

A NOVEL DATASET AND DEEP LEARNING BENCHMARK FOR CLASSICAL MUSIC FORM RECOGNITION AND ANALYSIS

SUPPLEMENTAL DATA AND APPENDICES

A. ADDITIONAL INFORMATION RELATED TO DATASET AND EXPERIMENTAL SETUP

A.1 Phrase Label Set

The Phrase Analyzer is constrained to a smaller set of possible labels than what appears in the dataset. More complex labels such as those used for Ritornello and Sonata forms (as well as varied repetition labels which would typically attach a prime or superscript) are reduced to the combination of the following sets (see project code [1]):

Large Parts = { A, B, C, D, Theme, Variation, CODA, End, Silence }

Phrases = { a, b, c, d, e, f, transition, codetta, section (abbr. "sec") }

Theme Variations = { characteristic, figural, melodic, ornamental, simplifying }

With a larger dataset, the Phrase Analyzer could be modified to predict labels more specific to the predicted form, such as a more in-depth analysis of Theme and Variation pieces and labels commonly used for Sonatas (Exposition, Primary Theme, Secondary Theme, Development, etc.) and fugues, alongside numerous derived forms (Sonatina, Concerto, etc.), but we found these to be viable enough for basic analysis while also preventing overfitting.

A.2 Phrase Analyzer Rubric

This appendix contains the "rubric" grading metric for the phrase analyzer label evaluation. Extraneous phrase labels are disregarded so as to not penalize due to the peak-picking algorithm output. As such, timestamps must ideally be paired to $< \pm 10$ seconds. Hence, the number of peak-picked timestamps must match the ground truth; if the ground truth has a greater number of timestamps, the most distant pairs are removed to create even pairs.

Each timestamp/label pair is assigned a score based on similarity to the ground truth using the following rubric:

- 1.00: Perfect
- 0.88: Subjectively correct (arguably true, such as the correct label occurring within ± 1 timestamp or being a valid **differentiated** part or phrase label)
- 0.75: Correct number of labels and/or half correct
- 0.66: Differentiated part but incorrect label
- 0.50: Correct part or time only

Then, the score s for each piece of music can be calculated as

$$s = \frac{1}{n} \sum_{i=1}^n grade(t_i) \quad (1)$$

\forall predicted phrase timestamp/label pairs $t \in T$. Hence, we can compute the overall performance accuracy of the model using the mean of all scores:

$$acc = \frac{1}{m} \sum_{j=1}^m s_j \quad (2)$$

$\forall s \in S$, where S is the set of all scores \forall pieces of music in the validation set.

B. ADDITIONAL EXPERIMENTAL RESULTS:

B.1 Phrase Analyzer Evaluation

Figure 1 displays the evaluation of the methods compared for the Phrase Analyzer, assessed using the grading rubric. For additional details regarding the preliminary models and experiments, see [2].

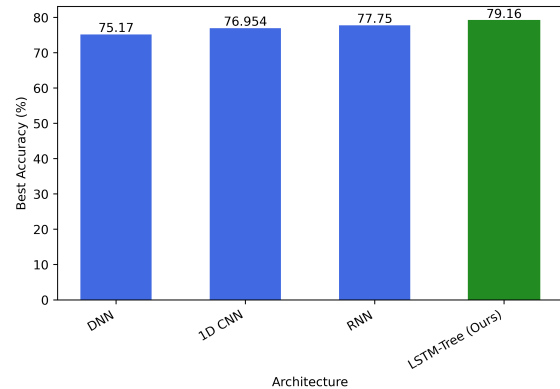


Figure 1. Phrase Analyzer: Comparison with related methods

B.2 Form Analyzer Parameters:

We choose the parameters to run our Form Architecture model on by doing a grid search. Figure 2 displays the results of a grid search for the optimal hyperparameters of the TreeGrad model for the Form Analyzer. The parallel coordinate plot displays the *accuracy* corresponding to the tuple of the three primary TreeGrad hyperparameters: *num_estimators*, *num_leaves*, and *learning_rate*. Each hyperparameter is represented by its own *y*-axis which also displays its range. For example, our selected hyperparameters, $\{num_estimators: 100, num_leaves: 31, learning_rate: 0.1\}$ yields the highest accuracy of 0.84 (along with 3 other top combinations).



