Durham University

Introduction to Music Computing

Symbolic representations of music data

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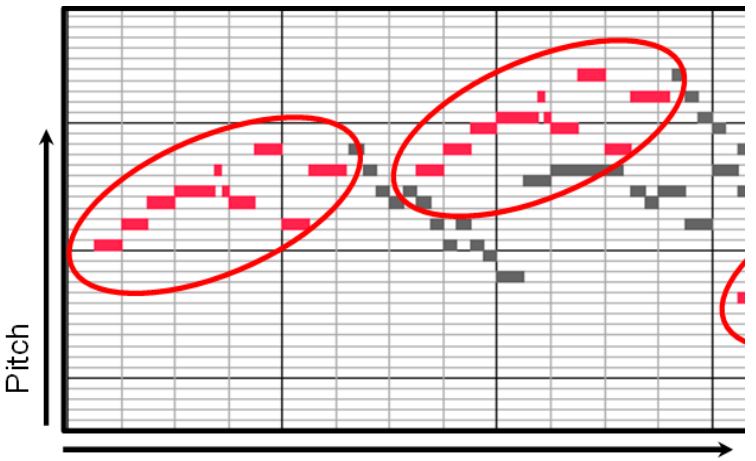
Piano roll representation

An **piano-roll representation** of a musical work shows us

- the pitches that we can hear
- the start time of each pitch
- the end time of each pitch

It is a **symbolic** representation, because it is based on a finite alphabet of letters or symbols



[FMP21] Fig 1.12

Piano roll

The origin of “piano roll” notation is in the design and construction of **player pianos** (dating from the 19th century)

An alternative form of music distribution

Punched holes control actuators that strike and release piano keys in sequence

Many formats, some allowing for “expression” such as relative loudness, use of pedal...

[FMP21] Fig 1.11

Automatic music transcription

We can estimate the piano-roll representation from an audio file, usually with the help of a **spectrogram** representation (why?)

This is part of the complex task of **automatic music transcription**, and effectively converts from audio representations to symbolic representations

What is not captured in piano-roll representations?

MIDI

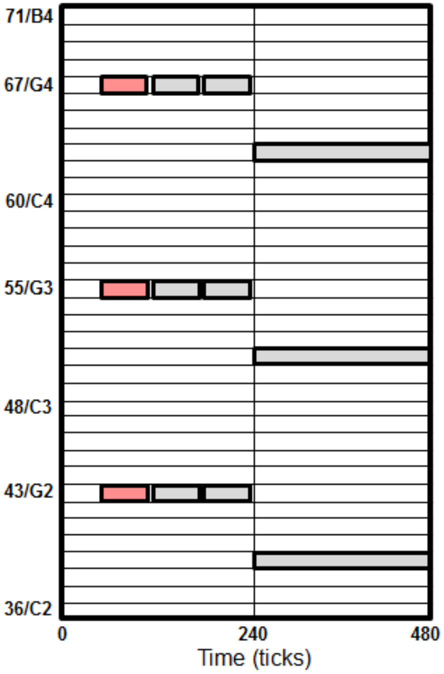
MIDI files are a standard means of representing music (and other time-based media) data

Origins as an interchange format

Event-based, with a tick length

Format 0, 1, 2 (different track/channel relation)

Also track-level metadata, pitch bend...

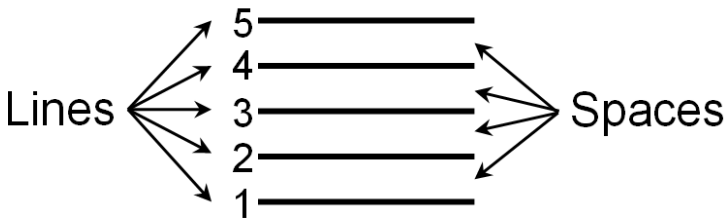


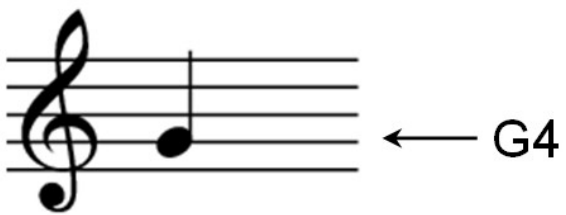
Time (Ticks)	Message	Channel	Note Number	Velocity
60	NOTE ON	1	67	100
0	NOTE ON	1	55	100
0	NOTE ON	2	43	100
55	NOTE OFF	1	67	0
0	NOTE OFF	1	55	0
0	NOTE OFF	2	43	0
5	NOTE ON	1	67	100
0	NOTE ON	1	55	100
0	NOTE ON	2	43	100
55	NOTE OFF	1	67	0
0	NOTE OFF	1	55	0
0	NOTE OFF	2	43	0
5	NOTE ON	1	67	100
0	NOTE ON	1	55	100
0	NOTE ON	2	43	100
55	NOTE OFF	1	67	0
0	NOTE OFF	1	55	0
0	NOTE OFF	2	43	0
5	NOTE ON	1	63	100
0	NOTE ON	2	51	100
0	NOTE ON	2	39	100
240	NOTE OFF	1	63	0
0	NOTE OFF	2	51	0
0	NOTE OFF	2	39	0

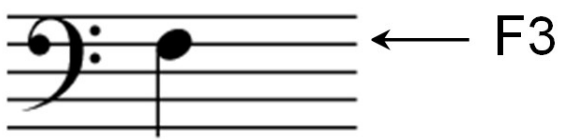
[FMP21] Fig 1.13

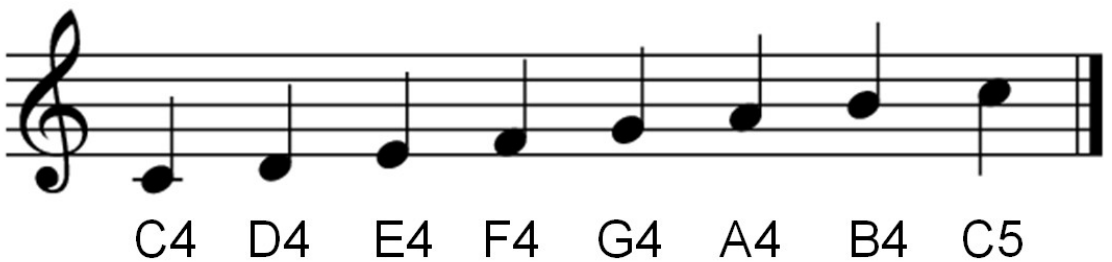
Pitch names and staff notation

Learn:
https://www.musictheory.net/lessons/10
https://www.musictheory.net/lessons/20
Practice:
https://www.musictheory.net/exercises/note



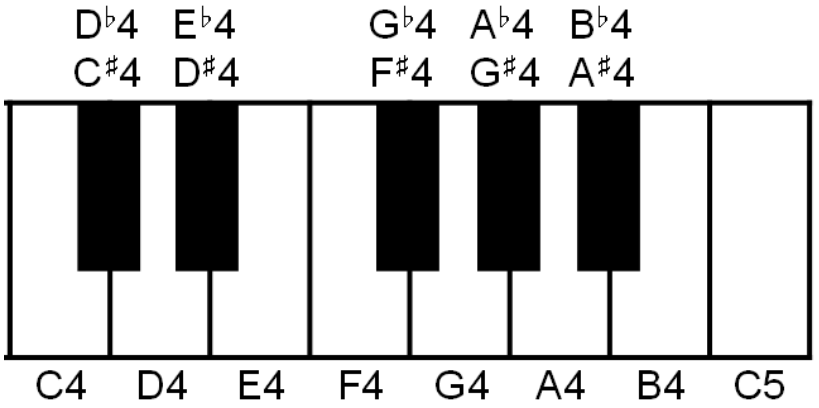


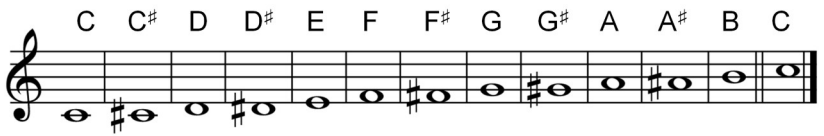


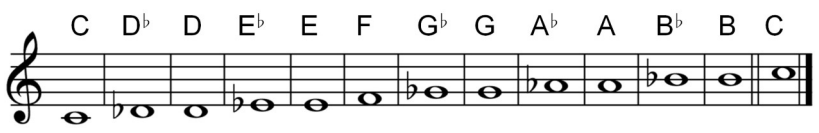


[FMP21] Fig 1.4

Pitch names and staff notation







Learn:
https://www.musictheory.net/lessons/10
https://www.musictheory.net/lessons/20
Practice:
https://www.musictheory.net/exercises/note

[FMP21] Figs 1.2 (adapted), 5.8

Intervals measure distance in pitch height

An **interval** is the pitch difference between two sounds with determinate pitches

We can describe intervals simply by counting the number of semitones between the two pitches

Clearly, this is linked to the notion of twelve-tone equal temperament

Common names for intervals

There is another naming system, which is more closely linked to music notation. For example:

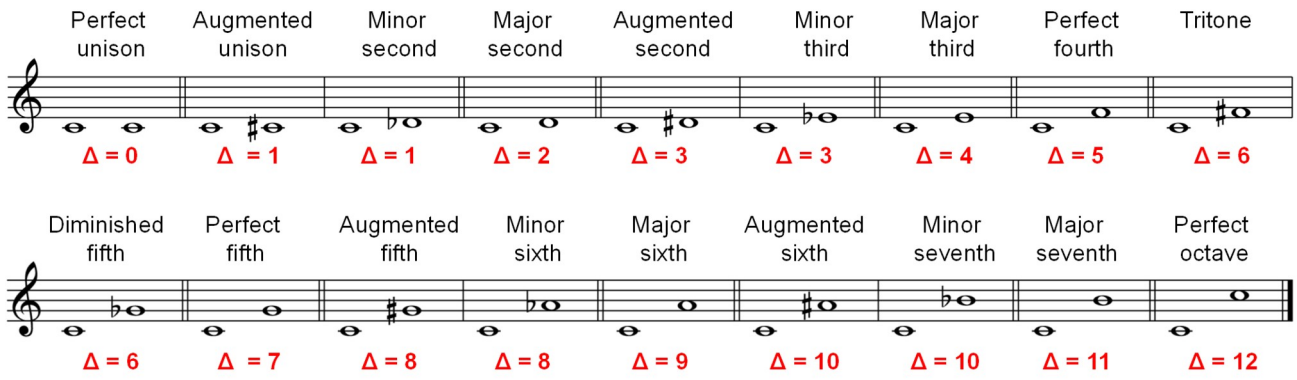
- minor second (= 1 semitones)
- minor third (= 3 semitones)
- perfect fourth (= 5 semitones)
- diminished fifth (= 6 semitones)
- (perfect) octave (= ? semitones)

In this naming system, an interval has a

- **quality** (e.g. minor, major, perfect etc.)
- **size** (e.g. second, third, seventh, eleventh etc.)

Intervals - Reference

Δ	Interval name	Interval	JI ratio
0	(Perfect) unison	C4 – C4	1:1
1	Minor second	C4 – D♭4	15:16
2	Major second	C4 – D4	8:9
3	Minor third	C4 – E♭4	5:6
4	Major third	C4 – E4	4:5
5	(Perfect) fourth	C4 – F4	3:4
6	Tritone	C4 – F♯4	32:45
7	(Perfect) fifth	C4 – G4	2:3
8	Minor sixth	C4 – A♭4	5:8
9	Major sixth	C4 – A4	3:5
10	Minor seventh	C4 – B♭4	5:9
11	Major seventh	C4 – B4	8:15
12	(Perfect) octave	C4 – C5	1:2



[FMP21] Figs 5.2, 5.3 (adapted)

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Application: Query by melody

- We can represent each tune as a sequence of melodic intervals from some starting point
- Insert tunes into database index
  - Convert each tune into a sequence of melodic intervals d_i (e.g. {-2, +3, +2, -7, ...})
- Query by melody
  - Convert a given query to sequence of melodic intervals q
- For each song in database, compute the similarity D(q, d_i), rank, and return
- **Improvements**: melody/query representation, indexing of fragments, domain-specific similarity measures

Chords

A chord can be thought of as a set of pitches.

A chord consisting of three pitches is a **triad**. Certain triads are fundamental to tonal music.

Examples of these triads are:

- **C** = {C, E, G}
- **G** = {G, B, D}
- **Am** = {A, C, E}
- **E♭** = {E♭, G, B♭}
- **F♯m** = {F♯, A, C♯}

In these definitions/examples, we do not make a note of the octave (cf. SPN). Why not?

Chord types

For this part, we restrict our attention to a subset of all possible chords, **triads**, and within that we focus for now on two types:

- **major triads** (e.g. **C**, **G**)
- **minor triads** (e.g. **F♯m**, **Am**)

major triads := two notes separated by a perfect fifth, and a third note which is a major third above the lower of the two notes

minor triads := two notes separated by a perfect fifth, and a third note which is a major third above the lower of the two notes

[FMP21] Fig 1.18

Key – We're not there just yet

"key" (or a comparable concept) is an important aspect of most tonal music

You may have heard people talk about music in a **major** key vs. music in a **minor** key

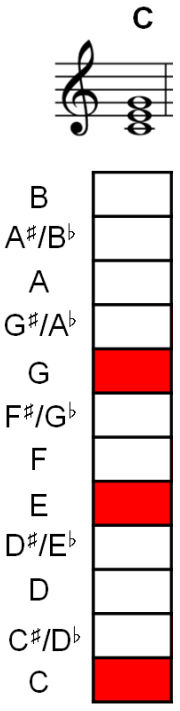
Key is related to the number and frequency the chords used in a piece, the contexts in which they are used, and other considerations.

