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Towards a quantum theory of musical creativity

Matthew Lovett

Abstract

The theoretical physicist Karen Barad's 2007 book *Meeting the Universe Halfway* was something of a manifesto for using a range of learning taken from quantum theory to rethink how it is that we understand ourselves and our place in the universe.

This chapter embraces Barad's challenge to *rethink thinking*, and puts forward a toolkit for rethinking musical creativity in terms of a set of quantum concepts. In an era when technological disruption is changing music making and music consumption beyond all recognition, we must ensure that our understanding of music remains equally contemporary, and forward-focused.

In Barad's reading, quantum theory equips us with a range of concepts and structures with which to understand how the paradigm works, including diffraction, entanglement, measurement, complementarity; all of which lead to a reconfiguration of accepted notions of 'objectivity' and 'phenomena'. In this paper, I apply these terms to musical creativity, to build a conception of a musical artefact as a 'quantum phenomenon'. In addition, the paper problematises traditional notions of authorship in the light of both quantum objectivity, and Barad's own neologism, agential realism.

Introduction

Writing about music has never felt so urgent to me. Much of my recent work has been concerned with the way in which music - whether we like to think of it as a creative practice, an industry, or, in the words of Jacques Attali, an 'immaterial pleasure' (Attali, 1985: 5) - is evolving; as familiar approaches to making, listening to, sharing and thinking about music are disrupted by technological change. As such, it is important to preface this chapter by framing it as part of a wider project that takes an experimental approach, on one hand, to developing insights into the nature of musical creativity, and on the other, to building a conceptual toolkit that can be used to describe music, along with processes involved in making it.

In the book *Meeting the Universe Halfway*, the theoretical physicist Karen Barad, presents a wide-ranging analysis of quantum physics that redefines the relationship between the movement of electrons and everyday acts of thinking and making things, thereby generating a materialist-realist philosophical model which she describes as 'agential realism' (Barad, 2007: 177). Her analysis enables her to place the act of making in a dynamic relationship with a broader consideration of the nature of time, suggesting that at a fundamental level, things are not simply made against a backdrop of constant time, but that things and time are created as part of an ever-changing topology of what she calls 'spacetime-matter' (Barad, 2007: 177). In addition, the book argues for an holistic conception of making that Barad terms 'intra-action', that encompasses the impacts and impressions that are 'made' by particle collision, along with archetypal human mark-making, through to the production of both human consciousness and the universe itself (hence the ambition of the book's title). As a musician, what interests me about Barad's work in this area, is that by extension, we can draw some conclusions about how the production of music can also be understood in the light of what we could call 'quantum thinking'. In what follows, via a close reading of a number of Barad's key terms and concepts, I set out to forge some basic principles of a quantum theory of musical creativity.

1) Quantum Thinking in context: Speculative Realism and Non-Philosophy

In putting forward a case for a quantum theory of musical creativity, the chapter is designed to recognise that such a theory is not only simply a contention, rather than an explanatory formulation that can stand for all

time, but that it is also only ‘a snapshot of a snapshot’. In other words, the ideas presented here reflect their own locatedness in time, along with their inability to apprehend anything more than a fragment of the critical and philosophical debates that are continually emerging from a range of global thinking practices. Just as any piece of music could be seen to be a composer’s or a performer’s ‘best approximation’ of all that is available to them at a given moment in time, so too does any formulation of thought represent a theorist’s best attempt to harness and apply a range of available formulations in a way that is intended to shed new light and offer new perspectives on - in this case - creative music practice.

The chapter is not intended as a philosophical genealogy, but there are two key innovations in contemporary thought that provide a useful context for Karen Barad’s work, demonstrating not only that there is a shared ancestry between recent practices in scientific and philosophical thinking, but also, that there is a conceptual landscape where shared ideas and themes - if not particular terms and strategies - are clearly in evidence. Barad’s book was published in 2007. That same year, a set of philosophical debates and ideas began to emerge around the idea of ‘Speculative Realism,’ after the ‘Speculative Realism Workshop’ was held at Goldsmiths, University of London (Urbanomic, 2007). The workshop brought together four key theorists, Ray Brassier, Graham Harman, Iain Hamilton Grant and Quentin Meillassoux, and in hindsight can be seen as a point of departure for much of what has informed current debate regarding materialist-realist thought.

