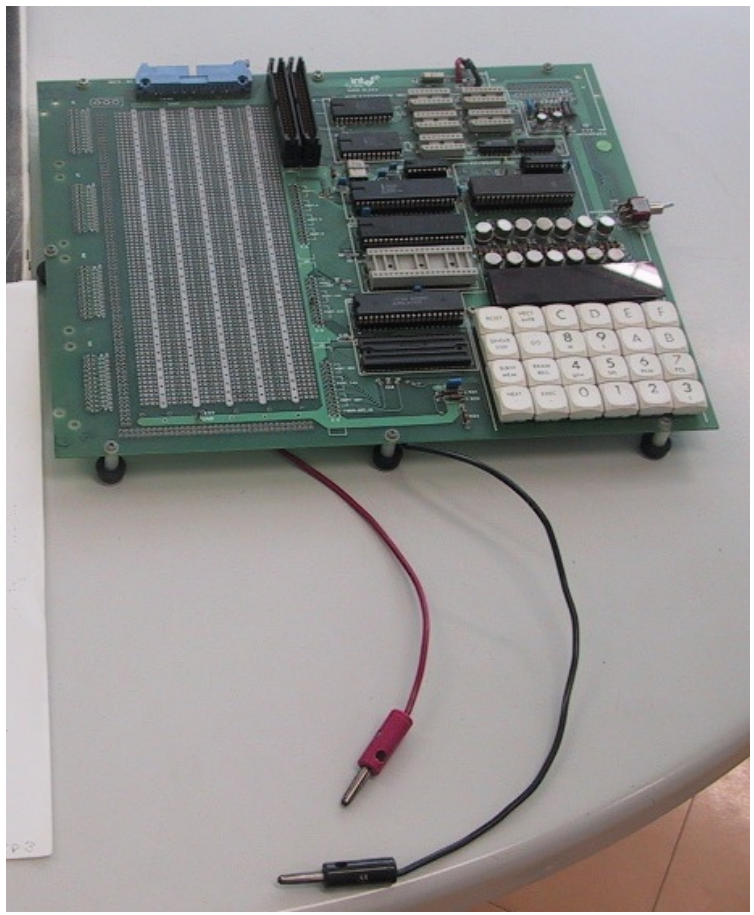
Music and computing at Minho

Back to 1978/79

Contribution to the JUVEMINHO'79 Youth Exhibition which took place in Braga, 1979.

The Electronics Lab of Minho University (founded 1973) prepares several demos for the exhibition.

Among these a multi-part **score interpreter** encoded in **assembly code** runs on an Intel SDK85 board (aside).

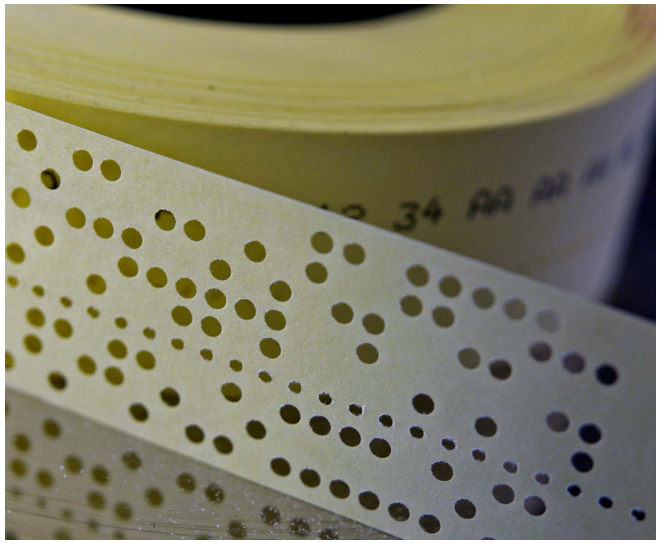


Back to 1978/79

Extra **2Kb** memory extension has to be bought for the code to fit in.

No **assembler** available — code written directly in **binary** notation.

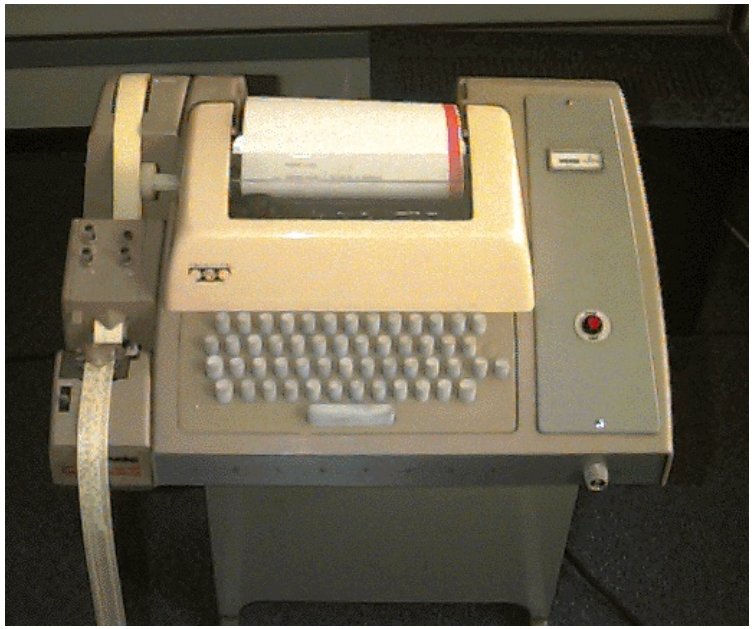
Program + 'scores' are saved in **punched tapes**.



Tapes are loaded from a **teletype** offered by CTT with no **documentation**, no **drivers** — that for SDK85 was built by trial-and-error on a breadboard.

Back to 1978/79

Written completely from scratch, the "synthesizer" sampled a 256 byte **sine wave** on a $\sqrt[12]{2}$ basis (12 notes per octave).



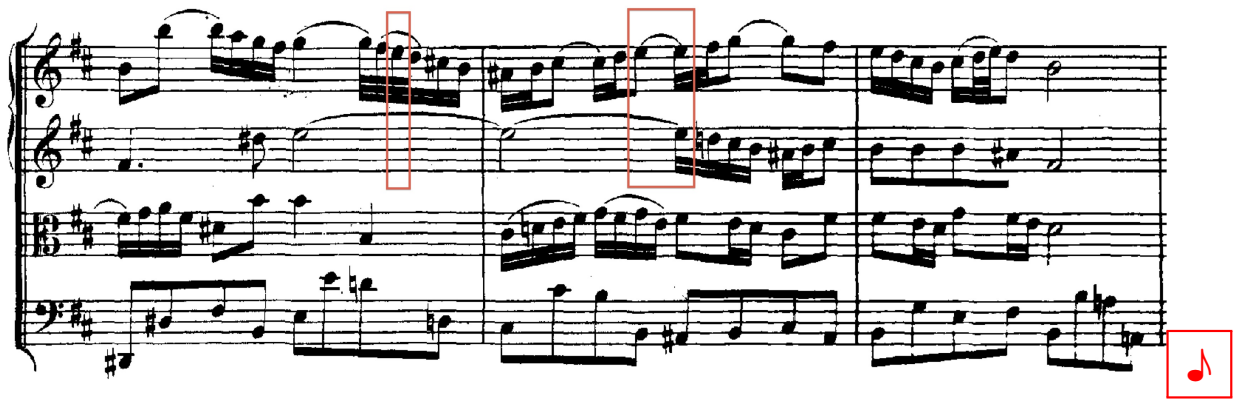
Part samples were produced in real-time, added together and sent to a **DA converter**, itself connected to an amplifier + speakers.