When it comes to triads (and intervals), major and minor just refer to qualities ("species") of collections of notes, nothing more

Simple representation for chords

Represent each chord as a multi-hot 12-place vector, where the entry is 1 if the chord contains the chroma at that place

The vector for **C** = {C, E, G} is shown on the right



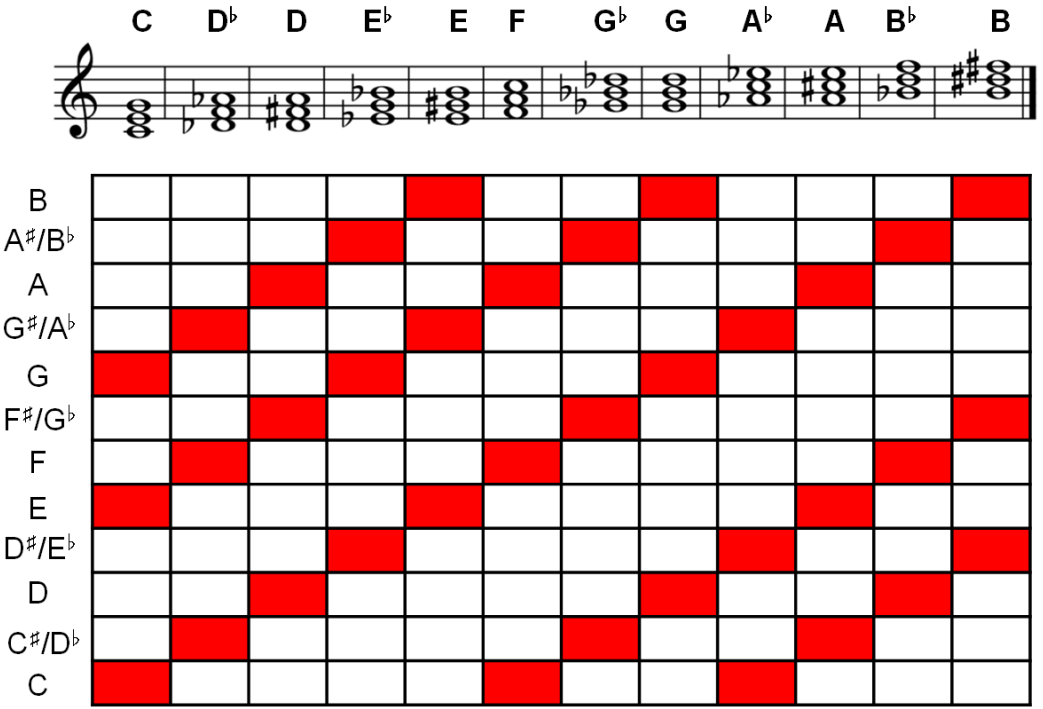
[FMP21] Fig 5.6 (adapted)

Simple representation for chords

Represent each chord as a multi-hot 12-place vector, where the entry is 1 if the chord contains the chroma at that place

Shown on the left are the major triads

Using indicator vectors is a classical way to represent subsets



[FMP21] Fig 5.6

Simple representation for chords

Represent each chord as a multi-hot 12-place vector, where the entry is 1 if the chord contains the chroma at that place

Can you complete the same grid for minor triads?

[FMP21] Fig 5.6 (adapted)

Another view on chords

- We have seen how we can “generate” the set of major (and minor) chords by performing a cyclic shift of the multi-hot vector
- Another common approach to modeling chords is to do as follows:
  - Assign each chroma (pitch class) to an integer mod 12
  - Conventionally: C = 0, C# = 1, etc.
  - Consider chords as collections of integers mod 12, called **pitch-class sets**: **Cm** becomes {0, 4, 7}
- Define some operations on these collections
  - e.g. $T_n(\{0, 3, 4\})$ → $\{(0 + n) \bmod 12, (3 + n) \bmod 12, (4 + n) \bmod 12\}$
- Study the equivalence classes of pitch-class sets these operations: “**set classes**”

Consonance and dissonance

An interval may be **consonant** or **dissonant.** The following intervals are considered consonant:

- unison, octave, perfect fifth, perfect fourth, major third, minor third
- major sixth, minor sixth

The following intervals are considered dissonant:

- others

By extension, we can also speak of the consonance and dissonance of particular **chords**, **scales**, pieces etc.

Δ	Interval name	Interval	JI ratio
0	(Perfect) unison	C4 – C4	1:1
1	Minor second	C4 – D♭4	15:16
2	Major second	C4 – D4	8:9
3	Minor third	C4 – E♭4	5:6
4	Major third	C4 – E4	4:5
5	(Perfect) fourth	C4 – F4	3:4
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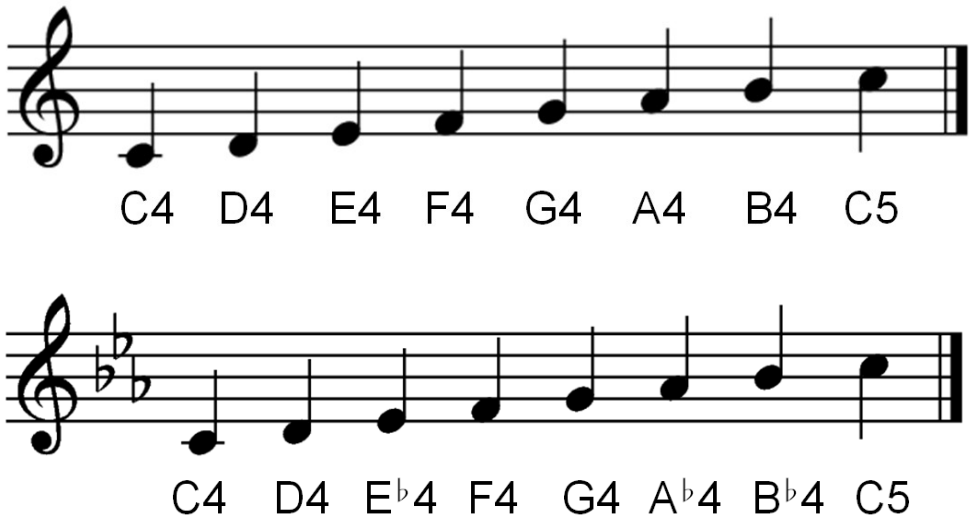
10	Minor seventh	C4 – B♭4	5:9
11	Major seventh	C4 – B4	8:15
12	(Perfect) octave	C4 – C5	1:2

[FMP21] Fig 5.3

Scales

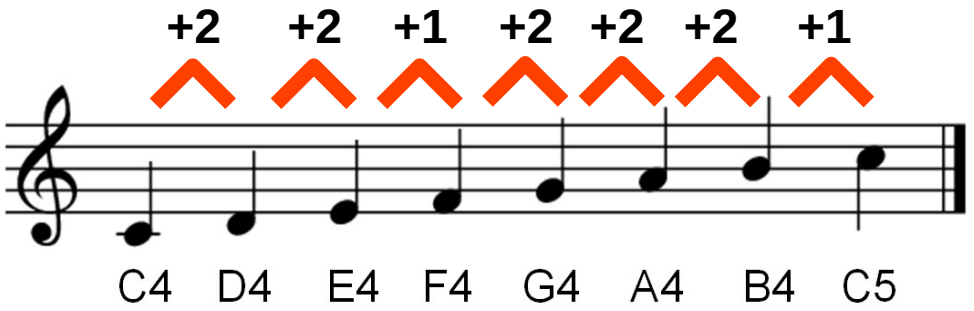
A **scale** is an ordered set of notes, conventionally ordered by ascending pitch. Here are two scales:



[FMP21] Fig 1.5

Scales

A **scale** is an ordered set of notes, conventionally ordered by ascending pitch. The following is an example of a **major scale**:



[FMP21] Fig 1.5

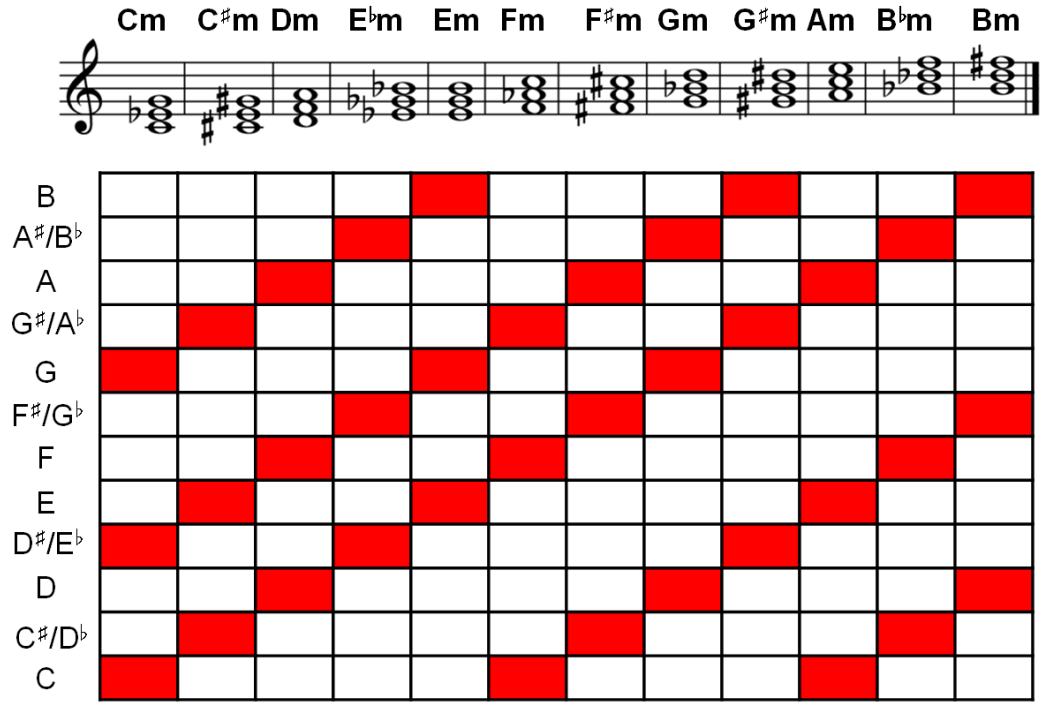
The scale can be defined by the pattern of intervals, here measured in semitones (cf. MIDI note numbers) starting from a given pitch.

The letter name of the starting pitch (the **key note**) gives the scale its identity (hence, **C major scale**)

Simple representation for chords

Represent each chord as a multi-hot 12-place vector, where the entry is 1 if the chord contains the chroma at that place

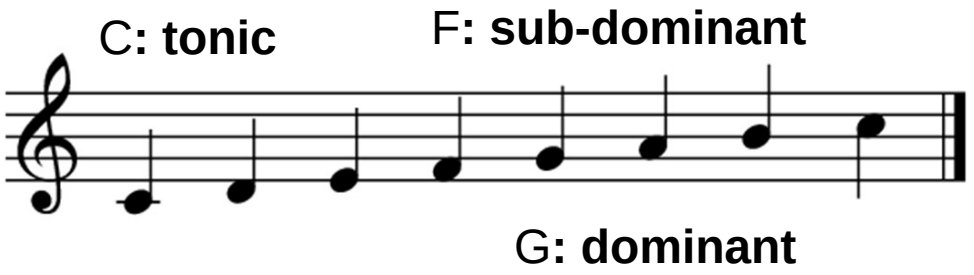
Can you complete the same grid for minor triads?



