

# Computing for Musicology (Course code: F104N5)

## 1. Introduction to the Course

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# 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**.

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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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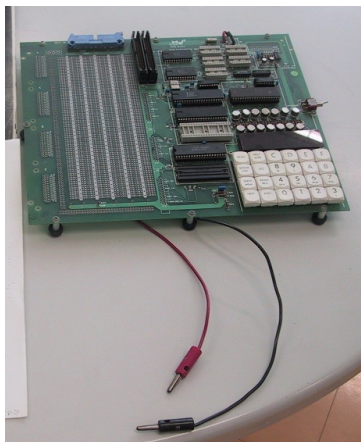
# Music and computing at Minho

## 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).

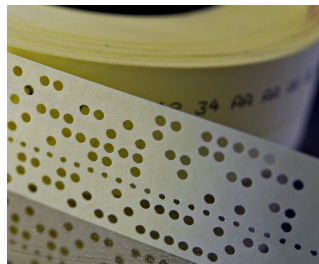


## Back to 1978/79

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:



The image shows a musical score for the 'Air' from BWV 1068. It consists of five staves: two for the first and second violins, and three for the piano accompaniment (treble and bass clefs). The score is in G major and 3/4 time. Two red boxes highlight specific moments where the first and second violins play the same note at the same time, illustrating a phase opposition issue. A red musical note icon is also present in the bottom right corner of the score area.

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<sup>1</sup> 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**?



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<sup>1</sup><http://www.wiki-score.org>.

## These slides as example

Text preparation and publishing:

*L<sup>A</sup>T<sub>E</sub>X*— *monumental resource sharing*  
via the *T<sub>E</sub>X'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”.

The screenshot shows the WikiScore interface. On the left is a sidebar menu with categories like 'Cultura', 'Actualidade', 'Sociedade', 'Educação', 'Desporto', 'Política', 'Economia', 'Ciência', 'Ambiente', 'Media', 'Vícios', 'Pquê?', and 'OPTIMUS ALIVE!12'. Above the menu is a large 'P3' logo. At the top, there are navigation tags: 'Desenho', 'Facebook', 'Humor', 'Ilustração', 'Viral', 'Crónica', 'Emigração', and 'Economia'. The main content area displays a musical score for 'Pagliacci, Quotono (1731-1798)' in 2/4 time, featuring parts for Corni, Trombe, Flautas, Clarinetas, Oboes, Violinos, Viola, and Cello. Below the score, there is a section titled 'Investigação' with the heading 'WikiScore: Universidade do Minho criou uma "Wikipedia" para a música' and a sub-heading 'O conceito da WikiScore foi inspirado na Wikipedia e a ideia surgiu na disciplina de Informática para a Musicologia'. The text is attributed to 'Texto de João Pedro Pereira • 15/06/2012 - 11:09'.

# Why the Wiki-score

Matrix format enables cooperative, concurrent editing of (part, section) music cells.

Matrix

	[S1] Gloria Select   Unselect	[S2] Fama Select   Unselect	[S3] Virtu Select   Unselect	[S4] Fama Select   Unselect	[S5] Gloria Select   Unselect	[S6] Virtu Select   Unselect	[S7] [Terceto] Select   Unselect	
Fol	1v	17v	24r	33r	39r	44r	51r	
	Build S1	Build S2	Build S3	Build S4	Build S5	Build S6	Build S7	
[P1] Tromba I Select   Unselect	S1 P1	∅	∅	∅	∅	∅	S7 P1	Build P1
[P2] Tromba II Select   Unselect	S1 P2	∅	∅	∅	∅	∅	S7 P2	Build P2
[P3] Corno da Caccia I Select   Unselect	S1 P3	∅	S3 P3	∅	∅	∅	S7 P3	Build P3
[P4] Corno da Caccia II Select   Unselect	S1 P4	∅	S3 P4	∅	∅	∅	S7 P4	Build P4
[P5] Oboe I Select   Unselect	S1 P5	∅	∅	∅	∅	S6 P5	S7 P5	Build P5
[P6] Oboe								

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<sup>2</sup> — truly scientific method calls for open data, for free verification.

