

# Music Arrangement via Quantum Annealing

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Lucas Kirby

17th January 2025

Durham University

2025-01-17

Music Arrangement via Quantum Annealing

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17th January 2025  
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## Theory

Music arrangement

Quantum annealing

## Methods

## Results

## Conclusions

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# Music Arrangement via Quantum Annealing

## └ Overview

1. Welcome to the talk!
2. As you can see, this slidedeck is a work in progress.

# Theory

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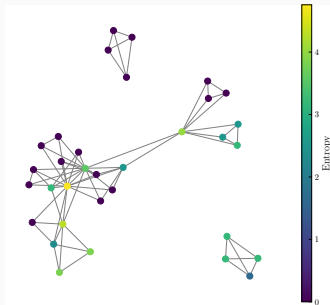
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Music Arrangement via Quantum Annealing  
└ Theory

Theory

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



Source: Wikimedia Commons

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## Music Arrangement via Quantum Annealing

- └ Theory
  - └ Music arrangement
    - └ Music arrangement

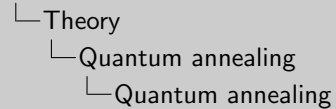
Music arrangement

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



- *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

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



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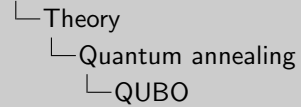
## Ising model

$$H(s) = - \sum_{i < j} J_{ij} s_i s_j - \sum_{i=1}^N h_i s_i$$

## QUBO

Quadratic Unconstrained Binary Optimisation

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



### Ising model

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How to combine them?

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└ Theory

└ Quantum annealing

How to combine them?

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# Methods



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

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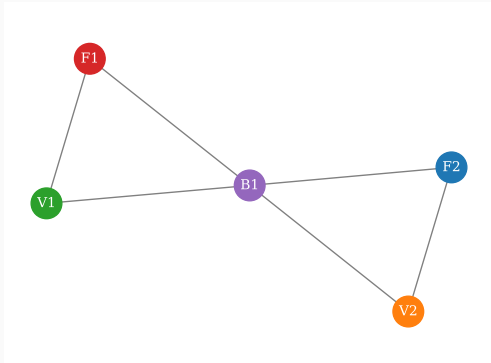
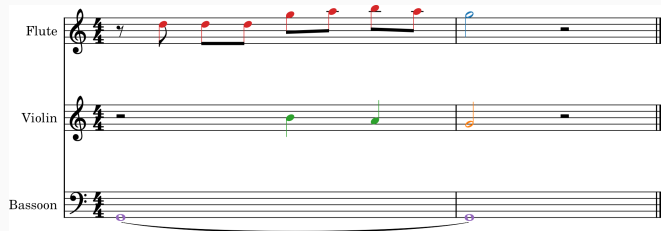
## Music Arrangement via Quantum Annealing

└─Methods

└─Problem formulation

- Problem formulation
1. Split parts into phrases
  2. Arrange phrases into a graph
  3. Solve graph problem using QPU
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# Toy example



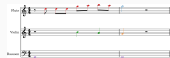
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## Music Arrangement via Quantum Annealing

└ Methods

└ Toy example

Toy example

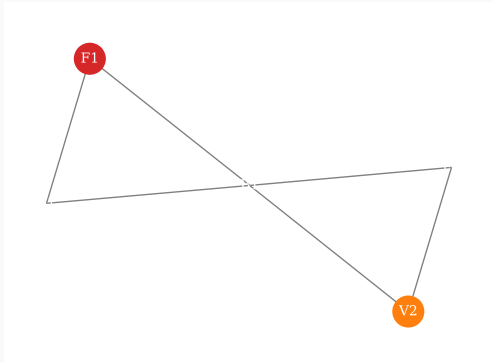
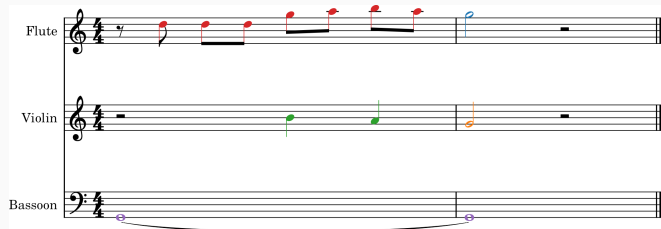


# Toy example

Flute

Violin

Bassoon



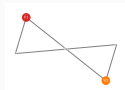
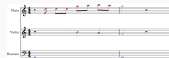
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## Music Arrangement via Quantum Annealing

└ Methods

└ Toy example

Toy example



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# Results



# Excerpt

Violin I

*Poco Adagio*

sotto voce

Violin II

*Poco Adagio*

sotto voce

Vinla

*Poco Adagio*

sotto voce

Violoncello

*Poco Adagio*

sotto voce

6

cresc.

10

*espress.*

*p*

*f*

*espress.*

*p*

*f*

cresc.

