physicsworld

QUANTUM COMPUTING FEATURE

Can we use quantum computers to make music?

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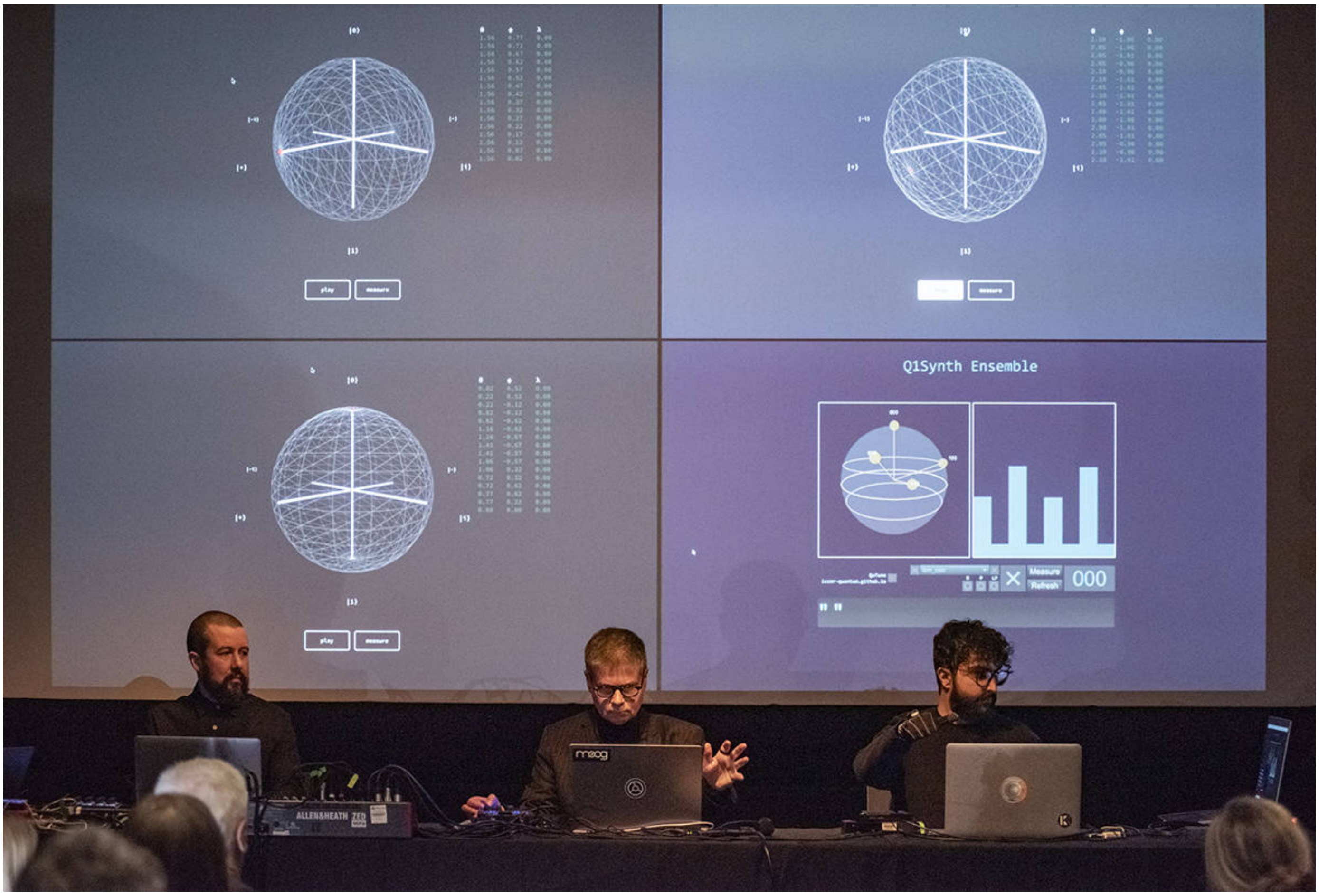
Computers and digital technology are central to the modern music industry – but what could quantum computers bring to the party? Philip Ball tunes in to an avant-garde band of musicians and scientists who are exploring how quantum computing can be used to make and manipulate music

