

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

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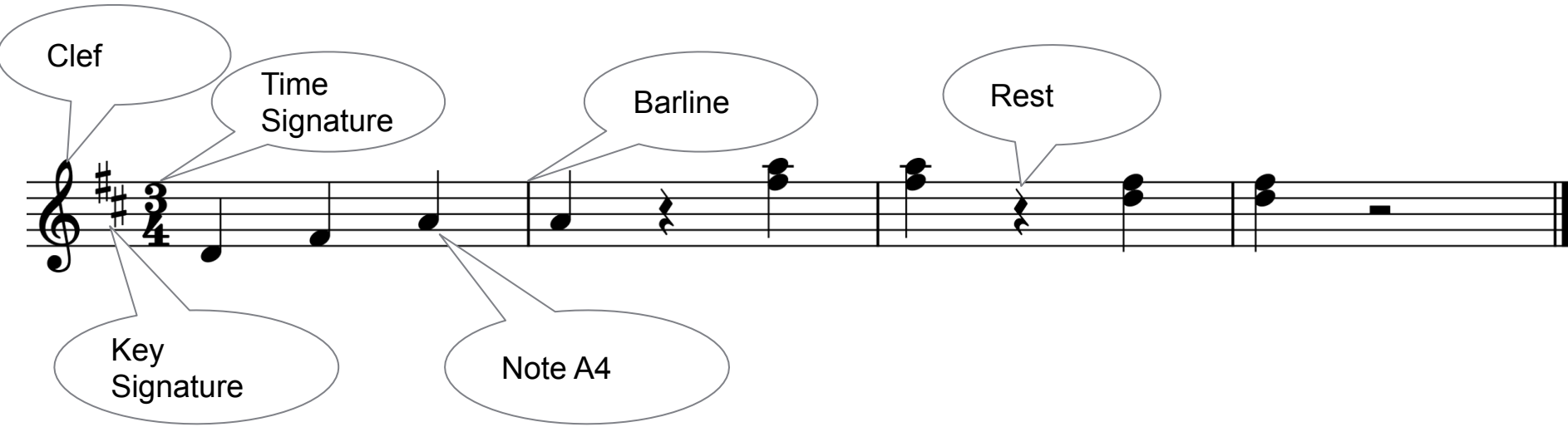
Introduction to Music Theory

In this section we will address:

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

From the point of view of musical representations and encoding.

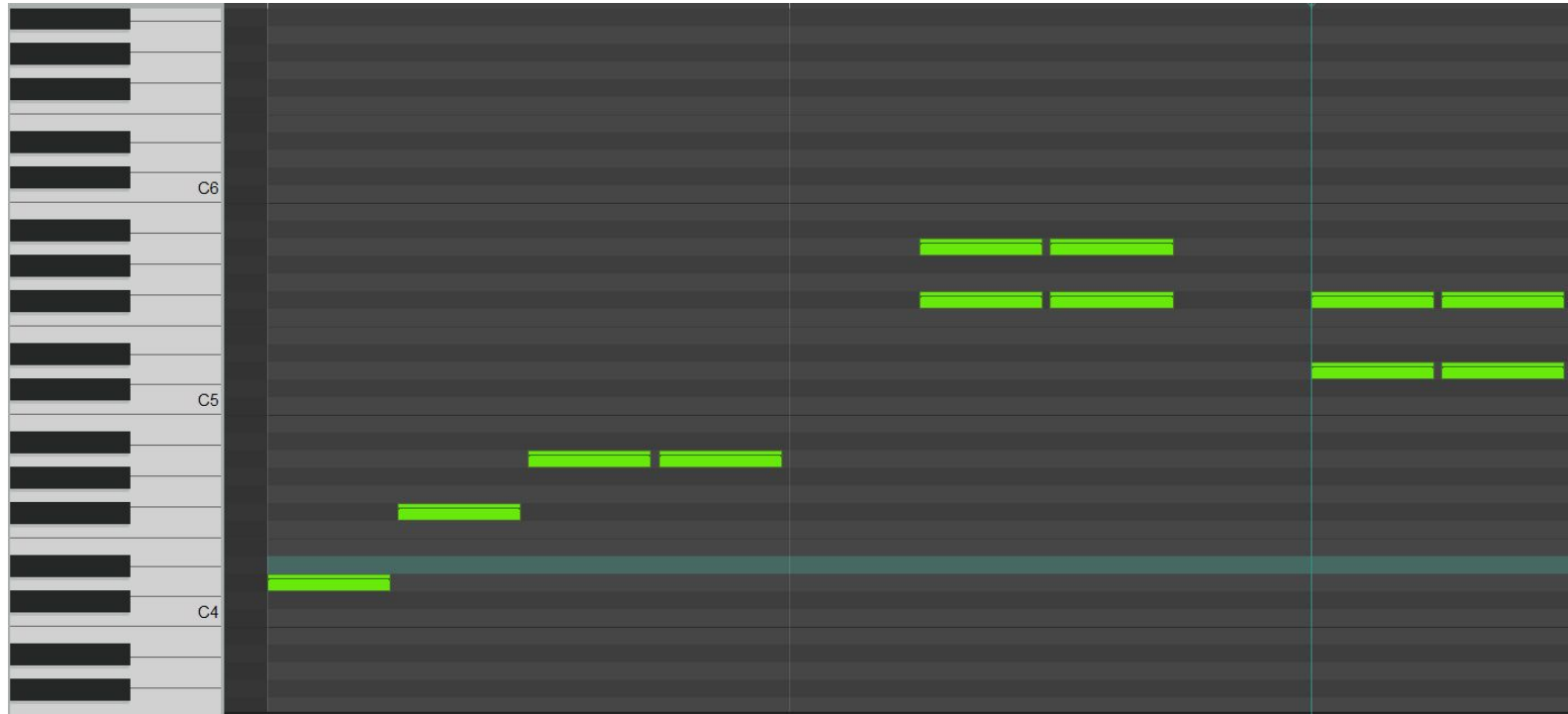
Music Representations



Music Representations - MUSICXML

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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



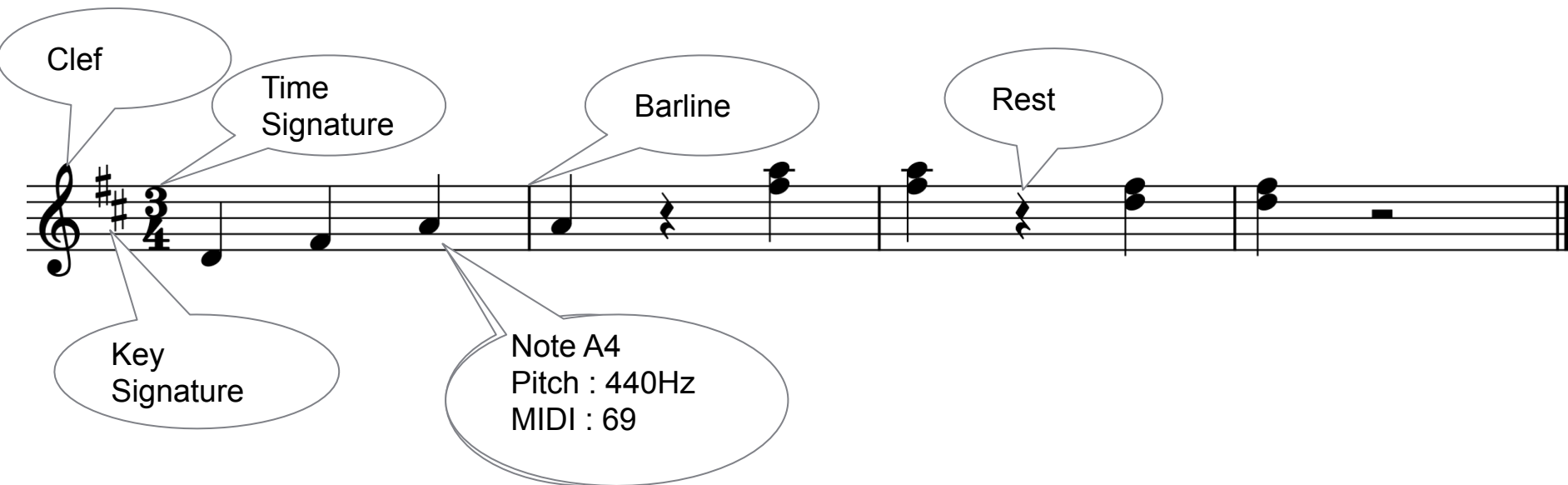
Music Representations - MIDI File

```
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

Music Representations



A musical staff diagram illustrating various components of music notation. The staff is a five-line horizontal line. At the beginning, there is a treble clef (Clef), followed by a key signature of two sharps (F# and C#) (Key Signature), and a time signature of 3/4 (Time Signature). The staff contains several musical notes and rests. A barline (vertical line) divides the staff into measures. A callout bubble points to a specific note, identifying it as Note A4 with a pitch of 440Hz and a MIDI number of 69. Another callout bubble points to a rest symbol, identifying it as a Rest.