Speculative Realism has come to stand for set of heterogeneous ideas and ambitions within continental philosophy, and is a term that has enabled a wider set of thinkers to begin to interrogate a particular way of orienting human thought to the world. In their own way, each of the four workshop participants formulated a perspective that facilitated the ‘speculative turn’ wherein it is understood that human thought is able to conceive of that which is not the product of human thought. This was the premise that gave the workshop, and the subsequent movement its name; the notion that beyond human thought, there is an absolute reality that does not have a provenance in that thought. Meillassoux’s book, *After Finitude*, explored this contention extensively, and one of his lasting contributions to the Speculative Realist debate was the idea that there is a ‘Great Outdoors’ to thought: that which is available to human imagination, but is wholly not the product of human imagination (Meillassoux, 2008: 7). As we shall see when we encounter Barad’s work, this sense of internal-externality is also a feature of her vision for agential realism, albeit couched in a markedly different way, indicating a wider recognition of this conundrum that goes beyond the scope of pure philosophy. Although debates have moved on, the influence of Speculative Realism can still be discerned in the work of a range of contemporary theorists, including Reza Negarestani (2014, 2018) and Timothy Morton (2013, 2018), whose work continues to investigate the complex relationship between human thought and the world of lived experience.

Where the Speculative Realists argued that human thought must be able to access something which is fundamentally ‘outside’ it, another continental philosopher, François Laruelle, whose career spans the early 1970s up to the present day, had also been engaged in a similarly radical project to develop the idea of ‘non-philosophy’. Across two relatively recent books, *The Concept of Non-Photography and Photo-Fiction, A Non-Standard Aesthetics*, Laruelle formulated the term ‘photo-fiction’, a concept designed to express the view that ‘the photo is not a degradation of the World, but a process which is “parallel” to it’ (Laruelle, 2011: 19). Laruelle’s wider project is beyond the scope of this chapter, but importantly, his innovations in this area do allow for a considerable orientation to towards creative practice, and his suggestion that we are ‘waiting for perhaps a music-fiction’ (Laruelle, 2012: 2), indicates the value that his insights might have for a study of music making. In *Photo-Fiction*, Laruelle also takes up an extended engagement with quantum theory, putting forward a sustained narrative that connects creative practice with his own conception of superposition:

‘[Photo-fiction] produces a fusion as superposition ... of the camera on one hand and philosophical discourse on the other, or even still of the photographer and the philosopher’ (Laruelle, 2012: 11-15).

Although Laruelle does not use the term ‘superposition’ in the strict sense that we shall encounter in Barad’s work, he nevertheless clearly acknowledges that it is a means of recognising and communicating how, at the moment a photograph is taken, a fusion occurs, of all of the component parts of that photographing moment. The camera, the photographer, the discourse of the discipline, the theoretical insights that set the determining features of the framing process; all this and more are in superposition, meaning that the outcome of the photographing process is, for Laruelle, temporarily unknowable.

At the same time that this contingent of continental philosophers had been engaged in developing speculative realist and non-philosophical treatises, Karen Barad had been exploring other aspects of poststructuralist theory, and wedding it to her own background in theoretical physics. However, what emerges from her work is a set of conceptual tools and analytical frameworks that demonstrate remarkable commonality with many of the conclusions arrived at by those working in Speculative Realist and non-philosophical discourses.

2) Diffraction and entanglement

Barad’s project presents a set of technical terms and concepts that are drawn from quantum physics, and uses them as a basis for building her own epistemological and ontological model of ‘agential realism’.

