Annuario in divenire a cura del Seminario Permanente di Filosofia della Musica
ISSN: 2465-0137

De Musica

Annuario in divenire del Seminario Permanente di Filosofia della Musica

Anno 2023 – Numero XXVII (2)

Numero monografico

L'esperienza dell'ascolto: dalla natura alla cultura/
The Experience of Listening: From Nature to Culture

a cura di

Domenica Bruni & Fabio Esposito

ISSN: 2465-0137
riviste.unimi.it/index.php/demusica

Sommario

Allegati

Quantum Aspects of the Musical Mind

Maria Mannone, Valeria Seidita, Antonio Chella

Abstract

The composer constantly makes choices: it is the composer, in fact, who chooses a melodic, rhythmic, harmonic path among the various, infinite possible paths between point A, the beginning, and point B, the end of a composition. The choice of one path over another, a local modification of a given path, can also be influenced by external factors. As it happens for the path of a charged particle in a magnetic field, the choice of the musical path can be influenced by personal style, culture, technical characteristics of the instruments, and combinations of instruments used. Even in quantum mechanics, there are “choices”: the state of a system appears as a superposition of possible eigenstates with different probability amplitudes. The act of measurement “forces” the system to choose a particular state: the observer influences the physics of the system. Like the famous example of Schrödinger’s cat, alive and dead at the same time until the box in which it is located is opened. From the choices of notes and musical paths to decision-making systems, we present some examples of the application of quantum mechanics to music. Among the applications of quantum computing, we mention a study on robots with associated musical descriptions. In particular, we consider the distributed intelligence of a swarm of robots and its possible musical description, from some existing works to our original application.

Keywords: Composition; Quantum mechanics; Quantum computing; Robot swarms.

Sommario
Il compositore compie costantemente delle scelte: è il compositore, infatti, a scegliere un percorso melodico, ritmico, armonico tra i vari, infiniti possibili cammini tra il punto A, l'inizio, e il punto B, la fine di una composizione. La scelta di un tragitto invece di un altro, e una modifica locale di un dato percorso, possono essere influenzate anche da fattori esterni. Come accade per il cammino di una particella carica in un campo magnetico, la scelta del percorso musicale può essere influenzata dallo stile personale, dalla cultura, dalle caratteristiche tecniche degli strumenti e dalle combinazioni degli strumenti utilizzati. Anche nella meccanica quantistica vi sono delle "scelte": lo stato di un sistema appare come una sovrapposizione di possibili autostati con diverse ampiezze di probabilità. L'operazione di misura "costringe" il sistema a scegliere uno stato particolare: l'osservatore influenza la fisica del sistema. Come il famoso esempio del gatto di Schrödinger, vivo e morto allo stesso tempo finché non si apre la scatola in cui si trova. Dalle scelte di note e percorsi musicali ai sistemi decisionali, presentiamo alcuni esempi di applicazione della meccanica quantistica alla musica. Tra le applicazioni del calcolo quantistico menzioniamo uno studio sulla traduzione musicale di alcuni parametrici robotici. In particolare, consideriamo l'intelligenza distribuita di uno sciame di robot e la sua possibile descrizione musicale, con alcuni esempi di applicazione, fra cui uno studio originale.
Parole chiave: Composizione; Meccanica quantistica; Calcolo quantistico; Sciami di robot.

1. Introduction

What does it mean to compose a musical piece? First of all, making choices. The composer continuously makes choices. Choices of themes, pitch material, instrument, and length. These are the constitutive elements of the musical discourse, at a symbolic level. The composer working with masses of sounds and synthesizers also has to make choices: he or she chooses which timbres to use, and which balance to give to all the sounds. The concept of choice does not only involve the constitutive objects but also the paths between them. Once one has identified items A and B, be they isolated notes, melodies, or whole short sections as paragraphs, the composer has to choose a path connecting them: how to get from A to B? The path can be rhythmic, harmonic, or melodic. It can involve changes in orchestration. The choices of the composer are also influenced by external factors, such as available musical instruments (looking for a performance), culture, personal style, and the period in which he or she lives. Before a choice, in the mind of the composer lives an indistinct range of possible colors, as the palette of a painter, where the colors get mixed up. The choice is an operation of the selection of an element from a superposition or mixing of a multitude of possible items. In this sense, the problem of choice that comes to the composer's mind has affinities with the role of choice in the physics of the small, that is, in quantum mechanics.