*p*

*f*

*p*

String Quartet No. 10 by Ludwig van Beethoven

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## Music Arrangement via Quantum Annealing

Results

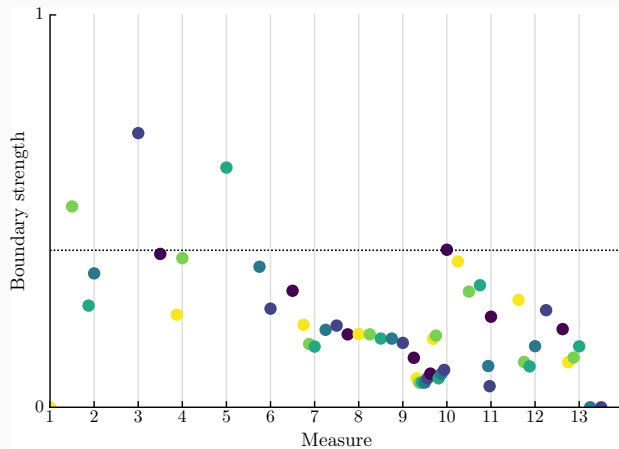
Excerpt

Excerpt

String Quartet No. 10 by Ludwig van Beethoven

# Phrase detection

## Local boundary detection model (LBDM)



Boundary strengths for the Violin I part

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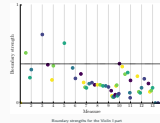
## Music Arrangement via Quantum Annealing

└ Results

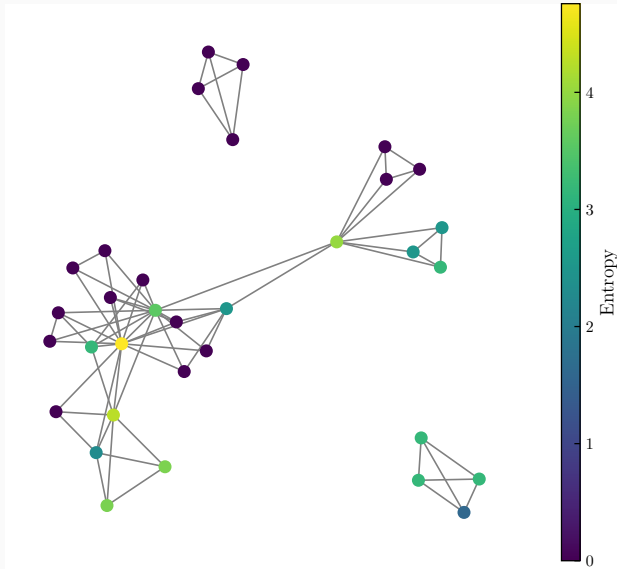
└ Phrase detection

Phrase detection

Local boundary detection model (LBDM)



# Problem graph

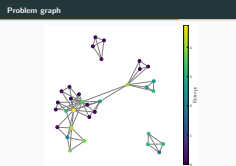


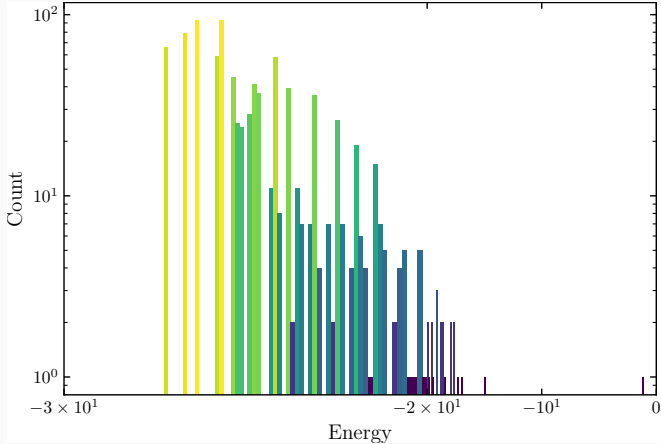
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## Music Arrangement via Quantum Annealing

└ Results

└ Problem graph





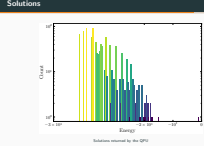
Solutions returned by the QPU

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Music Arrangement via Quantum Annealing

└ Results

└ Solutions



Lowest energy solution was -26.8 with a degeneracy of 34



$$\oiint_A \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$$

The *net electric flux* through any **closed** surface is proportional to the **enclosed charge**.

### Alert

This is an alert.

### Example

This is an example.

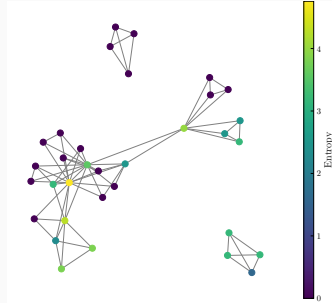
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**Alert**  
This is an alert.

**Example**  
This is an example.

- Volume rate of flow equal to divergence
- Summed over entire volume
- Equal to net flow across the boundary



Source: Wikimedia Commons

$$\iiint_V \nabla \cdot \mathbf{F} dV = \oiint_A \mathbf{F} \cdot d\mathbf{A}$$

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
## Music Arrangement via Quantum Annealing

└ Results

└ Apperance sync

Apperance sync

- Volume rate of flow equal to divergence
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Source: Wikimedia Commons

$$\iiint_V \nabla \cdot \mathbf{F} dV = \oiint_A \mathbf{F} \cdot d\mathbf{A}$$

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# Conclusions



$$\begin{aligned}\nabla \cdot \mathbf{E} &= \frac{\rho}{\varepsilon_0} \\ \nabla \cdot \mathbf{B} &= 0 \\ \nabla \times \mathbf{E} &= -\frac{\partial \mathbf{B}}{\partial t} \\ \nabla \times \mathbf{B} &= \frac{1}{c^2} \frac{\partial \mathbf{E}}{\partial t} + \mu_0 \mathbf{I}\end{aligned}$$

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