Underpinning almost all of the narratives that run throughout *Meeting the Universe Halfway* is Barad’s articulation of the work of two physicists, Niels Bohr and Erwin Schrödinger, and the book draws on Bohr’s work relating to the ‘wave-particle duality paradox’ (Barad, 2007: 83), and Schrödinger’s conclusions about the relationship between entanglement and observation (Barad, 2007: 276).

In simple terms, the wave-particle paradox refers to Bohr’s theoretical conclusions about the nature of electrons that he draws from his now famous ‘two slit’ thought experiment. Bohr did not perform this experiment, as he lacked the necessary resources, nevertheless, he painstakingly mapped out the imagined components and conditions. In this hypothetical, ‘gedanken’ experiment, a series of electrons are fired individually from a source towards two slits that stand in front of a screen that captures and show the final positions of the electrons (Barad, 2007: 267). In version one of the experiment, the arrival of the electrons is displayed on the screen in an interference pattern that suggests that a wave has hit the screen, rather than a series of individual particles. However, the electrons have been fired individually so this interference should not be possible. For Bohr, this suggested that the electrons had travelled through both of the two slits simultaneously. In the second version of the experiment, one of the two slits is adjusted in such a way that it is possible to detect which of the two slits the electrons have travelled through. This experiment, which has come to be known as the ‘which-path’ experiment, further complicates the situation. In this version, the electrons do arrive at the screen in a particle-like diffusion pattern. Barad refers to this as a ‘mixture’ (rather than an interference pattern, or a diffraction pattern), wherein each electron has a determinable position (Barad, 2007: 264). What Bohr’s experiment aimed to demonstrate, and what later experiments with quantum optics have proved, is that atomic and subatomic matter exhibits both particle-like and wave-like behaviour depending on how it is being observed (Barad, 2007: 307). It is this phenomenon sits at the very heart of quantum theory, and it is the underlying principle that Barad draws on throughout the book.

Barad also makes a sustained engagement with the concept of diffraction, which for her, denotes the way in which waves overlap and disturb each other:

‘Diffraction is a phenomenon that is unique to wave behaviour. Water waves exhibit diffraction patterns, as do sound waves, and light waves. Diffraction has to do with the way waves combine when they overlap and the apparent bending of and spreading out of waves when they encounter an obstruction’ (Barad, 2007: 28).

Indeed, from the examples she gives here, through to the wave-like behaviour of quantum objects, at the core of her work is a commitment to understanding the fundamental mechanics of the material world in terms of a diffractive ontology. In a technical sense, superposition occurs when the amplitudes of two overlapping waves combine to create a resultant wave, indeed for Barad, ‘diffraction patterns are evidence of superpositions’ (Barad, 2007: 83). Diffraction is categorically different from interaction, and Barad’s wave-based ontology operates on the principle that there is no preexisting form or identity that gives shape or

direction to a wave. Instead, everything that we understand to be the real world is the result of wave diffraction. As the basic building blocks of the world, it is therefore important to recognise that waves are not 'things', waves are disturbances; they are diffractions that continually overlap with other waves.

The nature of entanglement is also central to the model of quantum physics that Barad builds, and another foundation for her approach is the idea that 'space, time and matter do not exist prior to the intra-actions that reconstitute entanglements' (Barad, 2007: 74). In this regard, she moves more fully into an analysis of the key principles of quantum theory itself. But what is an entanglement? An entanglement, Barad informs us, which is a feature of quantum rather than classical physics, 'is a generalisation of a superposition to the case of more than one particle' (Barad, 2007: 270). Thus, if superposition denotes the combination of overlapping waves, then entanglement denotes a situation where particles interact (or 'intra-act'), and it becomes impossible to account for individual particles, separate from their *entangled* state.

