

Music Arrangement via Quantum Annealing

Lucas Kirby

30 January 2025

Department of Physics, Durham University

Overview

Motivations

Theory

Music arrangement

Quantum annealing

Methods

Results

Conclusions

Motivations

- Small lit review¹
- Quantum computer music
- My own novel adaption of the method
- THIS IS MY OWN IDEA

¹Emilios Cambouropoulos. **‘The Local Boundary Detection Model (LBDM) and its Application in the Study of Expressive Timing’**. In: *International Computer Music Association* (2011). ISSN: 2223-3881.

Theory

Music arrangement

- Adaptation of previously composed pieces for practical or artistic reasons
- Traditionally complex and time-consuming
- This study focuses on **reduction**

The image displays the beginning of the first movement of Beethoven's String Quartet No. 10, Op. 132. The score is written for four parts: Violin I, Violin II, Viola, and Violoncello. The tempo is marked 'Poco Adagio' and the key signature is B-flat major (two flats). The time signature is 4/4. The score shows the first few measures of the piece, with various musical notations including notes, rests, and dynamic markings such as 'cresc.' (crescendo) and 'p' (piano). The Violoncello part includes the instruction 'sotto voce' (softly).

Beethoven's String Quartet No. 10

Adiabatic quantum computing (AQC)

- *Materials* — heating and cooling a material to alter its physical properties
- *Quantum* — changing a quantum system from one Hamiltonian to another
- Done slowly and adiabatically to remain in the ground state

$$H(t) = \left(1 - \frac{t}{T}\right) H_0 + \frac{t}{T} H_p$$

Andrew Lucas. **‘Ising formulations of many NP problems’**.

English. In: *Frontiers in Physics* 2 (Feb. 2014). Publisher: Frontiers.

ISSN: 2296-424X. DOI: 10.3389/fphy.2014.00005. (Visited on 14/10/2024)

Ising model

$$H_p(\sigma^z) = \sum_{i < j}^N J_{ij} \sigma_i^z \sigma_j^z + \sum_{i=1}^N h_i \sigma_i^z$$

Initial state

$$H_0 = h_0 \sum_{i=1}^N \sigma_i^x$$

Lucas, 'Ising formulations of many NP problems'

Quadratic Unconstrained Binary Optimisation

$$f(x) = \sum_{i < j}^N Q_{i,j} x_i x_j + \sum_i^N Q_{i,i} x_i$$

- Encodes problem solution into Hamiltonian's ground state
- Sent to the QPU for optimisation

How to combine them?

Methods

Problem formulation

1. Split score into musical phrases
2. Arrange phrases into a graph
3. Solve graph problem using QPU
4. Construct arrangement from solution

1. Split score

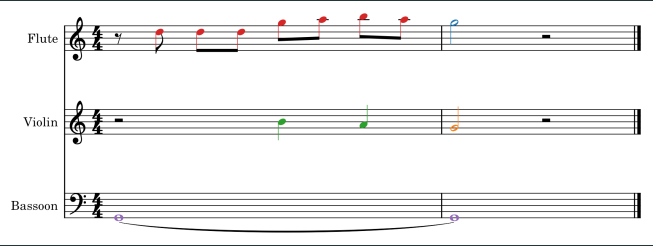
Local boundary detection model (LBDM)

$$S_i = x_i \times (r_{i-1,i} + r_{i,i+1})$$

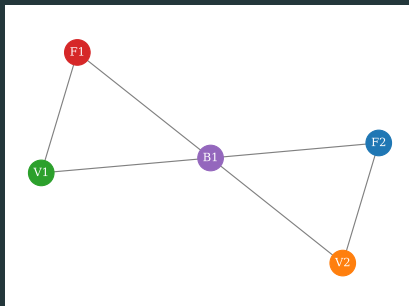
Emilios Cambouropoulos. **‘The Local Boundary Detection Model (LBDM) and its Application in the Study of Expressive Timing’**. In: *International Computer Music Association* (2011). ISSN: 2223-3881

A musical score for three instruments: Flute, Violin, and Bassoon, in 4/4 time. The Flute part (treble clef) has a sequence of notes: a quarter rest, an eighth note, a quarter note, a half note, a quarter note, and a half note, all in red. The Violin part (treble clef) has a half rest, followed by two quarter notes and a half note, all in green. The Bassoon part (bass clef) has a half rest, followed by a half note, and then a half rest. A purple line with circles at both ends spans the duration of the first half of the piece, from the first measure to the second measure.