The Goethe-Institut, opposite Imperial College in London, is not the kind of place you would expect to encounter cutting-edge avant-garde art. With its Neoclassical façade and a history of providing German language classes, it hardly seems the type of venue to host an event that includes musicians like Peter Gabriel and Brian Eno, along with a number of quantum physicists. But the sounds emanating from its lecture theatre last December were a far cry from the institute’s traditional image: drones, bleeps and bursts of wild beats more akin to the soundtrack of an experimental underground movie.

This was, in fact, the sound of quantum computing.



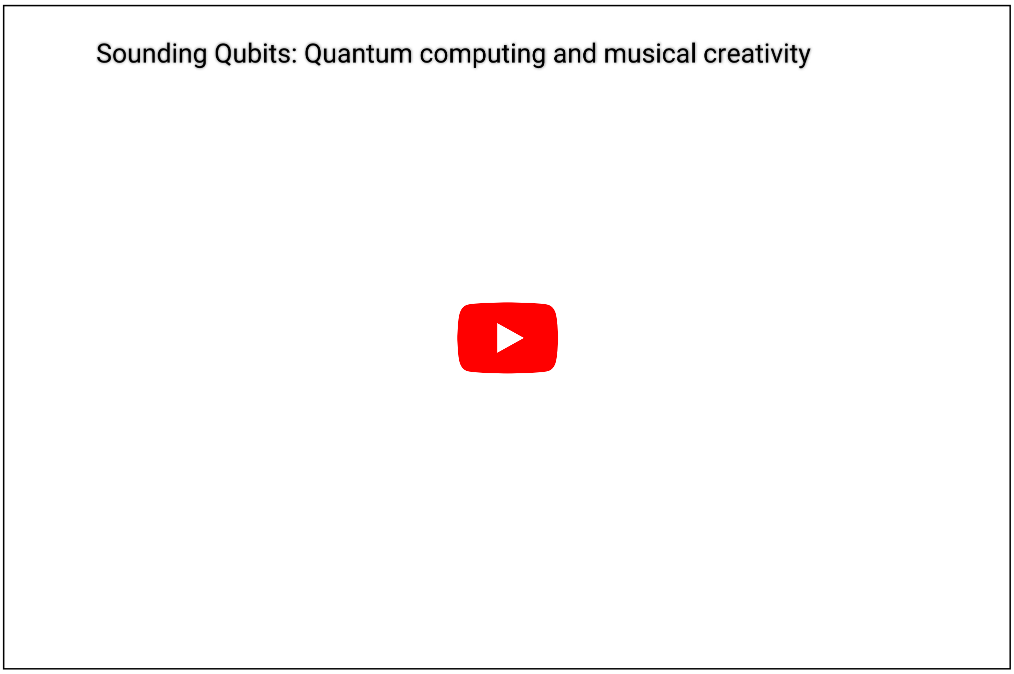
Where quantum physics meets music Eduardo Miranda (centre) at the Goethe-Institut in London, December 2022. (Courtesy: Goethe-Institut London | Photo: Pau Ros)

The event was attended by about 150 people, who were listening to an improvised musical performance orchestrated by the Brazilian composer and computer scientist Eduardo Reck Miranda, who is based at the University of Plymouth in the UK. In one piece, Miranda and two colleagues were each using their own laptops, which were connected to a quantum computer over the Internet, to control – via hand gestures – the state of a quantum bit (qubit). When that state was measured, the result dictated the characteristics of the sounds created by synthesizers back in London.

If that sounds bizarre – well, yes it truly did.

