

# Sound and Music Computing



*Silvan David Peter - Emmanouil Karystinaios*

# Who are We?

## **Silvan David Peter :**

Researcher in Music Information Research at the Institute of Computational Perception at JKU. Lecturer at JKU, University of Applied Arts Vienna. Sound & media artist.

## **Emmanouil Karystinaios:**

Researcher at the Institute of Computational Perception (JKU). Research Topics : Computational Musicology, Music Analysis, and Graph Neural Networks. Background in Musicology, Composition, and Mathematics.

# Organization Details

- 7 lectures between October 23 and January 24;
- Python Programming Language;
- Approximately biweekly soft exercises;
- Comprehension exercises during lectures;
- Final Project - A composition based on techniques discussed during lectures.

# Contents and Lectures

- Introduction to Music Theory
- Introduction to Machine Learning
- Tonnetz and Negative Harmony
- Deep Generation
- Formal Grammars for Symbolic Music Generation
- Agents and Reinforcement Learning
- Concert

# Sound and Music Computing



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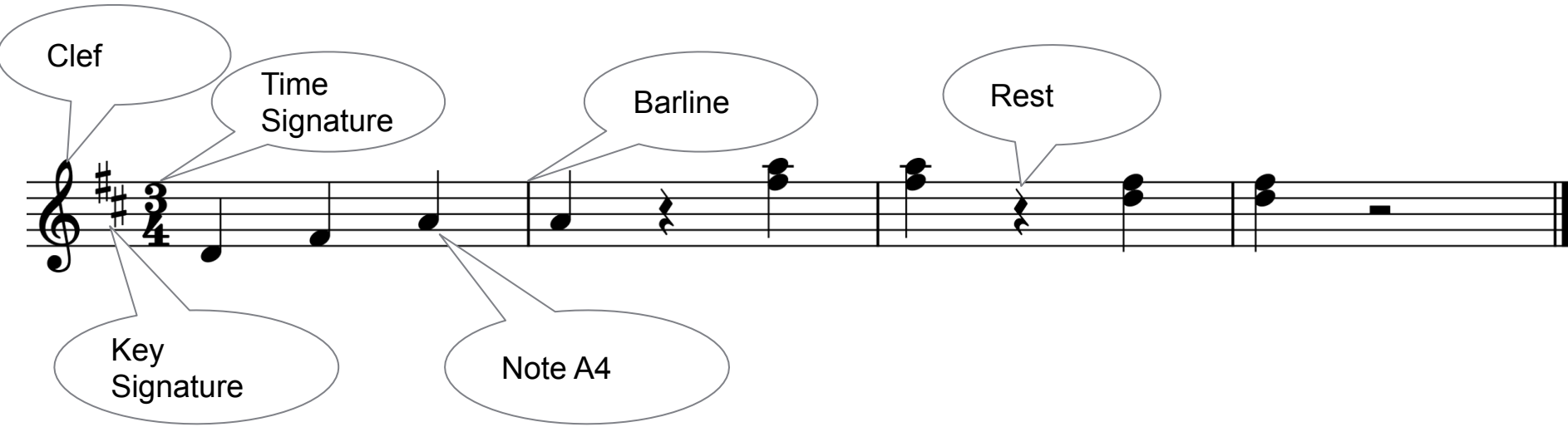
# Introduction to Music Theory

In this section we will address:

- Notes / Pitch / Temperament
- Chords and Harmony
- Rhythm

From the point of view of musical representations and encoding.

