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Article

Notes aren't real: An anti-framework for entangled instrument design

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Abstract

Interest is growing in how relational ontologies and more-than-human design methodologies – so-called 'entanglement' theories – might inform digital music research. To what extent does the growing popularity of such theories portend a change in technical or musical practices versus putting new gloss on long-standing ideas? Can or should entanglement theories be distilled into concrete design frameworks? This paper starts from the opposite premise: rather than offering an unambiguous roadmap for designers, entanglement theories are at their most powerful in destabilising ideas and worldviews that have become so ingrained as to become invisible. In digital musical instrument (DMI) design, this barely visible infrastructure consists partly of an ecosystem of stable, context-agnostic concepts about music: analytical descriptors such as notes, pitches, onsets and gestures which get inverted into the building blocks of sound-producing technical systems. However, design is not as simple as inverted analysis. This paper argues that treating familiar musical concepts as authoritative is responsible for several long-standing conundrums facing DMI research. The paper juxtaposes ideas from entanglement literature with brief vignettes concerning instruments new and old, arguing that musical instruments enact the very concepts they take as pre-existing, and that everything about musical discourse and practice should remain up for grabs.

Keywords: Agential realism; digital musical instruments; entanglement; MIDI; music technology

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1. Introduction: conspiracies and critiques

In 2017, in a flippant response to right-wing protesters at a US political rally, Peter McIndoe created the satirical conspiracy theory *Birds Aren't Real*,[1] alleging that the US government has systematically replaced all birds with drone replicas designed to spy on the American public. The fake conspiracy has grown to internet meme status, with a large social media following, a substantial merchandising operation, and physical-world manifestations including billboards and protest rallies. Though facetious, Birds Aren't Real serves as a pointed commentary on the fragmentary and low-trust information landscape of the present era, where claims seem to circulate at breakneck speed in direct proportion to their outlandishness.

This title of this paper, *Notes Aren't Real*, began as an exercise imagining what a similarly farcical but more esoteric conspiracy theory might look like in the rarefied niche of digital musical instrument (DMI) design (Figure 1). But upon living with the phrase, I became aware of a different level on which it might operate, as an invitation to meticulously unpick facets of musical practice that seem so obvious as to be entirely beyond question. In doing so, this paper seeks to enact a kind of *anti-framework* for instrument design: where the design frameworks commonly published in the human–computer interaction (HCI) and DMI design literature propose knowledge structures to guide and shape future research, this paper instead proposes that basic conceptual infrastructure such as notes, pitch and onsets *already* form a contextual and non-universal framework, and that alternate frameworks could exist.

This paper joins a growing tradition of critical enquiry within DMI research, including the coexistence of scientific and artistic research methodologies (Green 2014; Gurevich 2016), the complex political and epistemological stances of the NIME[2] community (Hayes and Marquez-Borbon 2020), its relationship to past eras of industrial engineering (McPherson et al. 2024) and present-day political-economic agendas of commercial instrument design (Morreale et al. 2020), and the problematising of rigid HCI-like success criteria for new instruments (Gurevich and Treviño 2007; Rodger et al. 2020), to name only a few. Like many of those papers, my proposition is not that instrument designers *should* follow a prescribed set of steps, nor that they *shouldn't* engage with the familiar conventions that come under the microscope in this paper.

Rather, responding to Snape and Born's contention that experimental digital music tools risk situating artistic practices within 'familiar and consolidated technical-and-aesthetic universes' (Snape and Born 2022: 246), I speculate that challenges of aesthetic clustering (and even music technology clichés) might extend deeper still, to the conceptual vocabulary we use to describe music and the way we take language to be a representation of pre-existing worldly phenomena. By treating even the most familiar concepts as acts of designerly responsibility which open specific

[1] https://birdsarentreal.com/

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[2] The International Conference on New Interfaces for Musical Expression (NIME) has been a particular locus of critical perspectives on musical instrument design in recent years.

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Figure 1. A new (fake) conspiracy theory. 'Wake up musicians!! Do your own research!!'.

possibilities while foreclosing others, other ways of thinking become possible which could yield new forms of musical and technical practice.

I will explore these arguments through so-called *entanglement* theories of HCI (Frauenberger 2019); these underpin a growing movement on *more-than-human design* (Sanches et al. 2022; Nicenboim et al. 2023) that declines to place human agency at the centre of every story but instead argues for a more dynamic and relational interplay between the material world, cultural and discursive systems. Entanglement perspectives are increasingly prevalent in instrument design (Melbye et al. 2021; Waters 2021; Symons 2022; Armitage and Magnusson 2023; Morrison and McPherson 2024; Tahiroğlu 2024), though it remains up for grabs whether they portend a major change in music-technical practices or mostly a shift in vocabulary around existing values. In this paper, I will draw especially on Karen Barad's metaphyiscs of *agential realism* (Barad 2007), explained further in Section 2, even as I share the view of Lindley et al. (2025) that design researchers can gain useful insights by drawing freely and discerningly from different theoretical canons without becoming enmeshed in the minutiae of any particular lexicon.