A vital consequence of Barad's reading of entanglement and diffraction, is that there is no difference whatsoever between the realms of the 'discursive' and the 'material' (Barad, 2007: 63). In Barad's account - which here draws on the work of both Michel Foucault and Judith Butler - both matter and meaning result from diffraction of meaning and matter; there is no categorical separation. Furthermore, Barad's ontological model is topological, and she proposes another neologism - 'spacetime mattering' (Barad, 2007: 179) - as a means to convey this fully entangled process that results in the production of time, space, matter and meaning. Also worth noting is Barad's view that there can be no distinction between the 'quantum' world of atomic and subatomic diffraction, and the world that we normally experience (a world traditionally described in terms of so-called 'classical physics'). The distinction is not a matter of *type*, it is simply a matter of *scale*: Barad's point is simply that atomic and subatomic behaviour is too small for humans to recognise. Thus, everything that exists - and everything that we experience - is the product of entanglement at a quantum level (Barad, 2007: 279). With the production of meaning and matter couched in such a way, the implications for thinking about the production of music as both a material phenomenon and a discursive practice are clearly considerable.

3) Indeterminacy and complementarity

The problematic nature of objects is another fundamental part of Barad's modelisation process. In this context, she works through a set of principles and concepts that relate to entanglement, indeterminacy, superposition and complementarity; often extending or modifying the contributions and ideas of Niels Bohr. Bohr is not without his critics in the wider field of theoretical physics, and indeed Barad acknowledges certain 'ambiguities' in his work with regard to 'correspondences [...] between theory and reality' (Barad, 2007: 122-3). I shall therefore make use of Barad's references to Bohr in the spirit in which she herself uses his work: as fundamental to current knowledge and understanding, but not without its limitations.

As she works deeper into the problematic nature of substance and determination that lies beyond a normally appreciable experience of the world, Barad brings into play the concept of complementarity:

'Bohr's indeterminacy principle can be stated as follows: the values of complementary variables (such as position and momentum) are not simultaneously determinate. The issue is not one of unknowability per se; rather it is a question of what can be said to simultaneously exist' (Barad, 2007: 118)

Throughout *Meeting the Universe Halfway*, Barad makes reference to the fundamental impossibility of measuring 'the position of a particle' (Barad: 2007, 109). If we wish to measure a particle, then we must be able to accurately account for its position, a measurement which itself can only be accurately captured if we also take into account the particle's momentum. However, following Bohr's principle, Barad informs us that a particle's position 'is determinate if and only if it is measured using a fixed platform'; whilst momentum can only be 'defined by an apparatus with a moveable platform' (Barad, 2007: 112). Barad also introduces

the concept of ‘complementarity,’ describing it as ‘the impossibility of drawing any sharp separation between an independent behaviour of atomic objects and their interaction with the measuring instruments’ (Barad, 2007: 308). What is at stake for Barad is that, because of complementarity, it is impossible to accurately measure anything, or precisely determine its exact position. In her exposition of Bohr’s analysis of the problematic nature of measurement, Barad describes the way in which position ‘must be defined by the circumstances required for its measurement’ (Barad, 2007: 111). Given what we now understand as the all-encompassing nature of quantum physics - that it is a theory which explains all of how the material world functions, not just selected parts of it - this ‘measurement problem’ must therefore have a bearing both at the quantum level, and at the level of everyday experience. Thus, it is important for us to recognise that any act of measurement will always impact on the object that is being measured.

Having laid the groundwork for how to understand the problematic nature of measurement, Barad then extends her analysis to put forward a claim about ontology. Acknowledging that it is impossible to measure things without the measurement apparatus impacting on the things that are being measured ‘entails a rejection of the classical metaphysical assumption that there are determinate objects with determinate properties and corresponding determinate concepts with determinate meanings’ (Barad, 2007: 127). Fundamentally, Barad is suggesting that, because it is impossible to measure something without creating problems and contradictions (as demonstrated by the impossibility of measuring position and momentum simultaneously), it must follow that there can never be an ultimate or absolute meaning for something. Measurement, and therefore meaning, must always be indeterminate. This is not to say that objective statements cannot be made about the world, for as we shall see, her agential realist model is designed to engage with that particular problem. However, objectivity is more complex than simply imagining that there are actually existing things-in-themselves.

