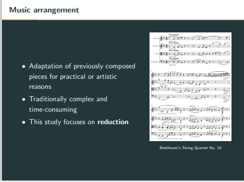
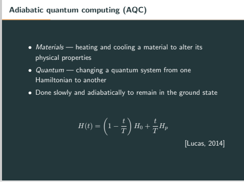
- What is music arrangement? What is quantum annealing?
- Methods used to solve the music arrangement problem
- Preliminary results from application of the method
- Concluding thoughts about this process



- Adaptation of music in terms of instrumentation, medium, or style
- Traditionally a complex process that requires a deep understanding of musical theory and structure
- Musically interesting whilst still remaining faithful to the source material
- Interest in automating this process
- Reduction is the rewriting of music for a smaller number of instruments (for example string quartet)



- Materials science, annealing is a slow heating/cooling process to make a material softer and less brittle
- Quantum computing, slow evolution of a system between Hamiltonians
- Done adiabatically (closed system), system remains in ground state

Quantum annealing

Ising model

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

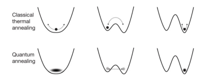
Initial state

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

[Lucas, 2014]

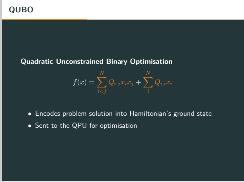
- How is this used to solve problems?
- Ising model, create a lattice of variables with two discrete values (spin up/down)
- Problem Hamiltonian, qubits σ^z, coupling strengths J_{ij} and field strengths h_i
- Initial state is a superposition of all possible states
- If problem solution is encoded within the ground state, system will give solution after evolution

Quantum annealing



[Johnson et al., 2011]

- What does this look like?
- Evolution of superposition to a particular state
- More efficiently escape from local minima via quantum tunneling
- Can solve harder problems with a more turbulent energy landscape



- How to encode a problem into a Hamiltonian?
- Similar form to the Ising model, but with binary variables (0 or 1)
- QUBO is a function to be minimised
- Set of binary variables x, matrix Q of real weights that describes interactions between variables
- Can read out variable values after evolution to give solution

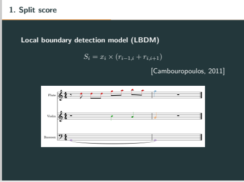
How to combine them?

- How to apply quantum annealing to the problem of music arrangement?

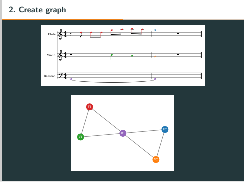
Problem formulation

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

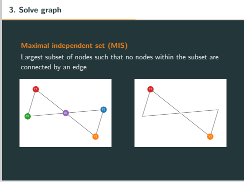
- Formulating arrangement as a problem to be solved via annealing, four-step process
- Split parts into musical phrases
- Arrange phrases into a graph (nodes and edges)
- Solve corresponding graph problem using quantum computing
- Construct final arrangement from the solution returned



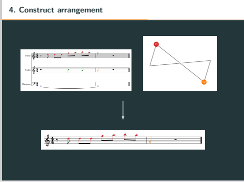
- First stage to separate each part of original score into phrases
- Phrases — smallest unit of music that preserves melody and structure
- Boundaries between phrases found using LBDM
- Measures the degree of change of a certain parameter between notes (explain equation)
- Check pitch and IOI
- Strengths above a threshold value are considered phrases



- Construct problem graph
- Each phrase becomes a node, edges between nodes if phrases overlap

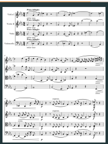


- Special case for reducing to a single monophonic part (one phrase played at a time)
- Solve problem graph using a graph theory problem called MIS
- Enforces that only one simultaneous phrase can be played at once
- Nodes can also be weighted to introduce preference for certain nodes e.g. musicality



- Take solution graph and combine selected nodes to create final arrangement

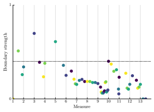
Excerpt



String Quartet No. 10 by Ludwig van Beethoven

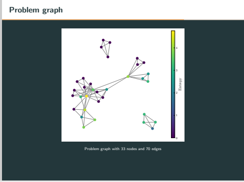
- Excerpt of String Quartet No. 10 in E-flat major, Op. 74, by Ludwig van Beethoven
- Chosen due to its relatively simple structure and smaller instrumentation, keeping the problem graph small

Phrase detection

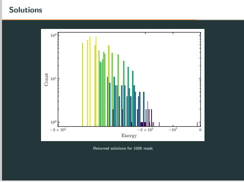


Boundary strengths for the Violin I part

- Example of the LBDM finding suitable boundaries for phrases
- Threshold value of 0.4 chosen, finds five phrases

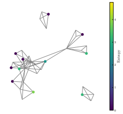


- 33 identified phrases (nodes) with 70 overlaps (edges)
- Nodes are weighted by the phrase entropy, how musically interesting the distribution of notes is



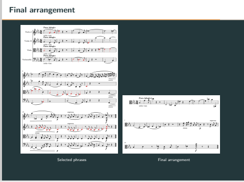
- Histogram of the returned solutions, only energies below zero shown
- Distribution of solutions due to the stochastic nature of annealing
- Lowest energy solution most musically interesting due to construction of weighted MIS QUBO
- (Lowest energy solution -26.8 with a degeneracy of 34)

Example solution



Solution graph returning a subset of 11 nodes

- Selected nodes from one of the lowest energy solutions
- Note in the cliques only one node could be selected



- Selected phrases from solution graph highlighted
- Phrases concatenated to create the final arrangement

Conclusions

- Successful in creating a valid single-part reduction
- Advantage over classical algorithms [Huang et al., 2012]
- Removes skill barrier for music arrangement

- Valid reduction gained from implemented method
- Monophonic lowest-energy solution
- Phrase identification and selection result in musically interesting final arrangement
- Displays some advantages over classical algorithms
- Does not require training data, costly in both time and resources
- Faster solve time compared to similarly-sized problems
- Method and more advanced versions of it removes the 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 [Pearce and Wiggins, 2001]

- Problem size — full piece has upwards of 1000 phrases, compare solve times with classical algorithms
- LBDM parameters — phrases should be short and similar in length, prevents important notes being hidden in long phrases with low entropy
- Physical limitations — note ranges, note change speed
- Multiple parts — need different problem formulation, colouring problem with each colour representing a reduced part
- Quality judgement — Turing-like test, present subjects with human-/computer-generated scores

LBDM

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

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

[Cambouropoulos, 2011]

- Boundaries always taken at beginning/end of piece
- Weightings derived by trial and error

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

[Lucas, 2014]

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

- Weighted MIS QUBO
- Lagrange paramters A/B determine the balance between constraint and objective

Phrase entropy

Shannon entropy

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

Probability distribution

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

[Li et al., 2019]

- Shannon entropy units in bits due to $\log_2$
- Distribution calculated for pitch and duration