'Scores' included a few two part INVENTIONS (e.g. BWV 779) by J.S. Bach as well as the four-part Air of the SUITE BWV 1068.

Back to 1978/79

The code would need a little fix, for notes of the same frequency in different parts could occasionally cancel each-other...

This was observed e.g. in the *Air* of BWV 1068, the superstar of the demo:



Horror — no E's in the 1st and 2nd violins at one particular demo!

The fix thereafter prevented any two parts from being in "phase opposition".

More recently

Hosting a "mirror" of the **Mutopia Project** (`http://eremita.di.uminho.pt/mutopia`) and contributing to the contents of this **score repository**.

Digital Archive of Portuguese Folk Music maintained by colleague J.J. Almeida.

From 2008/09 onwards:

- **Computing for Musicology** course
- 2nd year of the **Music Degree** (2007-) at Minho.
- **Music sciences** option.
- Introducing students to **computer-aided** musicology.

Computing for Musicology course

Emphasis on **cooperative work**.

Wiki-score web platform[1] initially developed for the **lab sessions** of the course.

Based on **open-source** software only — cheaper, more accessible, more flexible.

Learning from the 'open-source' experience: vast repositories **shared** world-wide — often 100s of people in the same project.

Large-scale production of shared contents — who does not know about **Wikipedia**?

[1] `http://www.wiki-score.org`.

These slides as example

Text preparation and publishing:

LaTeX— monumental resource sharing via the TeX's Users Group

Music sources:

ABC notation, preparation via EasyABC, *archived /shared over* **Wiki-score**

Audio clips:

Treated in Audacity, played by VLC (via generated MIDI)

Analytical processing:

Haskell — *examples later.*

Why the **Wiki-score**

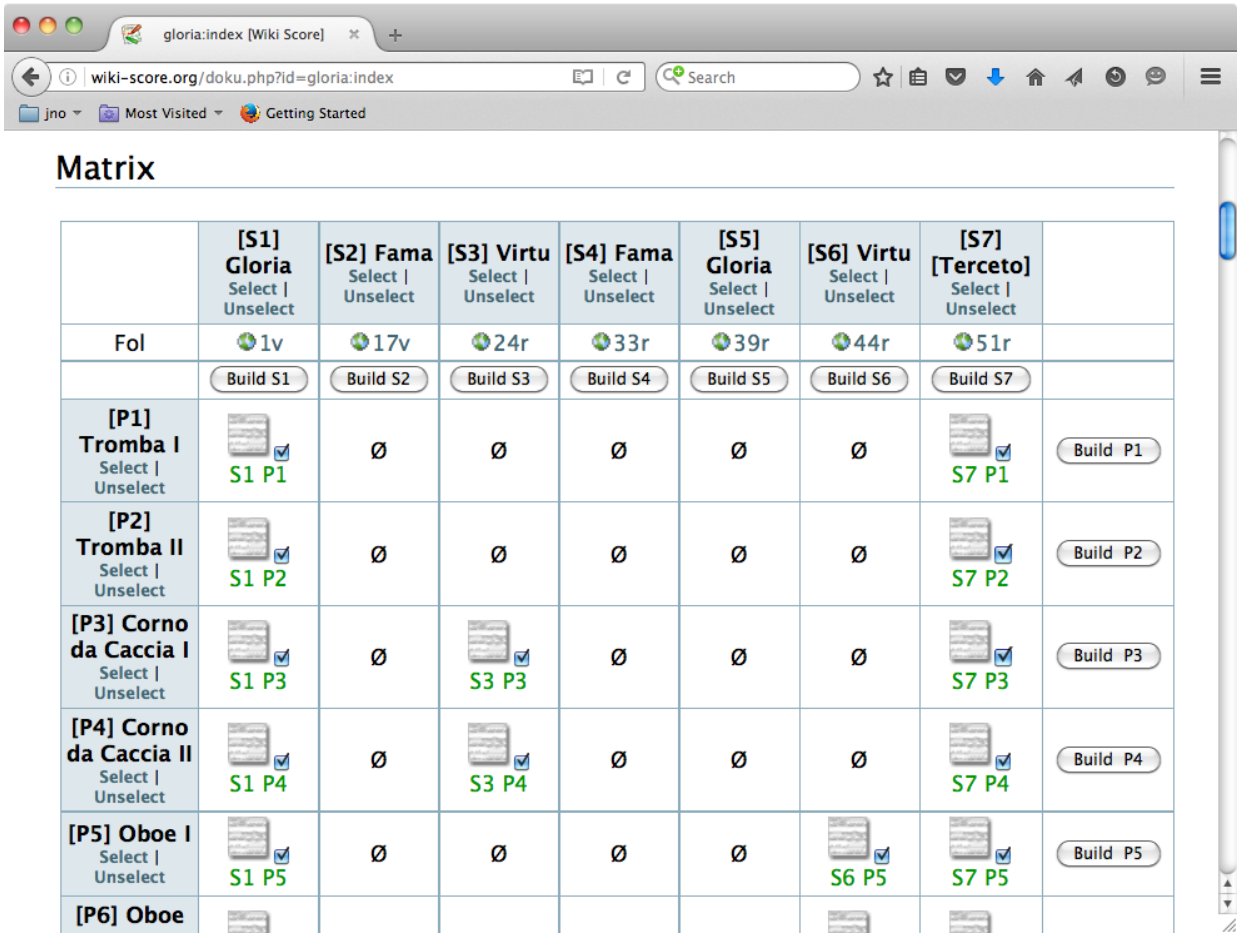
Towards electronic publishing of lost works buried in music archives.

Large-scale **cooperative** editing — see e.g. the **Demetrio a Rodi** opera by Gaetano Pugnani (1731-1798), with its 41 x 28 editing cells.

Platform prepared for "computer aided musicology".

Why the **Wiki-score**

Matrix format enables co-operative, concurrent editing of (part, section) music **cells**.



At any time the current version of the score can be generated in several open formats.

Why open score repositories

Without **shared** and **verifiable** data there is no chance for **true** science.

Scientific method is based on the **repetition** of a given experiment by (arbitrary) others.

Example: no **theorem** in mathematics is regarded as valid until a **proof** is given which is **not refuted** by other mathematicians.

Results in the **Human Sciences** usually stem from **statistic** treatment of **data sets**.

Open Data trend in science[2] — truly scientific method calls for open data, for free verification.

[2] Cf. DOI: 10.1080/00987913.2008.10765152, by Peter Murray-Rust of Cambridge Univ.

Why open score repositories

Open score repositories (OSR) — open-access, open format score archives available to any musicology scholar, for instance:

MUTOPIA PROJECT

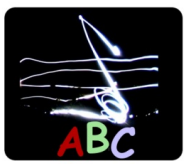
Notation: Lilypond

Gutenberg Project (music category)

Notation: MusicXML

Wikiscore Platform

Notation: ABC



Music versus Abstraction

The 3M rule

Music used to be part of the *Quadrivium*, a medieval university curriculum involving the "mathematical arts" of

- arithmetic
- geometry
- astronomy
- music

The "3M rule" : people who like **M**usic also like **M**aths and **M**aps.

Why is this?