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<sup>2</sup>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 <sup>3</sup>:

**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.



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<sup>3</sup>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

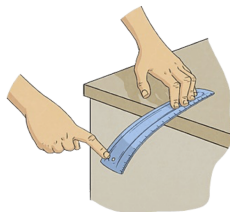
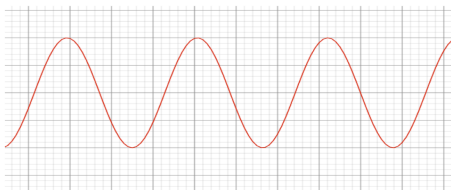
Music is one of the **pillars of culture**: every community, civilization etc has its own.

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.

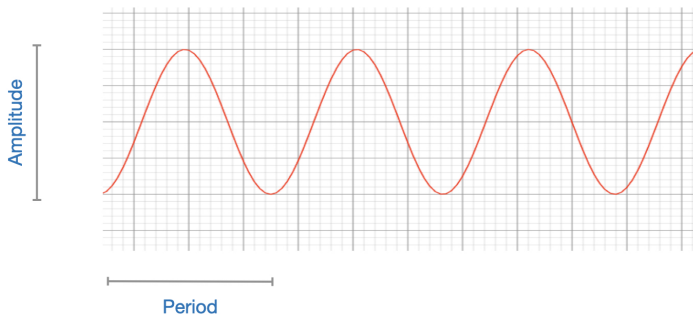


# How sound is produced



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

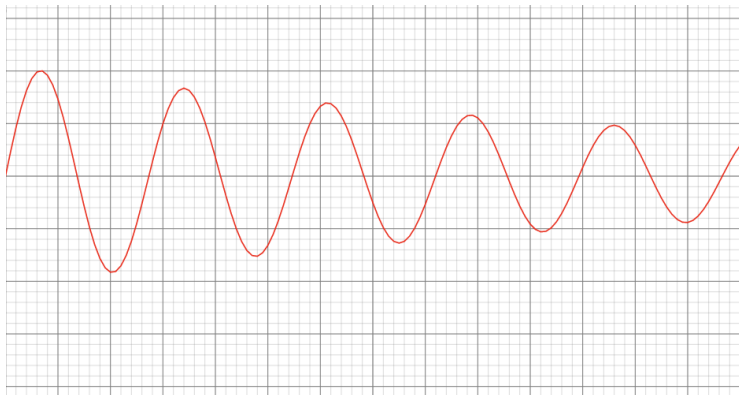
# How sound is produced



## 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 rhythmic perception of *rational numbers* (vulg. fractions),

Three staves of musical notation in 4/4 time, illustrating the division of time into smaller fractions:

- Staff 1: A whole note (1), followed by two half notes (1/2).
- Staff 2: Four quarter notes (1/4).
- Staff 3: Eight eighth notes (1/8).

A red square with a musical note icon is positioned at the end of the third staff.


and so on and so forth:

Three staves of musical notation in 4/4 time, illustrating further time division:

- Staff 1: Sixteen sixteenth notes (1/16).
- Staff 2: Thirty-two thirty-second notes (1/32).
- Staff 3: Sixty-four sixty-fourth notes (1/64).

A red square with a musical note icon is positioned at the end of the third staff.

## 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



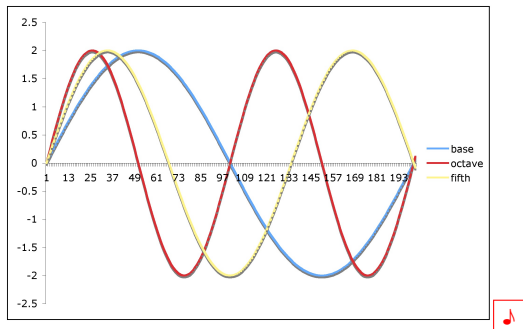
```
[2]: 1 % 2 + 1 % 4 + 1 % 8
      7 % 8
```

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*:

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



## Mastering pitch

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

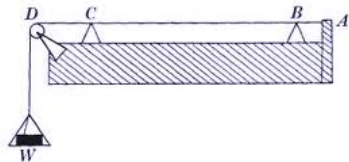
Interval	Descending	Ascending
<b>octave</b>	$1/2$	$2/1$
<b>fifth</b>	$2/3$	$3/2$
<b>fourth</b>	$3/4$	$4/3$