# Music Representations

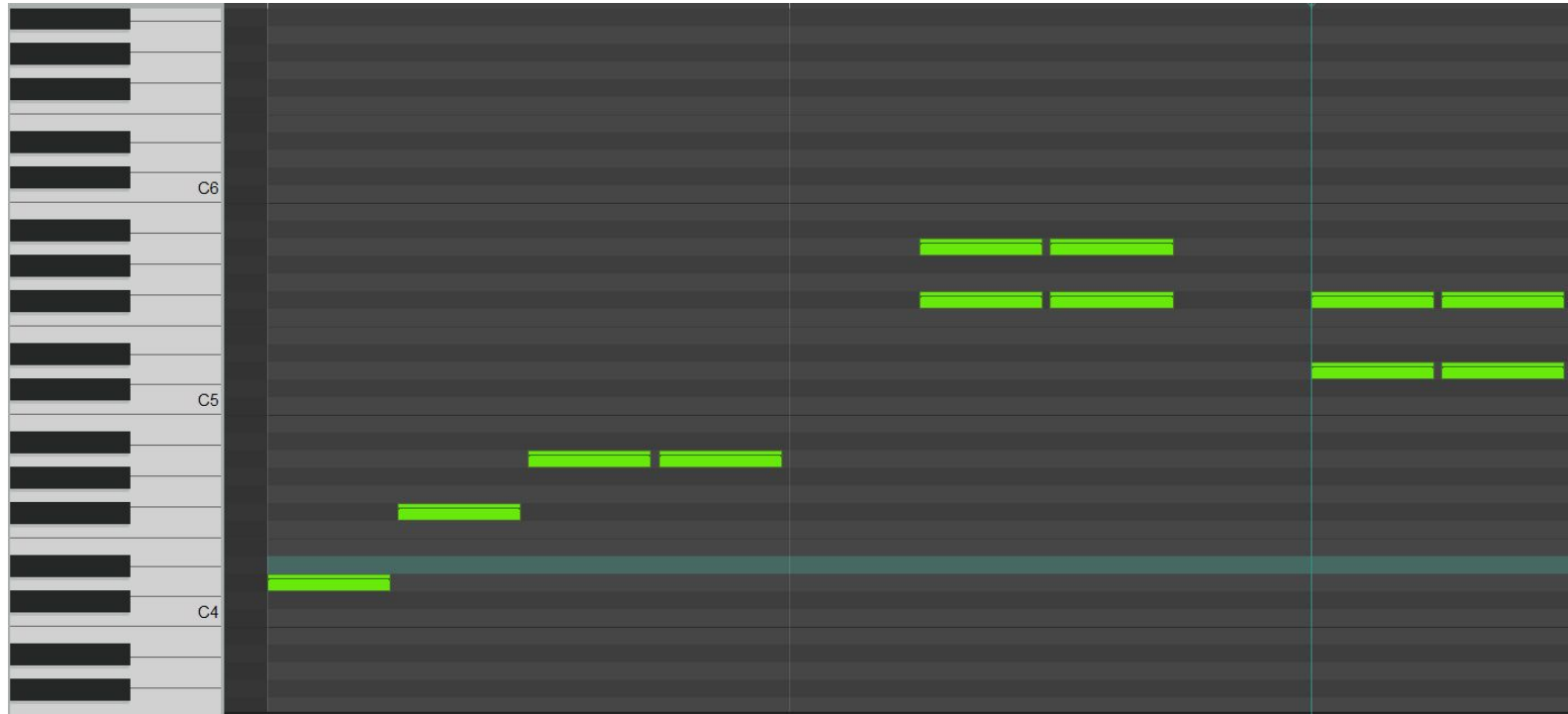


# Music Representations - MUSICXML

```
1.  <time>
2.    <beats>3</beats>
3.    <beat-type>4</beat-type>
4.  </time>
5.  <clef>
6.    <sign>G</sign>
7.    <line>2</line>
8.  </clef>
9. </attributes>
10. <note default-x="110.48" default-y="-45.00">
11.  <pitch>
12.    <step>D</step>
13.    <octave>4</octave>
14.  </pitch>
15.  <duration>1</duration>
16.  <voice>1</voice>
17.  <type>quarter</type>
18.  <stem>up</stem>
19. </note>
20.
```