> I want to develop machines that will help me be creative and will challenge my normal way of doing things
> Eduardo Miranda, University of Plymouth

In quantum computing, information is encoded in superposition states of entangled qubits, which allows some calculations to be carried out far more efficiently than is possible with classical machines. Although these devices are still prototypes mostly confined to the laboratories of tech giants such as IBM and Google, composers like Miranda are keen to discover what the new technology can offer them. "I want to develop machines that will help me be creative and will challenge my normal way of doing things," he says.



Quantum computing, Miranda believes, "promotes a different way of thinking, [which in turn] will lead to different ways of thinking about music." It's a view shared by Bob Coecke – another of Miranda's collaborators – who is a physicist at the Oxford-based quantum computing company Quantinuum. "If you change the way you look at things, and the language you use, you come out with completely new ideas," says Coecke.

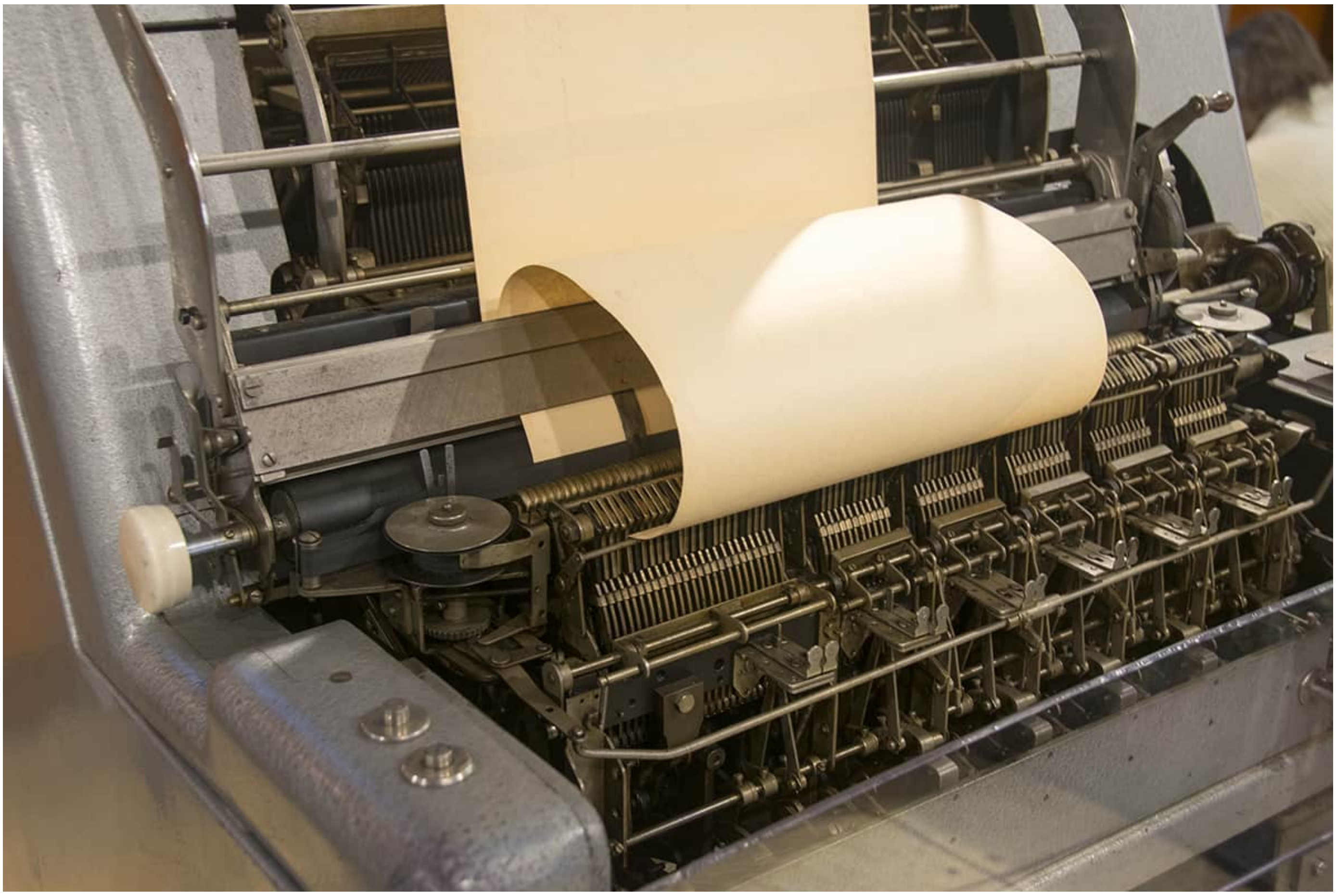
> I'm fascinated to know how [this music] works.
> Brian Eno, musician