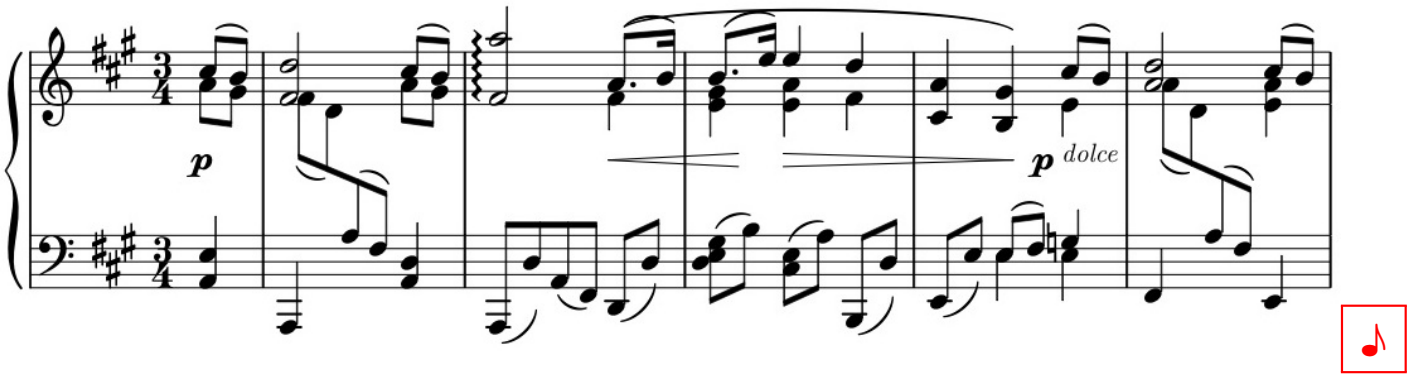
The 3M rule

- All three M's above have to do with **abstraction**.
- In fact, **music** is perhaps the most abstract of all arts: what does a piece of music (with no words) actually mean? Hard to say.

[I thank David Naumann (Stevens Institute of Technology-New York) for pointing me to this "rule".]

Abstraction

Opus 118, nr.2, by Johannes Brahms:



Questions: what does this piece *mean*? Does it *describe* anything? Does it imitate or recreate reality?

Answer: it means **nothing** — it is **abstract**:
vskip 1em

> *"Music is never about anything: music just 'is'!"*
>
> (L. Bernstein, 1st *Young People's Concerts*, 18-Jan-1958).

Abstraction

Quoting Jeff Kramer [3]:

Abstraction *is widely used in other disciplines such as* **art** *and* **music**. *For instance (...) Henri Matisse manages to clearly represent the* **essence** *of his subject, a naked woman, using only simple lines or cutouts. His representation* **removes** *all detail yet* **conveys** *much.*

[3] *Is Abstraction the Key to Computing?*, Commun. ACM, 50:4, pages 37–42, April 2007.

(Map) abstraction

The famous "abstract map" of London's Underground (1939):

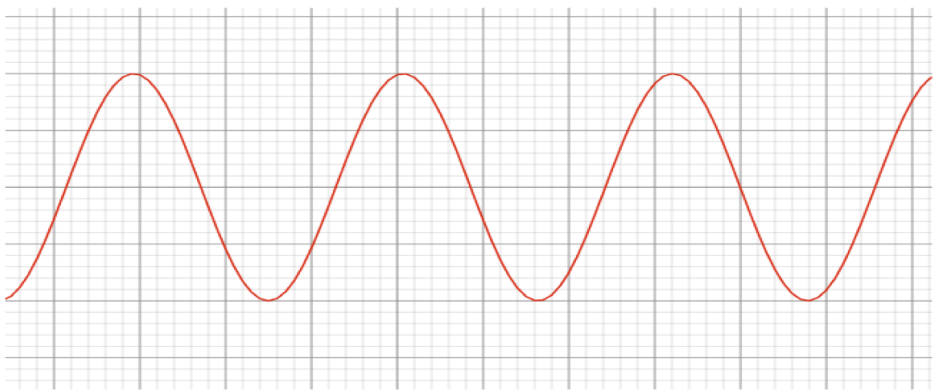
Music is about sound

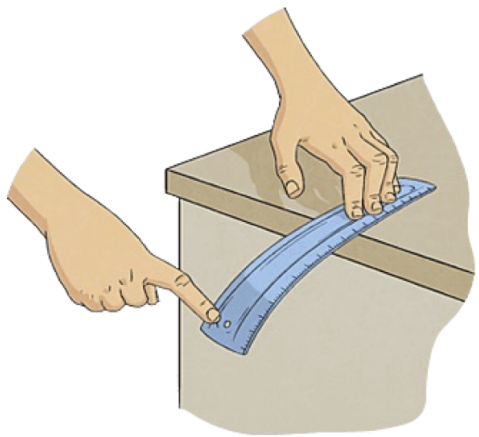
Music is one of the **pilars of culture**: every community, civilization etc has its own.

When/how did it start?

- One can imagine hominids marvelling at drumming and producing **random** sounds.
- Temptation to master the amazing world of sound must have taken place later; it implied **selection** and **abstraction** skills.
- Abstraction led to **music notation**; thus the **History** of Music was born.

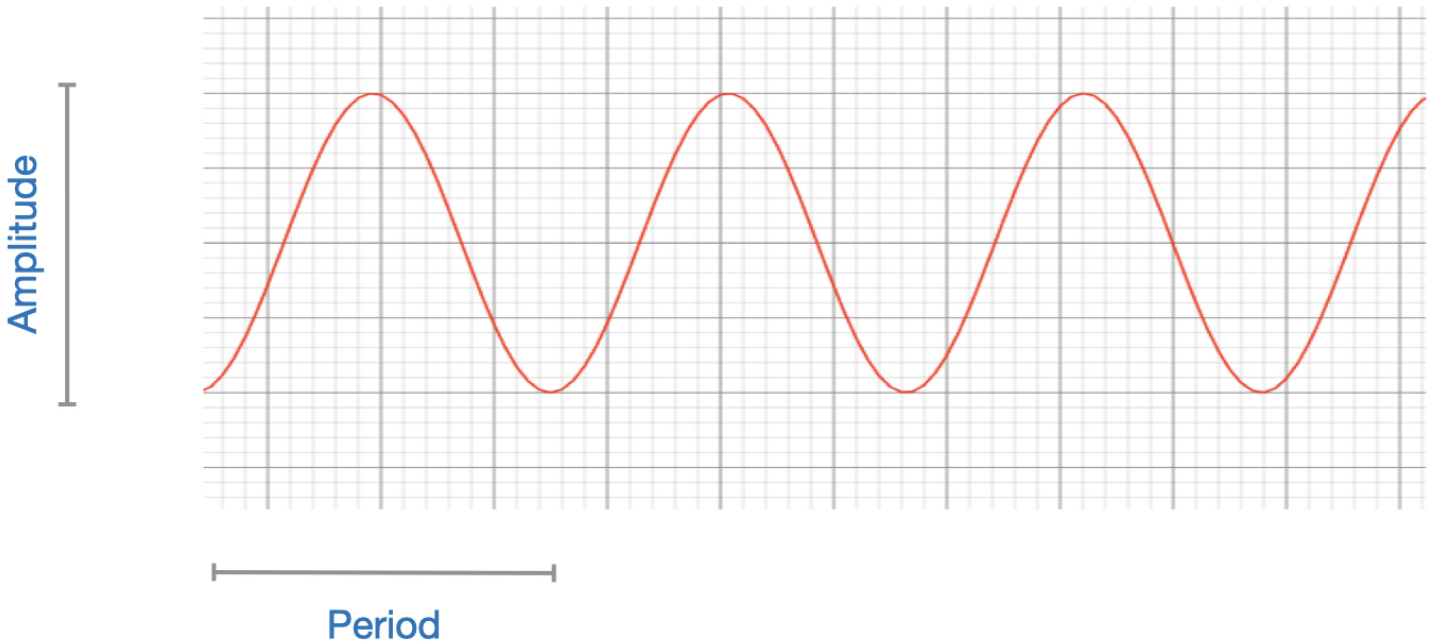
How sound is produced





Vibration can be faster or slower, resulting in higher or lower **pitches**.