# Music Representations - Pianoroll



# Music Representations - MIDI File

```
1.  MidiFile(type=1, ticks_per_beat=480, tracks=[
2.      MidiTrack([
3.          MetaMessage('track_name', name='Piano\x00', time=0),
4.          MetaMessage('time_signature', numerator=3, denominator=4, clocks_per_click=24, notated_32nd_notes_per_beat=8, time=0),
5.          MetaMessage('key_signature', key='D', time=0),
6.          MetaMessage('set_tempo', tempo=500000, time=0),
7.          Message('control_change', channel=0, control=121, value=0, time=0),
8.          Message('program_change', channel=0, program=0, time=0),
9.          Message('control_change', channel=0, control=7, value=100, time=0),
10.         Message('control_change', channel=0, control=10, value=64, time=0),
11.         Message('control_change', channel=0, control=91, value=0, time=0),
12.         Message('control_change', channel=0, control=93, value=0, time=0),
13.         MetaMessage('midi_port', port=0, time=0),
14.         Message('note_on', channel=0, note=62, velocity=80, time=0),
15.         Message('note_on', channel=0, note=62, velocity=0, time=455),
16.         Message('note_on', channel=0, note=66, velocity=80, time=25),
17.         Message('note_on', channel=0, note=66, velocity=0, time=455),
18.         Message('note_on', channel=0, note=69, velocity=80, time=25),
19.         Message('note_on', channel=0, note=69, velocity=0, time=455),
20.         Message('note_on', channel=0, note=69, velocity=80, time=25),
21.         Message('note_on', channel=0, note=69, velocity=0, time=455),
22.         Message('note_on', channel=0, note=78, velocity=80, time=505),
23.         Message('note_on', channel=0, note=81, velocity=80, time=0),
24.         Message('note_on', channel=0, note=78, velocity=0, time=455),
25.         Message('note_on', channel=0, note=81, velocity=0, time=0),
```

# Music Representations - Note Array

id	onset_beat	duration_beat	onset_quarter	duration_quarter	onset_div	duration_div	pitch	voice	divs_pq
p0n0	0	1	0	1	0	1	62	1	1
p0n1	1	1	1	1	1	1	66	1	1
p0n2	2	1	2	1	2	1	69	1	1
p0n3	3	1	3	1	3	1	69	1	1
p0n5	5	1	5	1	5	1	78	1	1
p0n6	5	1	5	1	5	1	81	1	1
p0n7	6	1	6	1	6	1	78	1	1
p0n8	6	1	6	1	6	1	81	1	1
p0n10	8	1	8	1	8	1	74	1	1
p0n11	8	1	8	1	8	1	78	1	1



# Exercise on Music Representation

What would you need to represent a music Element i.e.:

- a Note,
- a Key Signature,
- a Time Signature
- a Dynamics' Element

# Musical Encoding

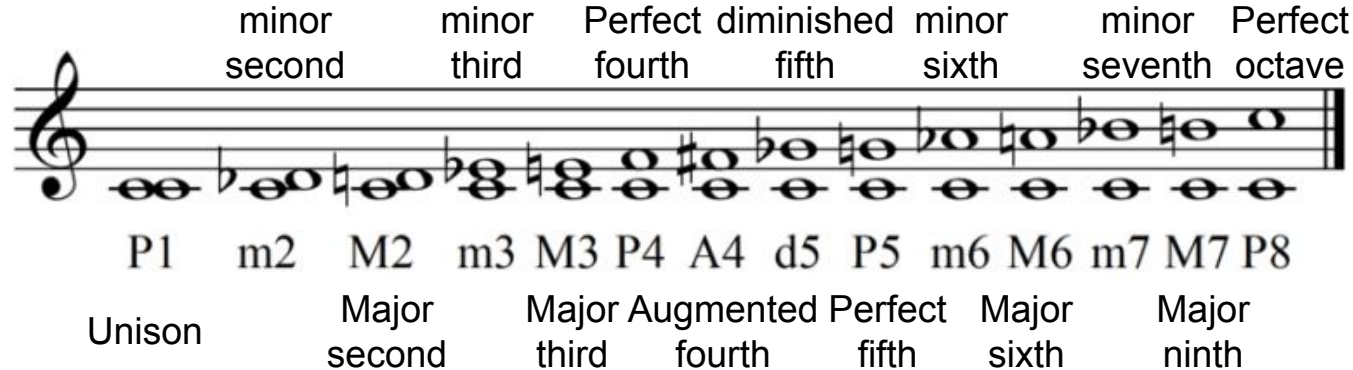
- What is a musical encoding?
  - Encoding is the conversion of Musical information into a specialized format for efficient transmission or storage. More generally from one communication protocol to another.
- Why do we need to encode?
  - To store information (save a score)
  - To communicate (from one musical language to another from score to tablature, pianoroll, etc.)
  - To formalize (create formal systems and prove properties)
  - To use intelligent systems (convert human readable score to numerical function for ML)

