Exploring the Possibilities of Quantum Music: Navigating a New Musical Frontier in Quantum Musical Space

http://tph.tuwien.ac.at/~svozil/publ/2023-QMusic-pres.pdf

Karl Svozil

ITP TU Wien, Vienna, Austria
svozil@tuwien.ac.at

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Collaboration & 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”, in “Quantum Computing in the Arts and Humanities An Introduction to Core Concepts, Theory and Applications”, Hg. Eduardo Reck Miranda, (Springer, 2022), arXiv:2108.05207 (2022), DOI: 10.1007/978-3-030-95538-0_5

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

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- 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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- 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

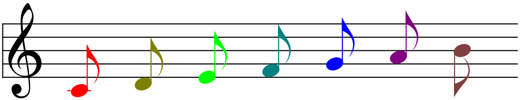
Realm of quantum expressibility III: Complementarity & Contextuality

- 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 realization I: 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 (reduced because it contains only seven tones) octave basis $\mathfrak{B}$ of $\mathbb{C}^7$: the basis elements are formalized by the Cartesian basis tuples

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

Quantum musical realization II: Quantum musical compositions

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 $\mathfrak{B}'$

Realm of quantum perception I: Can single quanta be perceived by human observers?

This is an open question, however there are indications that at least the human eye can "watch" single quanta.

Human rod cells respond to individual photons:

Selig Hecht and Simon Shlaer and Maurice Henri Pirenne, 1942, DOI: 10.1085/jgp.25.6.819 (Review: Gerald Westheimer, 2016, DOI: 10.1201/9781315373034-2).

Moreover, recent reports suggest that humans might be capable of subjectively "being aware" of the detection of a single-photon incident on the cornea with a probability significantly above chance: Jonathan N. Tinsley and Maxim I. Molodtsov and Robert Prevedel and David Wartmann and Jofre Espigulé-Pons and Mattias Lauwers and Alipasha Vaziri, 2016, "Direct detection of a single photon by humans", DOI: 10.1038/ncomms12172

Realm of quantum perception II: Classical perception of quantum musical parallelism

If a classical auditorium listens to the quantum musical state $|\psi\rangle$ which is a coherent superposition of classical tones the individual classical listeners may perceive $|\psi\rangle$ very differently; that is, they will hear only a *single one* of the different classical tones contained in $|\psi\rangle$.

Example of the classical perception of the quantum musical parallelism

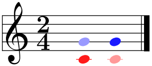
For the sake of a demonstration, let us try a two-note quantum composition. We start with a pure quantum mechanical state in the two-dimensional subspace spanned by $|\Psi_c\rangle$ and $|\Psi_g\rangle$, specified by

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

$|\psi_1\rangle$ 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

$$|\psi_2\rangle = \mathbf{X}|\psi_1\rangle = \frac{3}{5}|\Psi_c\rangle + \frac{4}{5}|\Psi_g\rangle = \frac{1}{5}\begin{pmatrix} 3 \\ 4 \end{pmatrix}. \tag{2}$$

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.



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

Hochschule Düsseldorf // Prof. Christian Jendreiko

Thank you for your attention!