One of the conceptual problems of quantum mechanics is precisely the role of the subject, the researcher, who, performing a measure, forces the matter to stick with a precise state. Each subsequent measure with the same measurement apparatus will give the same result with 100% probability amplitude (an eigenstate). Thus, the operation of measure in quantum mechanics is the so-called destructive measure.

2. Quantum and music

Quantum mechanics influenced the development of a branch of computer science, quantum computing, whose starting element is the qubit, that is, the quantum bit.

In computer science, the classic bit is a unit that can assume the values 0 or 1. It is used to store and process information, constituting the basis of binary computing. Its extension to the quantum domain leads to the quantum bit, that is, qubit. The qubit can assume not only the values 0 or 1 but all intermediate values, corresponding to the quantum superposed states, each one with a different probability amplitude. We remark here that the superposition in the quantum world is not only epistemic, that is, related to our human knowledge of the natural phenomenon; it is an ontological characteristic: the superposition of states is an effective condition of nature, which is disturbed by the operation of measure.

Quantum phenomena such as entanglement can be expressed in terms of qubits, where the state of a qubit depends on the state of the other one, showing non-locality effects. That is, the operation of measure on a qubit of the entangled state provokes an instantaneous collapse of the wave function also for the other qubit, even if located at a great distance from the first one. The use of qubits constitutes the basis of quantum computing, enabling quantum computers to perform tasks faster than classical computers. As a drawback, the use of quantum introduces a great amount of noise and it is rather unstable. Thus, the development of large quantum computers has to be balanced by an increased control of the systems.

Let us go back to the (human) composer. As a disclaimer, we remark that we do not know if the human mind does effectively work in quantum terms. The underlying idea here is to adopt, carefully and with some limits, a few key ideas from the quantum domain to describe processes and mechanisms of musical creativity. In the following, we summarize some instances of the application of quantum formalism or quantum computing approach to music.

Some early examples are constituted by the research by Putz and Svozil (2015) and Mannone and Compagno (2013; published 2022). Putz and Svozil (2015) consider single heights as quanta, and chords as superpositions. The quantum approach allows one to conceptualize, render, and perceive quantum music — and, according to the authors, quantum art in general. Phenomena such as entanglement and coherent superposition can provide new food for thought to creativity.

Mannone and Compagno, between 2012 and 2013, adapted to music a quantum criterion used to measure the amount of memory in a quantum open system. Given two distinct states at t_0, if their distinguishability over time is preserved, then the memory of their identity is preserved. The adaptation to music involves the inverse idea: in a musical piece, the degree of memory is higher if the distance (meant as the number of differences) between musical sequences is small. Clearly, a musical form A maintains structural memory, a minimalistic piece presents a way higher degree of memory, but a aleatoric piece of music is rather unpredictable. The empiric expectation was confirmed by quantitative measurements. The study was published in 2022.

Other theoretical applications involve the derivation of chords from the continuum of sounds (Beim Graben and Mannone, 2020). In this study, a quantum model of tonal music is considered, and it is proved that the associated Schrödinger equation in Fourier space is invariant under continuous pitch transpositions. It is also shown that such symmetry is broken in the case of chord transposition. The findings are consistent with the insights of Hermann von Helmholtz. In another recent study, Fugiel (2022) proposes on a quantum-like approach to describe melody perception, where classic intervals are replaced by acoustical qubits. The author considers two-level acoustic systems, on the model of a two-level atom, and uses Shepard tones for their modeling. Each qubit is thus considered as a superposition of a descending and a rising interval, forming an octave when played simultaneously. Human melodic perception is thus modeled as a sequence of periodic quantum measurements. Thanks to the destructive measure phenomenon, only an interval is perceived, either ascending or descending.

