

# Beethoven X

... mit KI / with AI ...

*Es könnte sein*

(It could be ... )

How do we get  
... from this ...

Scherzo zum 10ten = Symphonie.

*Violon*

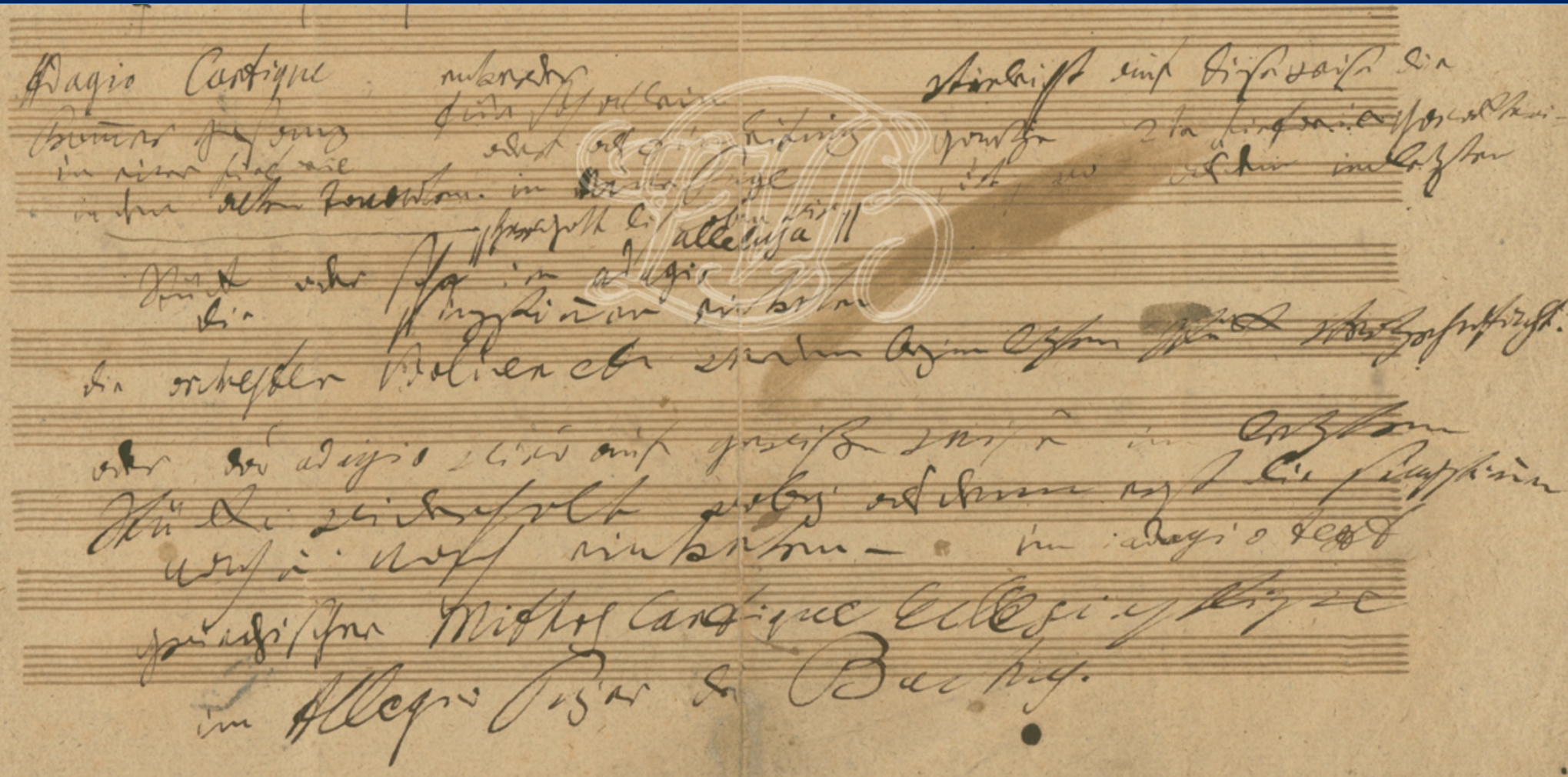
Violon part consisting of five staves of handwritten musical notation. The notation includes various rhythmic values, rests, and clefs, with some markings that appear to be 'III' or similar symbols.

*Corrig*

Corrig part consisting of four staves of handwritten musical notation. The notation includes notes, rests, and some markings, with the word 'Corrig' written above the first staff.

... and this ...

# Sketching in words ...



... to this?!



# HOW?

How *can* we?

- Practicalities

How *should* we?

- A 'suitable' style?

How might we *want to*?

- Human-computer collaboration?





# Thanks to:

Deutsche Telekom

The team, including ...

# Team!



Mark Gotham, 2021



„Ich bin wie allzeit ganz bei den Museen, ergeben u. finden das Glück meines Lebens.“

HERBERT LIPPE  
BILDFILM-REDAKTION

# More information:

<https://tinyurl.com/BeethovenX>

# How to 'generate' a symphony

1: Starting points

2: Setting the computer tasks

3: Computational architectures

# How to 'generate' a symphony

0: History

1: Starting points

2: Setting the computer tasks

3: Computational architectures

# 0. HISTORY

# History

- Commission for 2 symphonies (9<sup>th</sup> + 10<sup>th</sup>);
- LvB completes 9<sup>th</sup> done; sketches 10th;
- Not enough to attempt ‘completion’;
- ‘New’ sketches and completion of 1<sup>st</sup> mov.;
- Still not enough for the rest ... ?
- That’s what we attempt!



# 1. STARTING POINTS

# 1. STARTING POINTS: Musical sketches

Scherzo zum 10<sup>ten</sup> = Symphonie.

*Violon*

Violon part consisting of five staves of handwritten musical notation. The notation includes various note values, rests, and clefs, with some markings that appear to be figured bass or rhythmic indicators.

*Corrig*

Corrig part consisting of four staves of handwritten musical notation. The notation includes various note values, rests, and clefs, with some markings that appear to be figured bass or rhythmic indicators.

# Starting Points: Musical sketches



# Starting Points: Musical sketches

Musical sketch 1: Treble clef, 3/4 time, key signature of two flats. The first three measures are boxed in red.