2. Create graph



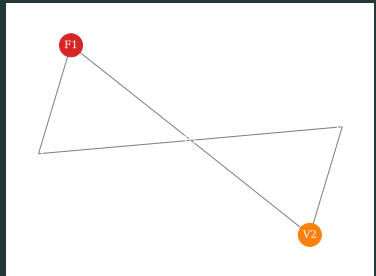
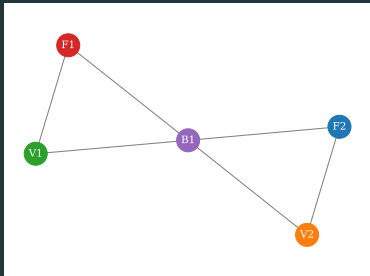
A musical score for three instruments: Flute, Violin, and Bassoon, in 4/4 time. The Flute part (top staff) begins with a quarter rest, followed by a sequence of eighth notes: G4, A4, B4, C5, D5, E5, and F5. The Violin part (middle staff) has a whole rest for the first two measures, then plays a half note G4 in the third measure and a half note A4 in the fourth measure. The Bassoon part (bottom staff) plays a whole note G2 in the first measure and a whole note A2 in the second measure, with a slur connecting the two notes. The score ends with a double bar line.



3. Solve graph

Maximal independent set (MIS)

Largest subset of nodes such that no nodes within the subset are connected by an edge



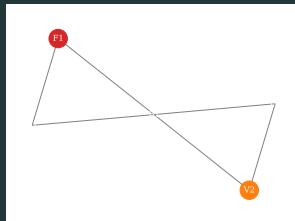
4. Construct arrangement

Flute

Violin

Bassoon

The score shows three staves in 4/4 time. The Flute staff has a melody starting with a quarter rest, followed by eighth notes G4, A4, B4, C5, D5, E5, and a quarter rest. The Violin staff has a melody starting with a quarter rest, followed by quarter notes G4, A4, and B4, and a quarter rest. The Bassoon staff has a melody starting with a quarter rest, followed by a half note G3, and a quarter rest. The notes are color-coded: red for Flute, green for Violin, and purple for Bassoon.



The constructed arrangement shows the Flute part in 4/4 time, starting with a quarter rest, followed by eighth notes G4, A4, B4, C5, D5, E5, and a quarter rest. The notes are color-coded: red for Flute.

Results

Excerpt

Poco Adagio

Violin I
sotto voce
Poco Adagio

Violin II
sotto voce
Poco Adagio

Viola
sotto voce
Poco Adagio

Violoncello
sotto voce
Poco Adagio

6

cresc.

cresc.

cresc.

10

espress.

p

f

espress.

p

f

cresc.

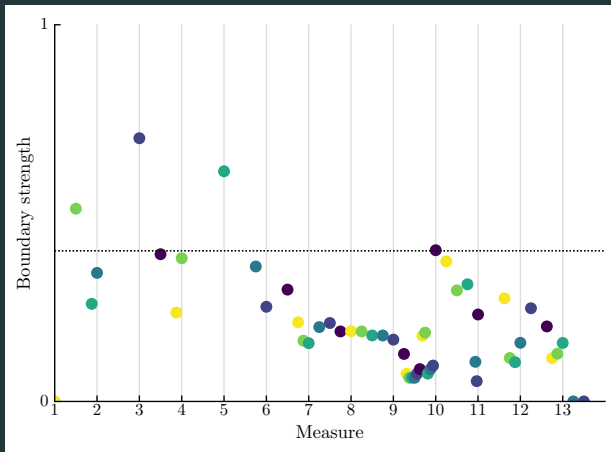
p

f

p

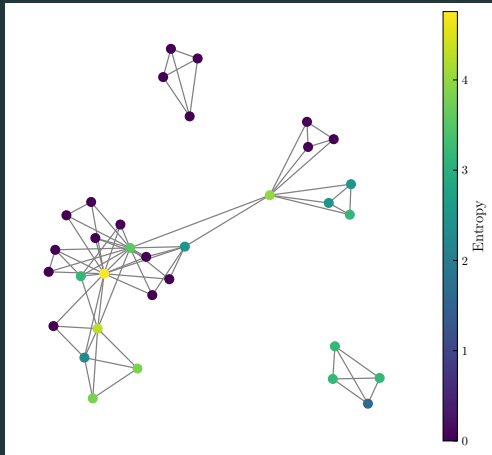
String Quartet No. 10 by Ludwig van Beethoven

