Conceptualizing Quantum Music
Quantum Musical Space

http://tph.tuwien.ac.at/~svozil/publ/2021-QMusic-pres.pdf

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Collaboration & Publications

- Volkmar Putz, University College of Teacher Education in Vienna (Pädagogische Hochschule Wien), Vienna, Austria

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- Publications
  - Volkmar Putz and Karl Svozil, "Quantum Music", Soft Computing 21(6), 1467-1471 (2017), DOI: 10.1007/s00500-015-1835-x
  - Volkmar Putz and Karl Svozil, "Quantum music, quantum arts and their perception", arXiv:2108.05207 (2019), submitted to *"Quantum Computing in the Arts and Humanities", E. R. Miranda (Ed.), 2022*

Realm of quantum expressibility I: Boolean algebras *versus* geometric, vector based, means

- Classical music is in terms of classical physical states based on Boolean algebras, power sets, set theoretic unions, intersections, complements, ...

Realm of quantum expressibility I: Boolean algebras *versus* geometric, vector based, means

- Classical music is in terms of classical physical states based on Boolean algebras, power sets, set theoretic unions, intersections, complements, ...
- Quantum music is vector based; pure states are vectors, temporal evolution is a generalized form of permutation (aka unitary one-to-one modulation) of that vector

Realm of quantum expressibility II: Parallelism & Entanglement

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- parallelization through coherent superposition (aka simultaneous linear combination) of classically mutually exclusive tones or signals that are acoustic, optic, touch, taste, or otherwise sensory
- entanglement not merely by classical correlation but by relational encoding of multi-partite states such that
  * any classical information is "scrambled" into relational, joint multi-partite/tonal properties
  * while at the same time losing value definiteness about the single constituents of such multi-partite states

  This can be seen as a sort of zero-sum game, a tradeoff between individual and collective properties

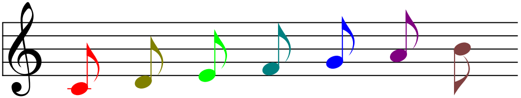
Realm of quantum expressibility III: Complementarity & Contextuality

- Complementarity associated with value (in)definiteness of certain tones or signals that is acoustic, optic, touch, taste, or otherwise: if one such observable is definite, another is not, and *vice versa*

Realm of quantum expressibility III: Complementarity & Contextuality

- Complementarity associated with value (in)definiteness of certain tones or signals that is acoustic, optic, touch, taste, or otherwise: if one such observable is definite, another is not, and *vice versa*
- Contextuality is an "enhanced" form of complementarity and value indefiniteness that can be defined in various ways, in particular, emphasizing homomorphic, structure-preserving nonembeddability into classical schemes

Quantum musical tones



$|\Psi_c\rangle$ $|\Psi_d\rangle$ $|\Psi_e\rangle$ $|\Psi_f\rangle$ $|\Psi_g\rangle$ $|\Psi_a\rangle$ $|\Psi_b\rangle$

Temporal succession of quantum tones $|\Psi_c\rangle$, $|\Psi_d\rangle$, ..., $|\Psi_b\rangle$ in the C major scale forming the octave basis $\mathfrak{B}$ of $\mathbb{C}^7$: the basis elements are formalized by the Cartesian basis tuples

$$
\begin{aligned}
|\Psi_c\rangle &= \left(0,0,0,0,0,0,1\right), \\
|\Psi_d\rangle &= \left(0,0,0,0,0,1,0\right), \\
&\ldots \\
|\Psi_b\rangle &= \left(1,0,0,0,0,0,0\right)
\end{aligned}
$$

Bundling octaves into single tones, compositions thereof

Pure quantum musical states are represented as unit vectors $|\psi\rangle \in \mathbb{C}^7$ which are linear combinations of the basis $\mathfrak{B}$; that is,

$$|\psi\rangle = \alpha_c|\Psi_c\rangle + \alpha_d|\Psi_d\rangle + \cdots + \alpha_b|\Psi_b\rangle, \tag{1}$$

with coefficients α_i satisfying

$$|\alpha_c|^2 + |\alpha_d|^2 + \cdots + |\alpha_b|^2 = 1. \tag{2}$$

A musical "composition"—indeed, any succession of quantized tones forming a "melody"—would be obtained by successive unitary permutations of the state $|\psi\rangle$. The realm of such compositions would be spanned by the succession of all unitary transformations $\mathbf{U} : \mathfrak{B} \mapsto \mathfrak{B}'$ mapping some orthonormal basis $\mathfrak{B}$ into another orthonormal basis $\mathfrak{B}'$

Classical perception of quantum musical parallelism

If a classical auditorium listens to the quantum musical state $|\psi\rangle$ in Eq. 1, the individual classical listeners may perceive $|\psi\rangle$ very differently; that is, they will hear only a *single one* of the different tones with probabilities of $|\alpha_c|^2$, $|\alpha_d|^2$, ..., and $|\alpha_b|^2$, respectively.

Example of the classical perception of the quantum musical parallelism

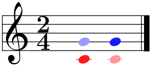
For the sake of a demonstration, let us try a two-note quantum composition. We start with a pure quantum mechanical state in the two-dimensional subspace spanned by $|\Psi_c\rangle$ and $|\Psi_g\rangle$, specified by

$$|\psi_1\rangle = \frac{4}{5}|\Psi_c\rangle + \frac{3}{5}|\Psi_g\rangle = \frac{1}{5}\begin{pmatrix}4\\3\end{pmatrix}. \tag{3}$$

$|\psi_1\rangle$ would be detected by the listener as c in 64% of all measurements (listenings), and as g in 36% of all listenings. Using the unitary transformation $\mathbf{X} = \begin{pmatrix}0 & 1\\1 & 0\end{pmatrix}$, the next quantum tone would be

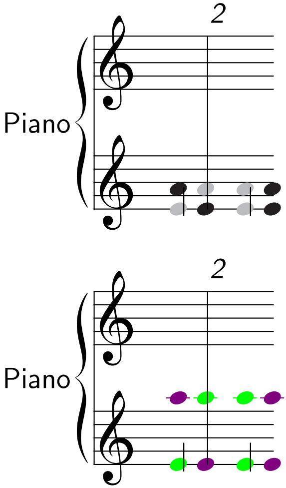
$$|\psi_2\rangle = \mathbf{X}|\psi_1\rangle = \frac{3}{5}|\Psi_c\rangle + \frac{4}{5}|\Psi_g\rangle = \frac{1}{5}\begin{pmatrix}3\\4\end{pmatrix}. \tag{4}$$

This means for the quantum melody of both quantum tones $|\psi_1\rangle$ and $|\psi_2\rangle$ in succession in repeated measurements, in $0.64^2 = 40.96\%$ of all cases $c - g$ is heard, in $0.36^2 = 12.96\%$ of all cases $g - c$, in $0.64 \cdot 0.36 = 23.04\%$ of all cases $c - c$ or $g - g$, respectively.



Entangled music, complementarity and contextuality

Please see our papers for a first inroad into these subjects . . .



Tradeoff quantum versus classical music, and how to experiencing it?

- Quantum music presents a novel form of musical expressibility and tonal forms
- Quantum music lacks some classical forms of musical expressibility—all that are not one-to-one; eg, "getting rid" of tones is only possible by transformation into other tones; no "silenzio"
- Quantum music may be "difficult" to perceive; and may sometimes involve paradoxical experiences—cf Schrödinger's cat or quantum jellyfish (late Dublin seminars) metaphors

Thank you for your attention!