Musical sketch 2: Treble clef, 3/4 time, key signature of two flats. The first two measures are boxed in red.

... Partly by analogy to other late-style melodies ...

Musical sketch 3: Bass clef, 6/8 time, key signature of three flats. The first three measures are boxed in red.

# Starting Points: Musical sketches

**Our scherzo (10th Symphony)**



**... inverted (9th Symphony)**



**op.110 Sonata**



**... inverted**



**Es Muss Sein!**

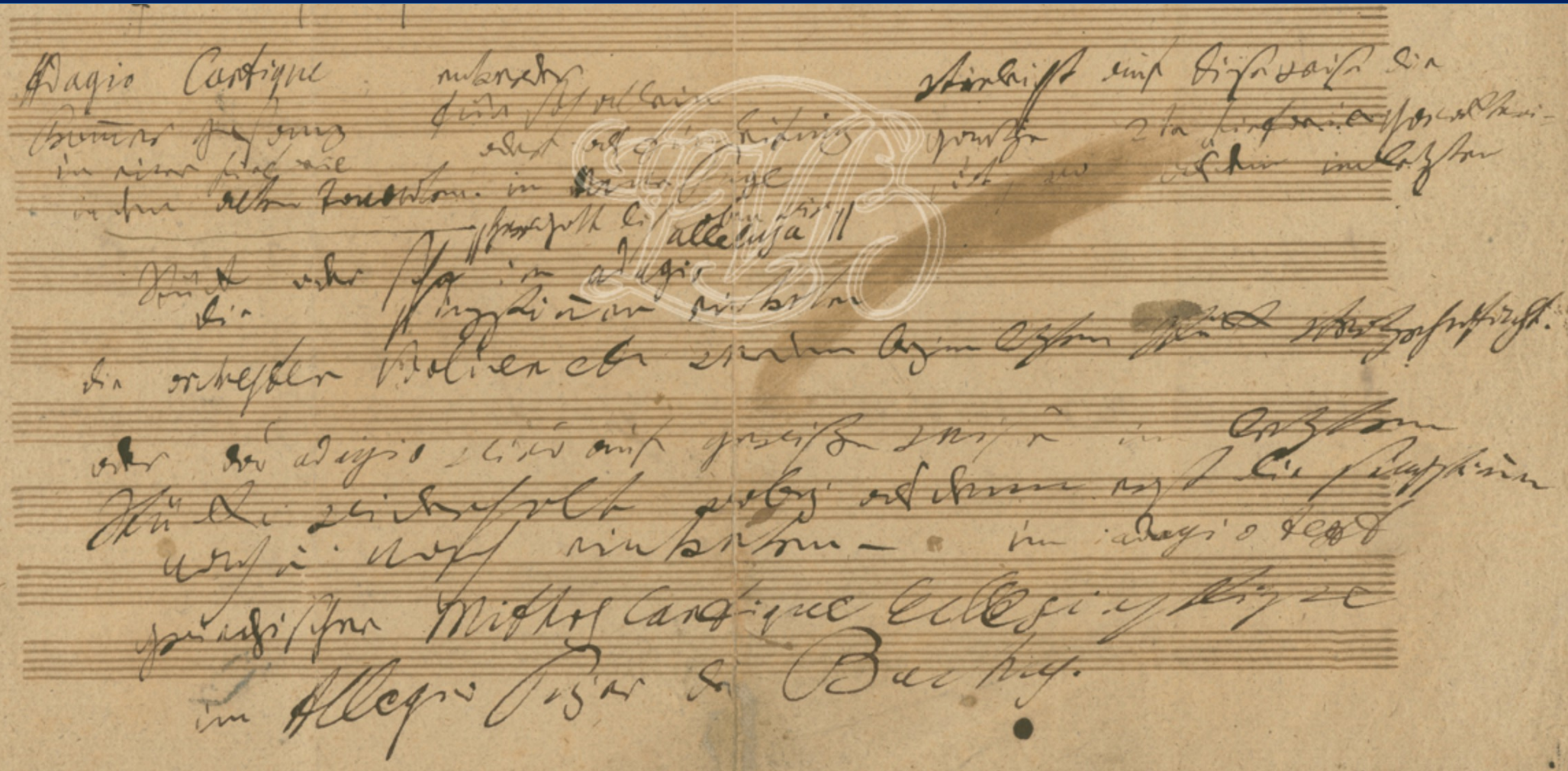


# *Discuss: Human or Computer?*

# 1. STARTING POINTS: Textual sketches



# Starting Points: Textual sketches



# Starting Points: Textual sketches

‘in den alten Tonarten’?

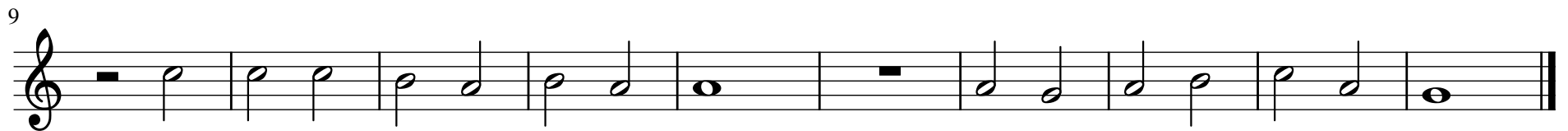
Heiliger Dankgesang eines Genesenen an die Gottheit, in der lydischen Tonart.  
(*Canzona di ringraziamento offerta alla divinità da un guarito, in modo lidico.*)

Molto adagio.

The image shows a musical score for a piece titled 'Heiliger Dankgesang eines Genesenen an die Gottheit, in der lydischen Tonart.' The score is in 4/4 time and consists of four staves. The first staff is the vocal line, marked 'sotto voce' and 'cresc. - p'. The second and third staves are for the right hand of a piano, also marked 'sotto voce' and 'cresc. - p'. The fourth staff is for the left hand, marked 'cresc. - p'. The music is in a Lydian mode, characterized by a major scale with a raised fourth degree. The tempo is 'Molto adagio'.