[FMP21] Fig 5.6 (adapted)

Scales

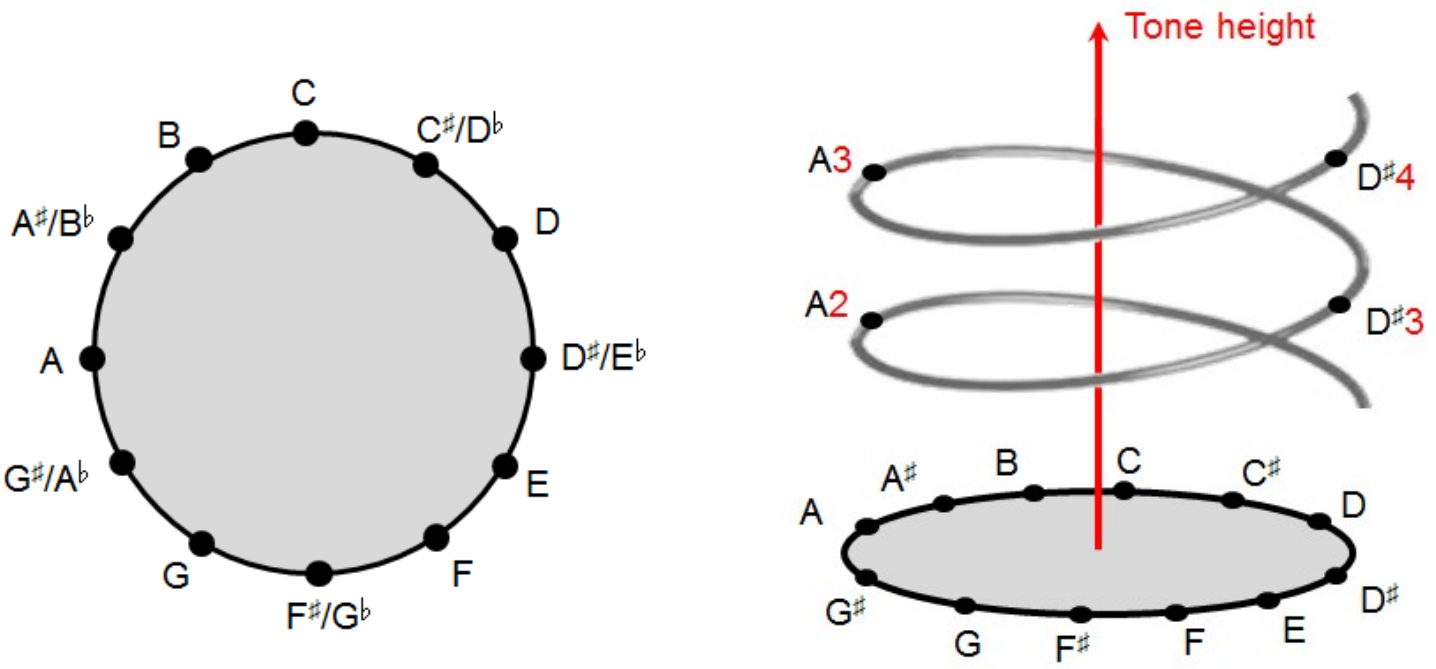
In the case of some scales, there are special names for the notes in the scale, relative to the key note:



[FMP21] Fig 1.5 (adapted)

In the case of a D major scale, what is the note name for the **tonic**? The **dominant**?

Perception of pitch height vs. pitch “class”



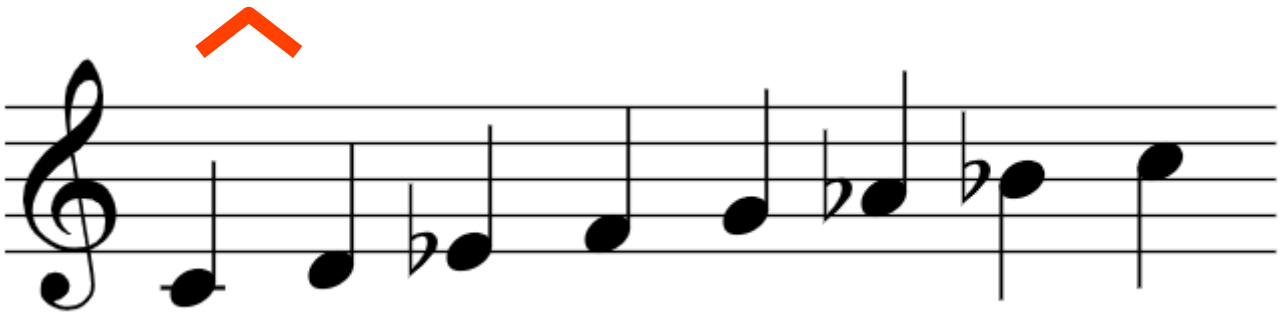
[FMP21] Fig 1.3

Scales

Some other scales, viewed as patterns of intervals measured in semitones:

- **natural minor:**
  - +2, +1, +2, +2, +1, +2, +2
- **Dorian:**
  - +2, +1, +2, +2, +2, +1, +2
- **whole tone:**
  - +2, +2, +2, +2, +2, +2
- **pentatonic:**
  - +2, +2, +3, +2, +3

Scales



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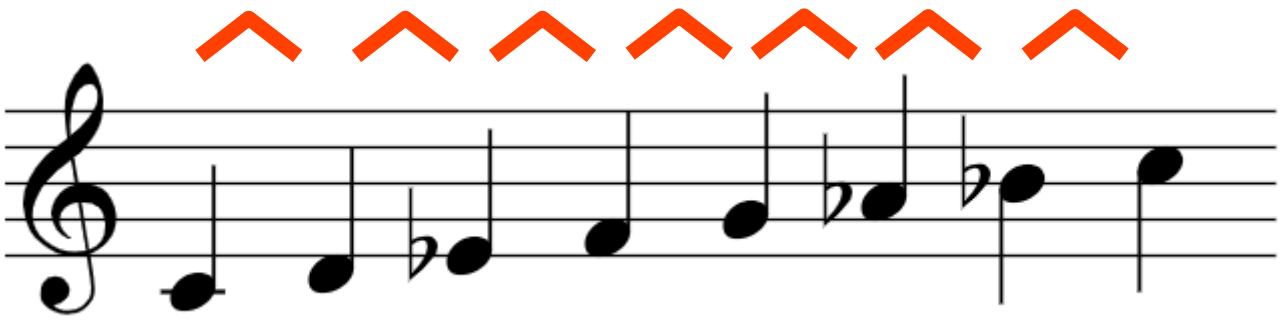
Scales



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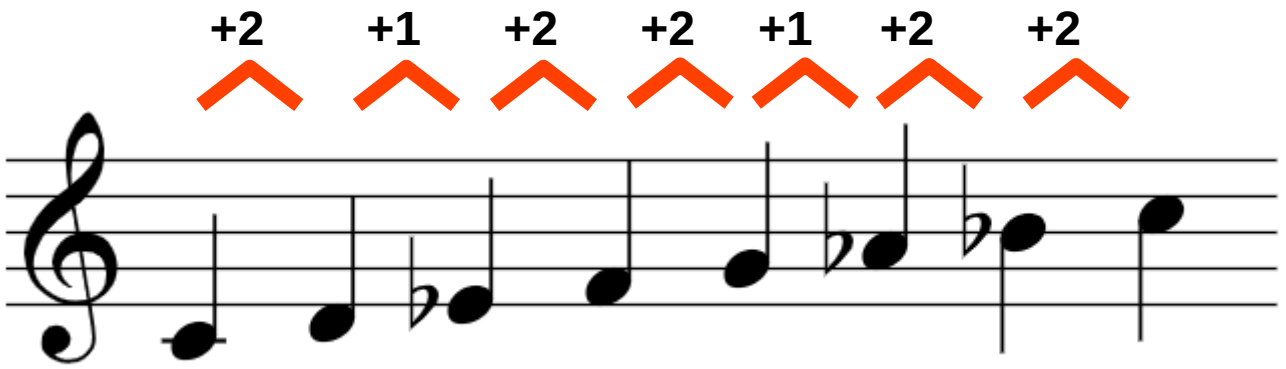
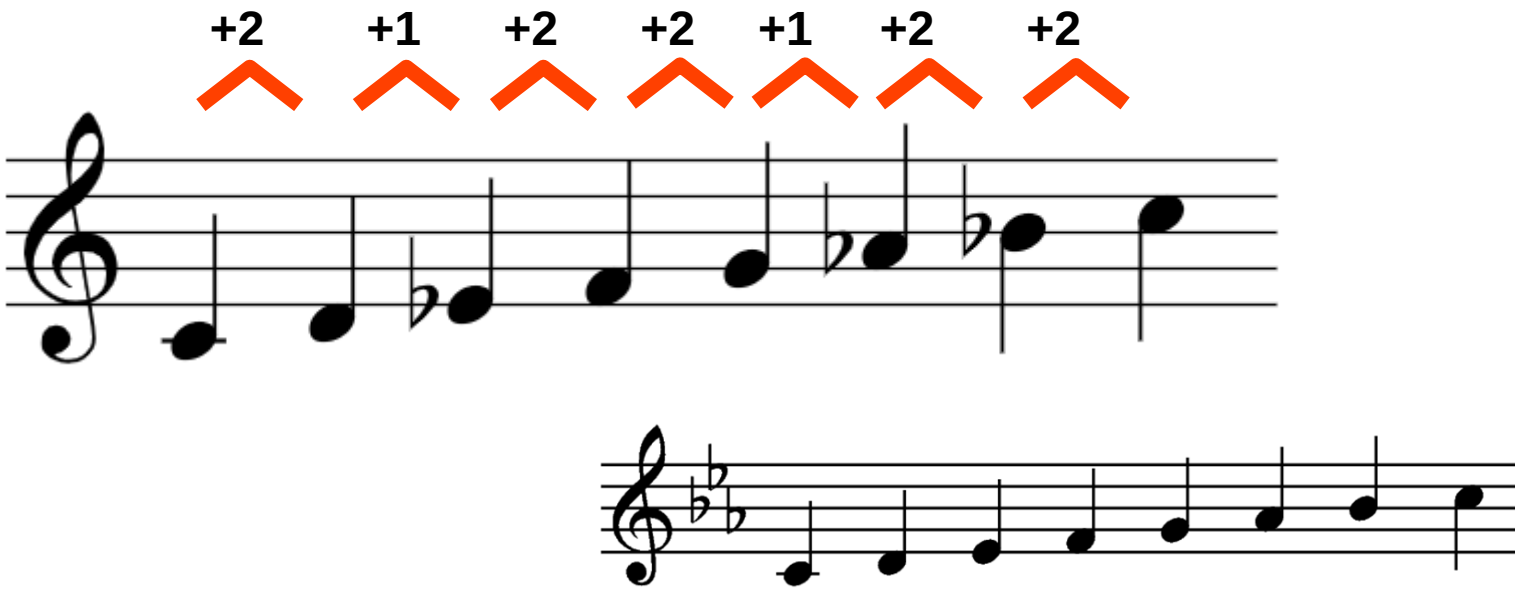
Scales

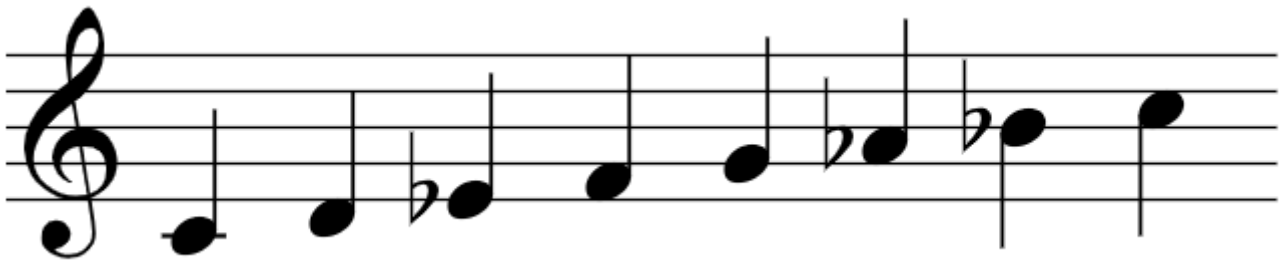


C natural minor

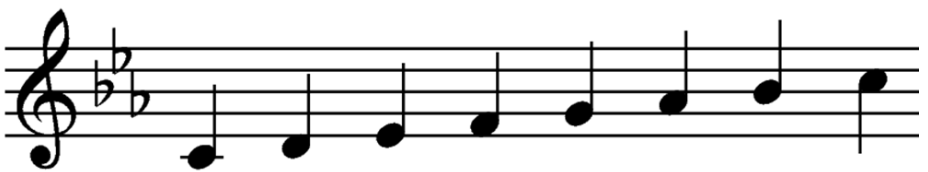
Scales



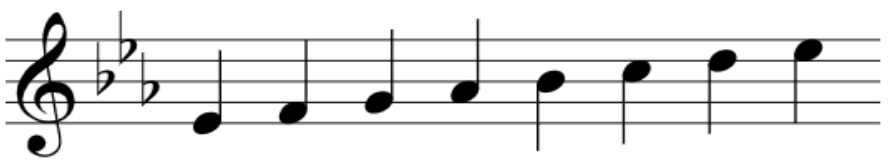
Scales



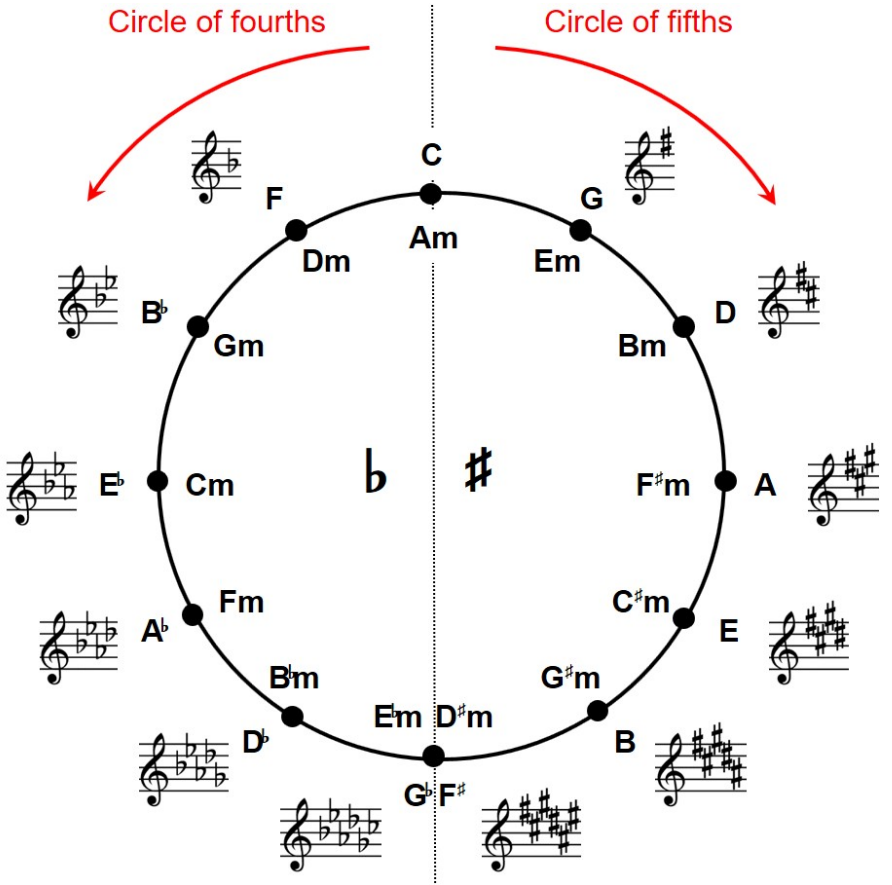
C natural minor



E♭ major



Scales – Key signatures



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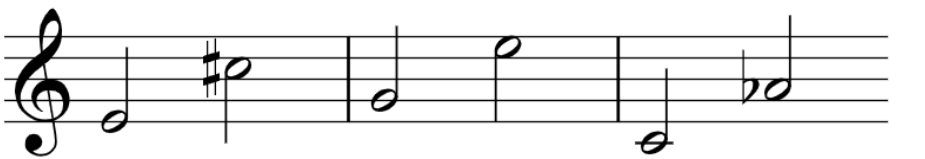
Succession and simultaneity – intervals

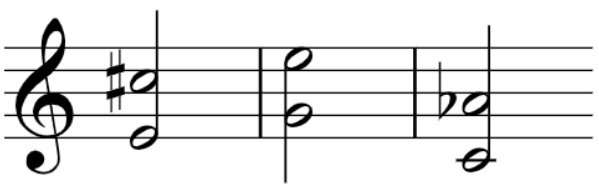
Music is more than intervals, chords, and scales.

