

Music Arrangement via Quantum Annealing

Lucas Kirby

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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. 131. 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 three flats (B-flat major or D-flat minor). 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)

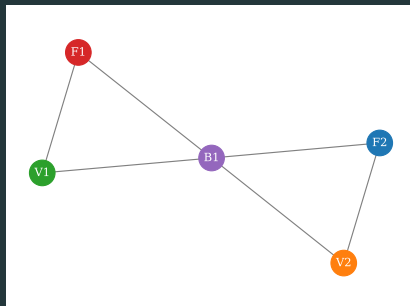
$$S_i = x_i \times (r_{i-1,i} + r_{i,i+1})$$

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 with red stems. The Violin part (treble clef) has a half rest, followed by two eighth notes and a quarter note, all with green stems. The Bassoon part (bass clef) has a half rest, followed by a half note, and a quarter note, all with purple stems. A curved line connects the two purple notes in the Bassoon part. The score ends with a double bar line.

2. Create graph

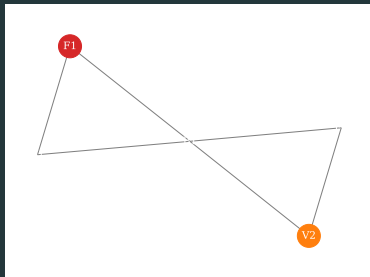
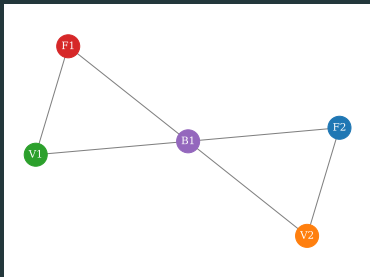
A musical score for three instruments: Flute, Violin, and Bassoon, in 4/4 time. The Flute part (top staff) begins with a quarter rest, followed by a quarter note G4, an eighth note A4, a quarter note B4, and a half note C5. The Violin part (middle staff) has a whole rest for the first two measures, then a quarter note D4 in the third measure, and a quarter note E4 in the fourth measure. The Bassoon part (bottom staff) has a whole rest for the first two measures, then a quarter note F3 in the third measure, and a quarter note G3 in the fourth measure. A purple line connects the Bassoon part to the Violin part, indicating a relationship between the two.



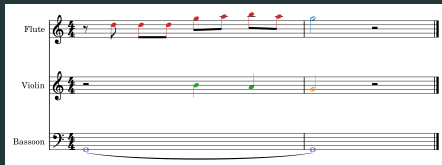
3. Solve graph

Maximal independent set (MIS)

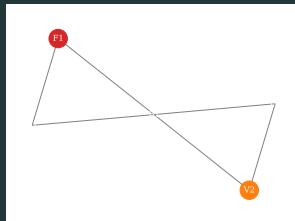
Largest subset of nodes such that no nodes within the subset are connected by an edge



4. Construct arrangement



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 (red), A4 (red), B4 (red), C5 (red), D5 (red), E5 (blue), and a final quarter rest. The Violin part (middle staff) begins with a quarter rest, followed by a sequence of quarter notes: G4 (green), A4 (green), B4 (orange), and a final quarter rest. The Bassoon part (bottom staff) begins with a half note G2 (purple) and a final quarter rest. A long horizontal line connects the two purple notes in the Bassoon part.



A single staff musical score in 4/4 time. It begins with a quarter rest, followed by a sequence of eighth notes: G4 (red), A4 (red), B4 (red), C5 (red), D5 (red), E5 (blue), and a final quarter rest. This staff represents the combined melody from the Flute and Violin parts of the original score.

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.