A comparison between perception and quantum measurement was previously proposed by Rocchesso and Mannone (2020), with a particular emphasis on voice. Voice can be considered as a probe to investigate the world of sound, thanks to the ability of the human voice to imitate salient features of complex sounds, despite the deep acoustic and timbral differences. Voice is described as a superposition of states along x, y, and z, identified as turbulence, molestation effects, and phonation, respectively. The formalism of quantum mechanics is borrowed, from the Pauli matrices to density matrices. The experiments of measurements confirmed the validity of the approach, called Quantum Vocal Theory of Sound.

Other applications of the quantum paradigm to music involve approaches of sonification. For instance, the output of a quantum computer can be mapped to sound parameters. The organization of the material, its careful selection, and the choice of the mapping procedure, are creative applications leading to concrete and experimental music.

The sonification is the process of mapping and representing data from a non-auditory domain to the auditory domain. Sonification allows people to exploit information through sound, allowing perceiving and understanding patterns, trends, or salient characteristics through auditory perception. However, the choice of sonification strategy has to be calibrated according to the scope of the operation: deriving sonic material for artistic creation; highlighting salient features of data; and adding a further sensory dimension to understanding and data analysis.

How does the mind of the composer work while dealing with a quantum source of data? It is possible to adopt different strategies (Miranda, 2022). An example is the "photonics" synthesis of sound, where the sounds are obtained through the count of photons detected at the end of a process (Miranda et al., 2022). Another instance of quantum sonification is the performance "Quantum Sound" with sounds obtained from the "superconductor tools," by the composer S. Topel and two physics grand students of Yale Quantum Institute (YQI), K. Serniak and L. Burkhart (Shelton, 2019).

In this performance, of the duration of 40 minutes, the quantum systems generated data, used to create sonic signals. The instruments were superconducting quantum devices maintained at temperatures close to absolute zero. The electrical signals coming from these devices were sonified by performers, keeping the main characteristics of the original data. The obtained sound presented a variety of effects, including noise, melodies, ominous sounds, and a "wobble" effect obtained via quantum noise. The creative aspect resided in the choice of performers to manipulate the incoming electronic signal and experiment with the output (Shelton, 2019). This experiment and similar ones aim to bridge the gap between art and science.

One may wonder, how the "quantum mind" of a composer deals with quantum-obtained material. While a possible source of sonic material is the parameters and value coming from real quantum computers, also the theoretical domain can constitute a source of inspiration. It is the case of the interface QuiKo (2020), where it is possible to create harmonic and rhythmic signals directly from the Bloch sphere. In quantum mechanics, the Bloch sphere is particularly well-known; it is a graphic representation of the space of quantum states. The interface QuiKo allows multiple MIDI files as input. New MIDI tracks are generated via entanglement effects; the new tracks inherit some rhythmic elements from the previous ones. The percussive and harmonic features are thus extracted from the MIDI files, and the information is mapped to unitary gates. In turn, the gates prepare qubits in specific states, whose measures lead to the selection — that is, to an automatic choice — of specific musical notes. The conceptual side consists of trying to conciliate the thinking style and the inspiration of composers who are engaged with music making.

We can thus say that the discussed quantum-derived music-making approach can shed light on the mental mechanisms of creation itself. The role of sonification can also be more indirect, and it can concern the auditory rendition of the movement of objects whose motion characteristics are connected to quantum in some way. It is the case of the sonification of movements of a robotic swarm with a pairwise quantum decision-making system (Mannone et al., 2022). Swarms of robots are agglomerate of multiple and simple robots, which exchange information locally and collectively perform a task that would be impossible for single units. Robotic swarms are often modeled upon the swarms existing in nature, for instance flocking birds, schilling fish, and foraging ants. Swarms are instances of distributed intelligence.

In Mannone et al. (2022), the sonification of individual motion is possible indirectly: slices of space are associated with pitches, thus the changing space coordinates of a single robot throughout space are mapped to pitches. In this way, a trajectory becomes a melody, and multiple trajectories of robots moving simultaneously become a polyphony. Tools of music theory from one side, and of sound signal processing for the other side, can thus be exploited to analyze the resulting musical sequences, and extract information. Our list is short and incomplete, as more and more applications of quantum mechanics and quantum computing to music have appeared in recent years.