One of the critical outcomes of Barad’s analysis of measurement is the contention that meaning is always something that comes into effect once something is being measured (or experienced). Meaning cannot exist in and of itself, because there is never a definite point where indeterminacy does not exist; in other words, there is literally no absolute and definite point, or moment, of complete determination (of meaning). Thus, Barad informs us, all of the components that make up the measurement-experience are what qualify as a ‘phenomenon’ (Barad, 2007: 139). In this sense, we can begin to understand Barad’s ideas in relation to Laruelle’s work on superposition, and indeed what we have already seen Barad exploring in terms of diffraction. Whether we are discussing a photograph or a piece of music, created artefacts - just like particles - do not have an objective or inherent meaning; there is always something indeterminate about them, and what is more, our act of listening cannot but help be framed by our own inherent indeterminacies, which manifest as certain ‘ways of listening’. Indeed, taking Barad’s point further, it is also essential to recognise that we ourselves are superpositions and processes of diffraction. Just as there is no absolute sonic object that we might choose to listen to, neither is there an absolute vantage point that we are listening from. Our listening is an entangled process that itself is both indeterminate and a constantly reforming topology: the things we listen to and the process of listening continually reformat the way that we listen, or in Karen Barad’s words, ‘we are part of that nature that we seek to understand’ (Barad, 2007: 26).

4) Apparatus as instrument; measuring as making

With these core components for engaging with quantum theory, we can now begin to apply a more theoretical approach to considering the possible consequences for musical creativity. As we have seen, whenever a measurement takes place, there is always some form of interaction between the measuring device and that which is measured. In other words, the act of measuring disturbs what is being measured and influences the results of the measurement. Barad’s analysis of the nature of measurement and of measuring devices, or apparatuses, is therefore of huge value when thinking about creative processes. Not only does this aspect of her work provide insight into how an apparatus might interact with the object of measurement, but it also enables us to further (re)define how we understand what ‘measurement’ might mean.

A conventional view of measurement would suggest that a device of fixed dimensions and properties is used to measure another fixed object whose dimensions we do not yet know. However, what Barad's analysis of quantum behaviour shows is that, not only it is impossible to make a measurement without impacting on the object being measured, but that there can be no such thing as a determinate object. Barad provides a number of practical examples to illustrate the problematic nature of measurement in practice, including Don Eigler's use of a scanning tunnelling microscope, a device used to 'sense the presence of an individual atom' (Barad, 2007: 355), along with the experiments conducted by Scully et al using 'quantum erasers' (Barad, 2007: 310). These experiments were designed to further interrogate the wave-particle paradox by first monitoring the movement of photons being emitted by an atom, and then erasing that information. The result was that, as with the 'which-path' experiment, when photons are observed as particles, then they behave as particles, and when they're left undetected, or when any trace of detection is erased, then they behave as waves.

This paradoxical behaviour gives rise to Barad's contention that measuring is a form of mark-making. Whilst it remains the case that 'measurement' is not the same as 'making', Barad nonetheless enables us to understand that measurement to some extent involves construction and fictioning, and in this way, her work brings together notions of making, marking and measuring, to create a continuum of productive principles. What is more, she extends the point to suggest that mark-making is a form of meaning-making. It is this relationship that enables Barad, as we have seen, to draw a line that connects discourse and matter, thus presenting us with the idea that the discursive and the material are each completely involved in the formation of the other.