They are useful abstractions that have **realisations** in actual music in a variety of ways.

e.g. minor sixth: successively (as a **melodic** interval)



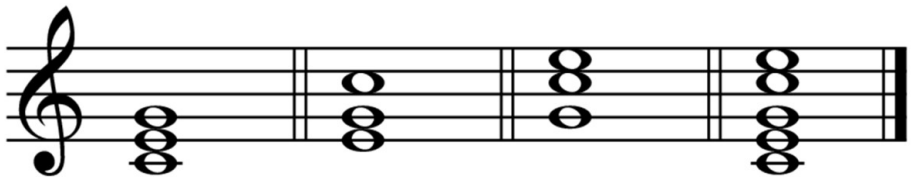
or simultaneously (as a **harmonic** interval)

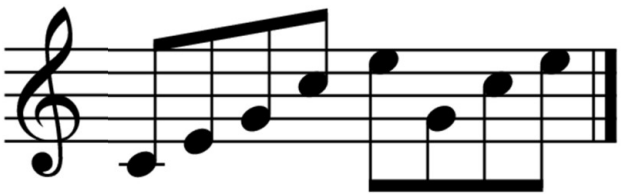


Succession and simultaneity – chords

Similarly, chords can be realised at the surface level of a musical work in different but related ways as follows:

All count as expressions of a C major triad



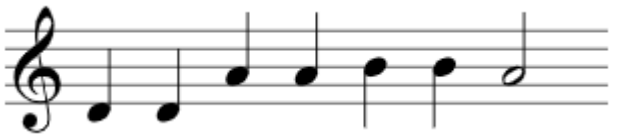


[FMP21] Fig 5.7 (adapted)

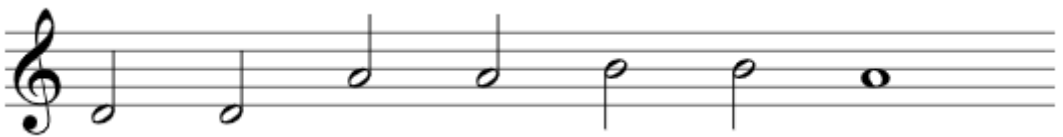
Rhythm

Musical events happen in time, so they have a start time and a duration. The goal of staff notation is to show this information at the same time as the pitch(es) played.

Some events are relatively short:

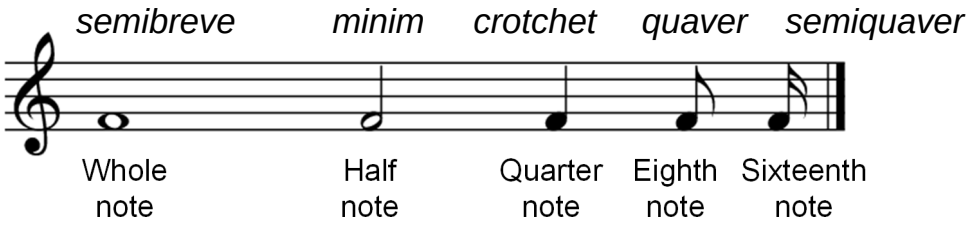


Some events are relatively long. Here, everything takes twice as long as above:

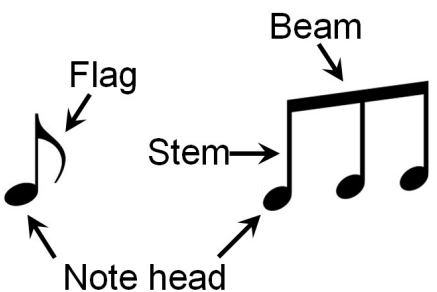


Rhythm

Here is a restricted “vocabulary” of possible rhythmic symbols



There is a small set of combining and grouping rules that quickly increase the density of ink on the page



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https://www.musictheory.net/lessons/12
https://www.musictheory.net/lessons/13
https://www.musictheory.net/lessons/14

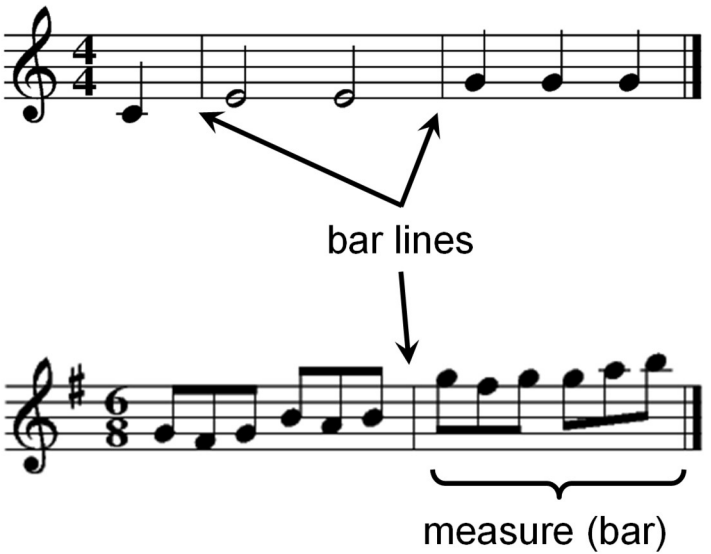
Create:
https://www.verovio.org/pae-editor.html

[FMP21] Fig 1.7

Rhythm

As in speech and poetry, there are common rhythmic patterns that occur frequently, including alternating patterns of stress and emphasis

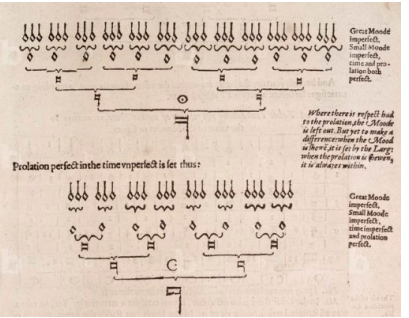
The **time signature** communicates some information (in advance) the patterns that make up the piece and are associated with conventional combining and grouping patterns



[FMP21] Fig 1.6

Plaine & Easie Code

- Legacy plaintext encoding of music dating from the 1960s [Brook et al. 1964]
  - (Spec under development: https://github.com/rism-digital/pae-code-spec)
- Designed for librarians cataloguing **incipits** (the first part of a musical document)
- Over 1.4M incipits encoded and indexed in RISM
- Example:
  - `{''6E'B8G}{GA}-''C{'3B8..G}`
- Supported by many libraries and tools but not practical for anything more than very brief examples
- Editor: https://www.verovio.org/pae-editor.html



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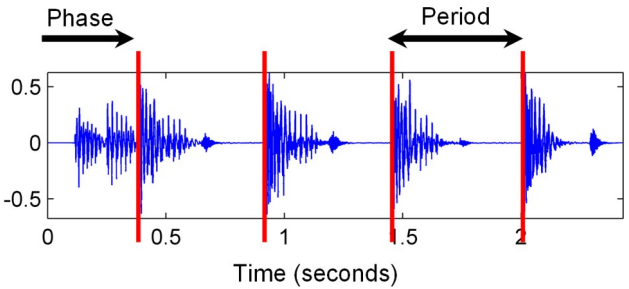

[FMP21 Fig. 6.1a]

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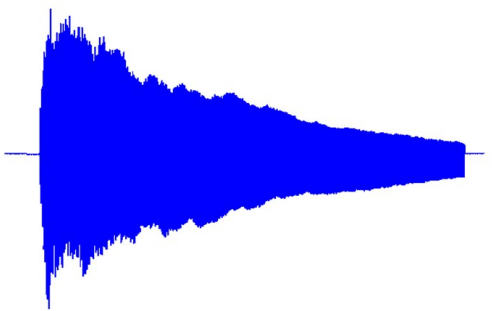

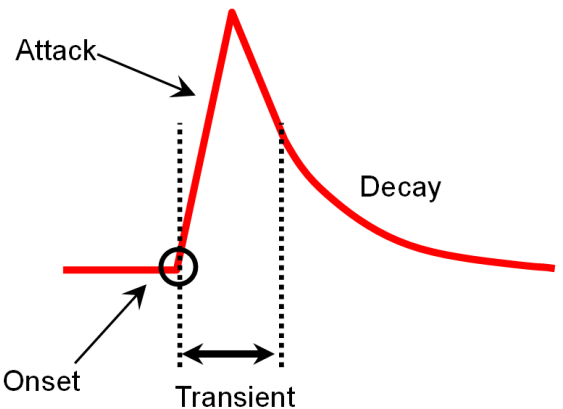

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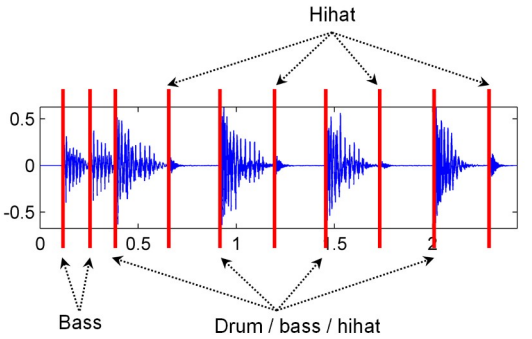

[FMP21 Fig. 6.1b]

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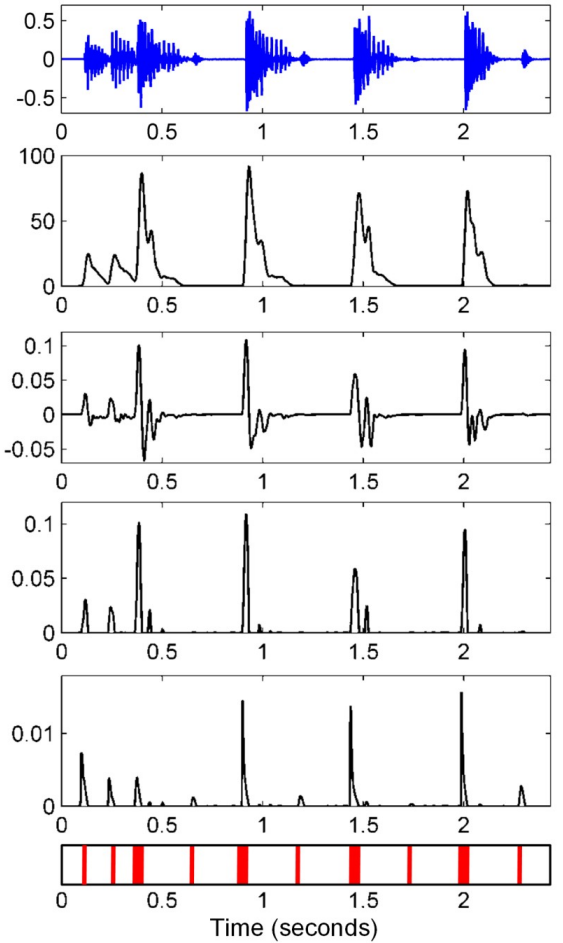

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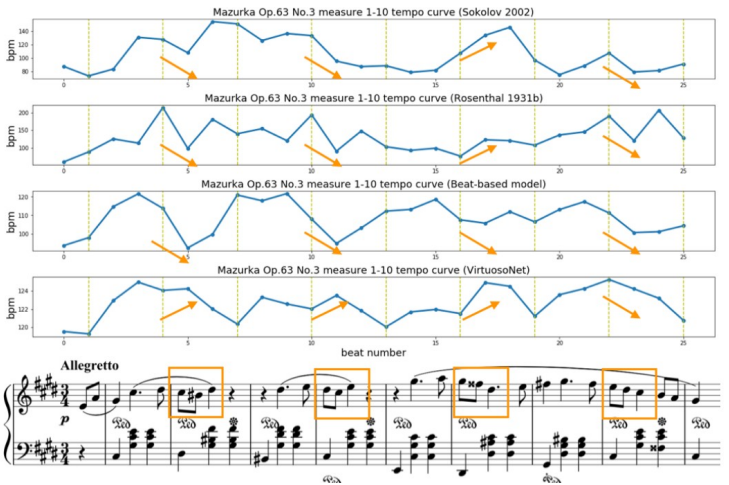