3. Conclusion

We conclude this short dissertation with a tentative reply to the question "Why?", referring to the use of quantum methods or laws or data in computer science, and, more specifically in domains other than physics, such as music. The answer to this" Why?" constitutes the motivation leading our composer to write A, then B, and finally choose a path to go from A to B.

Historically, the advent of quantum mechanics produced a crisis in different domains of science, not only in physics, and created at the same time the rise of a new way of thinking. The fact that the observer influences the physical state is something inconceivable in classical physics. The novelty of approaches introduced with quantum mechanics often impacts other disciplines. The novelty of methods can also lead to new solutions in fields such as computing, chemistry, and quantum cryptography.

Amongst the advantages of quantum computing, there is the potential for faster solutions to complex problems, and secure encryption thanks to entanglement and phenomena of periodic appearing-disappearing of entanglement. In music, all of that could be rendered as sudden silence, where there is no trace of the musical discourse: what will come right after?

The disadvantages of quantum technical developments include the requirement of extremely cold temperatures and stable environments, as well as limited scalability: building a large quantum computer is still technically challenging. Also, the error rates of qubits increase with the increase in the number of qubits. Moreover, quantum phenomena such as interference and decoherence constitute an obstacle to the exploitation of quantum devices. At this point, the composer is scratching his or her head. Does quantum computing help?, he asks him/herself. Yes, quantum computing may help model how the human mind works, and it can provide tools to formally investigate music and create new artworks. However, music creativity can only be partially helped and supported by techniques and machines. It is a human characteristic. Only human? No, creativity belongs to the world of living beings. Birds and fishes can create wonderful compositions with sands or leaves (Heinrich, 2013), and natural shapes themselves can be considered masterpieces produced by the relentless work of single animals concerning individual preferences about mate selection, not only related to survival but to aesthetics (Prum, 2017). Ultimately, even the laws of physics, including the counterintuitive ones of quantum mechanics, are the artwork of Someone. For the composer, it's now time to turn off the computer and go for a walk in nature.

References

BEIM GRABEN, P., MANNONE, M., "Musical Pitch Quantization as an Eigenvalue Problem", *Journal of Mathematics and Music*, vol. 14, n. 3, 2020, pp. 329-346.

FUGIEL, B., "Quantum-like Melody Perception", *Journal of Mathematics and Music*, vol. 17, n. 2, 2023, pp. 319-331.

HEINRICH, B., "The Biological Roots of Aesthetics and Art", *Evolutionary Psychology*, 2013, https://doi.org/10.1177/147470491301100031.

MIRANDA, E. (ed.), *Quantum Computing in the Arts and Humanities*, Springer, 2022.

MANNONE, M., SEIDITA, V., CHELLA, A., "Quantum RoboSound: Auditory Feedback of a Quantum-Driven Robotic Swarm", in *2022 31st*

IEEE International Conference on Robot and Human Interactive Communication (RO-MAN), Naples, 2022, pp. 287-292, preprint.

MANNONE, M., COMPAGNO, G., "Characterization of the Degree of Musical Non-Markovianity", *Journal of Creative Musical Systems*, 2022. Former version: ArXiV, 2013.

PRUM, O., *The Evolution of Beauty*, Doubleday, 2017.

PUTZ, V., SVOZIL, K., "Quantum Music", *Soft Computing*, vol. 21, 2017, pp. 1467-1471, https://doi.org/10.1007/s00500-015-1835-x.

ROCCHESSO, D., MANNONE, M., "A Quantum Vocal Theory of Sound", *Quantum Information Processing*, vol. 19, n. 292, 2020.

SHELTON, J., *Yale Science Hits the Stage: Quantum Sound*, Quantum Institute, 2019, https://quantuminstitute.yale.edu/publications/yale-science-hits-stage-quantum-sound, accessed online on September 28, 2023.

QUIKO, *QuiKo v0.1*, 2020, https://github.com/scottoshiro2/QuiKo_v0.1, accessed online on September 28, 2023.