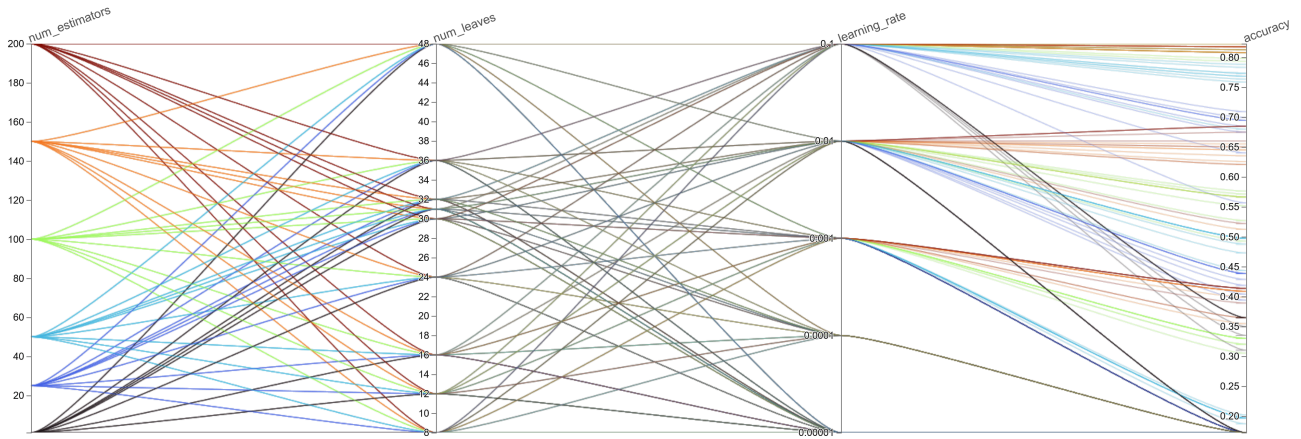


Figure 2. Accuracy of TreeGrad by Hyperparameters

C. SMFSA DATASET: DETAILS

This section contains the balance of classes in the dataset (see Figure 3) and an alphabetical listing of each piece of music used as training data for the model architecture grouped by their respective musical form.

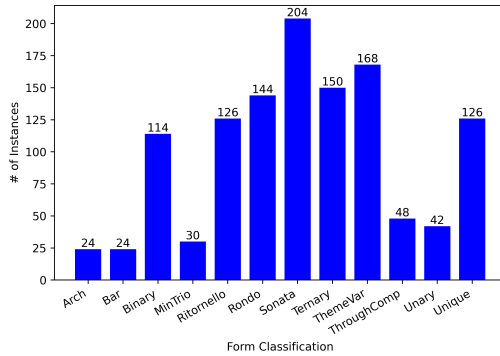


Figure 3. SMFSA Dataset Class Balance

Arch:

Bach, Johann Sebastian:
Well-Tempered Clavier, Vol. 1, Fugue No. 16 in G Minor
Barber, Samuel:
String Quartet Op. 11 – Mvt. 2 (“Adagio for Strings”)
Brahms, Johannes:
Rhapsody in E Flat Major, Op. 119, No. 4
Chopin, Frédéric:
Waltz, Op. 34, No. 1

Bar:

Bach, Johann Sebastian:
Jesu, Meine Freude, BWV 227 – Mvt. 1
Jesu, Meine Freude, BWV 227 – Mvt. 5
Jesu, Meine Freude, BWV 227 – Mvt. 9
Wachet auf, ruft uns die Stimme, BWV 140 – Mvt. 7

Binary:

Bach, Johann Sebastian:
Minuet in G Major, BWV Anh. 114
Partita No. 1 in B Minor, BWV 1002 – Mvt. 5
Suite in A Minor, BWV 818 – Mvt. 2
Well-Tempered Clavier, Vol. 1, Prelude No. 23

Well-Tempered Clavier, Vol. 1, Prelude No. 24
Chopin, Frédéric:
Prelude, Op. 28, No. 7
Handel, George Frideric:
Passepied in A Major, HWV 560
Recorder Sonata in A Minor, Op. 1, No. 4 – Mvt. 2
Haydn, Franz Joseph:
Piano Sonata No. 50, Hob.XVI:37 - Mvt. 2
Quartet, Op. 76, No. 5 – Mvt. 3
Symphony No. 101 (“Clock”) – Mvt. 3 (“Minuet”)
Mozart, Wolfgang Amadeus:
Magic Flute, No. 10
Magic Flute, No. 11
Magic Flute, No. 17
Scarlatti, Domenico:
Sonata, K. 158
Sonata, K. 159
Sonata in A Major, K. 322
Schubert, Franz:
Piano Sonata in E Major, D. 157 – Mvt. 2
Tchaikovsky, Pyotr Ilyich:
Nocturne, Op. 19, No. 4