[Shi 2023]

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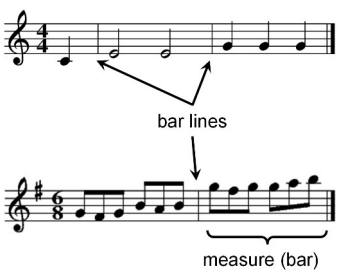
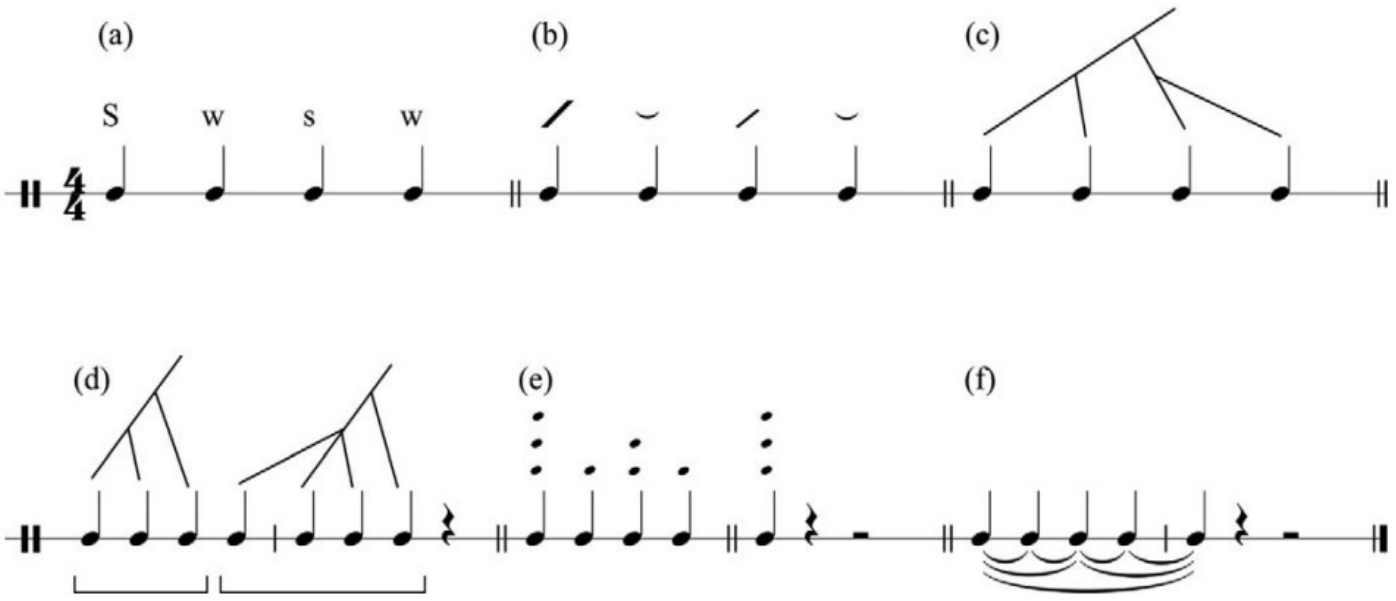


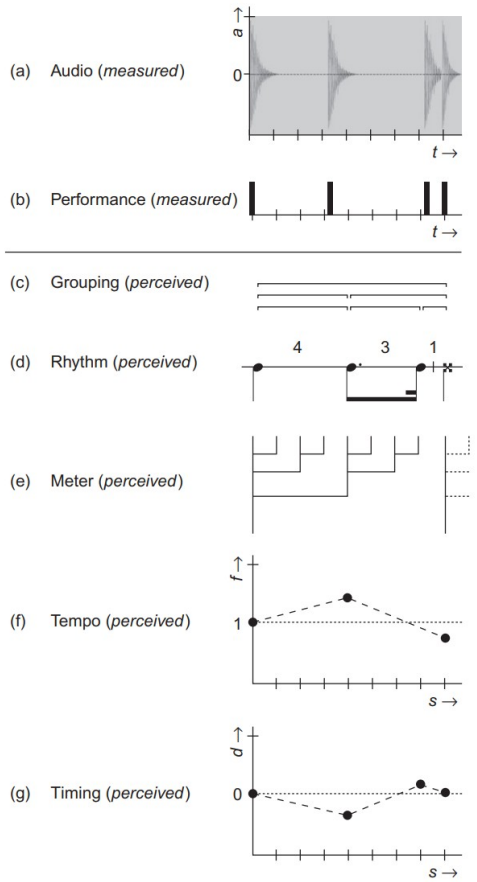
[FMP21] Fig 1.6

Metrical hierarchy – visual representations



[Lerdahl 2015]

Metrical hierarchy – representations applied



[Honing 2013]

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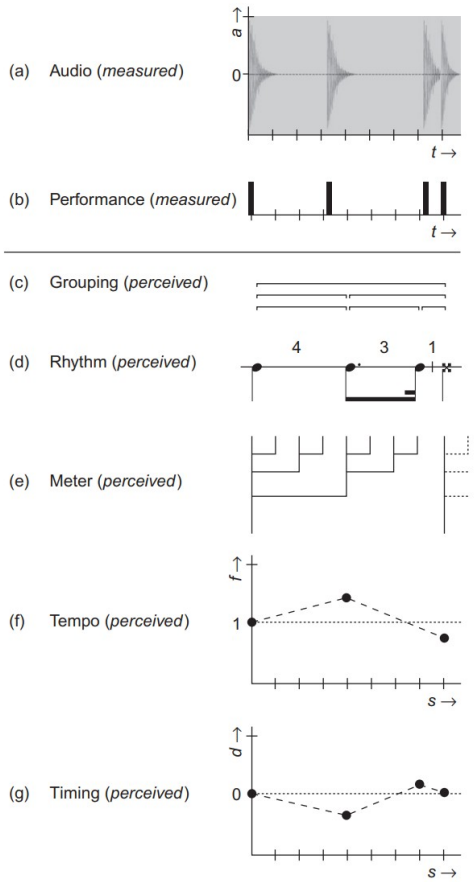

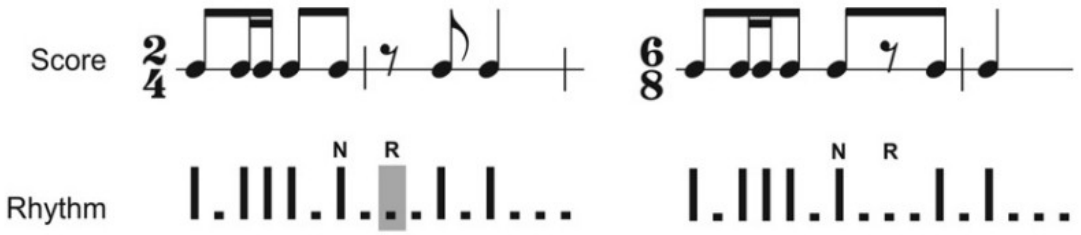

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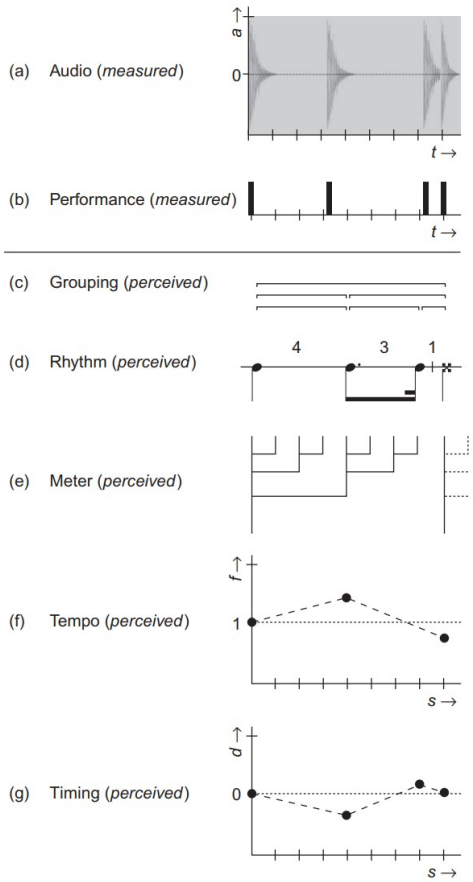

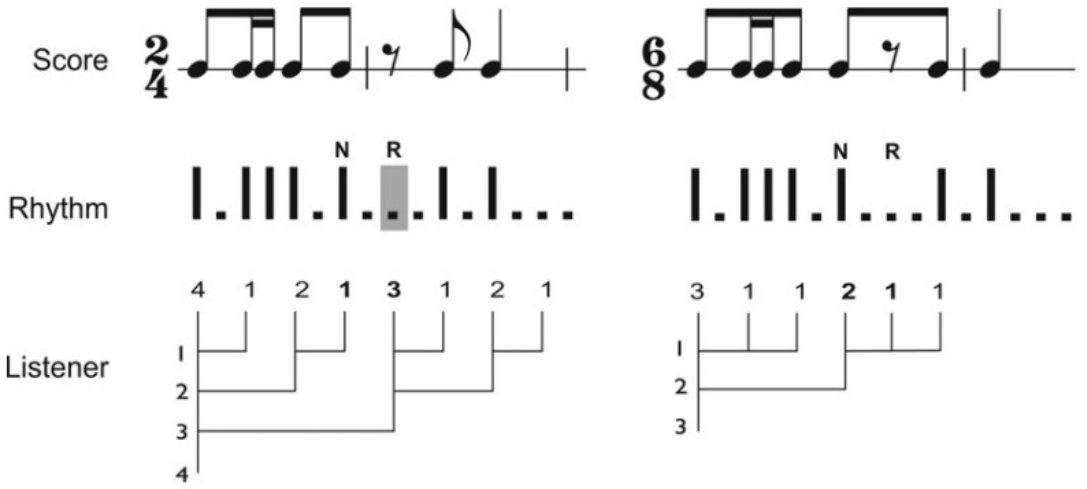

[Honing 2013]

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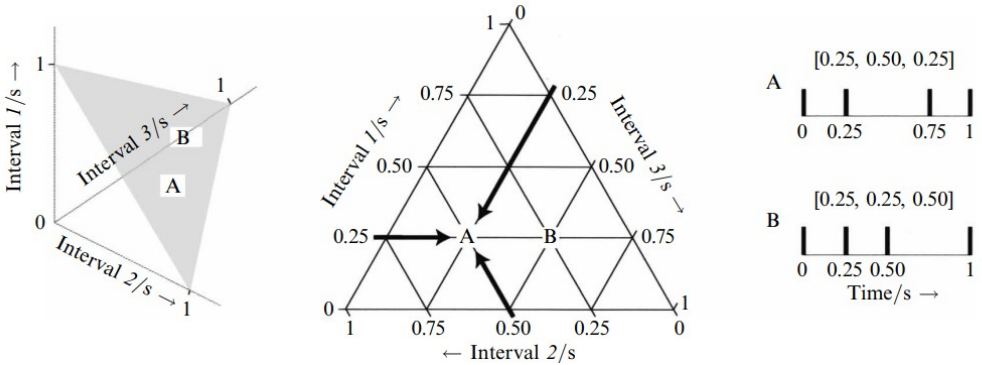
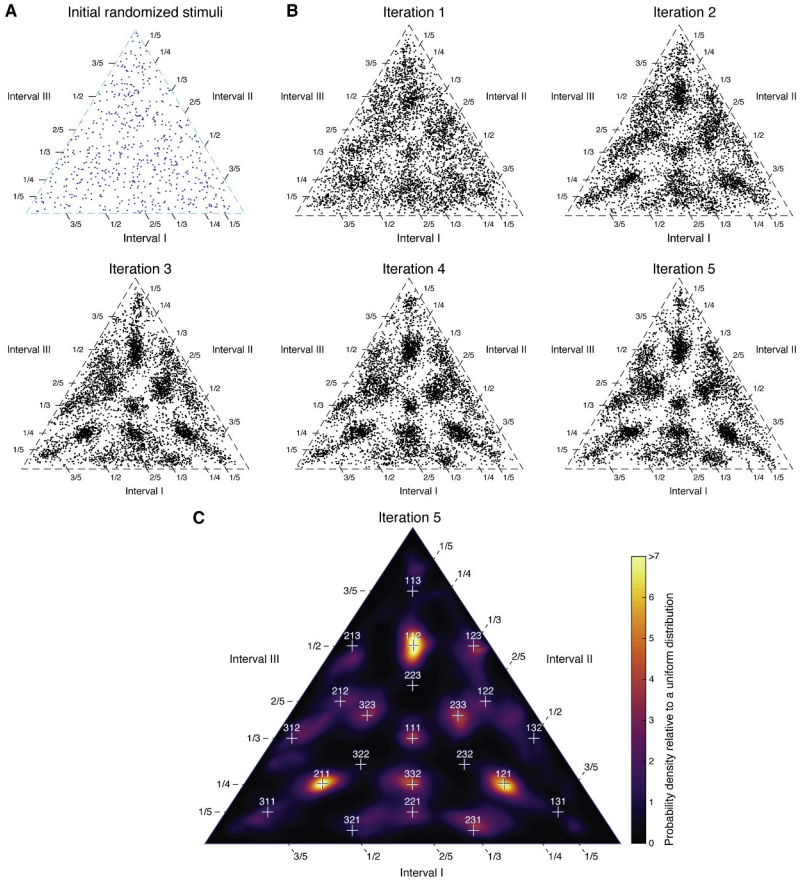
Metrical hierarchy – another perspective