Quantum music is currently a decidedly niche field – but one that is attracting some high-profile interest. Indeed the Goethe-Institut event was convened to mark the launch of a new book edited by Miranda, *Quantum Computer Music*, which claims to be the first-ever book on the subject (Springer, 2022). Coecke, meanwhile, is planning a quantum art/science mash-up in Oxford this year with Miranda and the Italian theorist Carlo Rovelli.

"I'm fascinated to know how [this music] works," said Eno after the Goethe-Institut performance in an interview with the institute. "It's difficult for me to make a judgement, because you don't know how much of those decisions were made by humans, and how much is coming out of that different kind of intelligence."

A natural partnership

The idea of using computer-like algorithms in music dates back to the 1840s, when scientist and mathematician Ada Lovelace first speculated about using Charles Babbage's Analytical Machine – a kind of steampunk calculating device made from intricate arrays of brass cogs and camshafts – to "compose elaborate and scientific pieces of music of any degree of complexity or extent". In some ways it was a natural partnership, for much of music itself has an algorithmic and mathematical basis, reflected by the symmetries apparent in the works of Baroque composers such as Johann Sebastian Bach.



Digital transformation The notion of using quantum computers for artistic purposes is part of a tradition that stretches back to Ada Lovelace, who wondered almost two centuries ago if Babbage's Analytical Engine could be used to create music. (Courtesy: Shutterstock/Libor Píška)

The use of chance and probability in "automated" composition became popular even earlier, in the *Musikalisches Würfelspiel* (musical dice games) of the 18th century, in which small pieces of music were assembled using dice rolls. One composition allegedly written by Mozart in 1787 may be an example of the genre. It would have been played by the performers rolling dice many times, with the number thrown on each occasion corresponding to a particular pre-written section of music. The result was a randomly stitched together composition that differed in every performance, which you can listen to at bit.ly/3HivOLk.

It was the element of randomness that attracted modern composers to computers in the early days of digital machines. In the 1950s and 1960s, John Cage was at the centre of a group of tech-loving New York-based musicians that included Yoko Ono and the late Japanese composer Toshi Ichiyanagi, whose ambiguous 1960 score *IBM for Merce Cunningham* was inspired by the punch cards of early computers. On display at the Museum of Modern Art in New York, his score is as much a work of art as an actual piece of music – how (if it all) it should be interpreted is up to any potential performer.

Cage was also one of several artists involved in the Experiments in Art and Technology collective, which included engineers from Bell Laboratories in New Jersey, where Cage would hang out to get ideas. By using chance, he explained, he hoped to avoid the trap of repeating himself in his compositions.

> "For now we're doing [quantum music] in a very naïve way because the machines are limited.
> Bob Coecke, Quantinuum