Minuet & Trio:

Bach, Johann Sebastian:
French Suite No. 3 (“Menuet and Trio”) – Mvt. 5 & 6
Beethoven, Ludwig van:
Minuet in G, WoO 10, No. 2
Brahms, Johannes:
Cello Sonata No. 1, Op. 38 – Mvt. 2
Mozart, Wolfgang Amadeus:
Minuet and Trio in G, No. 1, K. 1
String Quartet No. 14, K. 387 – Mvt. 2

Ritornello:

Bach, Johann Sebastian:
Art of Fugue, Contrapunctus No. 9
Invention No. 1
Invention No. 2
Invention No. 3
Invention No. 4
Invention No. 5
Invention No. 6
Invention No. 7
Invention No. 8
Invention No. 9

Invention No. 10
Invention No. 11
Invention No. 12
Invention No. 13
Invention No. 14
Invention No. 15
Well-Tempered Clavier, Vol. 2, Fugue No. 4
Well-Tempered Clavier, Vol. 2, Fugue No. 5
Well-Tempered Clavier, Vol. 2, Fugue No. 6
Well-Tempered Clavier, Vol. 2, Fugue No. 14
Well-Tempered Clavier, Vol. 2, Fugue No. 20

Rondo:

Bach, Johann Sebastian:

Violin Concerto in E Major, BWV 1042 – Mvt. 3

Beethoven, Ludwig van:

Rage Over a Lost Penny, Op. 129

Sonata No. 2 in A Major, Op. 2, No. 2 – Mvt. 4

Sonata No. 3 in C Major, Op. 2, No. 3 – Mvt. 4

Sonata No. 8, Op. 13 ("Pathétique") – Mvt. 2

Sonata No. 8, Op. 13 ("Pathétique") – Mvt. 3

Violin Sonata No. 4, Op. 23 – Mvt. 3

Brahms, Johannes:

Ein Deutesches Requiem – Mvt. 4

Quartet for Piano and Strings, Op. 25 – Mvt. 4

Chopin, Frédéric:

Piano Concerto No. 1 in E Minor, Op. 11 – Mvt. 3

Rondo in C Minor, Op. 1

Dvořák, Antonín:

Cello Concerto in B Minor, Op. 104, B. 191 – Mvt. 3

Rondo for Cello and Orchestra in G Minor, Op. 94

Haydn, Franz Joseph:

Piano Sonata No. 50 in D Major, Hob.XVI:37 – Mvt. 3

Symphony No. 101 ("Clock") – Mvt. 4

Trio No. 39 in G Major, Hob.XV:25 – Mvt. 3

Mahler, Gustav:

Symphony No. 5 – Mvt. 5

Mozart, Wolfgang Amadeus:

Piano Sonata K. 331 – Mvt. 3

Piano Sonata in C Major, K. 467 – Mvt. 3

Sonata No. 3, K. 281 – Mvt. 3

Sonata No. 8, K. 310 – Mvt. 3

Sonata No. 14, K. 457 – Mvt. 3

Sonata No. 15, K. 494 (Rondo)

Stravinsky, Igor:

Firebird Suite – Mvt. 9 ("Rondeau des Princesses")

Sonata:

Beethoven, Ludwig van:

Leonora Overture No. 2, Op. 72

Quartet No. 14, Op. 131 – Mvt. 2

Quartet No. 15, Op. 132 – Mvt. 1

Quartet No. 16, Op. 135 – Mvt. 4

Sonata No. 5, Op. 10, No. 1 – Mvt. 2

Sonata No. 8, Op. 13 ("Pathétique") – Mvt. 1

Sonata No. 14 ("Moonlight"), Op. 27, No. 2 – Mvt. 1

Sonata No. 21, Op. 53 – Mvt. 1

Sonata No. 29, Op. 106 – Mvt. 1

Sonata No. 30, Op. 109 – Mvt. 2

Symphony No. 9 – Mvt. 1

Violin Sonata No. 1, Op. 12, No. 1 – Mvt. 1

Brahms, Johannes:

Cello Sonata No. 1, Op. 38 – Mvt. 3

Clarinet Sonata, Op. 120, No. 2 – Mvt. 1

Symphony No. 1 – Mvt. 4

Symphony No. 3 – Mvt. 4

Tragic Overture, Op. 81

Haydn, Franz Joseph:

Quartet, Op. 77, No. 1 – Mvt. 1

Sonata No. 48 in C Major, Hob.XVI:35 – Mvt. 1

Symphony No. 94 ("Surprise") – Mvt. 1

Symphony No. 100 – Mvt. 1

Symphony No. 102 – Mvt. 1

Symphony No. 103 ("Drumroll") – Mvt. 1

Symphony No. 104 – Mvt. 4

Mendelssohn, Felix:

Symphony No. 4 ("Italian") – Mvt. 1

Symphony No. 4 ("Italian") – Mvt. 4

Mozart, Wolfgang Amadeus:

Overture (from The Magic Flute)

Piano Sonata K. 545 – Mvt. 1

Piano Sonata No. 8, K. 310 – Mvt. 1

Sonata in C Major K. 279 – Mvt. 1

Sonata in G Major K. 283 – Mvt. 1

Sonata K. 333 – Mvt. 3

Symphony No. 36 ("Linz"), K. 425 – Mvt. 1

Symphony No. 39, K. 543 – Mvt. 1

Ternary:

Bach, Johann Sebastian:

Cantata No. 78 (Jesu der du meine Seele) – Mvt. 2

Beethoven, Ludwig van:

Quartet, Op. 135 – Mvt. 3

Sonata No. 4, Op. 7 – Mvt. 2

Sonata No. 12, Op. 26 – Mvt. 3

Sonata No. 15, Op. 28 – Mvt. 3

Symphony No. 3 (Eroica) – Mvt. 2

Brahms, Johannes:

Ein Deutesches Requiem – Mvt. 1

Ein Deutesches Requiem – Mvt. 2

Ein Deutesches Requiem – Mvt. 3

Ein Deutesches Requiem – Mvt. 5

Ein Deutesches Requiem – Mvt. 7

Intermezzo, Op. 118, No. 2

Intermezzo, Op. 119, No. 2

Chopin, Frédéric:

Mazurka, Op. 7, No. 1 (No. 5)

Mazurka, Op. 63, No. 3

Polonaise in A Major, Op. 40, No. 1

Prelude, Op. 28, No. 12

Prelude, Op. 28, No. 13

Waltz in A Minor, Op. 34, No. 2

Fauré, Gabriel:

Requiem, Op. 48 – Mvt. 2 ("Offertory")

Handel, George Frideric:

The Trumpet Shall Sound (from Messiah)

Waft Her, Angels, to the Skies (from Jephtha)

Lang, Josephine:

Two Lieder, Op. 28, No. 1 – Traumbild

Mendelssohn, Felix:

Song without Words, Op. 53, No. 5

Schumann, Robert:

Nachtstücke, Op. 23, No. 3

Theme and Variation:

Bach, Johann Sebastian:

Chaconne from Partita No. 2 in D Minor, BWV 1004

Crucifixus from Mass in B Minor, BWV 232

Magnificat in D Major, No. 5, BWV 243

Passacaglia in C Minor for organ, BWV 582

Violin Concerto in E Major, BWV 1042 – Mvt. 2
 Beethoven, Ludwig van:
 Diabelli Variations, Op. 120
 Piano Sonata No. 12 in Ab Major, Op. 26 – Mvt. 1
 Quartet No. 15 in A Minor, Op. 132 – Mvt. 3
 Quartet No. 16, Op. 135 – Mvt. 2 (mm. 143-190)
 Sonata No. 10 in G Major, Op. 14, No. 2 – Mvt. 2
 Symphony No. 5 – Mvt. 2
 Symphony No. 7 – Mvt. 2
 Symphony No. 9 – Mvt. 3
 Thirty-Two Variations for piano in C Minor, WoO 80
 Brahms, Johannes:
 Symphony No. 4 – Mvt. 4
 Variations on a Theme by Haydn
 Debussy, Claude:
 String Quartet in G Minor, Op. 10 – Mvt. 2
 Dvořák, Antonín:
 Tema con Variazioni, Op. 36
 Handel, George Frideric:
 Suite No. 7 in G Minor – Mvt. 6 (“Passacaille”)
 Haydn, Franz Joseph:
 Piano Variations in F Minor, Hob.XVII:6
 Piano Trio in G Major, Hob.XV:25 – Mvt. 1
 Mozart, Wolfgang Amadeus:
 Concert Rondo, K. 382
 Piano Concerto in C Minor, K. 491 – Mvt. 3
 Theme with Variations from Sonata, K. 284
 Twelve Variations “Ah, vous dirai-je, maman”, K. 265
 Purcell, Henry:
 When I Am Laid in Earth (from Dido and Aeneas)
 Schubert, Franz:
 Der Doppelgänger (Schwanengesang), D. 957
 Vivaldi, Antonio:
 Concerto in A Minor (2 Violins), Op. 3, No. 8 – Mvt. 1

