

# Music Arrangement via Quantum Annealing

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Lucas Kirby

18th January 2025

Durham University

2025-01-18

Music Arrangement via Quantum Annealing

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18th 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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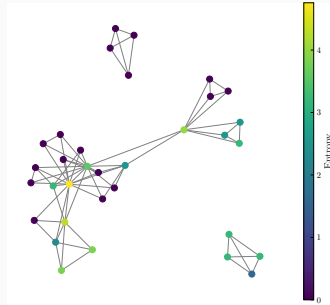
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Music Arrangement via Quantum Annealing  
└ Theory

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

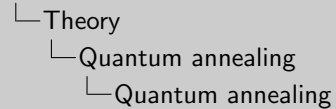
Music arrangement

- 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

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

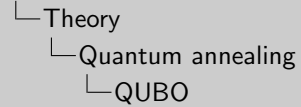
## QUBO

Quadratic Unconstrained Binary Optimisation

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

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## Music Arrangement via Quantum Annealing



QUBO

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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

# Problem formulation

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

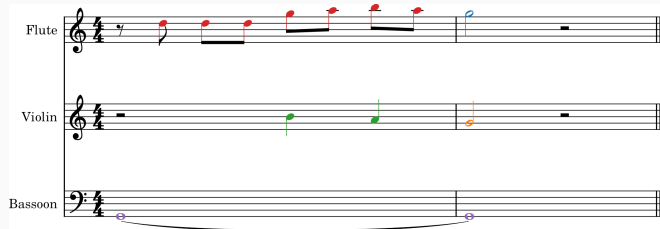
### └─Methods

### └─Problem formulation

# 1. Split parts

## Local boundary detection model (LBDM)

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



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## Music Arrangement via Quantum Annealing

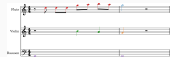
### Methods

#### 1. Split parts

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Local boundary detection model (LBDM)

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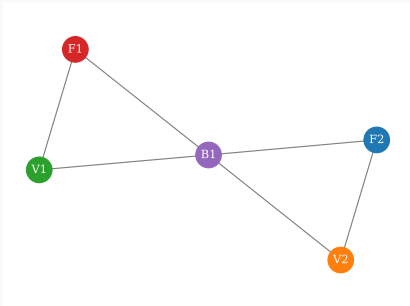
## 2. Create graph

Flute

Violin

Bassoon

The image shows a musical score for three instruments: Flute, Violin, and Bassoon. The Flute part is in the treble clef and has a sequence of red eighth notes. The Violin part is in the treble clef and has a sequence of green eighth notes. The Bassoon part is in the bass clef and has a single purple eighth note. A curved line connects the first and last notes of the Bassoon part.



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## Music Arrangement via Quantum Annealing

└ Methods

└ 2. Create graph

Each phrase becomes a node  
Edges between nodes if phrases overlap

2. Create graph

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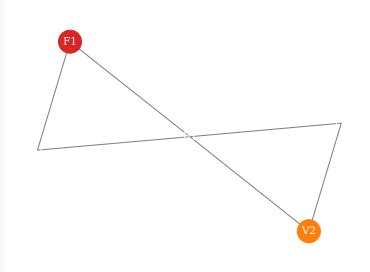
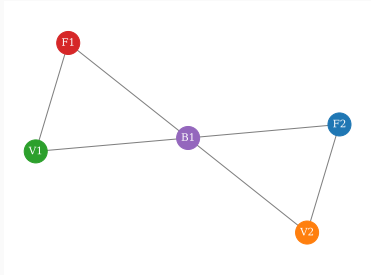


### 3. Solve graph

#### Maximal independent set (MIS)

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

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



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### Music Arrangement via Quantum Annealing

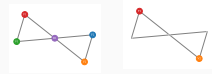
#### └ Methods

#### └ 3. Solve graph

3. Solve graph

**Maximal independent set (MIS)**  
Largest subset of nodes such that no nodes within the subset are connected by an edge.

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

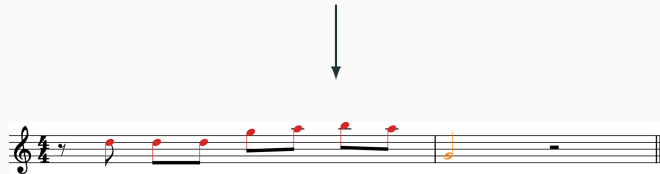
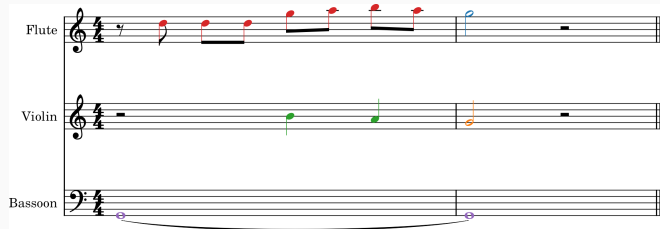


## 4. Construct arrangement

Flute

Violin

Bassoon



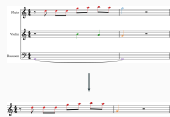
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## Music Arrangement via Quantum Annealing

└ Methods

└ 4. Construct arrangement

4. Construct arrangement



Take selected nodes and combine to create final arrangement

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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*

cresc.