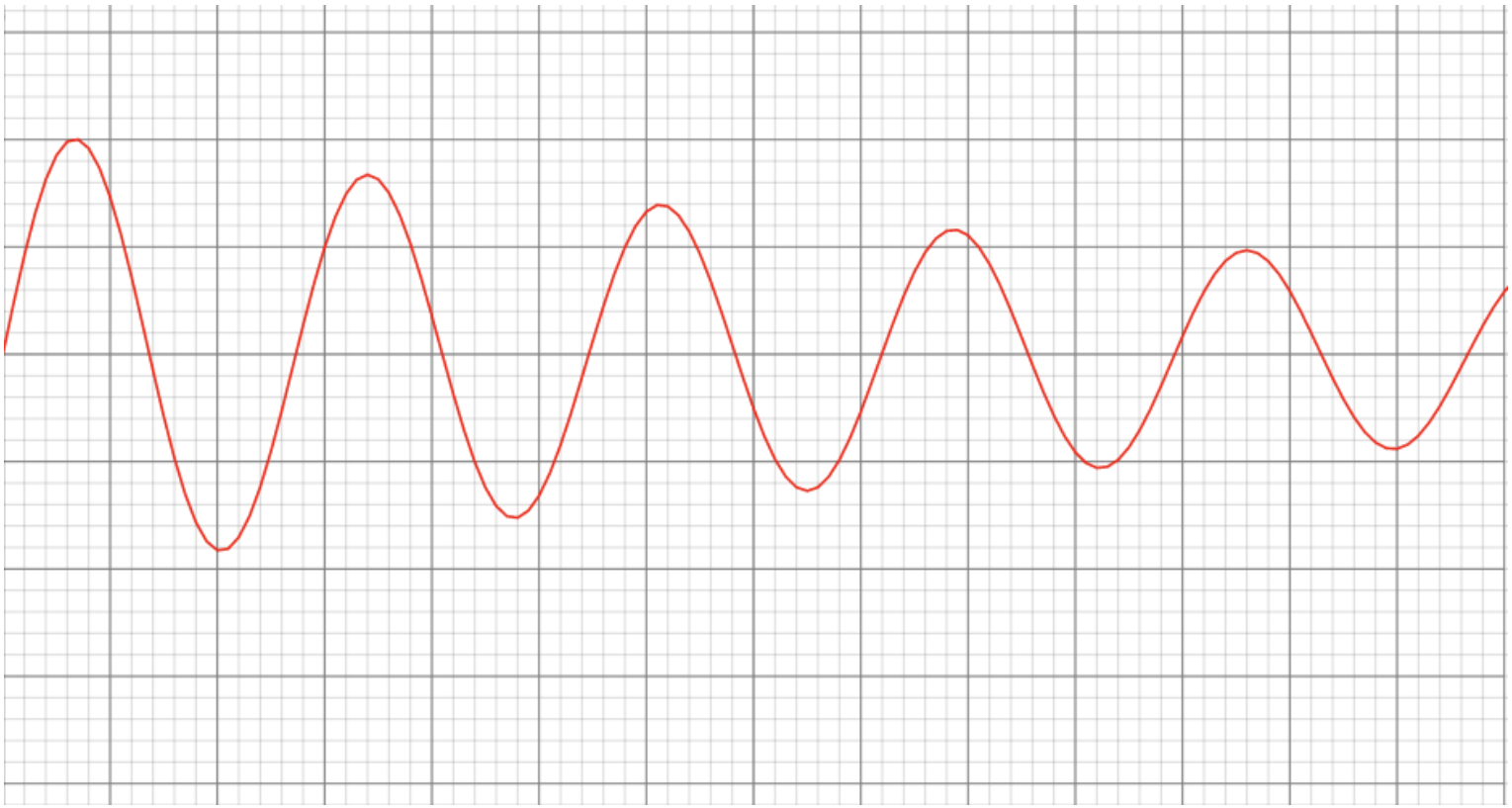
How sound is produced



Period and **amplitude**

How sound is produced

Percussion:



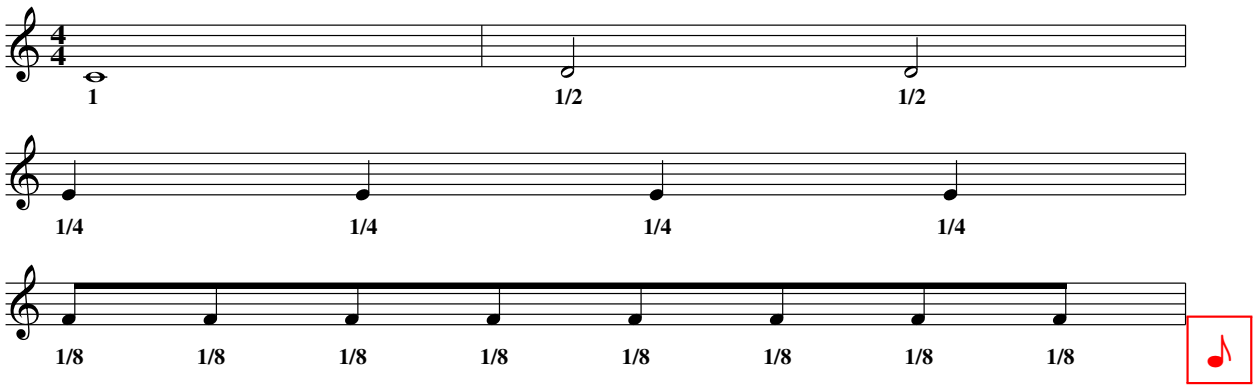
Amplitude decay (energy loss).

Glossary in one slide

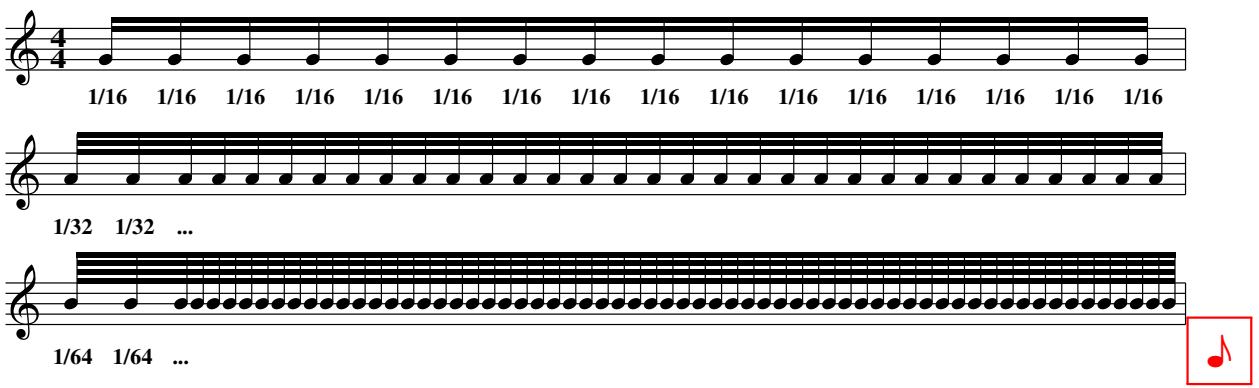
Sound	**vibrations** *that travel through the air or another medium and can be heard when they reach the ear.*
Period	*the interval of time (T) between successive occurrences of the same state in an* **oscillatory** *or cyclic phenomenon.*
Frequency	*the* **rate** *of vibrations producing sound ($f = 1/T$).*
Pitch	*the quality of a sound governed by the rate of vibrations producing it*
Amplitude	*the* **maximum extent** *of a vibration or oscillation, measured from the position of rest.*
Rhythm	*the systematic arrangement of musical sounds, principally according to* **duration** *and periodic stress.*

Mastering time

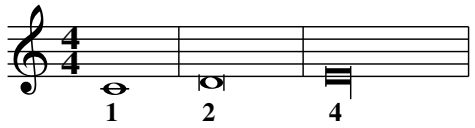
Time division as rythmic perception of *rational numbers* (vulg. fractions),



and so on and so forth:



Mastering time

The other way around: 

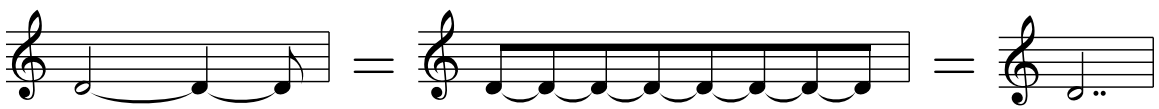
, etc.