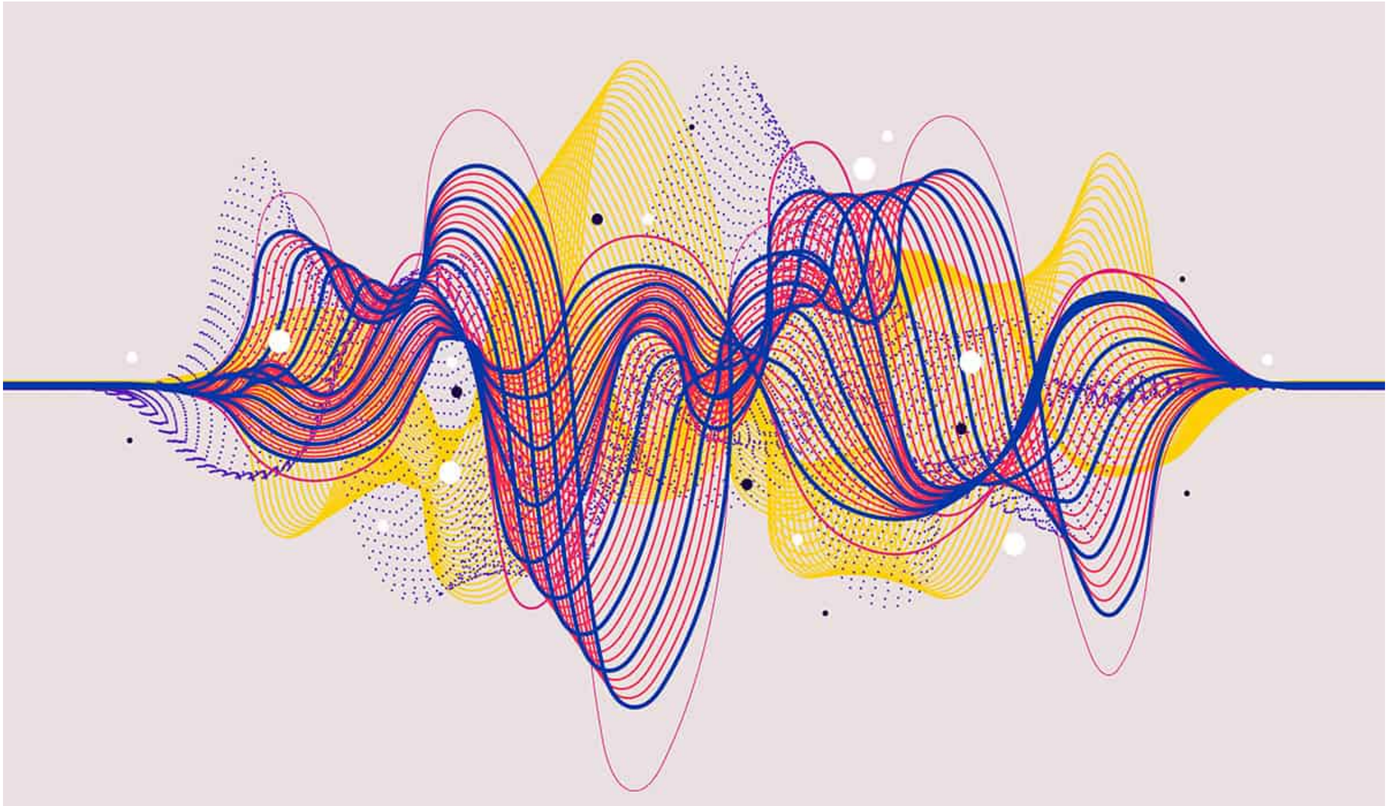
In the 1960s and 1970s the Greek-French composer Iannis Xenakis – a student of the French composer Olivier Messiaen – incorporated computers, algorithms and various stochastic processes into his composing methods. Meanwhile, the Paris-based IRCAM institute, founded by composer Pierre Boulez, became a hub of avant-garde music in the 1970s, making extensive use of computers, signal generators, magnetic tape and other electronic resources.

Digital-information technology is now central to the production and reproduction of mainstream music. Some of the signal-processing algorithms and hardware that are ubiquitous in music and video today were developed at Bell Labs – and it would be hard to imagine the modern music industry without that kind of digital tech. It was surely inevitable, then, that as quantum computers morphed over the last two decades from a theoretical proposal to real machines, musicians would be curious about what these devices might do for them.