*p*

*f*

*p*

*f*

String Quartet No. 10 by Ludwig van Beethoven

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## Music Arrangement via Quantum Annealing

Results

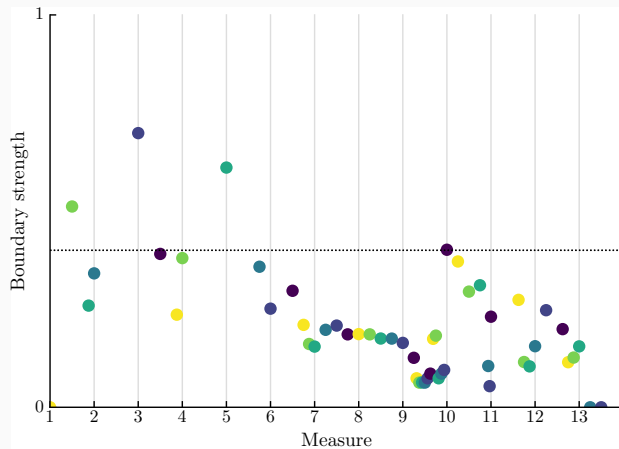
Excerpt

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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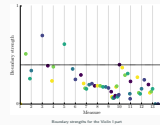
## Music Arrangement via Quantum Annealing

└ Results

└ Phrase detection

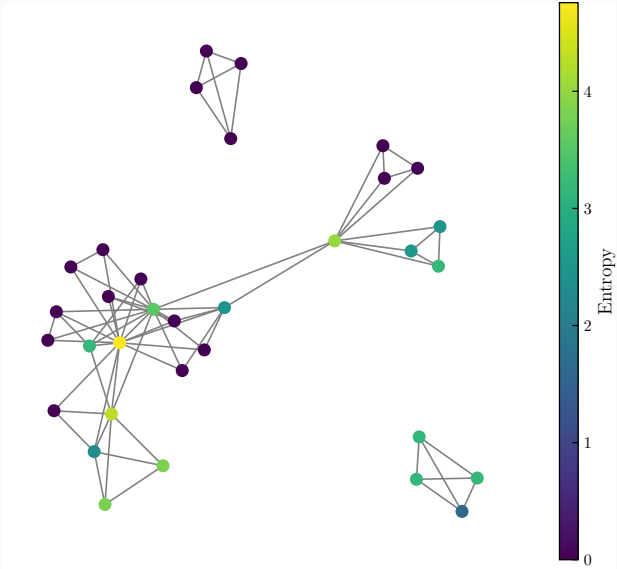
Phrase detection

Local boundary detection model (LBDM)





# Problem graph

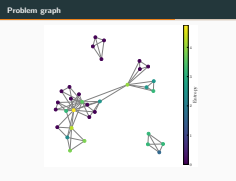


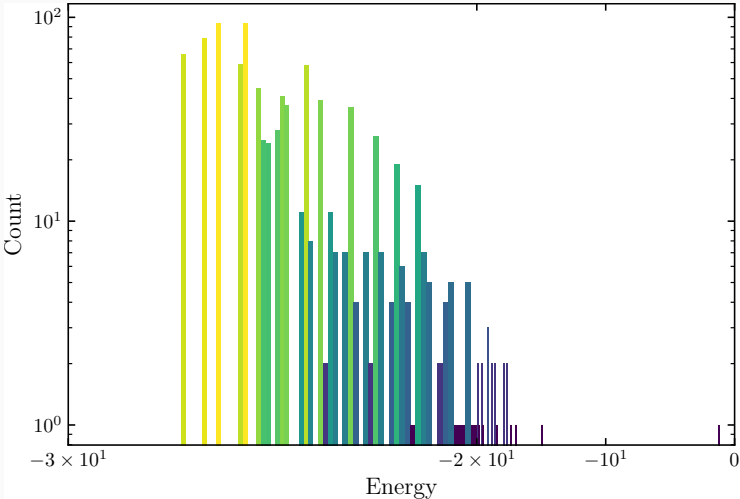
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## Music Arrangement via Quantum Annealing

└ Results

└ Problem graph





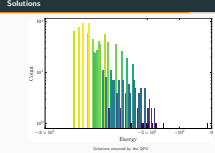
Solutions returned by the QPU

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# Music Arrangement via Quantum Annealing

└ Results

└ Solutions



Lowest energy solution was -26.8 with a degeneracy of 34

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Music Arrangement via Quantum Annealing

└─Results

└─Example solution

Example solution

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

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

## Alert

This is an alert.

## Example

This is an example.

### Results

### Blocks

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

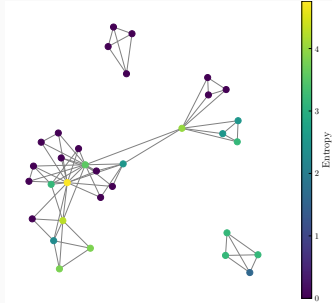
The net electric flux through any **closed** surface is proportional to the **enclosed charge**.

**Alert**  
This is an alert.

**Example**  
This is an example.

# Apperance sync

- 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

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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



# Equation gather

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

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Music Arrangement via Quantum Annealing

└─ Conclusions

└─ Equation gather

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