The anti-framework in this paper should not be read as criticism that current work is fatally flawed, nor as a specification for creating more useful technologies. Agre (1997), in critiquing AI research of the 1990s, wrote that engineering design methods 'make claims in the context of practical problems, and so the legitimate criticisms relate solely to issues of utility . . . . Critics will be asked, "what's your alternative?", within a tacit system of discursive rules that virtually rules out alternatives from the start. All the same, I think that the very concept of "alternatives" is misleading, and that it is actually impossible to achieve a radical break with the existing methods of the field. This is because AI's existing language and technical practice, like any disciplinary culture, runs deeper than we are aware'. For this reason, with only a few exceptions, I do not want to sort existing instrument designs into successes and failures. I especially do not seek to elevate my own past work as offering Agre's 'radical break', a project that can only come from many years of deep thinking across a community. Rather, in scrutinising the discursive rules of DMI deign, I hope to highlight that all of the following can be true: 'that a tool is useful; that it is partial and limited; that a skilled designer can work within those limits and know when to deploy other tools; and also that overstating its generality or objectivity can lead to problems' (McPherson et al 2024).

For the same reason, I do not propose to make authoritative claims about what entanglement theories ought to mean for instrument design writ large. I wholly endorse the sentiment of Norman et al. (2025) who 'do not consider it appropriate to offer unifying frameworks or mappings with often hidden authoritarian implications'. On the contrary, I emphasise the specificity of my perspective by turning periodically to my personal experience as a classically trained viola player and discuss how the persistent frictions I experience between that part of my musical life and my professional status as a DMI researcher have helped me grapple with some of the thornier philosophical issues raised by entanglement theory.

2. Entanglement theory for NIME

Language has been granted too much power. – Karen Barad (2003)

Science and engineering research, including a substantial proportion of present-day HCI, inherits from a philosophical tradition of *positivism*, which proposes that an objective reality exists prior to, and independent of, any act of observation (Frauenberger 2019). The positivist tradition proposes that knowledge is built through controlled measurement and logical deduction, discovering universal principles which are independent of the observer. Positivism is widely influential across natural and human sciences (Crabtree 2025), though it has long been critiqued from social constructivist perspectives which hold that knowledge is produced through language and social systems, leading to long-standing 'science wars' between advocates of different philosophies of knowledge (Frauenberger 2019). Positivism has also come under criticism in feminist scholarship as privileging certain perspectives as representing objective truth: Haraway (1988) describes this as the 'God trick' of 'seeing everything from nowhere'.

2.1. Representationalism in music technology

As Barad (2003) observes, a central tenet of both positivist and constructivist worldviews is *representationalism*: 'the power of words to mirror preexisting phenomena'. Barad elaborates: 'The idea that beings exist as individuals with inherent attributes, anterior to their representation, is a metaphysical presupposition that underlies the belief in political, linguistic, and epistemological forms of representationalism. Or, to put the point the other way around, representationalism is the belief in the ontological distinction between representations and that which they purport to represent; in particular, that which is represented is held to be independent of all practices of representing'. In the representationalist worldview, words and symbols enjoy special status by pointing to things that already exist in the world, and coming to terms with what they mean and how they relate to one another gets us to closer to understanding objective truth.

Representationalism is widely accepted in music technology research, especially in music informatics (Born 2020, sec. 2.3). This includes the premise that music can be considered an objective 'thing' rather than a process or activity – for example, that datasets of recorded audio tracks *are* music for all practical purposes.[3] Representationalism also underpins the 'retrieval' of conceptual information from signals, including transcription from audio to scores of discrete events characterised by pitch, loudness and timing, or the classification of audio tracks by genre, emotion or other factors, as if these words and numbers hold stable, universally agreed meanings across contexts and cultures. Instead, as Born

[3]As Georgina Born reminds us, 'musical sound – as an aural, non-representational abstraction – is never experienced as pure and autonomous. Whether it is perceptually focal or not, musical sound invariably comes to us not only embodied in the socialities of musical performance but inflected by other social processes and relations, infused by beliefs and discourses, embedded in physical and technological environments, and thus entangled in "mixed realities"' (Born 2012).

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(2020) argues, purported universals in music informatics bear traces of an 'I-methodology' (Oudshoorn et al. 2004) where engineers who are disproportionately White, male and versed in mainstream Western pop music seek to create widely applicable tools by imagining their perspectives to represent a universal musical subject. Born sees 'a risk of teleology in beginning with existing tools derived from the analysis of Western pop and seeing if they "work" for some fragmentary, decontextualised trait extracted from the total socio-musical existence' of another musical tradition (Born 2020, 197).