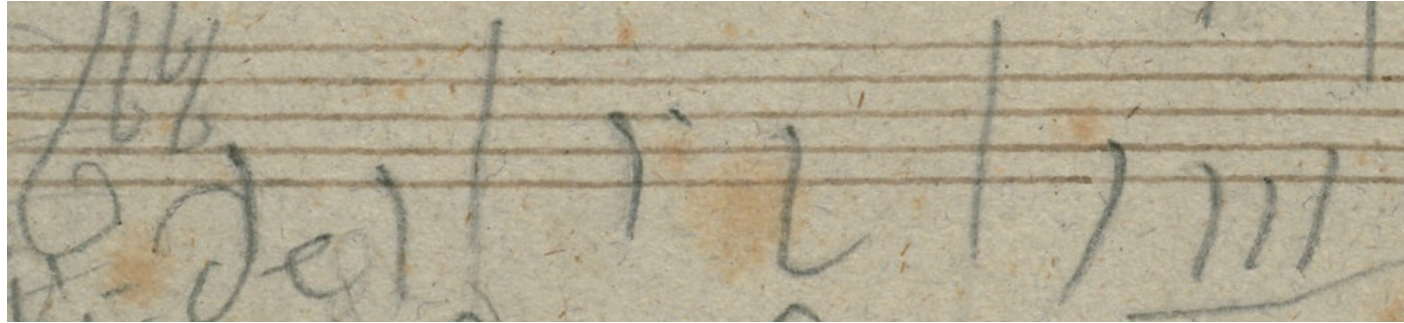
# Starting Points: Textual sketches

**‘Herr Gott Dich loben wir’?**



# Starting Points: Retrospection?

Slow theme sketch:



Slow movement of the 'Pathétique' Piano sonata (no.8 / op.13):

152

*Adagio cantabile.*

A musical score for the slow movement of the 'Pathétique' Piano sonata, Op. 13, No. 8. The score is in 2/4 time and features a treble and bass clef. The tempo is marked 'Adagio cantabile'. The music is in a key with three flats (B-flat major or D-flat minor). The score includes various musical notations such as slurs, ties, and fingerings. The first measure is marked with a circled '5' and the second measure with a circled '10'. The score is written on a grand staff with a brace on the left side.

# *Discuss: Human or Computer?*

# 1. STARTING POINTS: Training Corpus

# Training Corpus: Fugues

# Movement 'prototypes': Fugues

## **Whole movements by Beethoven so titled:**

- Op.35: Variations and Fugue ('Eroica Variations')
- Op.133: Große Fuge
- Op.137: Fugue in D major
- WoO 31: Fugue for Organ
- Hess 29-31: Preludes and Fugues
- Hess 64 / WoO 215: Fugue for keyboard
- Hess 238: 9 Fugues for 4 Voices
- Hess 244: 2 Triple Fugues for 4 Voices
- Hess 315: Fugue
- Hess 326: Fugue for piano in C major
- Hess Anh. 57: Fugue "Dona nobis pacem"



# Movement 'prototypes': Fugues

## **Whole movements by Beethoven so titled:**

- **Op.35: Variations and Fugue ('Eroica Variations')**
- Op.133: Große Fuge
- Op.137: Fugue in D major
- WoO 31: Fugue for Organ
- Hess 29-31: Preludes and Fugues
- Hess 64 / WoO 215: Fugue for keyboard
- Hess 238: 9 Fugues for 4 Voices
- Hess 244: 2 Triple Fugues for 4 Voices
- Hess 315: Fugue
- Hess 326: Fugue for piano in C major
- Hess Anh. 57: Fugue "Dona nobis pacem"

# Movement 'prototypes': Fugues

## **Whole movements by Beethoven so titled:**

- Op.35: Variations and Fugue ('Eroica Variations')
- Op.133: Große Fuge
- Op.137: Fugue in D major
- WoO 31: Fugue for Organ
- **Hess 29-31: Preludes and Fugues**
- Hess 64 / WoO 215: Fugue for keyboard
- Hess 238: 9 Fugues for 4 Voices
- Hess 244: 2 Triple Fugues for 4 Voices
- Hess 315: Fugue
- Hess 326: Fugue for piano in C major
- Hess Anh. 57: Fugue "Dona nobis pacem"

# Movement 'prototypes': Fugues

Opus	Piece	Mvt / part
Op.101	Piano Sonata no.28	4
Op.106	Piano Sonata no.29 (Hammerklavier)	1
Op.106	Piano Sonata no.29 (Hammerklavier)	4
Op.110	Piano Sonata no.31	3 (1st part)
Op.110	Piano Sonata no.31	3 (2nd part)
Op.120	Diabelli Variations	Variation 32

Partial works by Beethoven ... for piano

# Movement 'prototypes': Fugues

Opus	Piece	Mvt / part
Op.55	Symphony No. 3	2
Op.55	Symphony No. 3	4
Op.67	Symphony No. 5	3
Op.92	Symphony No. 7	2
Op.125	Symphony No. 9	1
Op.125	Symphony No. 9	2
Op.125	Symphony No. 9	4

Partial works by Beethoven ... for orchestra

# Movement ‘prototypes’: Fugues

## **Which fugues?**

Only

- ... by Beethoven?
- ... orchestral?
- ... complete works (no drafts / fugato sections)?

# *Discuss: Human or Computer?*

# Training Corpus: Movement Types

# Movement 'prototypes': Sonatas

Opus	Mvt no	Mvt TYPE	Movement name	Key
Op.2/1	1	1	Allegro	f
Op.2/1	2	2	Adagio	F
Op.2/1	3	3	Menuetto: Allegretto	f
Op.2/1	4	4	Prestissimo	f



# Movement 'prototypes': Sonatas

Opus	Mvt no	Mvt TYPE	Movement name	Key
Op.2/1	1	1	Allegro	f
Op.2/1	2	2	Adagio	F
Op.2/1	3	3	Menuetto: Allegretto	f
Op.2/1	4	4	Prestissimo	f
Op.27/2 "Moonlight"	1	2?	Adagio sostenuto	c#
Op.27/2 "Moonlight"	2	3	Allegretto	Db
Op.27/2 "Moonlight"	3	4	Presto agitato	c#
Op.109	1	1?	Vivace ma non troppo—Adagio espressivo	E
Op.109	2	3?	Prestissimo	e
Op.109	3	2?	Andante molto cantabile ed espressivo	E