Recall:

Natural numbers — 1, 2, 3, 4, ...

Rational numbers — 1/2, 2/3, 1/3, ..., n/m, ... where n and m are natural numbers

Rational number arithmetics — e.g. $\frac{1}{2} + \frac{1}{4} + \frac{1}{8} = \frac{7}{8}$, cf.



Therefore:

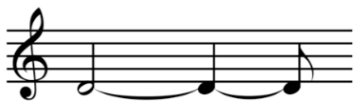
> *Need for a computer language able to calculate with rational numbers*

We shall use the **Haskell** language for this.

Calculating with rational numbers

jno.ipynb

Code



[2]:
```
1 % 2 + 1 % 4 + 1 % 8
```

```
7 % 8
```

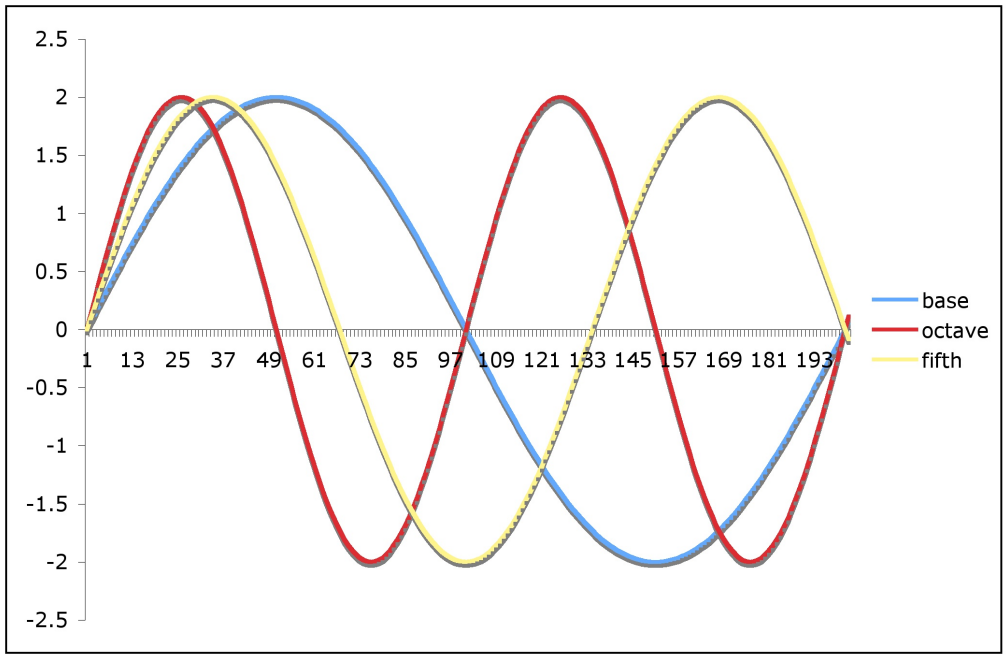
Outros cálculos fracionários

[12]:
```
2 % 3 + 3 % 2

(3 % 2) * (3 % 2)

1/(3%2)
```

```
13 % 6
9 % 4
2 % 3
```

Mastering pitch

Very early in the history of mankind, humans spotted the congruence of pitches f, $3/2\,f$, $2\,f$,



that is, (perfect) *fifths* and *octaves*:

$$\begin{aligned} \mathit{fifth}\ f &= \frac{3}{2} f \\ \mathit{octave}\ f &= 2f \end{aligned}$$

Mastering pitch

Stacking these up and down we obtain 6 ascending and descending intervals:

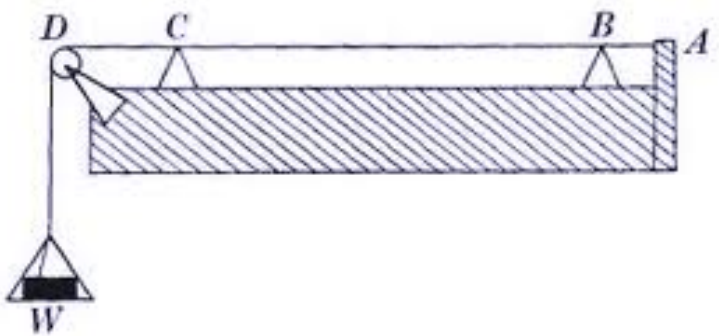
Interval	Descending	Ascending
octave	1/2	2/1
fifth	2/3	3/2
fourth	3/4	4/3

Acoustics: pressing a string stretched by nails on either end (or a violin string, for instance), each interval corresponds to the inverse proportion of the vibrating segment of the string. Eg. the interval of a fifth (3/2) corresponds to 2/3 of the length of the string.

Mastering pitch

Glossary continued:

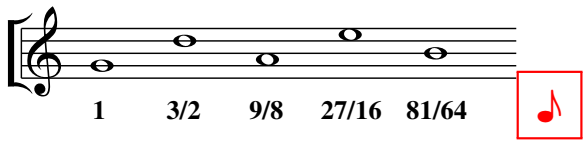
Monochord consisted of a single string stretched over a sound box, held taut by pegs or weights on either end. It used a **moveable** bridge to change pitch.



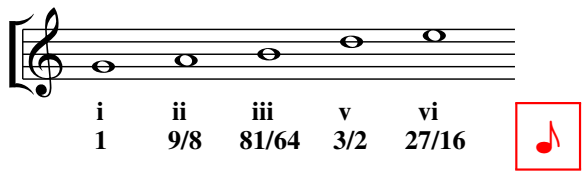
It was used as an instrument as early 300 BC by **Euclid**, and as a scientific instrument by **Pythagoras** as early as the 6th century BC. Its origins extend into prehistory.

Pentatonic scales

Elementary scales built on top of fifths and octaves:



that is (sorting):



Let us compute these figures:

$$
\begin{aligned}
i &= 1 && \text{-- base} \\
v &= 3 \,\%\, 2 * i && \text{-- fifth up} \\
ii &= 3 \,\%\, 4 * v && \text{-- fourth down} \\
vi &= 3 \,\%\, 2 * ii && \text{-- fifth up} \\
iii &= 3 \,\%\, 4 * vi && \text{-- fourth down}
\end{aligned}
$$