A quantum revolution

Publicly available quantum computing resources are, however, relatively limited, so Miranda is restricted to using a seven-qubit, cryogenically-cooled IBM Quantum device housed in New York, accessed via the cloud. Miranda admits that there is nothing, so far, in the quantum algorithms he uses to craft his compositions that couldn't also be simulated with a classical computer. "For now we're doing [quantum music] in a very naïve way because the machines are limited," adds Coecke.

Still, as Miranda explains, some of the algorithms he is developing would already be computationally expensive and slow on classical devices, and hard to implement live in real time in a concert. But speed of computation is not really the main issue when it comes to using quantum physics to compose music. Currently the big appeal of quantum algorithms is, rather, as a source of randomness in musical choices.



Strange impact The weird physics behind quantum computers could transform how we make music. (Courtesy: iStock/Sandipkumar Patel)

As with some earlier computer-based music, particular parameters of the musical score, such as the pitch or duration of a note, can be assigned to random choices made by the machine. But whereas classical computers offer only a kind of algorithmically generated pseudo-randomness, quantum devices access the genuine randomness involved in the outcome of a quantum measurement. The universe, you might say, makes the choices. What's more, this can be done in real time.

> "How do we grow and develop if we don't explore other avenues?
> Craig Stratton, violinist

Miranda imagines a composer assigning a particular algorithm to a piece of music, which is then played out via a quantum computer during a performance. In other words, the quantum computer can be remote, as it was at the London event, but simply sends its measurement results back to, say, a classical tone generator. "You set up the conditions, but you're not completely sure what it will produce until the piece is performed," Miranda says. "The performance will be unique for that particular moment."

The Goethe-Institut event showed other ways in which quantum music might work. In one piece, the British violinist Craig Stratton improvised a short tune. The pitch and duration of each note were represented as quantum states that were then sent to the IBM computer in New York. There, the device processed the states to formulate a response that was "re-musicalized" and played back in London by a tone synthesizer (in that event using a saxophone sound) moments later.

Deep-learning AI algorithms for such musical “call-and-response” improvisation have already been devised. But according to Miranda, those algorithms tend to produce mere pastiches of the music they are trained on. Quantum computers, in contrast, will probably behave “more like a partner than an imitator”. Indeed the computer-generated melodic responses to Stratton’s improvisations sounded little like the stimuli that provoked them, retaining just a few tantalising echoes of the initial sounds.

Stratton, who found the process intriguing, believes that quantum computers certainly have a place in the development of music. “How do we grow and develop if we don’t explore other avenues?” he asks.

Bloch heads

In another piece, Miranda and his Plymouth colleagues Pete Thomas and Paulo Itaborai used various computer interfaces to manipulate “Bloch spheres”. Named after the Nobel-prize-winning physicist Felix Bloch, these spheres are geometrical figures that describe the vector components of a two-level quantum system (the points on the surface being pure states and those on the inside being mixed states). At the London event, Miranda and Itaborai wore a movement-sensing ring and glove to transmit control signals by hand gestures to a laptop, while Thomas used a panel of knobs.

That’s handy By wearing a movement-sensing ring and glove, performers at the Goethe-Institut event in London were able to “measure” the qubit in an IBM quantum computer in New York, thereby “collapsing” it into an output state, the value of which determined the sound generated by three synthesizers back in London. (Courtesy: Goethe-Institut London)

These signals were fed to a quantum circuit running remotely on the IBM quantum computer, which allowed the musicians to rotate the orientation of a Bloch sphere (a visual representation of which was projected onto a screen behind the performers). At certain times the performers could choose to “measure” their qubit, thereby “collapsing” it into a definite but fundamentally unpredictable output state. (You can have a go yourself on a classical simulation of the process at bit.ly/41fXVnr).

> “ The sound that results will always be surprising. We don’t know what it will be until we do the measurement
> Eduardo Miranda, University of Plymouth

The value of this state was then used to determine the parameters of the sound generated by three sound synthesizers assigned to each performer. “The sound that results will always be surprising,” Miranda says. “We don’t know what it will be until we do the measurement.” The three performers then responded to what they heard with their subsequent hand movements, making the outcome a constant collaboration both between each musician and their instrument and also with each other.