# Starting Points: Length and Structure

# Starting Points: Length

Initial plans based on:

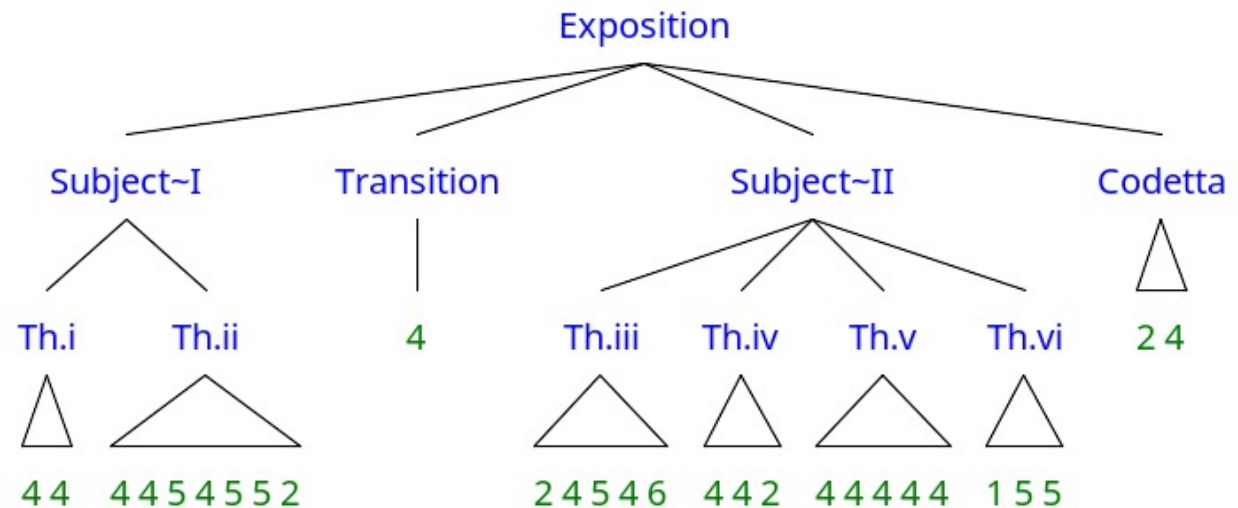
- **Movements lengths**  
E.g. →

Sym.Mvt	Measures	QuarterLength
3 i	697	2,083
3 ii	249	494
3 iii	455	1,358
3 iv	482	950
4 i	513	2,048
4 ii	105	312
4 iii	405	1,195
4 iv	361	718
5 i	503	1,012
5 ii	257	370
5 iii	377	1,122
5 iv	447	1,730

# Starting Points: Structure

Initial plans based on:

- Movements lengths
- **Formal structure** →



# Starting Points: Structure (Melodic)

Initial plan based on:

- Movements lengths
- Formal structure
- **Melodic Structure** →

Offset	Measure	Beat	Theme	Instrument
0	0	3a		Violoncello
13	5	1a		Violino I
43	15	1a		Flauti
55	19	1b		Corni in Es
79	27	1b		Violino II
134	45	2a		Violoncello
145	49	1a		Violino I
156	52	3a		Violoncello
168	56	3a		Viola
182	61	2a		Violino I
211	71	1b		Violino II
259	87	1b		Violino II

# *Discuss: Human or Computer?*

# Starting Points: Structure (Melodic)

Initial plan based on:

- Movements lengths
- Formal structure
- **Melodic Structure**

A musical score for three instruments: Violino I, Violino II, and Viola. The score is written on a single staff in 2/4 time, with a key signature of two flats (B-flat and E-flat). The music begins with a treble clef and a 7-measure rest. The first two measures are for Violino I, featuring a quarter note 'a' followed by a half note with a fermata. The next two measures are for Violino II, also featuring a quarter note 'a' followed by a half note with a fermata. The final two measures are for the Viola, featuring a quarter note 'a' followed by a half note with a fermata. The score ends with a final note on a whole note.

# 2. SPECIFIC GENERATION TASKS



# Specific tasks

Sketch fragment



Extend melody ...



Add accompaniment parts (short score)  
Add accompaniment parts (short score)



Add doublings etc (orchestration)  
Add doublings etc (orchestration)

a.

Fragment → Melody

(Where is the tune?)

(What is a tune?)

# Fragment → melody

## Melody Score Based on Symphony 5-i

Beethoven

The image shows a musical score for a melody based on the first movement of Beethoven's Symphony 5. The score is written in 2/4 time and features three staves: Violino I, Violino II, and Viola. The key signature is two flats (B-flat and E-flat). The melody is characterized by a rhythmic pattern of eighth notes and quarter notes, often starting with a grace note. The score includes dynamic markings such as 'a' (allegro) and 'f' (forte), and phrasing slurs. The first staff is labeled 'Violino I' and the second 'Violino II' and 'Viola'. The third staff is labeled 'Violino I'.

- Identify where 'the tune' is throughout the movement
- Stiches those parts together

b.  
Melody →  
Accompaniment  
Harmonisation

# Harmonisation

- Learn from score (counterpoint)
  - Part pairs 1-2, 1-3, 2-3 ...

# Harmonisation

- Learn from score (counterpoint)
  - Part pairs 1-2, 1-3, 2-3 ...
- Learn from harmonic analyses:
  - Automatic →

Some sense of *tonal harmony* is common to a very wide range of musics, including most Western Classical music, as well as most jazz, pop, rock, and much more besides. [Roman numeral analysis](#) focuses on recording chords, specifying the triad quality (major, minor...), seventh (where applicable), inversion (bass note), and any modifications (such as added and altered notes).

This application allows you to perform a Roman Numeral analysis on any symbolic score (see below) using a machine-learning approach [published in \[1\]](#).

## Analyze the harmony of your scores

Upload Files...



... or drop your scores here

## Output

.csv

.dez

.rntxt

post-processing

annotated .musicxml

feedback

⚠ Annotated .musicxml and feedback might be slow!