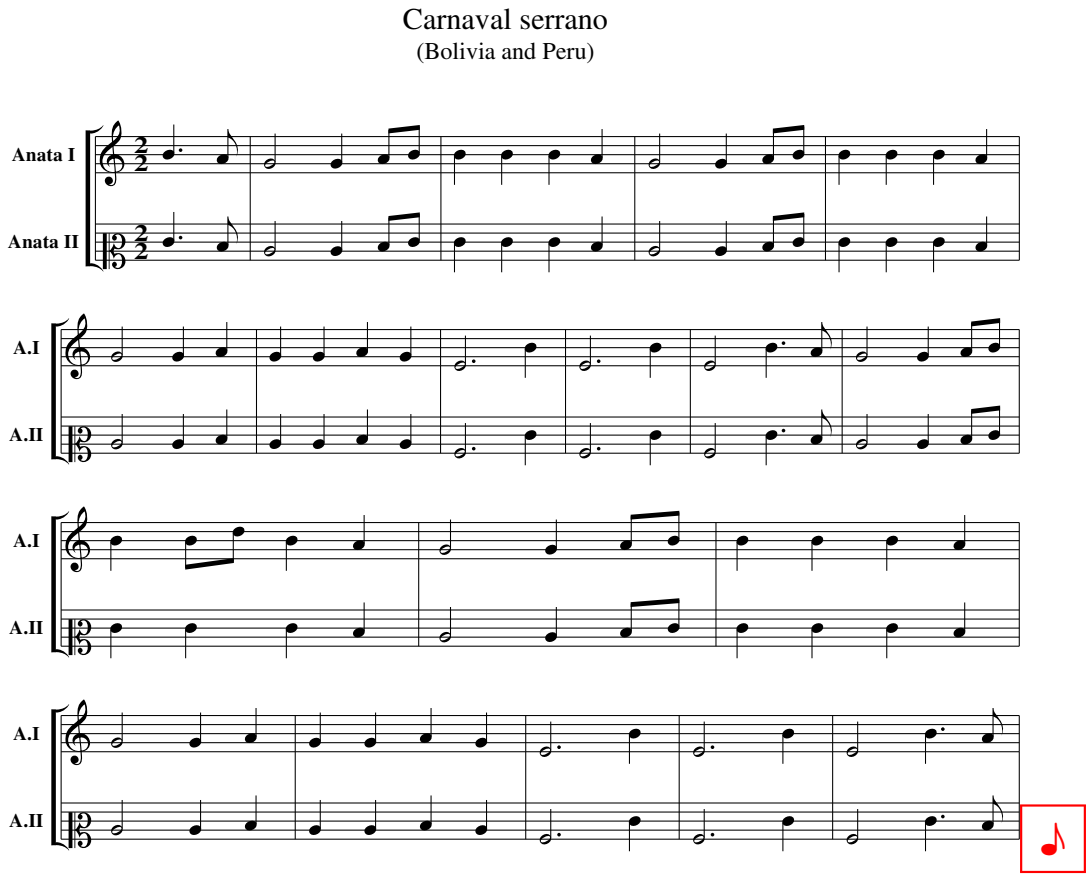
```
[3]: i = 1
     v = 3 % 2 * i
     ii = 3 % 4 * v
     vi = 3 % 2 * ii
     iii = 3 % 4 * vi
```

```
[4]: sort [i,v,ii,vi,iii]
     [1 % 1,9 % 8,81 % 64,3 % 2,27 % 16]
```

Pentatonic heritage

Source: "Carnaval Serrano" (Peru-Bolivia), in *Flutes from the Andes* by Guillermo De La Roca. Epm Music B000027YVO.

Carnaval serrano

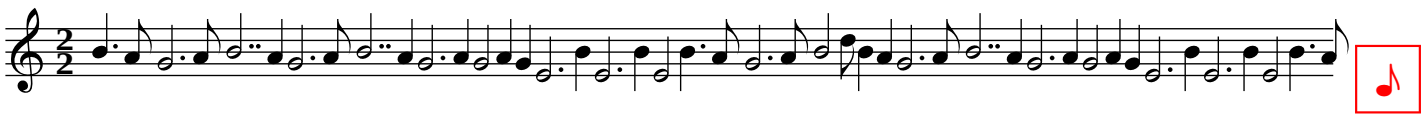


Anata *instrument popular in Jujuy's carnival (Argentina) very close to the "tarka" Boliviana: it is a flute dulce made of a piece of soft wood of light colour.*

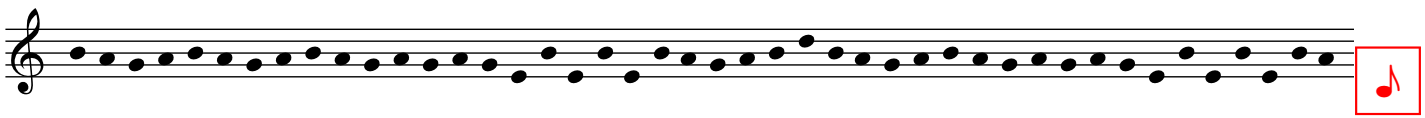
Checking for "pentatonicity"

The following is a first illustration of the Haskell library we shall be using and developing to assist in musical analysis:

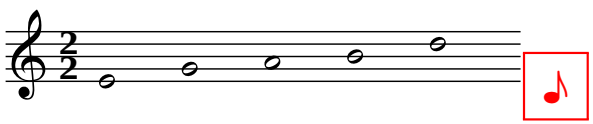
- run *nrep* to remove repeated notes [4]:



- rhythm out:



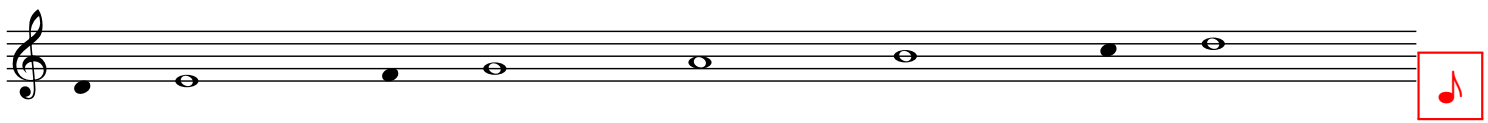
- run *nub* (removes repeated pitches) and *sort* to obtain the underlying scale:



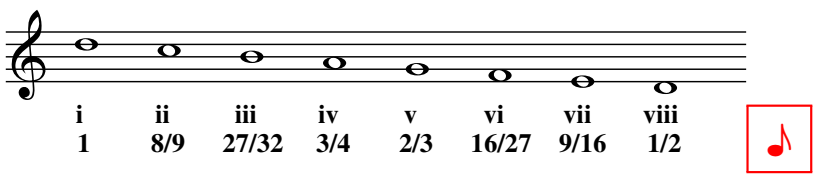
[4] Actually using Anata II transposed a fifth higher

Pythagorean tuning

Pythagoras is credited with having devised a system of tuning based solely upon the interval of a fifth. It all amounts to "filling in the gaps" of the pentatonic scale we've already obtained, leading to the Greek **Phrygian** mode (wrongly referred to as Dorian by medieval scholars) [5]:



Because Greek modes were descending, we should write



How do we compute these figures? See the exercises which follow.

[5] New pitches in black.