Clef

Time Signature

Barline

Rest

Key Signature

Note A4
Pitch : 440Hz
MIDI : 69

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

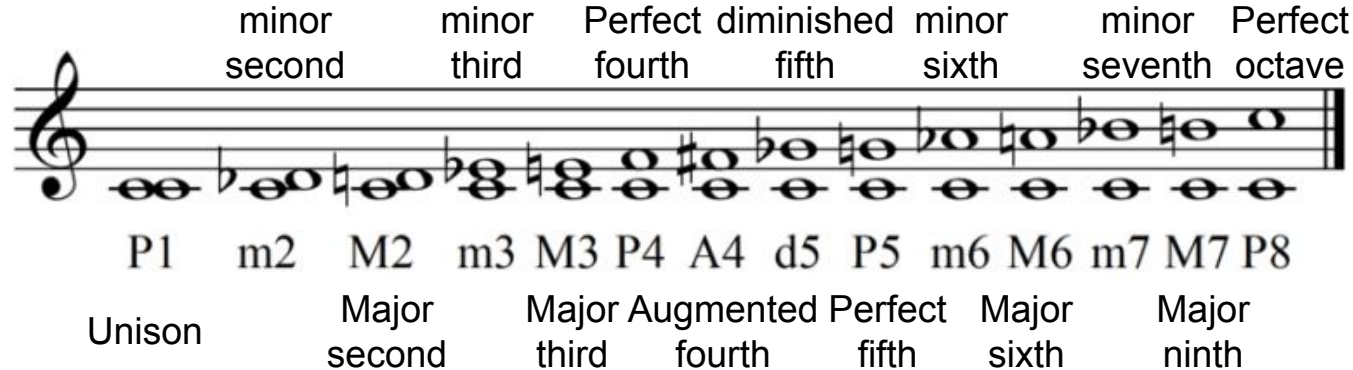
- What is a musical encoding?
 - Encoding is the conversion of Musical information into a specialized format for efficient transmission or storage. More generally from one communication protocol to another.
- Why do we need to encode?
 - To store information (save a score)
 - To communicate (from one 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 (unison), C2 (minor second), D2 (major second), E2 (minor third), F2 (major third), G2 (perfect fourth), A2 (augmented fourth), B2 (diminished fifth), C3 (perfect fifth), D3 (minor sixth), E3 (major sixth), F3 (minor seventh), G3 (major seventh), and A3 (perfect octave). The intervals are labeled above and below the staff.

Interval	Quality	Number
Unison	Perfect	1
Minor second	Minor	2
Major second	Major	2
Minor third	Minor	3
Major third	Major	3
Perfect fourth	Perfect	4
Augmented fourth	Augmented	4
Diminished fifth	Diminished	5
Perfect fifth	Perfect	5
Minor sixth	Minor	6
Major sixth	Major	6
Minor seventh	Minor	7
Major seventh	Major	7
Perfect octave	Perfect	8

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.