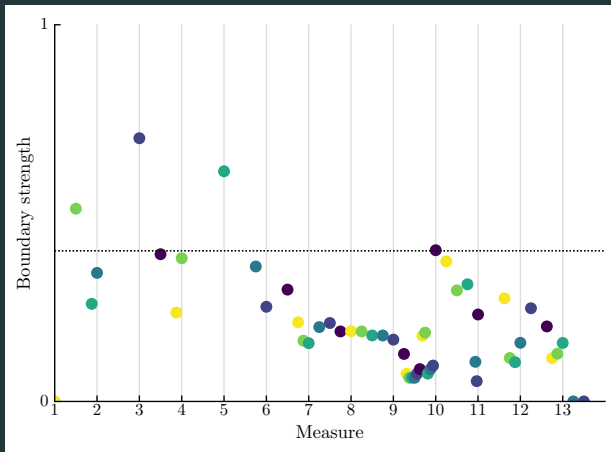
p

f

p

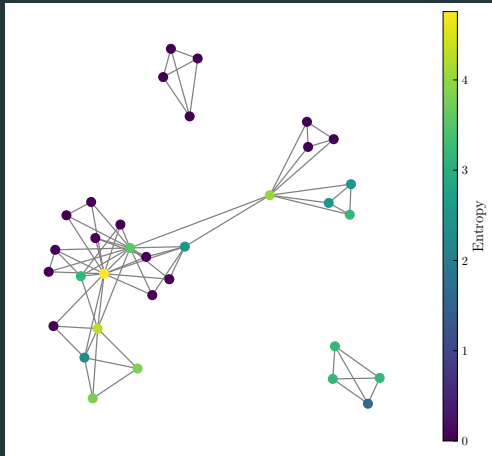
String Quartet No. 10 by Ludwig van Beethoven

Phrase detection



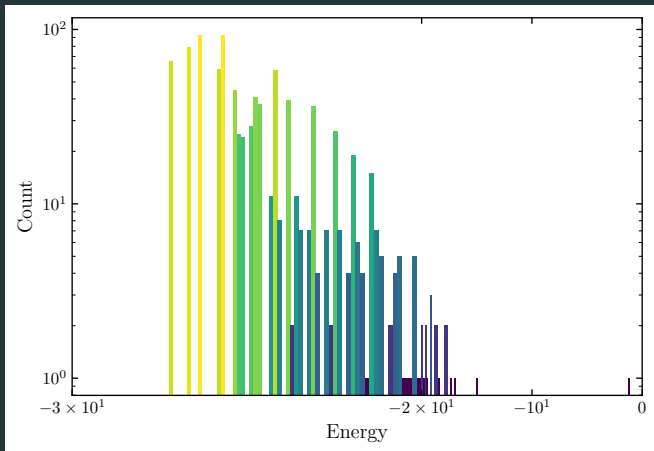
Boundary strengths for the Violin I part

Problem graph



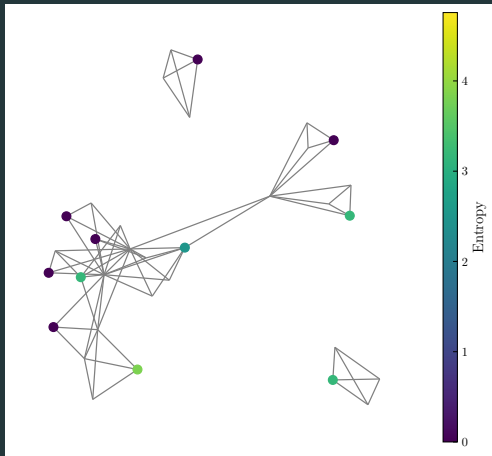
Problem graph with 33 nodes and 70 edges

Solutions



Returned solutions for 1000 reads

Example solution



Solution graph returning a subset of 11 nodes

Final arrangement

Poco Adagio

Violin I
sotto voce
Poco Adagio

Violin II
sotto voce
Poco Adagio

Viola
sotto voce
Poco Adagio

Violoncello
sotto voce

6

cresc.

cresc.

cresc.

10

espress.

p

f

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!

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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)