Miranda calls the performance a rehearsed improvisation. “We practised it before a few times and agreed to a few things we would do, pretty much like what jazz players do,” he says. On this occasion all three qubits were independent, but Miranda is keen to find ways of entangling the qubits so that each is dependent on the others – making the musicians themselves literally coupled in new ways.

A new kind of music

Melody maker Maria Mannone, who is a theoretical physicist at the University of Palermo, is part of a growing band of researchers at the cross-over between quantum physics and music. (Courtesy: Maria Mannone/Lu Zang)

Harnessing quantum computing for making music is “like learning how to play a new musical instrument” says Maria Mannone, a theoretical physicist working on quantum information at the University of Palermo in Italy, who is also a composer. “We have to learn how to play the music we want, but, at the same time, the specific features of the new instrument can create constraints and suggest particular ideas.”

Miranda suspects that one way to exploit the possibilities is to get a quantum computer to come up with unexpected musical fragments that provide the kernels of ideas for the composer to develop, rather in the way in which AI-generated music is currently being used. “I’m trying,” he says, “to get the machine to give me material that I wouldn’t come up with myself – ideas that I can work with.”

> “Everything, especially in the sciences, can be a source of inspiration
>
> Maria Mannone, University of Palermo, Italy

One of the current obstacles to the expansion of the field is the sheer unfamiliarity and technical complexity of quantum mechanics itself. Miranda’s new book *Quantum Computer Music* is not a manual for the faint-hearted, being filled with wavefunctions and matrix algebra. Musicians will be daunted, while the physicists and engineers who understand the theory tend to have little knowledge of musical traditions.

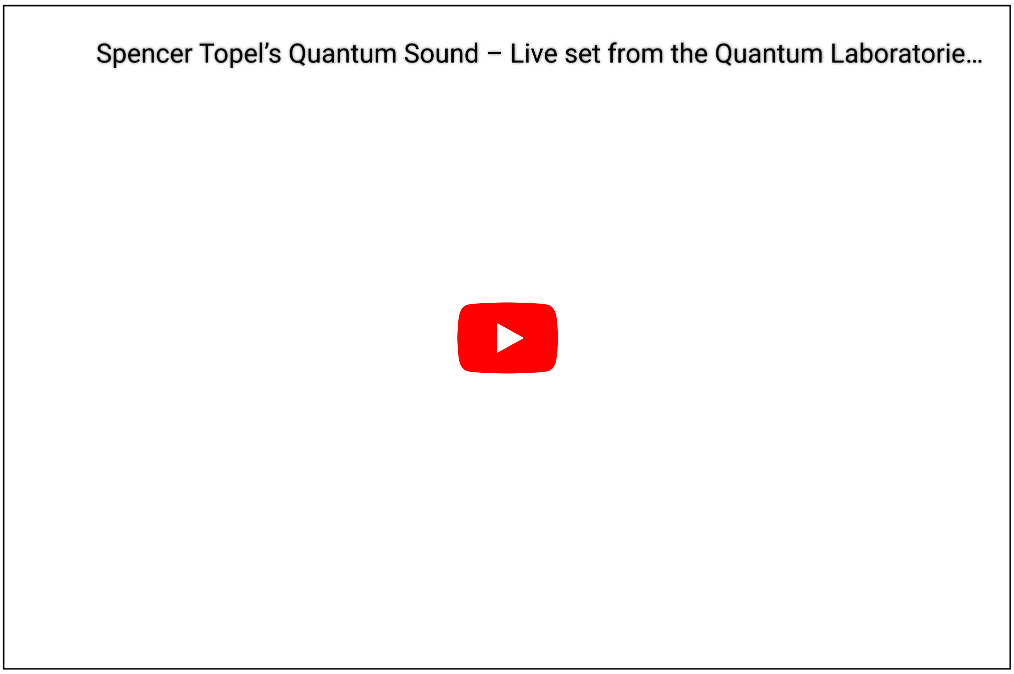
But he hopes that user-friendly interfaces will be developed that will lower the entry barrier, just as they have for computing generally. Miranda’s qubit rotations, for example, are controlled by simple hand gestures, rather like the way in which the theremin – an electronic musical instrument – is played.