## Try some of these examples

Bach, Prelude in C  
Major (mxl)

Beethoven, Waldstein  
sonata (xml)

Schumann, Fugue on  
B.A.C.H. (krn)

Vivaldi, The Winter  
(mei)

Joplin, The Entertainer  
(mid)

# Harmonisation

- Learn from score (counterpoint)
  - Part pairs 1-2, 1-3, 2-3 ...
- Learn from harmonic analyses:
  - Automatic (<http://roman.algomus.fr>)
  - Human (<https://github.com/MarkGotham/When-in-Rome/>)



# Harmonisation

- Learn from score (counterpoint)
  - Part pairs 1-2, 1-3, 2-3 ...
- Learn from harmonic analyses:
  - Automatic (<http://roman.algomus.fr>)
  - Human (<https://github.com/MarkGotham/When-in-Rome/>)
- **Structured representation →**

# Structured representation

First system of musical notation (measures 1-3). The treble clef contains a continuous eighth-note accompaniment. The bass clef contains a simple harmonic accompaniment. Measure 1 is in C major (C:I). Measure 2 is in the key of D minor (ii42). Measure 3 is in the key of E-flat major (V65).

C: I

ii42

V65

Second system of musical notation (measures 4-7). Measure 4 is in C major (I). Measure 5 is in D minor (vi6). Measure 6 is in G major (G: V42). Measure 7 is in E-flat major (I6).

I

vi6

G: V42

I6

Third system of musical notation (measures 8-11). Measure 8 is in F major (IV42). Measure 9 is in D minor (ii7). Measure 10 is in G major (V7). Measure 11 is in C major (I).

IV42

ii7

V7

I

# Structured representation

The image displays a musical score with two systems. Each system consists of a piano score and an analysis staff. The piano score is written in C major, 4/4 time, and features a repeating eighth-note pattern in the right hand and a bass line in the left hand. The analysis staff shows the harmonic structure with chords and their Roman numerals.

**System 1:**

- Piano:** Right hand plays a repeating eighth-note pattern (C4-E4-G4-A4). The left hand plays a bass line (C3-G2-A2-F2).
- Analysis:** The first measure contains a C major triad (C4-E4-G4) labeled "C: I". The second measure contains a D minor dyad (D4-F4) labeled "ii42".

**System 2:**

- Piano:** The right hand continues the eighth-note pattern. The left hand continues the bass line.
- Analysis:** The first measure contains a D minor dyad (D4-F4) labeled "V65". The second measure contains a C major triad (C4-E4-G4) labeled "I".

# Harmonisation

- Learn from score (counterpoint)
  - Part pairs 1-2, 1-3, 2-3 ...
- Learn from harmonic analyses:
  - Automatic (<http://roman.algomus.fr>)
  - Human (<https://github.com/MarkGotham/When-in-Rome/>)
- Structured representation
- Automatic feedback →

# Automatic feedback

9 *a tempo* *p*

nicht. Ich wollt', im Grün spa - zier - te die  
not. I would I knew a fair - er, sweet

*f* *f* *p*

V iiø7 III+7VI7 bII#7 V7 i iv6 iiø43 V

Detailed description: This is a musical score for a vocal and piano piece. It starts at measure 9, marked 'a tempo'. The vocal line begins with the lyrics 'nicht. Ich wollt', im Grün spa - zier - te die' and continues with 'not. I would I knew a fair - er, sweet'. The piano accompaniment features a bass line with chords and a treble line with melodic fragments. A blue arrow points from the text box below to the first piano chord in measure 9, which is labeled 'iiø7'. The score includes dynamic markings like 'f' and 'p'.

## PITCH COVERAGE =====

I rate the pitch coverage at about 93.63%. In the following cases, the chord indicated does not seem to capture everything going on:

Measure 9, beat 1, iiø7 in g minor, indicating the pitches ['A', 'C', 'E-', 'G-'] accounting for successive slices of [['A4', 'C5', 'E-5', 'G5', 'E-6'], ['A4', 'C5', 'E-5', 'G5', 'E-6']].

Match strength estimated at 80.0%.

How about:

m9 b1 iiø7 for the slice ['A4', 'C5', 'E-5', 'G5', 'E-6']

# https://fourscoreandmore.org/ working-in-harmony/

Try it yourself!

*Part of Working in Harmony*

Select another score

## Download

 [Boulanger, Lili - Attente](#)

or (experimental): [view in browser](#)

Hint: you can open these musicXML file in any relevant software like MuseScore, Sibelius, or Finale. If you don't already have a preference, try [MuseScore](#) which is free and open source.

## Analysis

Complete the template with your own Roman numeral analysis. Feel free to work offline in any text editor (simply cut'n'paste the text back in when you're done).

Composer: Lili Boulanger  
Title: Attente score.xml  
Analyst:  
Proofreader:  
Note: Template generated automatically. Please check thoroughly.

Time Signature: 4/4  
m1 b1  
m2 b1

Reset

Submit analysis

c.  
Short score →  
Orchestral score  
(‘De’-) Orchestration

# Short score → orchestral score



Short score for strings in 4/4 time. The score includes dynamics such as *fp* (fortissimo piano) and *f* (fortissimo).



Orchestral score for the same passage, including parts for Flauti, Oboi, Clarinetti in C, Fagotti, Corni in C, Trombe in C, Timpani in C. G., Violino I, Violino II, Viola, and Violoncello e Basso. The score includes dynamics such as *fp*, *cresc.*, *f*, and *p*.



# Short score $\leftarrow ? \rightarrow$ orchestral score

Reverse engineer ...

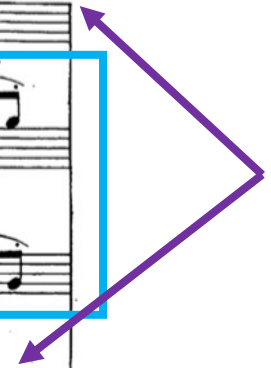
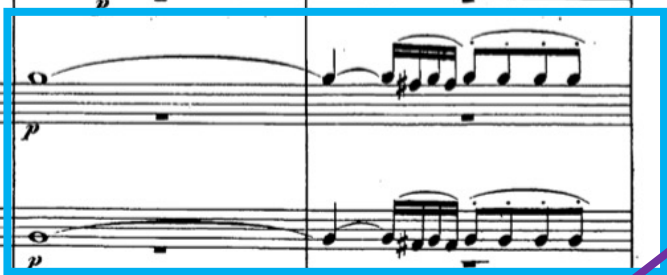
Orchestral scores (>):