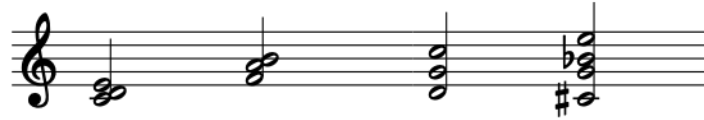
The most commonly used Since the WTC by J.S. Bach is the **Equal Temperament** dividing the octave in 12 semitones.

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**

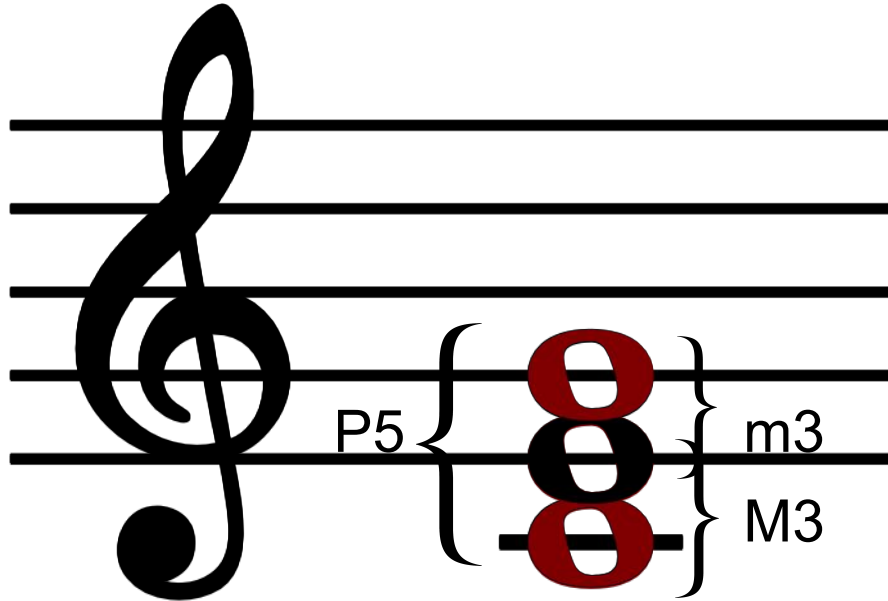


- In Western tonal music, the most common/important chords are conventional **triads**, which consist of **3 notes**:
 - Root + third and fifth “above” the root
 - The 4 basic triads are Major, Minor, Augmented and Diminished
 - The chords are named after the root (e.g., C major is the major chord with root C)
- Chords with more notes exist, and are extensively used in many genres (e.g., jazz)
 - F9 \flat 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 three notes grouped with a brace. The intervals between the notes are labeled: P5 (Perfect Fifth) and M3 (Major Third) for Major; P5 (Perfect Fifth) and m3 (minor Third) for Minor; d5 (diminished Fifth) and m3 (minor Third) for Diminished; and A5 (Augmented Fifth) and M3 (Major Third) for Augmented. The notes are: Major (C4, E4, G4), Minor (C4, E♭4, G4), Diminished (C4, E♭4, G♭4), and Augmented (C4, E♯4, G4).

Triad Type	Interval 1	Interval 2
Major	P5	M3
Minor	P5	m3
Diminished	d5	m3
Augmented	A5	M3

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

Major




Diagram of a major scale on a five-line staff. The notes are: C (tonic), D (supertonic), E (mediant), F (subdominant), G (dominant), A (submediant), and B (leading tone). The leading tone is labeled in red text above the staff.

tonic supertonic mediant subdominant dominant submediant leading tone

Minor





Diagram of a minor scale on a five-line staff. The notes are: C (tonic), D (supertonic), E-flat (mediant), F (subdominant), G (dominant), A-flat (submediant), and B-flat (subtonic). The subtonic is labeled in red text below the staff.