Exercises

Exercise 1: Let Haskell compute figures *ii*, *iii*, *vi* and *vii* knowing that, in the Pythagorian tuning,

- *ii* is a (perfect) fourth above *v*
- *vi* is a (perfect) fifth below *ii*
- *vii* is a (perfect) fourth below *iv*
- *iii* is a (perfect) fifth above *vii*

□

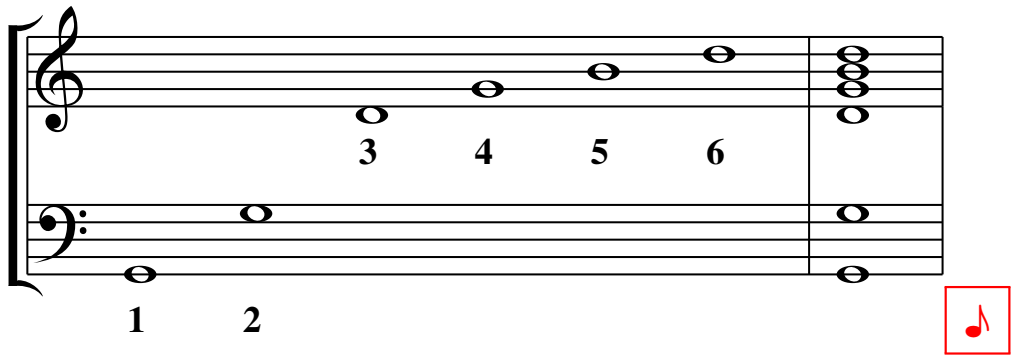
Exercise 2: Use Haskell to compute the following figures of the Pythagorian tuning:

- one tone $= 8/9$ (or $9/8$)
- one semitone $= 243/256$ (or $256/243$)

□

The *sestina*

Many centuries later, 16c theoreticians tried and explained tuning in terms of the **sestina**, as follows:

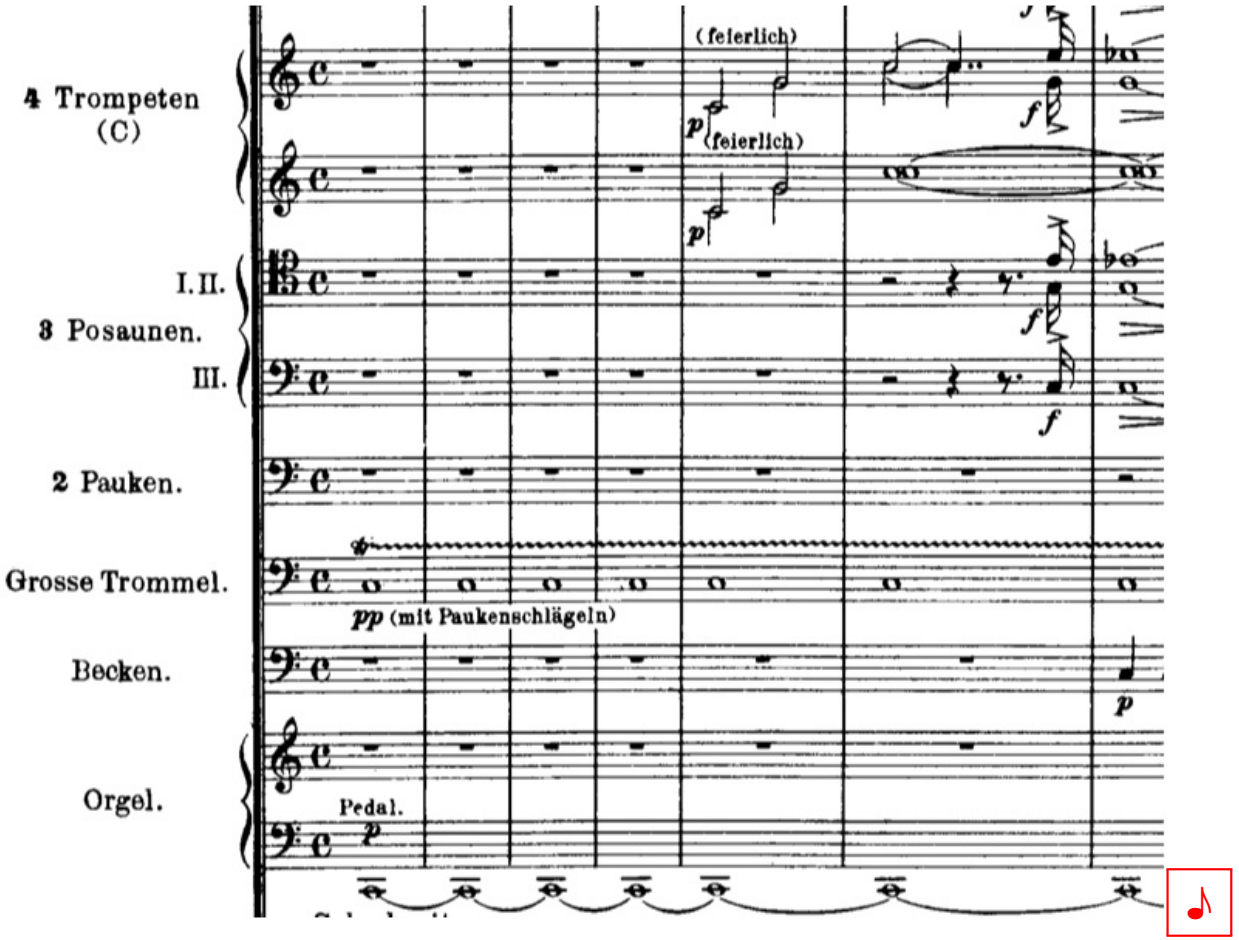


leading to intervals as follow:

Interval	Descending	Ascending
octave	1/2	2/1
fifth	2/3	3/2
fourth	3/4	4/3
major third	4/5	5/4
minor third	5/6	6/5

The *sestina*

As in the introductory bars of R. Strauss (1864-1949)'s op.30 (*Also sprach Zarathustra*):



Harmonic series

Pitches 1 to 6 are but the beginning of the **harmonic series**

Harmonic series contain all the integral multiples of a pitch as far as the series extends (f, $2\,f$, $3\,f$, ..., $6\,f$, ...).

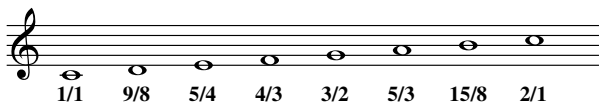
The process of decomposing a periodic tone into its harmonics is known as **harmonic analysis**, as developed by Daniel Bernoulli (1700 - 1782) and Jean Baptiste Joseph Fourier (1768 - 1830) in his thesis *Analytical Theory of Heat*, 1822.

Harmonic series tuning is not free of defects: e.g., stacking two major seconds doesn't yield the same as one major third, $\frac{9}{8} \times \frac{9}{8} = \frac{81}{64}$, different from $\frac{80}{64} = \frac{5}{4}$. (This mismatch $\frac{81}{80}$ is known as the **syntonic comma**.)

Just intonation (Zarlino)

Further to octaves (2/1), perfect fifths (3/2) and perfect fourths (4/3), **just intonation** fixes major thirds (5/4) and minor thirds (6/5) according to the **sestina**.

This system, already devised by the Helenistic scientist Ptolemy (2c BC), has the advantage of staying within small proportions:

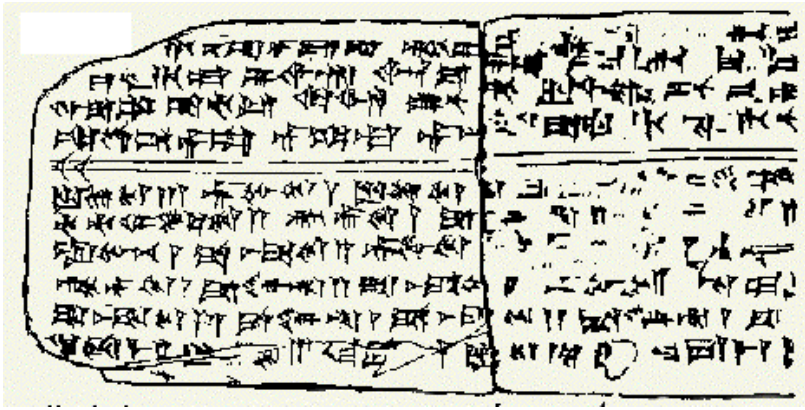


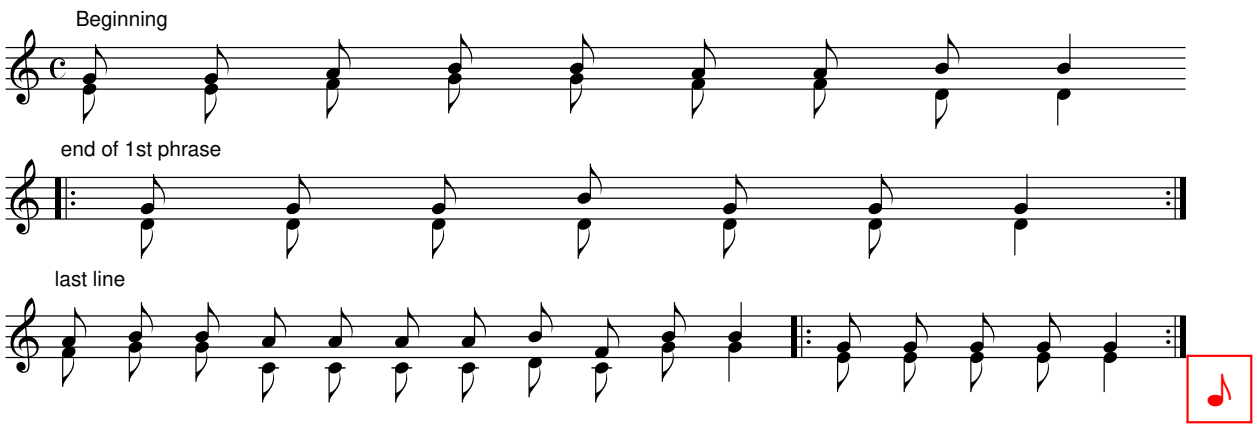
It was ignored during the entire Medieval period and only re-surfaced with the development of polyphonic harmony.

It became widely known after Gioseffo Zarlino (1517-1590) published his *Institutioni Armoniche* in 1558.

Thirds and sixths — older than previously thought?

Believed to be the oldest "score" known, in cuneiform notation (Ugarit, Syria, 3400 years ago):

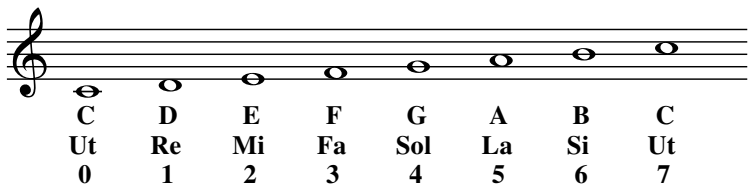




Source: Kilmer, A.D. (1971) *The Discovery of an Ancient Mesopotamian Theory of Music*. Proceedings of the American Philosophical Society 115, 131-149.

The advent of musical notation

- How to represent pitches? Can't we abstract from the actual figures?
- Latin **letters** used instead, or **names**, or indices of positions in heptatonic scales:



- **Diatonicism** in music (cf. tones, semitones, tetrachords, etc)
- Western music notation — semi-graphical *abstract* notation based on **pentagrams**, clefs, etc. capturing diatonicism (note positions), and so on.

"All semitones are created equal. . ."

Eventually, by the end of the 16c fretted instruments became tuned using

Equal temperament

all semitones are the same
minor second = 1 semitone
major second = 2 semitones
minor third = 3 semitones
...
octave = 12 semitones, where

$$up\_one\_semitone\ f \quad = \quad 2^{\frac{1}{12}} f$$

made famous by J.S. Bach (1685–1750)'s **Well-tempered Clavier**.

Equal temperament

Summary:

note name	index	interval
C	0	1
C#/Db	1	$2^{\frac{1}{12}}$
D	2	$2^{\frac{2}{12}}$
D#/Eb	3	$2^{\frac{3}{12}}$
$\vdots$	i	$\vdots$
Bb/A#	10	$2^{\frac{10}{12}}$
B	11	$2^{\frac{11}{12}}$
C	12	$2^{\frac{12}{12}}$

For more about (the amazing world of) **musical tuning** systems see e.g.

`http://www.peterfrazer.co.uk/music/tunings/acoustics.html`

by Peter A. Frazer.

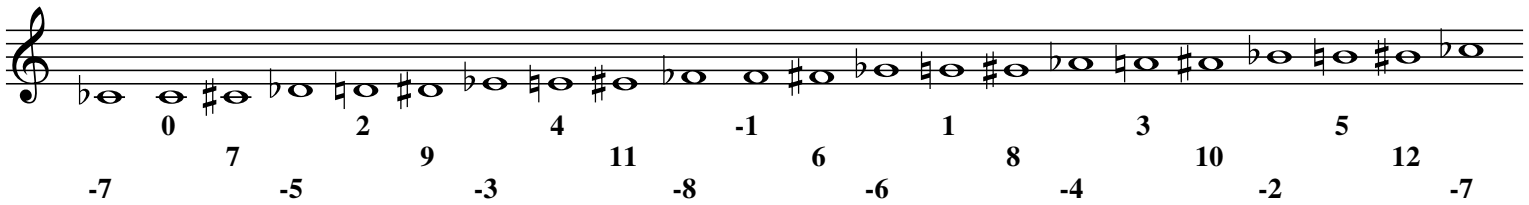
ABC notation for music description

The **ABC notation** adopts the Anglo-saxonic use of letters to denote pitch, e.g.:

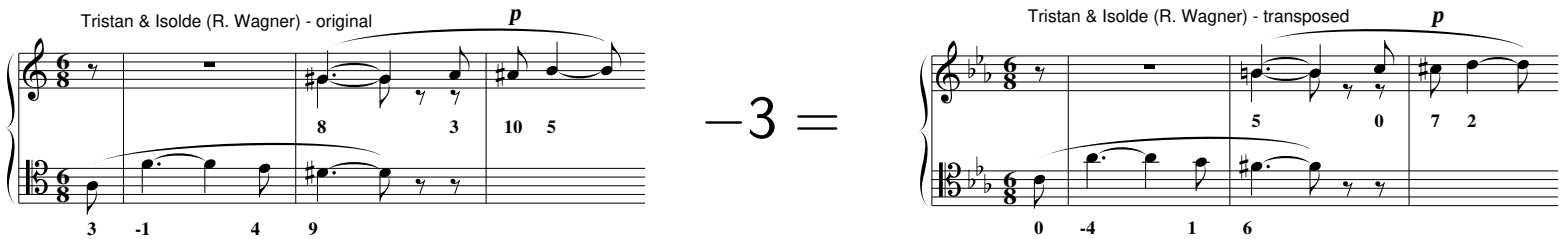
```
X: 3
T: Bouree (BWV996v)
C: J.S. Bach   (1685-1750)
M:6/8
L:1/8
K:Em
   z2 e f2 g-  | g2 fe2^d- |^d2 ef2 B- |B2 ^c^d2 e- |
   e2=d c2  B- | B2 AG2F-  |F2GA2B-    |B2 A GFE-  |
   E2 e f2 g-  | g2 fe2^d- |^d2 ef2 B- |B2 ^c^d2 e- |
   e2=d c2  B- | B2 AG2F-  |F2G-G3     |           |
```

Back to mastering pitch

Complete and unambiguous numeric representation of pitch:



This grants **transposition** by simple subtraction/addition, e.g.:



We shall come back to this representation later on in this course.

What next?

- It should be clear by now that we need to learn how to write programs in Haskell handling **numbers** and **proportions**
- On the other hand, we need to be able to deal with **characters** and **words** as well, cf. note names, lyrics, etc
- Finally, we should be able to handle — both **analyse**, transform and re-interpret — the musical texts themselves, that is, **scores** denoting (possibly polyphonic) streams of musical **events**.

See the next set of slides.

References

J.M. Wing. Computational thinking. *Commun. ACM*, 49(3): 33–35, 2006. DOI.