Barad frequently returns to the phrase 'marks on bodies' (Barad, 2007: 232), which is a reference to the way in which one body, or thing, interacts with another body, and in so doing a trace of that interaction is left on each body. The example of the scanning tunnelling microscope demonstrates this in a practical way, whereby the same technology that is used to sense an atom can also be used to manipulate an atom, so for Barad there is a very real question around the relationship between sensing and mark-making. What is more, the phrase 'marks on bodies' directly correlates with Barad's claim about the entangled nature of matter and meaning; such that marks on bodies become the ultimate trace of the superposition of the discursive and the material. In a detailed exposition on the nature of apparatuses, Barad stresses the importance of recognising the deep involvement that measuring apparatuses have with the objects of measurement. Indeed, she contends that 'concepts obtain their meaning in relation to a particular physical apparatus' (Barad, 2007: 120), and as part of a list of attributes of apparatuses, she suggests that 'apparatuses produce differences that matter - they are boundary-making practices that are formative of matter and meaning, productive of, and part of, the phenomena produced' (Barad, 2007: 146). So saying, Barad's affirmation of the non-neutrality of apparatuses indicates that not only do we come to see something in a particular way because of the way that we are looking at it, but, because there was not a determinate thing that existed before the point of observation, the apparatus of observation is actually part of the thing that is being observed. The apparatus therefore not only influences the thing that is observed, it produces it. This is the intrinsic 'boundary-making' property of the apparatus, which from an opposite viewpoint can be taken to mean that any instrument - a guitar for example - can be thought of as an apparatus of measurement. A guitar is not only a luthier's 'best approximation' of acoustics, harmonic theory, woodwork, metalwork and electronics, but when used to create music, it is also the musician's measurement apparatus to take a reading and express the results of their understanding of and facility with a number of discourses, including harmonic theory, manual dexterity, melody writing, chord voicing, stylistic knowledge to name just a small number of variables that are pertinent to playing an acoustic guitar. Making a guitar, and making a piece of music are acts of 'boundary making', and a guitar and a piece of music are phenomena in the way that Barad describes. Both are the result of a significant number of material and discursive practices, and both can be said to 'produce' the guitarists and the listeners that engage with them. A human who has learned to play the guitar, could be said to have been 'guitarred', and someone who has either written a piece of music or had a focused experience of listening to a piece of music could be said to have been 'musicked'. This blurring of the boundaries between

the observation device and the observed is critical to a broader understanding of the implications of using quantum theory to think about creativity and the production of meaning. It is worth quoting Barad at length to see the extent of her vision in this regard:

‘Since there is no inherent distinction between object and instrument, the property measured cannot meaningfully be attributed to either an abstract object or an abstract measuring instrument. That is, the measured value is neither attributable to an observation-independent object, nor is it a property created by the act of measurement. [Therefore] measured properties refer to phenomena, remembering that the crucial identifying feature of phenomena is that they include “all relevant features of the experimental arrangement.”’ (Barad, 2007: 120).

This passage demonstrates that it is the measurement process itself, including all of the issues that complementarity throws up, that comprises and defines ‘real’ experience. The fact that an experience is not observer-independent, does not make it less real, or less authentic. Rather, it is this very act of complicity between measurement and measured that produces the ‘real’ phenomenon. And to return once more to ‘marks on bodies’, it is therefore vital to recognise that making and playing guitars, and making and listening to music are all phenomena that reveal that music does have a part to play in the reconfiguring of bodies. But this does grant music any special status: music, just like every other phenomenon, cannot help but continually do this.

If we accept Barad’s significant problematisation of the nature of determinable bodies, and the intertwined nature of observer-observed interactions, then how do we make an account for objective reality? There are certain resonances between Barad’s perspectives on the relationship between creative processes and entanglements and Laruelle’s ideas about the production of photo- and music-fictions via superposition. However, her commitment to the deep entwinement and interdependence of the world’s material and discursive components does suggest that Meillassoux’s radical innovations to prove the existence of an actually-existing objective real that sits *outside* of human thought, may bear some reconsideration.