# Note Naming Conventions

- Accidentals ( $\sharp$ ,  $\times$ ,  $\natural$ ,  $\flat$ ,  $\flat\flat$  ).
  - Sharp ( $\sharp$ ): Raise a note by a semitone
  - Double sharp ( $\times$ ): Raise the notes two semitones
  - Flat ( $\flat$ ): Lower a note by a semitone
  - Double Flat ( $\flat\flat$ ): Lower a note by a tone
  - Natural ( $\natural$ , it is usually implicit): resets the previous accidentals
- Pitch Classes: 12 of them:
  - $B\sharp/C$ ,  $C\sharp/D\flat$ ,  $D$ ,  $D\sharp/E\flat$ ,  $E/F\flat$ ,  $E\sharp/F$ ,  $F\sharp/G\flat$ ,  $G$ ,  $G\sharp/A\flat$ ,  $A$ ,  $A\sharp/B\flat$ ,  $B/C\flat$
- Pitch Spelling: “musical orthography”
  - Pitch class + (alteration) + octave
  - Central C is C4

# Intervals

- **Intervals:** Relation between notes (Pairwise distance)
- **Relative pitch:** We (humans) recognize a musical context (e.g., melody) by the relationships of its notes (i.e., the intervals) rather than the notes themselves
- Names of Intervals



A musical staff in treble clef showing intervals between notes. The notes are: C1, C2 (minor second), C#2 (major second), D2 (minor third), D#2 (major third), E2 (perfect fourth), F2 (diminished fifth), F#2 (perfect fifth), G2 (minor sixth), G#2 (major sixth), A2 (minor seventh), A#2 (major seventh), and B2 (perfect octave). Above the staff, the intervals are labeled: minor second, minor third, Perfect fourth, diminished fifth, minor sixth, minor seventh, and Perfect octave. Below the staff, the intervals are labeled with abbreviations: P1, m2, M2, m3, M3, P4, A4, d5, P5, m6, M6, m7, M7, P8. At the bottom, the intervals are labeled with their common names: Unison, Major second, Major third, Augmented fourth, Perfect fifth, Major sixth, Major seventh, and Major ninth.

Interval	Abbreviation	Common Name
Unison	P1	Unison
Major second	M2	Major second
Minor second	m2	Minor second
Major third	M3	Major third
Minor third	m3	Minor third
Perfect fourth	P4	Perfect fourth
Augmented fourth	A4	Augmented fourth
Diminished fifth	d5	Diminished fifth
Perfect fifth	P5	Perfect fifth
Major sixth	M6	Major sixth
Minor sixth	m6	Minor sixth
Major seventh	M7	Major seventh
Minor seventh	m7	Minor seventh
Perfect octave	P8	Perfect octave



# Consonant and Dissonant Intervals

- **Consonant vs. Dissonant Intervals**
  - Consonant:
    - Unison, Octave, Perfect fifth (Perfect);
    - Fourths, thirds, sixths (Imperfect).
  - Dissonant everything else!

# Equal Temperament

Temperament refers to the division of the octave into tones, semitones, microtones, etc.