[Desain and Honing 2003]



[Jacoby and McDermott 2017]

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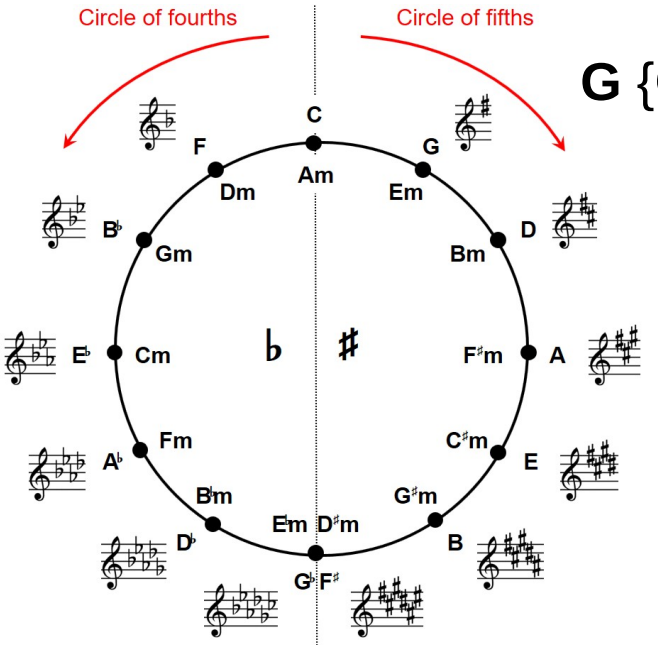
Key and scale

C {C, D, E, F, G, A, B}



G {G, A, B, C, D, E, F#}

[FMP21] Fig 5.10

Modulation

Modulation is another term for a change of key

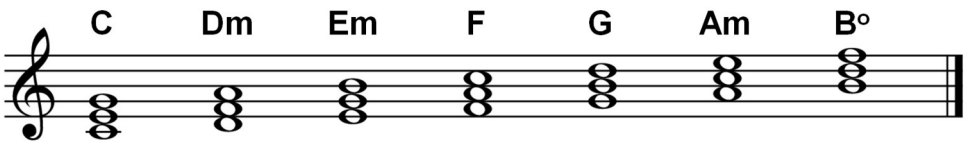
Several things contribute to our sense of what key we are in:

- scale: what collection best explains (covers) the notes we hear
- harmonic context: what chords precede and succeed
- harmonic content: what is the structure of the chord we are at
- **melodic context**: what notes precede and follow
- **melodic content**: what notes are prominent
- key context: what key (or mixture of keys) are we already in
- form: where are we in the overall journey of the piece of music

voice-leading

Building triads using scale members

Consider the set of triads that can be build using only the members of the C major scale



[FMP21] Fig 5.11

All are major or minor, apart from the chord built on B (a **diminished triad**)

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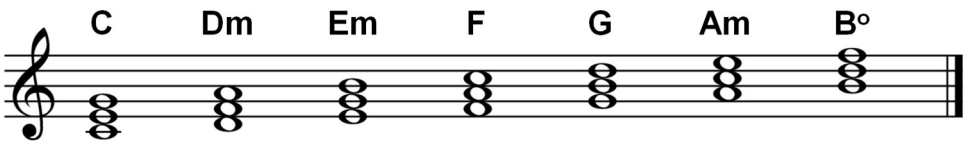

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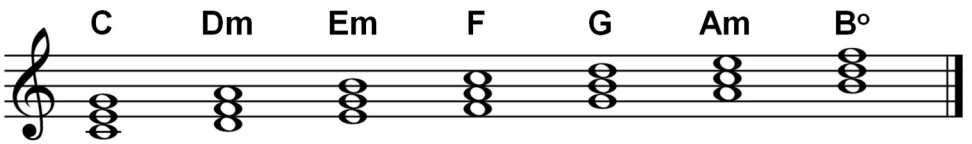

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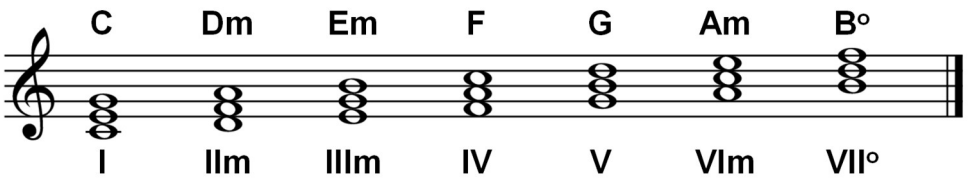
Roman numeral notation

Roman numerals can be used to identify triads (and other chords) with reference to a given scale

We use the Roman numeral equivalent of the scale degree (i.e. index) of the note on which the triad is built

We also can read off the quality of the triad:

- no qualifier: major
- m: minor (alternatively, lower case RN)
- o: diminished (alternatively, lower case RN + o)



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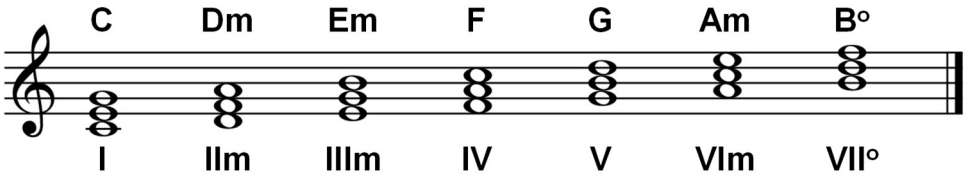
For the above reason, we also frequently refer to triads by the alternative name of the scale degrees presented earlier (but don't get confused with function)

I: tonic

IV: sub-dominant



[FMP21] Fig 5.11

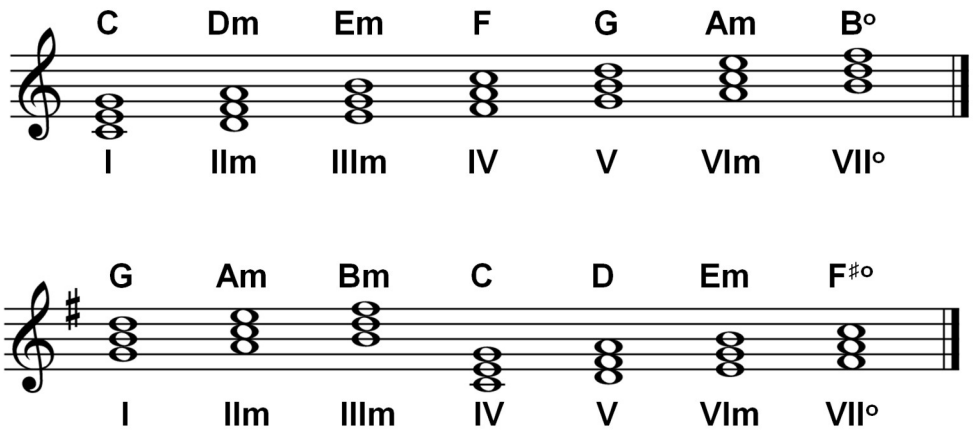
V: dominant

Roman numeral notation

As Roman numeral notation is with reference to a scale, the “same” triad – i.e. the same collection of pitches - can have multiple different Roman numerals associated with it

Shown here is how **G** in the context of the triads built on the C major scale is **V**

...but in the context of the G major scale is **I**



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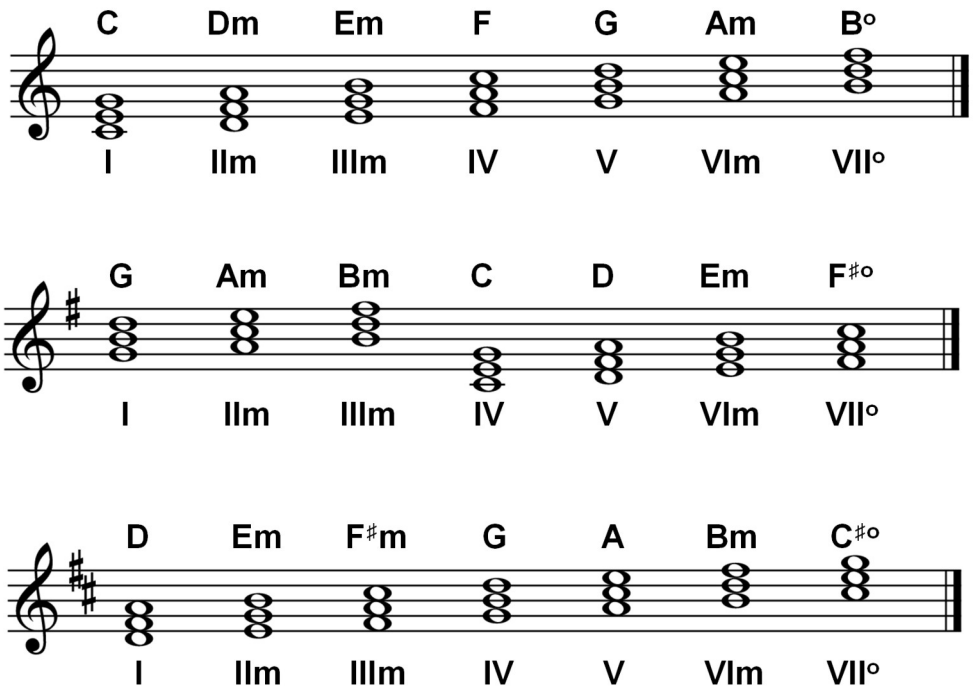
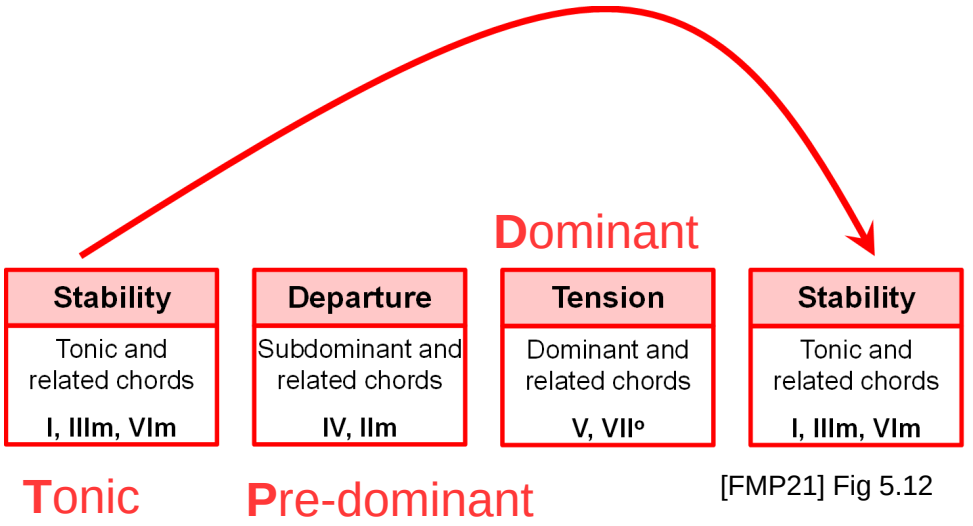


[FMP21] Fig 5.11

Function and the sense of tension

Functional labels help us to reason about the constraints on what chords sound good with each other (in succession)



[FMP21] Fig 5.12

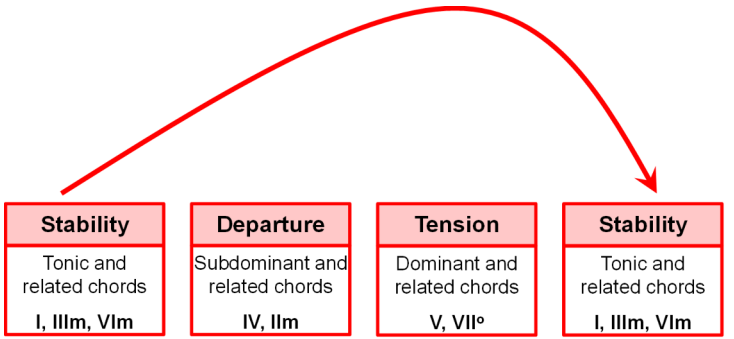
Function and the sense of tension

Chord progressions are stock patterns

Roman numeral notation allows us to think of them in a key-generic way

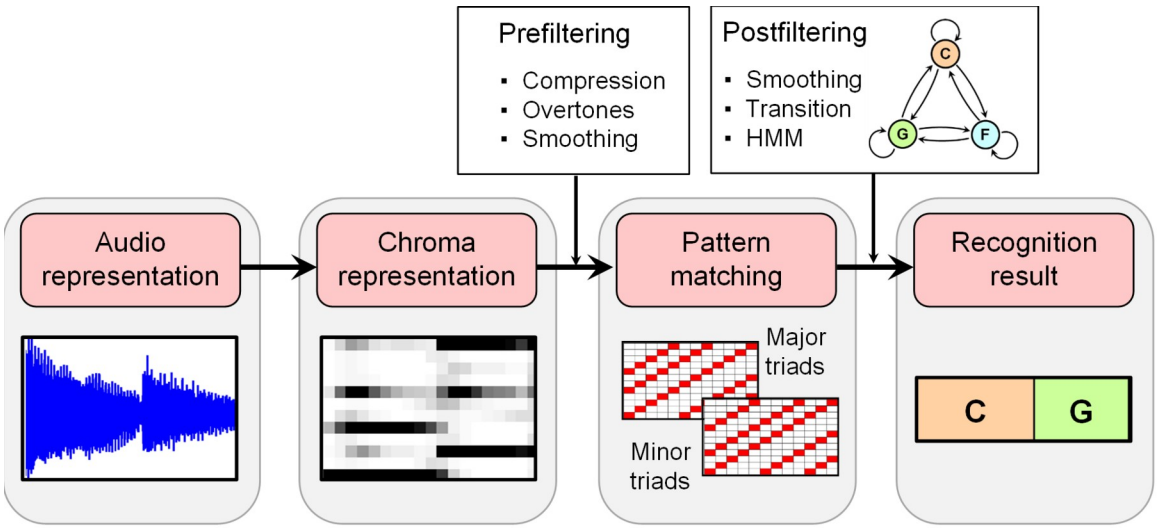
- I – ii – IV – V – I
- I – I – I – I – IV – IV – I – I – IV – I – I
- vi – IV – I – V

and allow us to spot patterns across many pieces, even writing down and ultimately learning grammars that specify musical productions



[FMP21] Fig 5.12

Back to chord recognition again



[FMP21] Fig 5.13

Effect of choice of scales on overall consonance of a generative music work

Consider a simple generative music work that consists in two separate instruments playing an **isochronous** sequence of notes, with pitches drawn at random from a given scale

What is the effect of the choice of scale on the overall degree of consonance of this piece of music?