- Lots of players
- Much 'doubling' of the same material

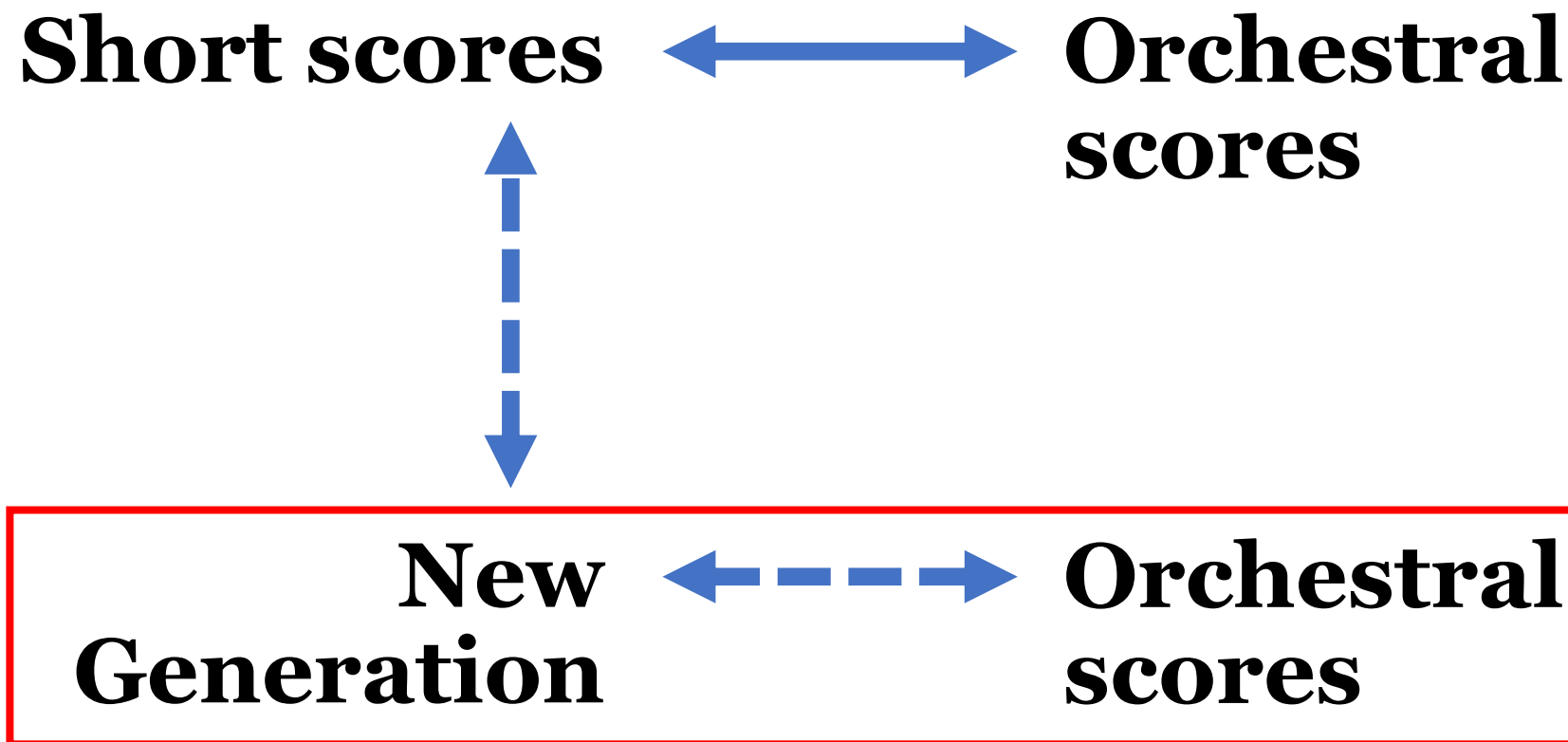
The image displays a page of an orchestral score with ten staves. From top to bottom, the staves are labeled: Flauti., Oboi., Clarinetti in C., Fagotti., Corni in C., Trombe in C., Timpani in C. G., Violino I., Violino II., Viola., and Violoncello e Basso. The score is written in a common time signature (C) and features various dynamic markings including *sf*, *cresc.*, *f*, and *p*. The woodwind and string sections show complex rhythmic patterns and dynamics, while the brass and timpani parts are more sparse. The string parts include markings for *pizz.* (pizzicato) and *arco.* (arco).

Flauti.  
Oboi.  
Clarineti in C.  
Fagotti.  
Corni in C.  
Trombe in C.  
Timpani in C. G.  
Violino I.  
Violino II.  
Viola.  
Violoncello e Basso.

The image shows a page of a musical score for a symphony orchestra. The instruments listed on the left are Flauti, Oboi, Clarineti in C, Fagotti, Corni in C, Trombe in C, Timpani in C. G., Violino I, Violino II, Viola, and Violoncello e Basso. The score is written in 2/2 time and features dynamic markings such as *sp*, *cresc.*, *f*, and *p*. A blue rectangular box highlights a section of the woodwind parts (Flauti, Oboi, Clarineti in C, and Fagotti) in the fifth measure. A purple arrow points from the right side of this box towards the Fagotti part. A red rectangular box highlights a section of the string parts (Violino I, Violino II, Viola, and Violoncello e Basso) in the fifth measure. A green arrow points from the right side of this box towards the Violoncello e Basso part.