Another approach is being pioneered by Jim Weaver, a quantum scientist at IBM’s Yorktown Heights Research Center in New York, who has developed the Quantum Toy Piano. It’s a musical tool that uses a quantum computer to generate melodies and harmonies probabilistically, using the inherent randomness of measuring qubit states to assign the notes.

Weaver has already developed such ideas into the Quantum Music Playground, in which a user-friendly interface allows the user to manipulate quantum states to create multi-instrument compositions. “[People] can fiddle around until the music sounds the way they’d like it to,” Weaver says. “It’s music of the Bloch spheres,” he quips, alluding to the old notion of a cosmic “music of the celestial spheres” (the idea that the relative movements of the Sun, Moon and planets are a form of music).

This system actually runs on a classical simulation of quantum states conducted by a conventional computer, rather than a real quantum device. This is because it requires complete knowledge of the quantum state – which can’t be done for a real qubit because a measurement collapses the state. Weaver, who sees the tool as educational as well as musical, hopes it can help students (and musicians) develop an intuition for quantum-computing algorithms. The work might not only change music but benefit quantum science too.

Another option for overcoming the technical barriers will be for musicians to embed themselves in the quantum research community. That's the approach taken by the American composer Spencer Topel, who in 2019 was artist-in-residence at Yale Quantum Institute, home to quantum-technology experts such as Michel Devoret and Robert Schoelkopf. During his stint at Yale, Topel created a live performance in which the music was produced from measurements of the dynamics of the superconducting quantum devices used as qubits in most current quantum computers.



Musicians could benefit from learning a bit of quantum mechanics, too. "Composers have to be knowledgeable," Mannone points out, "because everything, especially in the sciences, can be a source of inspiration." Indeed the level of knowledge required need not be so daunting. As she points out, some of those now writing quantum code for other applications "do gorgeous work while having only a basic knowledge of quantum gates and principles".

In her own work, Mannone has used quantum physics to analyse music – for example, by using a technique developed to quantify the memory of open quantum systems to measure the amounts of repetition and similarity that appear in musical compositions (*Journal of Creative Music Systems* doi.org/10.5920/jcms.975).

Hear all about it

If you're wondering where you might be able to hear quantum music for yourself, Miranda has his sights set on a live performance at a concert hall through a forthcoming collaboration with the London Sinfonietta. He also foresees this kind of composing infiltrating less formal settings such as clubs, perhaps via the "live coding" movement, a new performance art in which DJ-like coders write programs to control audio-visual media in an improvised and interactive way, perhaps combined with dance, poetry and music (you can listen to an example at bit.ly/3Z8hUDg).

To stimulate the growth of the community, in November 2021 Miranda collaborated with IBM Quantum and Quantinuum to host the first International Symposium on Quantum Computing and Musical Creativity. "We don't yet know what the possibilities for quantum music are," said Quantinuum's founding chief executive Ilyas Khan in the Goethe-Institut event – and it may be that as quantum music matures it will bear little resemblance to what today's pioneers are doing. "These first two to three years are experimental," he says.

Miranda hopes that it might become possible to express – in sound – quantum concepts such as entanglement and coherence that are hard to intuit intellectually. "That's the holy grail," he says. "I want to achieve this but I don't know how." But for Coecke, it's all about catalysing a switch to quantum thinking. "If you put things together in the quantum world, suddenly a new universe of possibilities emerges."

Philip Ball is a science writer based in the UK, whose latest book is *The Book of Minds* (2022), e-mail p.ball@btinternet.com