What do we even mean by “overall” consonance?

Application: Music Mouse

Laurie Spiegel's **Music Mouse**

- 1985-6: Apple Macintosh
- 1986-7: Amiga (with David Silver)
- 1988: Atari ST (David Silver)

Remade by Tero Parviainen (https://teropa.info/musicmouse/)

Amiga version **available on Internet Archive** for emulation

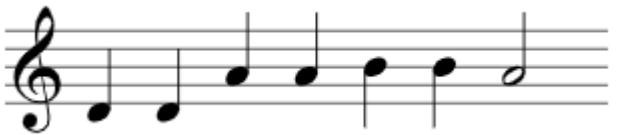
See also, a write up in **Amiga World (March 1988)**

Photo: Rob Onadera (c. 1980s?)

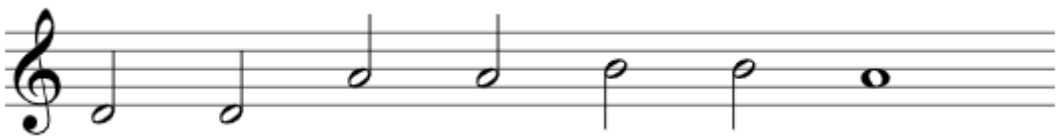
Rhythm

Musical events happen in time, so they have a start time and a duration. The goal of staff notation is to show this information at the same time as the pitch(es) played.

Some events are relatively short:

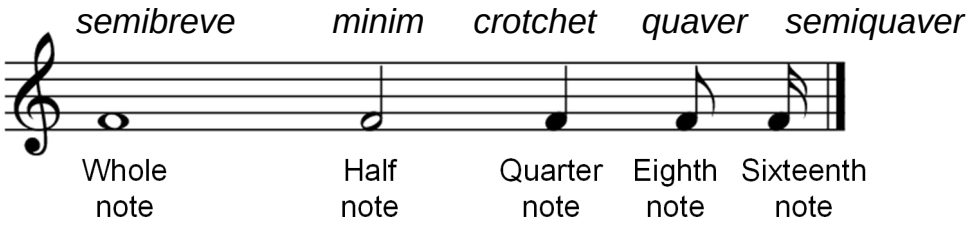


Some events are relatively long. Here, everything takes twice as long as above:

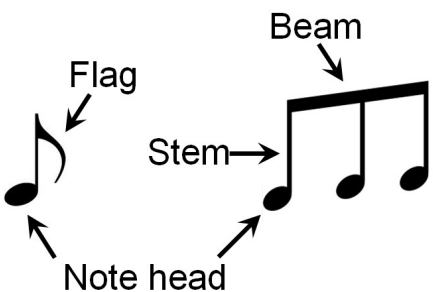


Rhythm

Here is a restricted “vocabulary” of possible rhythmic symbols



There is a small set of combining and grouping rules that quickly increase the density of ink on the page



Learn:
https://www.musictheory.net/lessons/11
https://www.musictheory.net/lessons/12
https://www.musictheory.net/lessons/13
https://www.musictheory.net/lessons/14

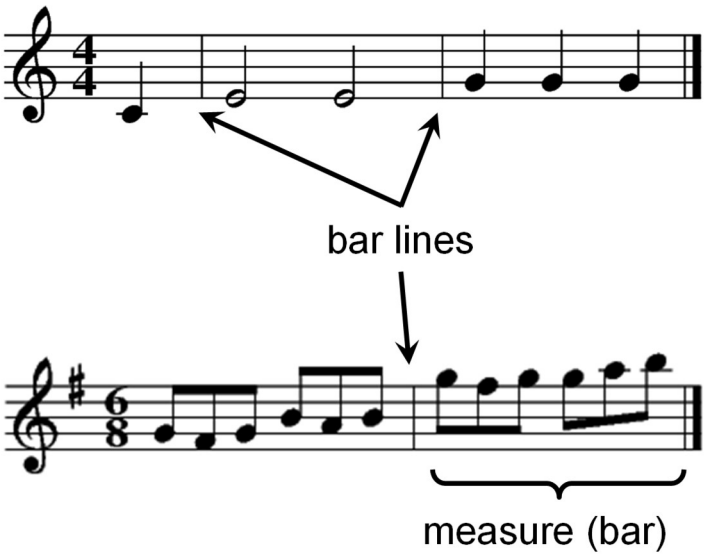
Create:
https://www.verovio.org/pae-editor.html

[FMP21] Fig 1.7

Rhythm

As in speech and poetry, there are common rhythmic patterns that occur frequently, including alternating patterns of stress and emphasis

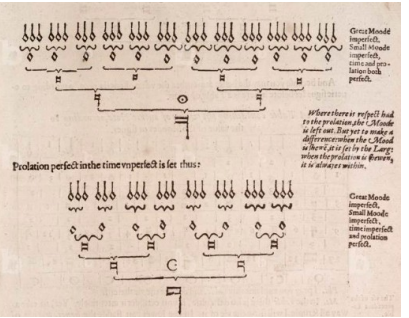
The **time signature** communicates some information (in advance) the patterns that make up the piece and are associated with conventional combining and grouping patterns



[FMP21] Fig 1.6

Plaine & Easie Code

- Legacy plaintext encoding of music dating from the 1960s [Brook et al. 1964]
  - (Spec under development: https://github.com/rism-digital/pae-code-spec)
- Designed for librarians cataloguing **incipits** (the first part of a musical document)
- Over 1.4M incipits encoded and indexed in RISM
- Example:
  - `{''6E'B8G}{GA}-''C{'3B8..G}`
- Supported by many libraries and tools but not practical for anything more than very brief examples
- Editor: https://www.verovio.org/pae-editor.html



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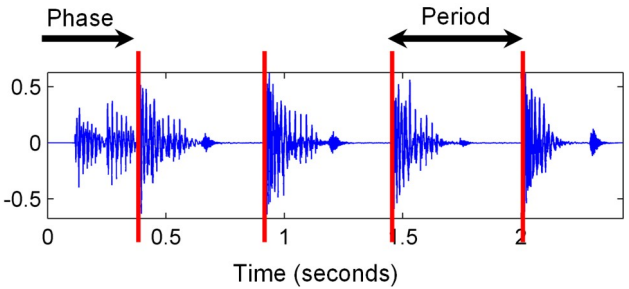

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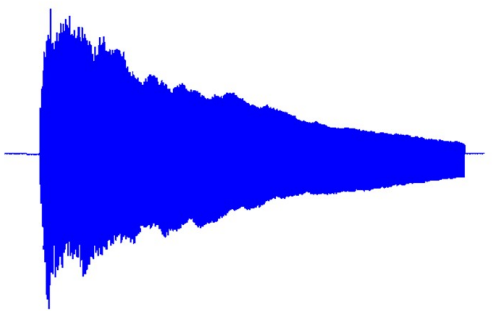

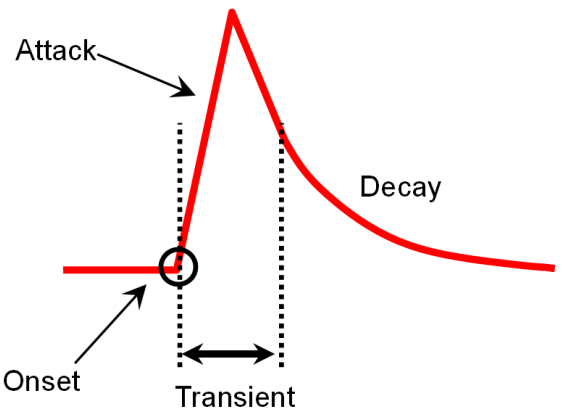

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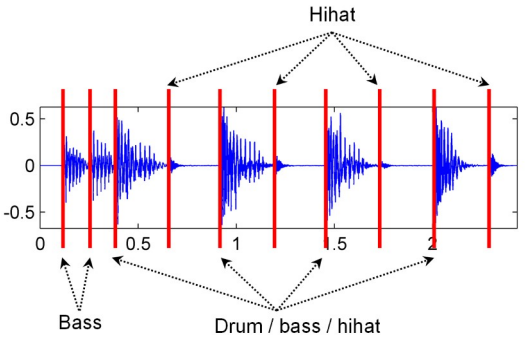

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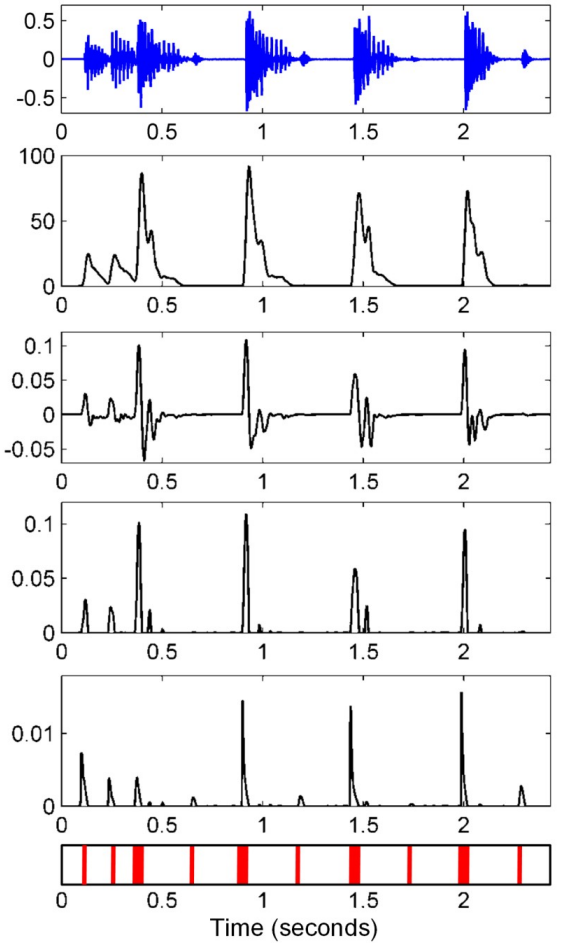

[FMP21 Fig. 6.3]

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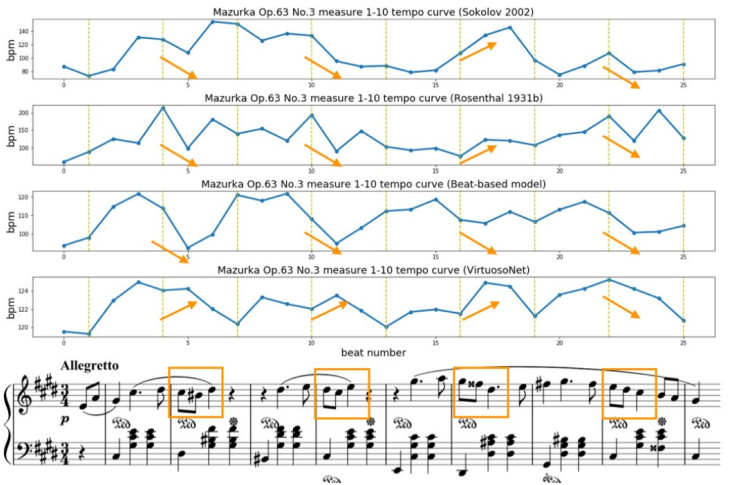

[Shi 2023]