# Short score $\leftrightarrow$ orchestral score



# 3. MACHINE LEARNING

# Continuation

## Input:

- Sketch

## Output:

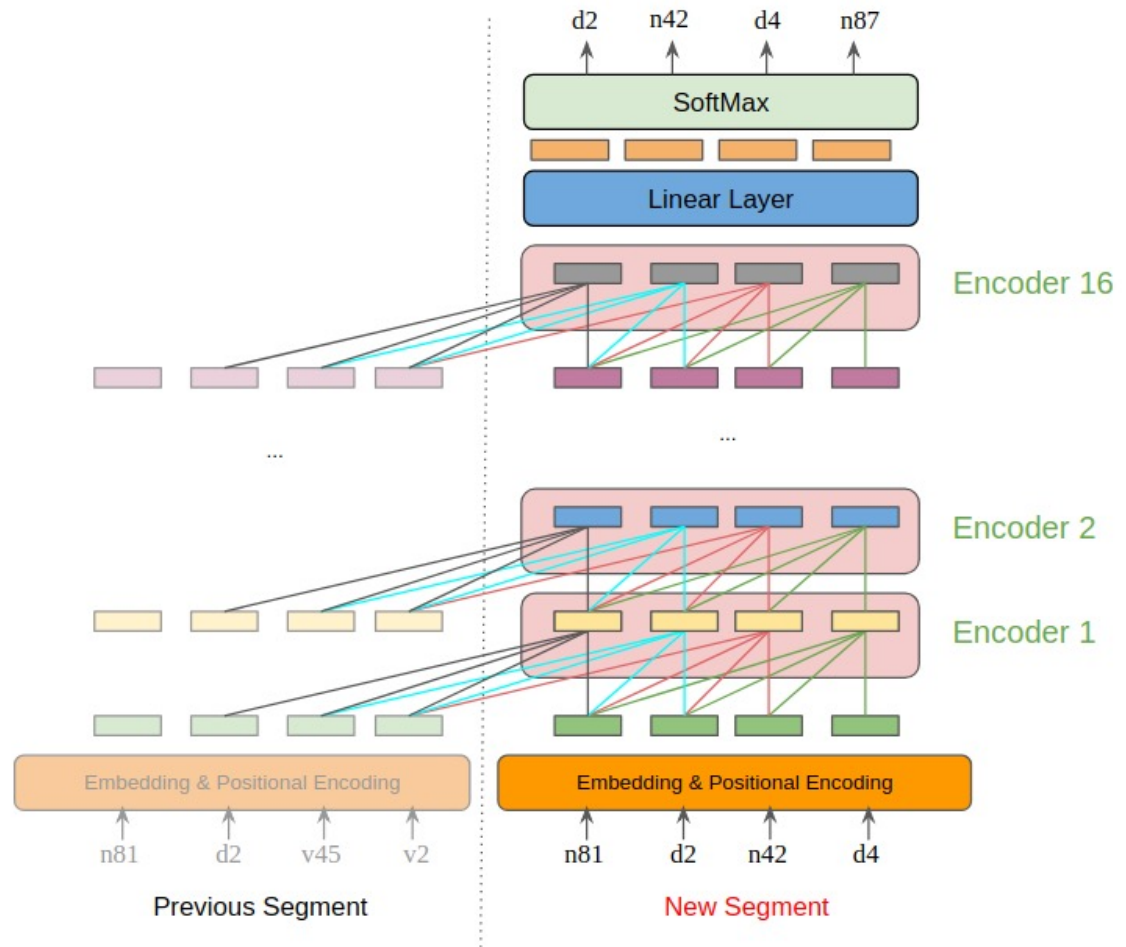
- Longer passage!

## Notes:

- Specialized

## Structure:

- Attention



# Harmonization

## Input:

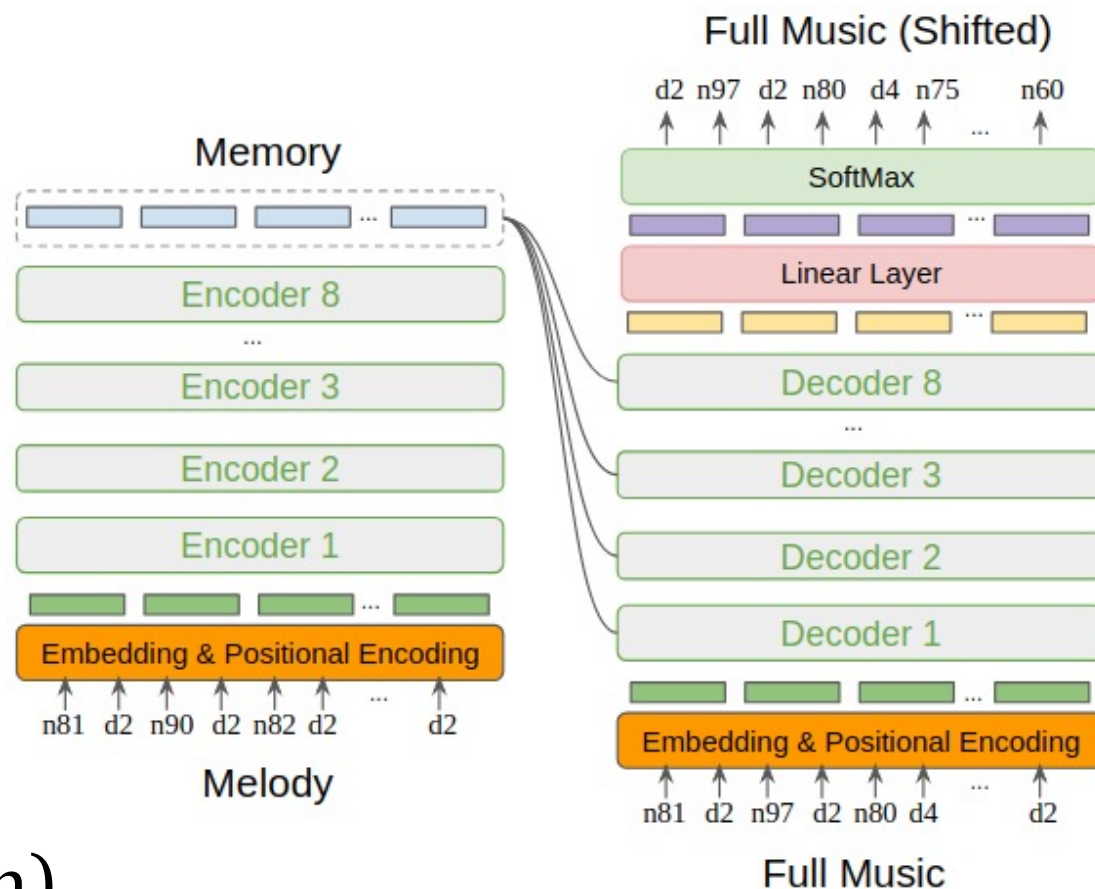
- Melody

## Output:

- Harmonization

## Structure:

- Transformer
- Encoder-decoder
- (cf. machine translation)