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

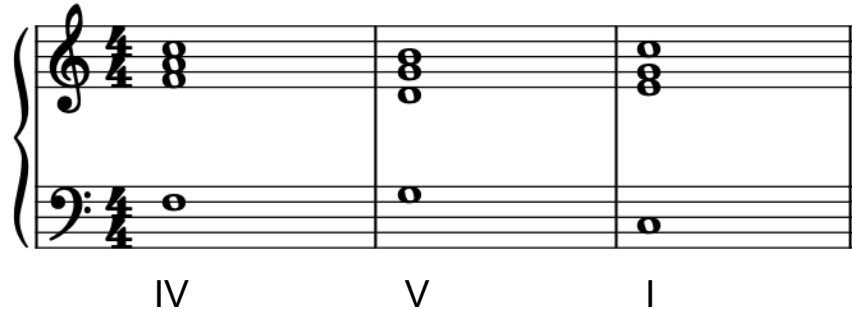


I	II	III	IV	V	VI	VII
tonic	supertonic	mediant	subdominant	dominant	submediant	leading tone
C Maj	D min	E min	F Maj	G Maj	A min	B dim

Cadences

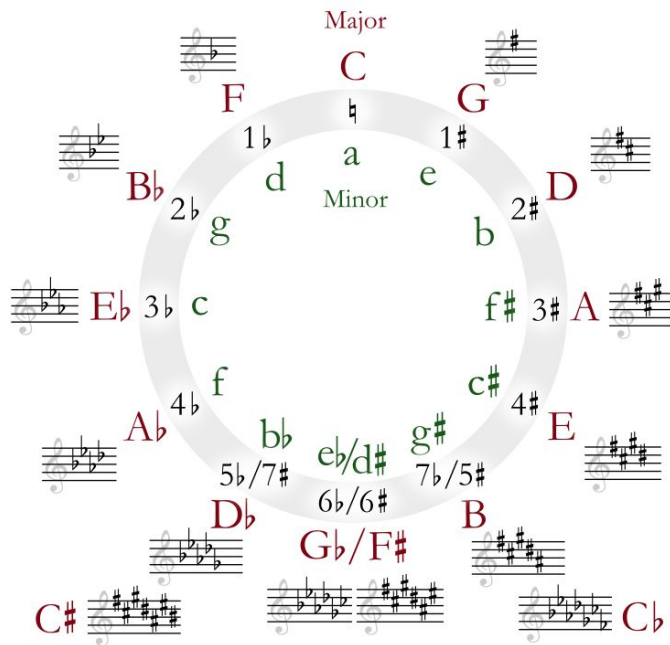
A cadence is particular combinations of Melodic (Voice Leading) and Harmonic progressions.

Perfect Augmented Cadence



Circle of Fifths

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



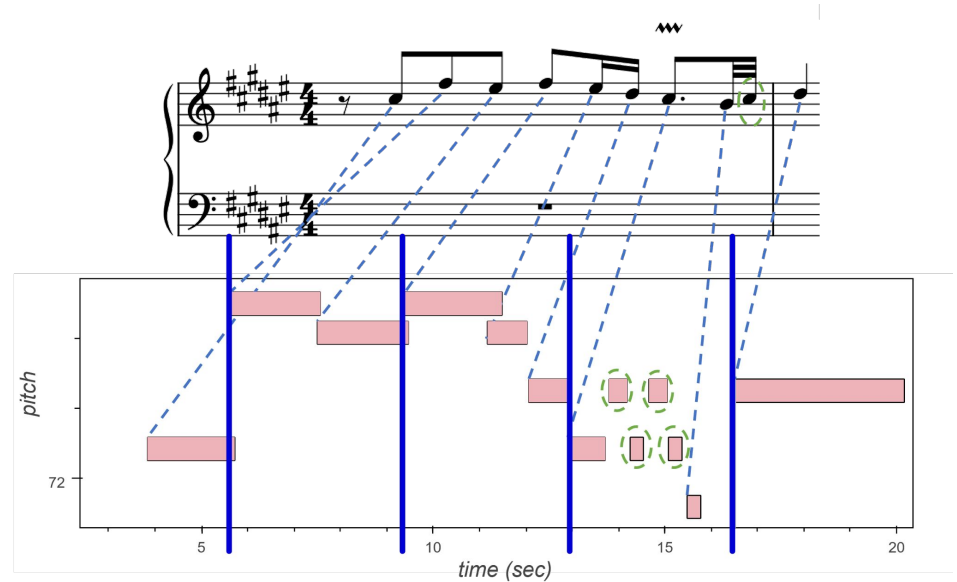