Durham University

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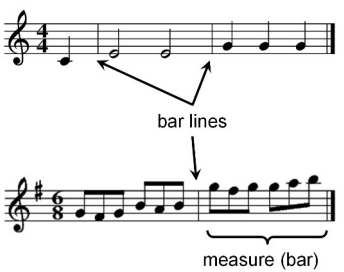
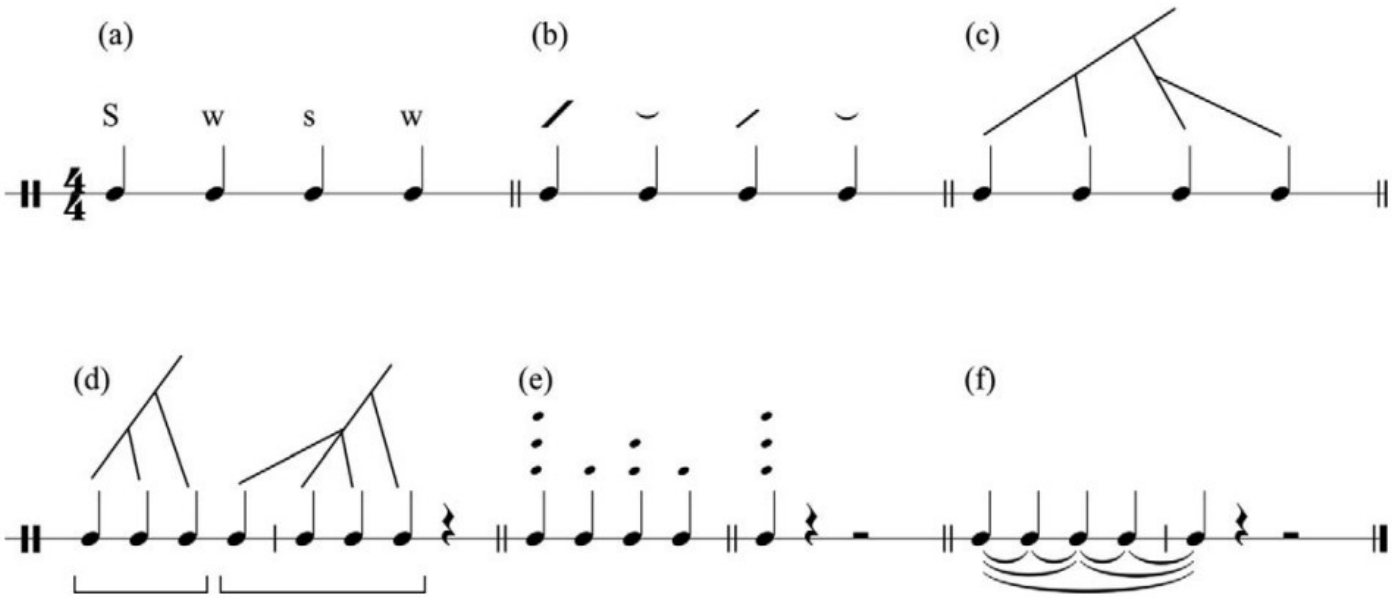
In staff notation, the time signature can be thought of as a short-hand for a conventional meter and its associated hierarchy

When a particular time signature (hence, meter) is in operation, this has effects on how rhythms are notated.



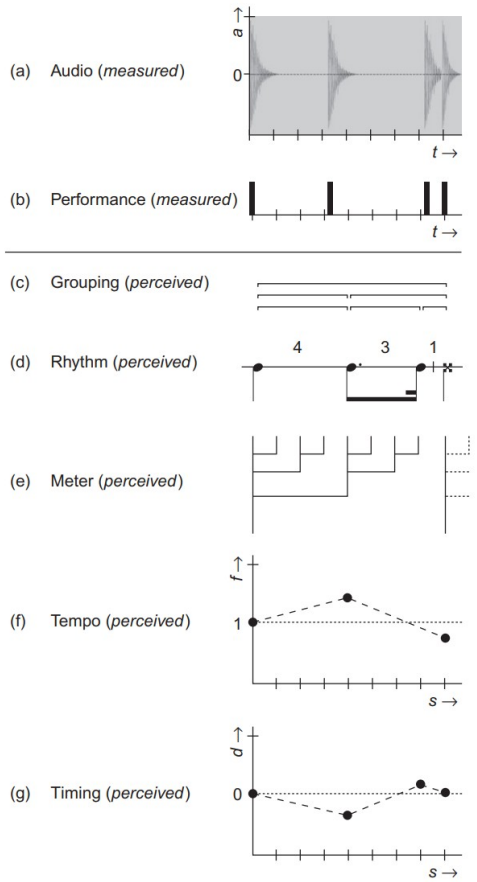
[FMP21] Fig 1.6

Metrical hierarchy – visual representations



[Lerdahl 2015]

Metrical hierarchy – representations applied



[Honing 2013]

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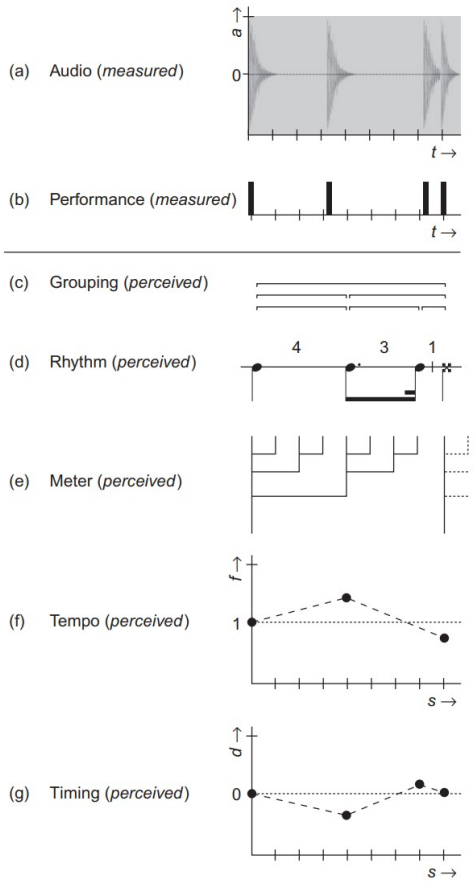
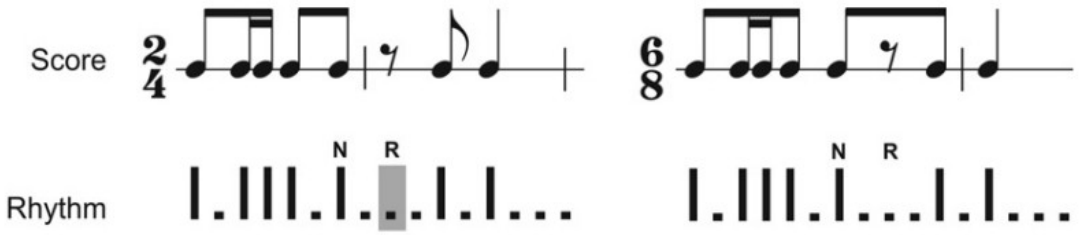
Metrical hierarchy – representations applied





[Honing 2013]

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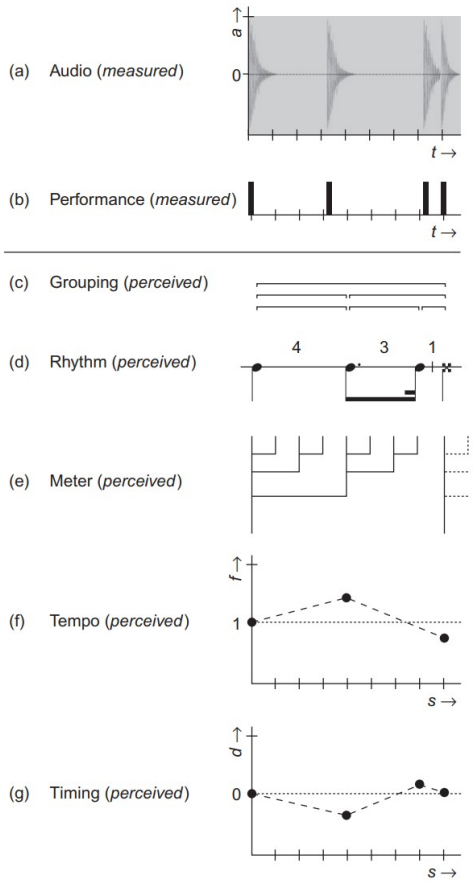
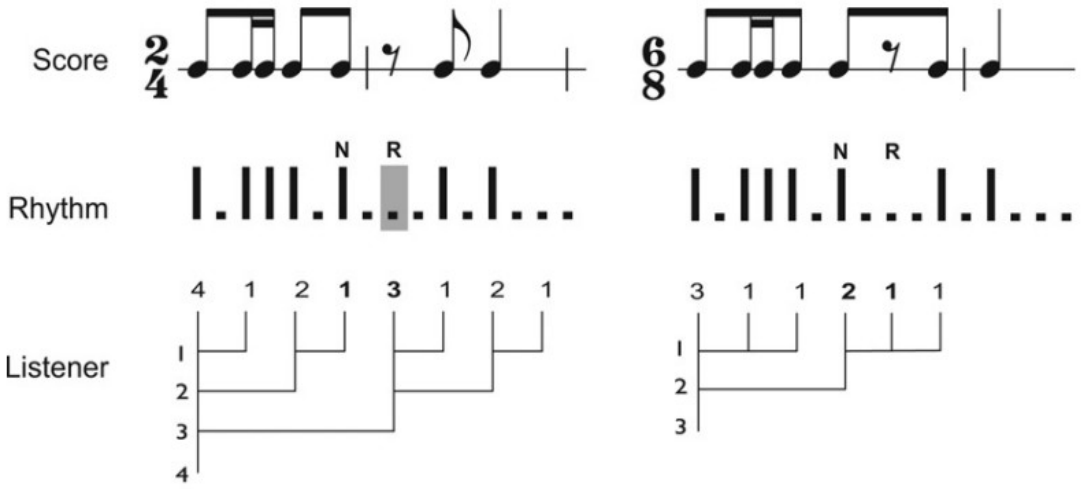
Metrical hierarchy – representations applied





[Honing 2013]

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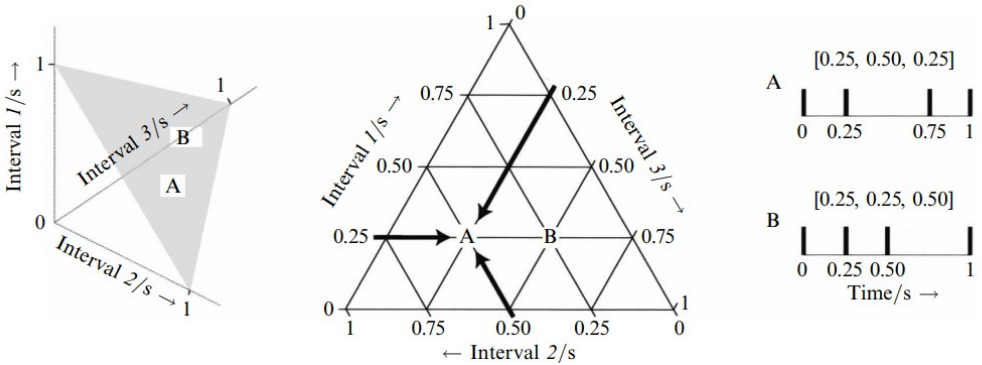
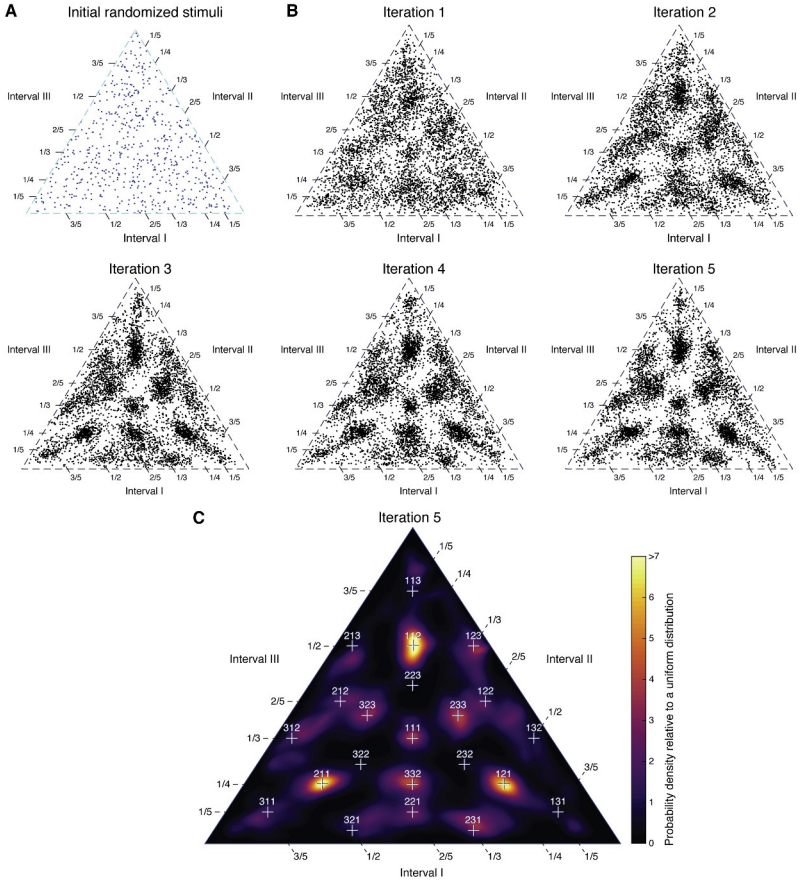
Metrical hierarchy – another perspective



[Desain and Honing 2003]



[Jacoby and McDermott 2017]

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