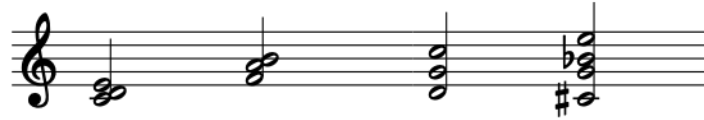
The most commonly used Since the WTC by J.S. Bach is the **Equal Temperament** dividing the octave in 12 semitones.

## Frequency Ratios in Equal Temperament

Interval	Frequency ratio as a power of the twelfth root of 2	Decimal Equivalent (to the nearest two thousandth)
Unison	$(\sqrt[12]{2})^0 = 1.0000$	1.0000
Minor Second	$(\sqrt[12]{2})^1 = 1.0595$	1.0595
Major Second	$(\sqrt[12]{2})^2 = 1.1225$	1.1225
Minor Third	$(\sqrt[12]{2})^3 = 1.1892$	1.1892
Major Third	$(\sqrt[12]{2})^4 = 1.2599$	1.2599
Perfect Fourth	$(\sqrt[12]{2})^5 = 1.3348$	1.3348
Tritone	$(\sqrt[12]{2})^6 = 1.4142$	1.4142
Perfect Fifth	$(\sqrt[12]{2})^7 = 1.4983$	1.4983
Minor Sixth	$(\sqrt[12]{2})^8 = 1.5874$	1.5874
Major Sixth	$(\sqrt[12]{2})^9 = 1.6818$	1.6818
Minor Seventh	$(\sqrt[12]{2})^{10} = 1.7818$	1.7818
Major Seventh	$(\sqrt[12]{2})^{11} = 1.8897$	1.8897
Octave	$(\sqrt[12]{2})^{12} = 2.0000$	2.0000

# Chords

- Chord: a collection of **notes** that are heard as if sounding **simultaneously**

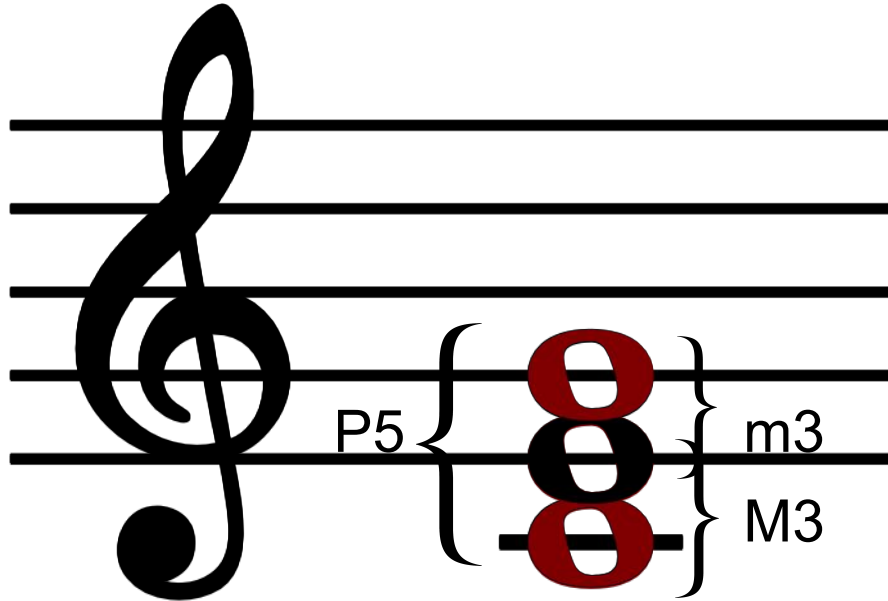


- In Western tonal music, the most common/important chords are conventional **triads**, which consist of **3 notes**:
  - Root + third and fifth “above” the root
  - The 4 basic triads are Major, Minor, Augmented and Diminished
  - The chords are named after the root (e.g., C major is the major chord with root C)
- Chords with more notes exist, and are extensively used in many genres (e.g., jazz)
  - F9 ♭ 5, Gsus2add6



# Chord structure: Major chord

Major chord



# Chord structure: Triads

The image displays four triads on a single musical staff in treble clef. Each triad is represented by a vertical line with a bracket indicating the interval between the root and the third. The intervals are labeled as follows:

- Major:** P5 (Perfect Fifth) and M3 (Major Third).
- Minor:** P5 (Perfect Fifth) and m3 (minor Third).
- Diminished:** d5 (diminished Fifth) and m3 (minor Third).
- Augmented:** A5 (Augmented Fifth) and M3 (Major Third).