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Rhythm

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

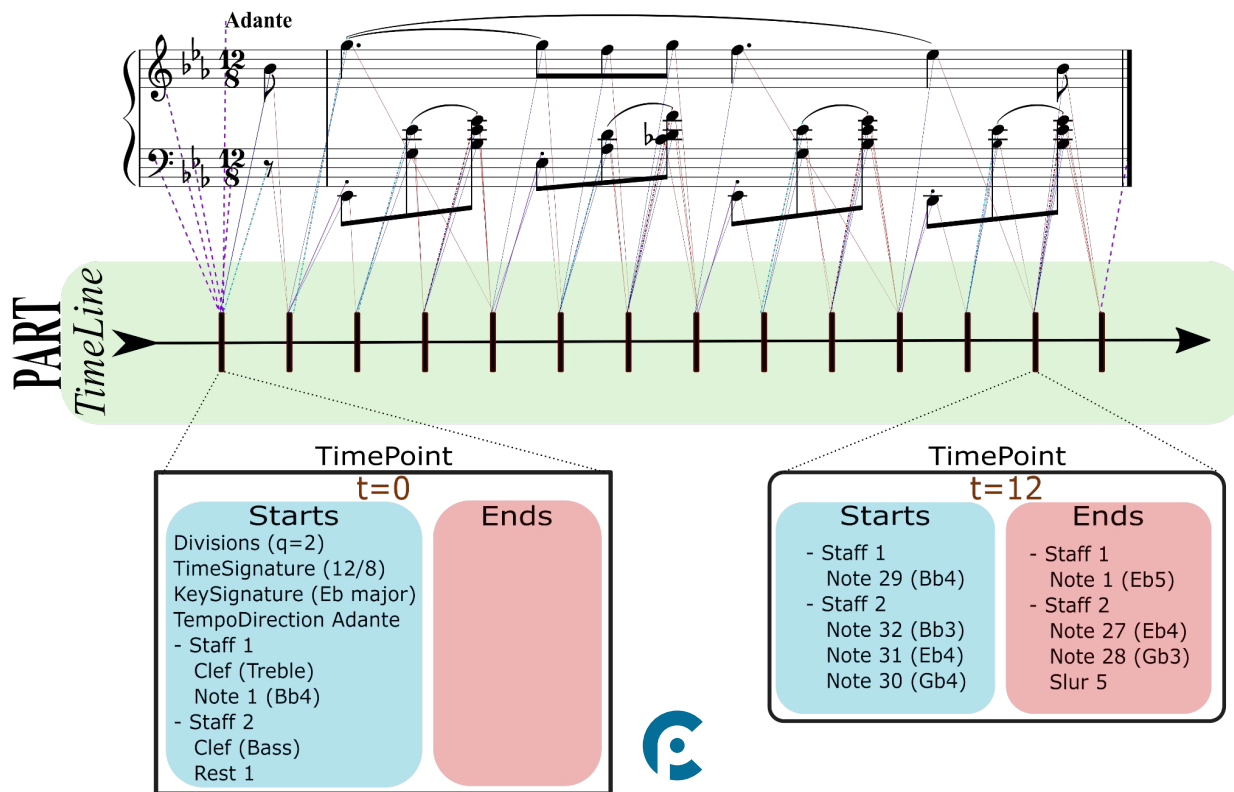
- Divisions (used in MIDI file encoding)
- Fractions of Beat
- Musical Duration encoding

Encoding of a Score (*partitura*)

Chopin Op.9 No.2

Bar.1

Chopin



Meter, Time Signature

Repeating stress patterns
Counting

Texture and Form

Poly-/Bi-/Homo-/Hetero-/Monophony

Music history?

Counterpoint

Forms

What is musical form

elements Motives, phrases,...

Forms: Binary, ternary, rondo, sonata?

Instrumentation