**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:

$i = 1$             -- base  
 $v = 3 \% 2 * i$     -- fifth up  
 $ii = 3 \% 4 * v$     -- fourth down  
 $vi = 3 \% 2 * ii$     -- fifth up  
 $iii = 3 \% 4 * vi$     -- fourth down

```
[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

Carnaval serrano  
(Bolivia and Peru)

The image displays a musical score for 'Carnaval serrano' in 3/4 time. It consists of four systems of music. Each system has two staves: Anata I (top) and Anata II (bottom). The first system shows the initial melody and accompaniment. The second system continues the piece with some melodic variation. The third system shows further development of the melody. The fourth system concludes the piece, with a red square highlighting the final note on the Anata II staff.

**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 <sup>4</sup>:



- rhythm out:



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



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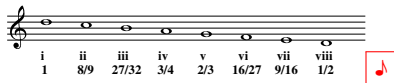
<sup>4</sup>Actually using Anata II transposed a fifth higher

## 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) <sup>5</sup>:



Because Greek modes were descending, we should write



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

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<sup>5</sup>New pitches in black.

## Exercises

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



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

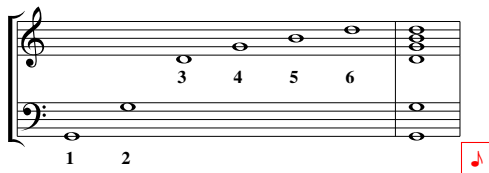
- one tone =  $8/9$  (or  $9/8$ )
- one semitone =  $243/256$  (or  $256/243$ )





## 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*):

4 Trompeten (C)

3 Posaunen. I. II. III.

2 Pauken.

Grosse Trommel.

Becken.

Orgel. Pedal.

(*feierlich*)

*p* (*feierlich*)

*pp* (mit Paukenschlägeln)

*p*

## 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 ( $f, 2f, 3f, \dots, 6f, \dots$ ).

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 Hellenistic scientist Ptolemy (2c BC), has the advantage of staying within small proportions:

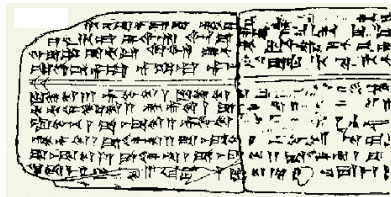


It was ignored during the entire Medieval period and only re-surfaced with the development of polyphonic harmony.

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):



Beginning

end of 1st phrase

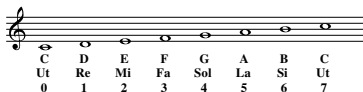
last line

The image displays three staves of musical notation in a modern staff system. The first staff is labeled "Beginning" and shows a sequence of notes. The second staff is labeled "end of 1st phrase" and shows a sequence of notes. The third staff is labeled "last line" and shows a sequence of notes. A red square highlights a red note on the third staff.

**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

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

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:

A musical staff in treble clef showing a sequence of notes. Below the staff, a series of integers represents the pitch of each note. The notes and their corresponding integers are: G4 (0), A4 (7), B4 (2), C5 (9), D5 (4), E5 (11), F5 (-1), G5 (6), A5 (-6), B5 (1), C6 (8), D6 (3), E6 (10), F6 (5), G6 (12), and A6 (-7).

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

Two musical staves are shown side-by-side, separated by an equals sign and a minus sign (-3). The left staff is titled "Tristan & Isolde (R. Wagner) - original" and the right staff is titled "Tristan & Isolde (R. Wagner) - transposed". Both staves show a piano accompaniment with a melody line and a bass line. The original piece has a key signature of one flat (B-flat major) and a time signature of 3/4. The transposed piece has a key signature of two flats (B-flat major transposed down three semitones to G major) and a time signature of 3/4. The piano part of the original has notes with fingerings 3, -1, 4, 9. The piano part of the transposed version has notes with fingerings 0, -4, 1, 6. The melody line of the original has notes with fingerings 8, 3, 10, 5. The melody line of the transposed version has notes with fingerings 5, 0, 7, 2.

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.