Below the staff, the names of the triads are written: Major, Minor, Diminished, and Augmented.

**What would you need to encode a chord?**

# Scales

- 12 pitches: The Chromatic Scale



- Subsequences: The Major / Minor Scales
- (but there are dozens of others...)
- **Why scales?** -> Collection of notes that create relatively harmonious sounding intervals/triads
- **Why pitch spelling?** Scales are defined in intervals relative to a tonic note (no absolute reference!)

# Tonality

- **Tonality** refers to a **hierarchy** of notes/chords by relations of **stability/instability**, **attraction** and **directionality**
  - In tonal music, there is a note/chord (the **tonic**) that serves as the **center of gravity** of the other pitches in the scale
  - The **key** of a piece/song indicates which chord is the tonal center:
    - Examples: Beethoven's Fifth Symphony in **C minor**
  - **Cadences**: chord sequences leading towards this center



# Key Signature

- The key signature indicates the key (tonality) of a piece of music in the score
- Human Composers are lazy by nature! Imagine having to write all of the alterations by hand!

# Scale Degrees

A scale degree is the role that each note “plays” in a key

The image displays two musical staves. The top staff is labeled 'Major' on the left and shows a scale with notes on a five-line staff. Below the staff, the first six notes are labeled: 'tonic', 'supertonic', 'mediant', 'subdominant', 'dominant', and 'submediant'. The final note is labeled 'leading tone' in red text above the staff. The bottom staff is labeled 'Minor' on the left and shows a scale with notes on a five-line staff. Below the staff, the first six notes are labeled: 'tonic', 'supertonic', 'mediant', 'subdominant', 'dominant', and 'submediant'. The final note is labeled 'subtonic' in red text below the staff.

Major

tonic supertonic mediant subdominant dominant submediant leading tone


Minor

subtonic

# Scale Degrees and Roman Numeral

Roman Numeral representation: Abstracts the **function** of each chord within a key:

We can express chord progressions independently of the key

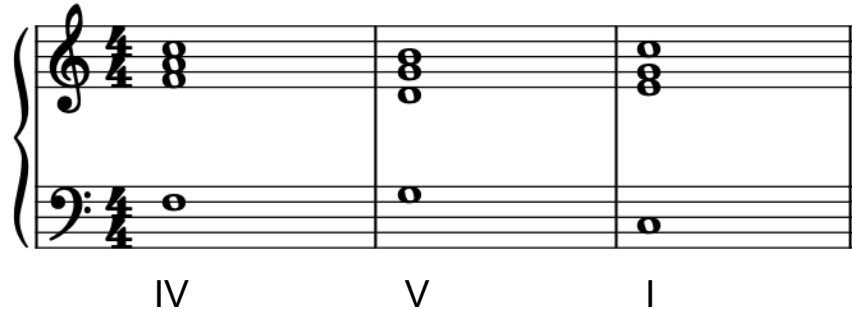


I	II	III	IV	V	VI	VII
tonic	supertonic	mediant	subdominant	dominant	submediant	leading tone
C Maj	D min	E min	F Maj	G Maj	A min	B dim