Phrase detection



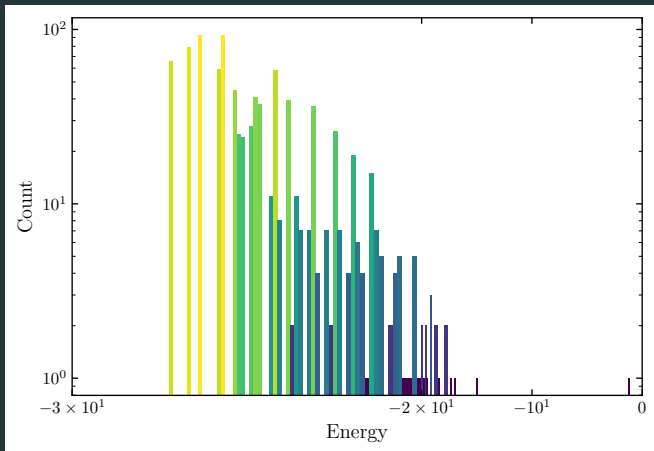
Boundary strengths for the Violin I part

Problem graph



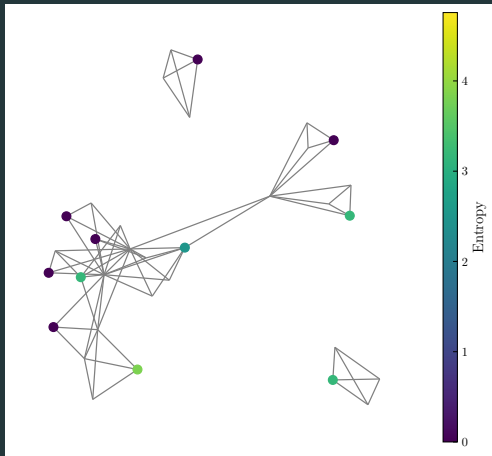
Problem graph with 33 nodes and 70 edges

Solutions



Returned solutions for 1000 reads

Example solution



Solution graph returning a subset of 11 nodes

Final arrangement

Poco Adagio
sotto voce

Violin I

Violin II

Viola

Violoncello

6

cresc.

cresc.

cresc.

10

espress.

p

f

cresc.

p

f

p

f

Selected phrases

Poco Adagio
sotto voce

7

espress.

cresc.

p

12

f

Final arrangement

Conclusions

Conclusions

- Successful in creating a valid single-part reduction
- Advantage over classical algorithms Jiun-Long Huang, Shih-Chuan Chiu and Man-Kwan Shan. **‘Towards an automatic music arrangement framework using score reduction’**. In: *ACM Trans. Multimedia Comput. Commun. Appl.* 8.1 (Feb. 2012), 8:1–8:23. ISSN: 1551-6857. DOI: 10.1145/2071396.2071404. (Visited on 05/12/2024)
- Removes skill barrier for music arrangement



Future work

- Increased problem size
- Parametric variation of LBDM
- Physical limitations of instruments
- Reduction to more than one part
- Quality comparison of computer arrangements M. Pearce and Geraint A. Wiggins. **'Towards A Framework for the Evaluation of Machine Compositions'**. In: *Proceedings of the AISB'01 Symposium on Artificial Intelligence and Creativity in the Arts and Sciences*. 2001

Thank you!

Music Arrangement via Quantum Annealing

Lucas Kirby

30 January 2025

Department of Physics, Durham University

Boundary strength

$$S_i = x_i \times (r_{i-1,i} + r_{i,i+1})$$

$$r_{i,i+1} = \frac{|x_i - x_{i+1}|}{x_i + x_{i+1}}$$

Normalisation

$$S'_i = \frac{S_i - \min(S_i)}{\max(S_i) - \min(S_i)}$$

Weighting

$$S = \frac{1}{3} (S'_{\text{pitch}} + 2S'_{\text{IOI}})$$

Cambouropoulos, 'The Local Boundary Detection Model (LBDM) and its Application in the Study of Expressive Timing'

$$f(x) = A \sum_{ij \in E} x_i x_j - B \sum_i W_i x_i$$

Lucas, 'Ising formulations of many NP problems'

$A/B \geq 2 \max(W)$ to weight the constraint term more heavily than any objective term

Phrase entropy

Shannon entropy

$$H(X) := - \sum_i P(x_i) \log_2 P(x_i)$$

Probability distribution

$$P(x_i) = \frac{n_i}{N}$$

You Li et al. **‘Automatic Piano Reduction of Orchestral Music Based on Musical Entropy’**. In: *2019 53rd Annual Conference on Information Sciences and Systems (CISS)*. Mar. 2019, pp. 1–5. DOI:

10.1109/CISS.2019.8693036. URL:

<https://ieeexplore.ieee.org/document/8693036>

(visited on 27/12/2024)