5) Objectivity, intra-action, agential realism

To complete this construction of a beta ‘quantum toolkit’, we can therefore turn to Barad’s perspectives on objectivity, which will include an acknowledgement of her broader ambition to construct a new philosophy-physics. What becomes clear from Barad’s questioning and analysis of critical theory and the collected histories of quantum physics, is that, for her, these lines of enquiry always fall short of their real potential to construct a far more radical view of the mechanics of the world. Rather than falling short herself of a fuller articulation of what could be called a ‘radical objectivity’, she instead develops two terms - ‘intra-action’ and ‘agential realism’ - in order to describe and explain what an ontology based on quantum theory could look like. Of paramount importance here, is that Barad argues against one of the most widely recognised theories in quantum physics, the theory of wavefunction collapse, as immortalised in the image of ‘Schrödinger’s Cat’. The cat in question was in fact another gedanken experiment, designed by Schrödinger to illustrate how, upon observation - similar to Bohr’s ‘which-path’ experiment - a wave would ‘collapse’ into an observable state. The famous analogy is that, prior to observation, depending on whether or not poison has been released into a box in which a cat has been sealed, the said cat is both alive and dead. Schrödinger’s point was that the ‘blurring’ that takes place at the microscopic level, wherein a wave does not exhibit particle-like behaviour until it is observed (or ‘collapsed’), cannot hold at the macroscopic level of ‘everyday’ reality (Barad, 2007:276). Barad reports that for Schrödinger, it was ‘quite ridiculous’ to think that it would be possible to imagine a cat in a box existing in a manner that was analogous to a uncollapsed subatomic wave, and the experiment was designed to illustrate this (Barad, 2007: 276-7).

However, Barad, steps beyond Schrödinger’s - or indeed Bohr’s - terms of reference to claim that ‘there is no “collapse” that transforms a superposition or entanglement ... into a definite state upon measurement’

(Barad, 2007: 345); we do not step out of an entangled state to observe the world in an objective manner. In short, the collapse never happens. Instead, the world is a relentless series of entanglements and superpositions - diffractions - that simply involve each other in a never-ending continuum of topological change. To return to an earlier analogy, what we might have previously understood to be a collapse of a wave into a particle formation, is instead simply a 'snapshot' of a moment. Understanding entanglement and superposition as constituent parts of an ongoing topology means that, not only do we see particles rather than waves because we are looking for particles, but the entire moment within which the snapshot occurs is also produced by the taking of the snapshot. Again, this is what Barad means by the term 'spacetime mattering', in that everything about the registering of particles on a screen in Bohr's hypothetical experiment is simultaneously the product and the producer of a point on a topology. This provides us with another compelling opportunity to think about music. As an explicitly time-based activity, a piece of music not only has a duration, which can be measured against already-existing clock-time, but it also creates its own topological timeframe. In this regard, we can understand how music happens within a given temporal timeframe which is itself a phenomenon, but music also creates the time that it exists in, which is to say that music makes 'marks on bodies' in the way that it 'times' our experience and 'times' the world. A composition understood as a time-based sonic phenomenon will clearly draw on a wide range of available materials, but it is Barad's contention that the phenomenon consists of specific components such as location, environment, time of day, listening equipment that do not simply affect the quality of 'the listening experience', but determine the nature of the phenomenon. It is a question of recognising what the experience of listening to a piece of music is. As a phenomenon, it is not something that is limited to the relationship between a listener and a set of sounds. Instead, the entanglement that forms the topological moment of listening to a piece of music will always be comprised of multiple parts, of which the listener and the music itself are just a small number.

To return to the subject of objectivity, Barad is clearly aware of slipping all-too-too easily into a solipsistic mode, and points out that although 'there is no absolute condition of exteriority to secure objectivity [...] this doesn't mean that objectivity is lost. Rather, objectivity is a matter of exteriority-within-the-phenomenon' (Barad, 2007: 345). So saying, Barad affirms that the non-human and non-subjective are still radically present within phenomena. What is more, we are part of that exteriority, and at the same time, it is part of us and the things that we make. Because there are no determinate 'things' in the world, with inherent properties, then it is difficult to apprehend such an 'exteriority-within-the-phenomenon,' but Barad counters this by referring back to the idea of mark-making:

'Objectivity is a matter of accountability to marks on bodies. Objectivity is not based on an inherent ontological separability, a relation of absolute exteriority, but on an intra-actively enacted agential separability, a relation of exteriority within phenomena' (Barad, 2007: 340).