Through-Composed:

Bach, Johann Sebastian:
 Chromatische Fantasie und Fuge, BWV 903
 Brahms, Johannes:
 Ein Deutsches Requiem – Mvt. 6
 Fauré, Gabriel:
 Requiem, Op. 48 – Mvt. 1 (“Introit and Kyrie”)
 Requiem, Op. 48 – Mvt. 3 (“Sanctus”)
 Requiem, Op. 48 – Mvt. 5 (“Agnus Dei”)
 Requiem, Op. 48 – Mvt. 6 (“In Paradisum”)
 Schubert, Franz:
 Die Schöne Müllerin, Op. 25, No. 3 (“Halt!”), D. 795
 Erlkönig

Unary/Strophic:

Bach, Johann Sebastian:
 Well-Tempered Clavier, Vol. 1, Prelude No. 2
 Chopin, Frédéric:
 Nocturne in D Flat Major, Op. 27, No. 2
 Prelude, Op. 28, No. 1
 Prelude, Op. 28, No. 2
 Prelude, Op. 28, No. 4
 Prelude, Op. 28, No. 9
 Prelude, Op. 28, No. 23

Unique:

Bach, Johann Sebastian:
 Well-Tempered Clavier, Vol. 1, Prelude No. 9
 Well-Tempered Clavier, Vol. 1, Prelude No. 21
 Berlioz, Hector:

Symphonie Fantastique – Mvt. 1
 Symphonie Fantastique – Mvt. 3
 Symphonie Fantastique – Mvt. 4
 Symphonie Fantastique – Mvt. 5
 Brahms, Johannes:
 Intermezzo, Op. 119, No. 3
 Alto Rhapsody, Op. 53
 Chopin, Frédéric:
 Ballade in G Minor, Op. 23
 Prelude, Op. 28, No. 24
 Debussy, Claude:
 L’après-midi d’un faune
 Prelude No. 10 (“The Engulfed Cathedral”)
 Fauré, Gabriel:
 Élégie, Op. 24
 Mahler, Gustav:
 Symphony No. 4 – Mvt. 1
 Mozart, Wolfgang Amadeus:
 Fantasia, K. 475
 Magic Flute, No. 3
 Schubert, Franz:
 Winterreise, No. 5
 Winterreise, No. 11
 Winterreise, No. 16
 Strauss, Richard:
 Don Juan, Op. 20
 Wagner, Richard:
 Prelude to Tristan und Isolde

D. DATASET FEATURES

This appendix contains the list of extracted signal features. The tabulated dataset contains the mean and variance of the following 2D features:

- Mel Spectrogram SSM
- MFCC Spectrogram SSLMs (Euclidian and Cosine distances),
- Chromagram SSLMs (Euclidian and Cosine distances)
- STFT Chromagram
- Constant-Q Transform Chromagram
- Energy Normalized Chromagram (CENS)
- Mel Spectrogram
- MFCC Spectrogram
- Spectral Bandwidth
- Spectral Centroid
- Spectral Contrast
- Spectral Flatness
- Spectral Rolloff
- Polynomial Features
- Tonal Centroid Features (Tonnetz)
- Zero Crossing Rate
- Tempogram
- Fourier Tempogram

E. REFERENCES

- [1] D. Szelogowski, “Form-nn,” Apr 2022. [Online]. Available: <https://github.com/danielathome19/Form-NN>
- [2] —, “Deep learning for musical form: Recognition and analysis,” Master’s thesis, Apr 2022. [Online]. Available: <https://doi.org/10.13140/RG.2.2.33554.12481>