# Bridge

## Input:

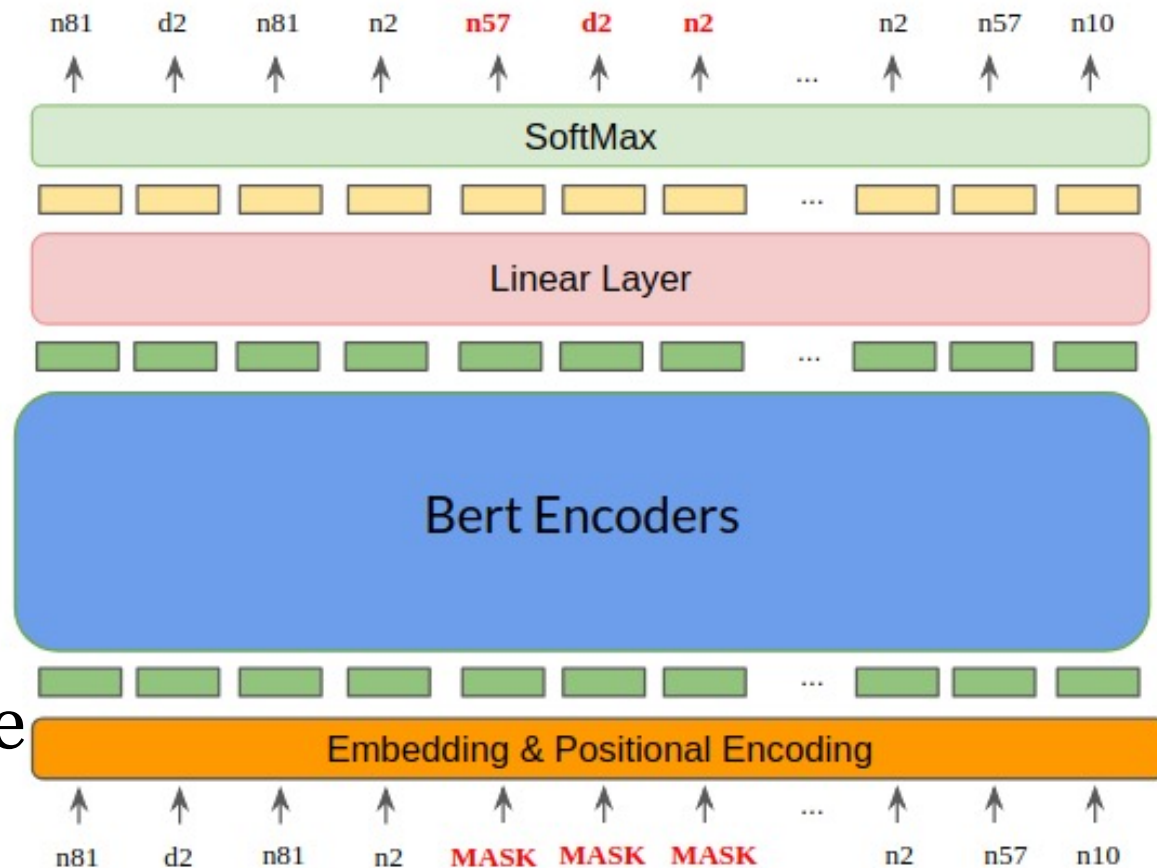
- Two passages

## Output:

- Connection between

## Structure:

- Attention encoder
- Mask 'missing' passage



# Orchestration

## Input:

- Single lines

## Output:

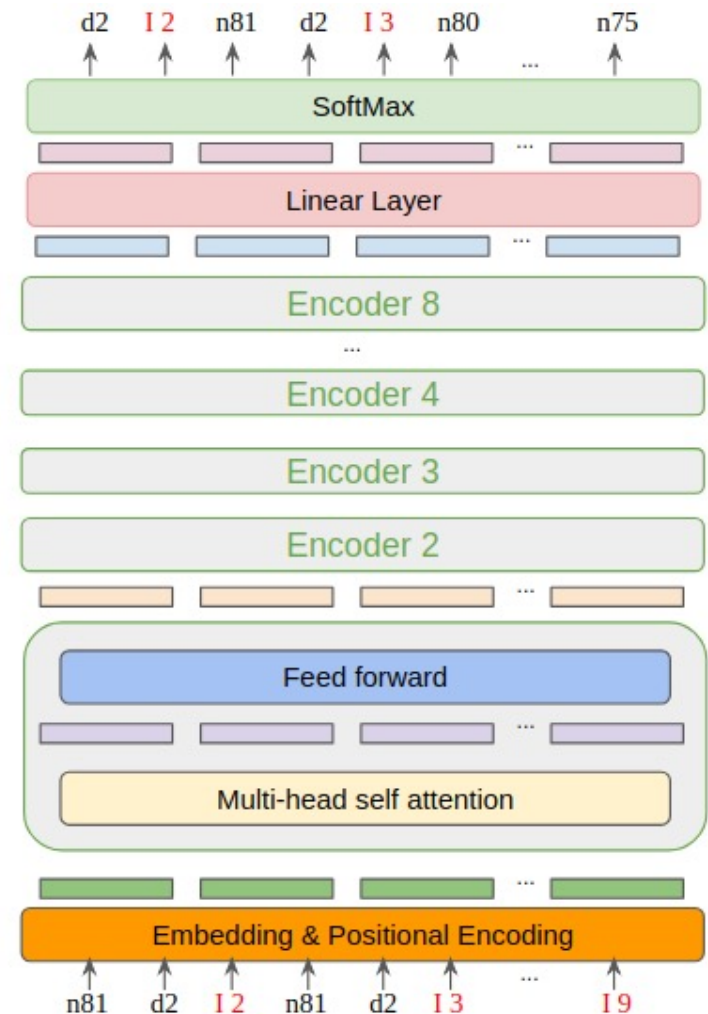
- Full orchestra

## Notes:

- Temporal enforcement

## Structure:

- Stacked transformer encoders





# Parting words

# Parting words

Lots of roles for humans!

What kind of interaction do we want

- ... even with unlimited data / infrastructure
- ... even for free composition?

What do we learn along the way

- About music?
- About creativity?
- About collaboration?

# Thank you!