Recognising that exteriority is not an already-existing phenomenon, Barad makes use of the notion of intra-activity to convey how exteriority is produced within a diffractive process. Intra-action is different from interaction, in that interaction suggests that two or more self-contained bodies are engaging with each other, whereas intra-action speaks of a process whereby two or more bodies are produced as a result of their overlapping. Again, the importance of Barad's commitment to the simultaneous processes of producing and being produced cannot be over-emphasised here, and it is her contention that humans, as much as pieces of music, are entanglements and superpositions, rather than clearly delineated and sealed formations, which means that we do not ever stop being bound up and produced by the other entanglements that we become entangled with.

Exteriority and agency are thus key to Barad's model, and she stresses that in an agential realist model, 'agency is not aligned with human intentionality or subjectivity [...] Crucially, agency is a matter of intra-acting; it is an enactment, not something that someone or something has' (Barad, 2007: 177-8). Again, Barad returns to the notion that exteriority and agency are produced by certain, local conditions, and that just as a

phenomenon encompasses all of the elements that led to its production, which means that it could exist at no other point in space and time than where it happens to be, then so too is exteriority absolutely conditioned by its time and place of emergence. Thus, a subjective experience of a phenomenon is therefore part of the objective instantiation of that phenomenon. In Barad's model, subjective experience is part of a coming-into being of an objective exteriority, and vice-versa. With reference to the way in which apparatuses produce boundaries and delineations, Barad defines a measurement as an 'agential cut', and states that such a cut,

'provide[s] a contingent resolution of the ontological inseparability within the phenomenon and hence the conditions for the objective description: that is, it enables an unambiguous account of marks on bodies, but only within the particular phenomenon' (Barad, 2007: 348).

This passage contains all of the relevant components of the agential realist model: the components of a phenomenon and the phenomenon itself are contingent, there is no underlying, absolute reason for things being the way they are; the components of a phenomenon are inseparable, and as much as they come together to produce a given phenomenon, each component is concurrently producing and being produced by every other component; every phenomenon is particular, and although there is no underlying, pre-existing cause or reason for a phenomenon existing in a particular way, a phenomenon cannot be other than it is, the component parts make it what it is in all of its specificity; and finally the agential cut produces an unambiguous account, because it is a measurement both of the phenomenon, and of the production of the phenomenon, and in so doing, the agential cut acknowledges its own role in that production process. Thus to an extent, Barad is building a model that acknowledges the problems of comprehending and engaging with that which is contextual and located, and at the same time completely contingent.

Conclusions

We are, and will always be, inside phenomena. We can never look at, or listen to the world from the outside, although the outside is always part of any phenomenon that we make. What is essential for thinking about musical creativity in terms of quantum theory is that we recognise the importance of locatedness and specificity. Making and listening to a piece of music involves a vast number of components, and yet it will always be 'this' piece of music that we make or listen to, and only 'this' piece. Making a piece of music draws on all available resources, perhaps in a way that we had not previously recognised, and this making process 'cuts' into the world, leaving traces that affirm that for all we might want to think that listening to music is a matter of personal taste, music 'musics' us. Barad informs us that the physicist Max Planck understood energy to be 'quantised' and exchanged in discreet amounts, often too small for us to register. She also says that 'we don't notice the furniture being rearranged in a room when we switch the light on', although strictly speaking, this is what is happening (Barad, 2007: 108). Whilst its effects might be too small to notice at times, not only is music part of the world we make, but it is part of the world that makes us; indeed, *music makes the world that makes us*. Although this chapter has only provided an initial mapping of opportunities for generating a quantum theory of music, it is clear that thinking about music in terms of superposition, entanglement, exteriority, topology and mark-making can recalibrate a number of seemingly familiar narratives.

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