# Cadences

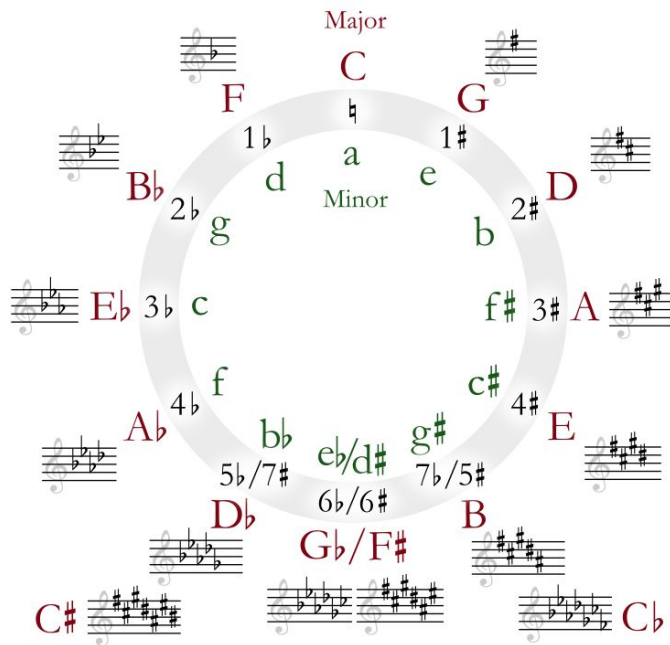
A cadence is particular combinations of Melodic (Voice Leading) and Harmonic progressions.

Perfect Augmented Cadence



# Circle of Fifths

- How close are different keys?
  - How many notes are different between the keys?
- Neighbor tonality:
  - $\pm 1$  fifth (1 alteration different)
  - Relative Minor (a minor third descending)
- Parallel Minor/Major:
  - Same root but different mode
  - They are not very close



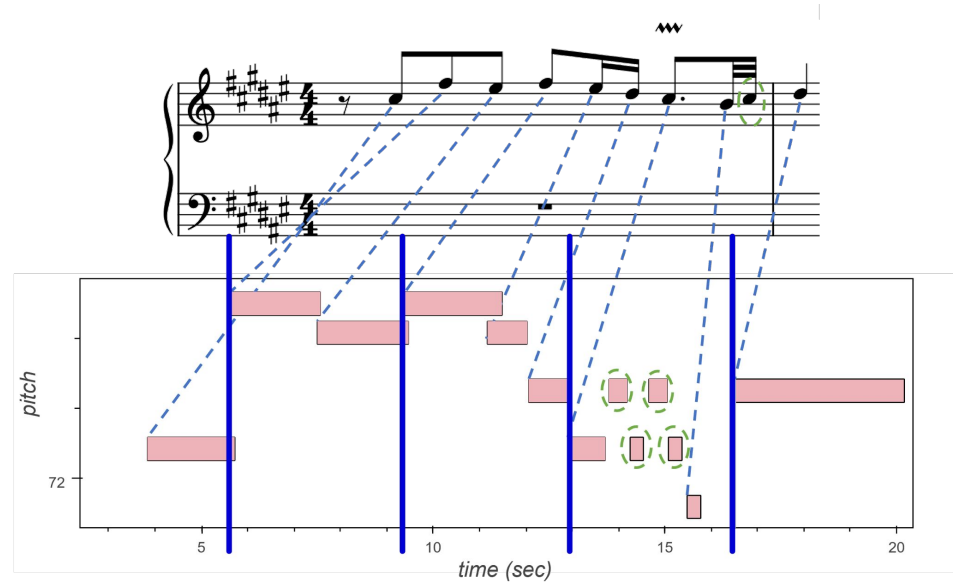
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<https://commons.wikimedia.org/w/index.php?curid=4463183>

# Rhythm

# Note durations

Notation,  
Onset (score position) vs. duration

Articulation: (staccato, legato)



# Exercise

- **Think of different ways you could encode onset and duration.** (Hint MIDI)
- What about articulation?

## **Examples of onset and duration units.**

- Divisions (used in MIDI file encoding)
- Fractions of Beat
- Musical Duration encoding



# Some Onset and Duration Encodings

- Divisions (used in MIDI file encoding)
- Fractions of Beat
- Musical Duration encoding

# Encoding of a Score (*partitura*)

## Chopin Op.9 No.2

Bar.1

Chopin