Much has been written in recent years about the resultant challenges of diversity and ethics in music informatics and related fields (Huang et al. 2023; Gómez-Cañón et al. 2025; García-Benito 2025), particularly with the increasing use of AI systems for music analysis and generation at scale (Morreale 2021; Sturm et al. 2024; Morreale et al. 2025; Morrison and McPherson 2026). Here, it suffices to question (as I have at greater length in Morrison and McPherson 2024; McPherson et al. 2024) whether these words and concepts were ever truly embedded in the music to begin with, or whether such analyses have the effect of reifying *post hoc* descriptors *about* music into its purported generative basis (Van der Schyff 2015). To put it a different way: if an automated music transcription system turns an audio file into MIDI or sheet music without obvious errors, has it therefore rediscovered at least part of the true and neutral basis for that music? Transcription is undeniably useful for practical analytical tasks, including performance-related tasks such as automatic score following; however, the question of whether words and symbols faithfully represent (rather than co-create) reality has important implications for the design of tools to create music.

2.2. Entanglement should mean more than just interaction

Before continuing, I would like to lay down a personal marker on my use of terminology from Barad's agential realism (HCI-and NIME-adjacent summaries of which can be found in Frauenberger 2019; Reed et al. 2024). Barad reads insights from Niels Bohr's quantum 'philosophy-physics' through the feminist scholarship of Judith Butler and Donna Haraway (and vice versa) to challenge existing systems of scientific knowledge and representation. Barad's project does not reject all science or the idea of a knowable reality; rather, agential realism proposes that the fundamental units of existence are not things ('independent objects with inherent boundaries and properties') but *phenomena*: 'relations without preexisting relata' (Barad 2003: 815). For this reason, agential realism is often described as a 'relational ontology' (Frauenberger 2019), and putting relations at the foundation of existence leads Barad to a reconfiguring of terminology: *intra-action* (rather than interaction); *diffraction* (rather than reflection); *agential cuts* (bringing into existence localised patterns of cause and effect) and many more.

While the application of the Baradian lexicon to HCI and music technology can take many valid forms, there is a risk of researchers adopting these new terms as drop-in replacements for more familiar ones, leading to confusion on what entanglement theories might have to offer. For example, it isn't necessary or helpful to use entanglement (or intra-action, or any other Barad-ism) to describe the movement and collisions of billiard balls on a table; classical physics is perfectly adequate for this.[4] Similarly, plenty of insightful literature exists on mutually interacting musical stakeholders (O'Modhrain 2011; Marquez-Borbon and Stapleton 2015) and on the relationships between performers and instruments (Jack et al. 2017; Nijs 2017; Tuuri et al. 2017). Insofar as these sources assume that 'human' and 'instrument' are categories with well-defined boundaries and identities, entanglement thinking is not needed to make such points.

My interest in entanglement theories is rather in how they can destabilise concepts we take for granted, by proposing that boundaries are enacted rather than inherent. Barad draws out this point using Niels Bohr's famous proposition that the apparatus of measurement is inseparably entangled with the thing that it measures – observer and observed mutually produce the phenomenon (and each other). As Barad puts it, 'concepts are specific material configurations' (Juelskjær and Schwennesen 2012: 12) rather than representations mirroring an underlying reality. This suggests that words like 'instrument', 'player', 'gesture', 'composition' and even 'music' do not refer to stable, context-independent concepts; instead, the concepts are enacted through specific and localised materials, practices and relationships (Sergeant 2016; Reed et al. 2024).

With this in mind, when I say '*X* isn't real', more precisely I mean that *X* does not have an inherent identity independent of its relations, and conversely that the word for '*X*' doesn't have a stable meaning representing something that already exists in the world. Instead, the act of describing or measuring *X* is what brings *X* into being in the first place, in a process that should always remain open to scrutiny.

3. Notes aren't real

Nothing comes without its world – Donna Haraway (1997)

Notes are omnipresent in digital music. The MIDI standard, codified in 1982 by a self-appointed consortium of mostly North American and Japanese keyboard and synth companies, remains the dominant symbolic format in commercial music software, and it was also the *lingua franca* for most interactive music systems of the 1980s and 1990s, from controllers like Waisvisz's *The Hands* (1985) to open-ended software like early Max (prior to Max/MSP) (Puckette 2002). Complaints on the limitations of MIDI and proposals for alternate standards are nearly as old as MIDI itself (Loy 1985; Moore 1988; McMillen 1994). More recent scholarship has explored the many ways MIDI promotes a *claviocentric* (i.e., keyboard-focused) ideology (Diduck 2018; Morrison and McPherson 2024), not least through its assumption that music decomposes into discrete notes characterised by an instantaneous onset and an integer specifying pitch in (typically equal-tempered) semitones (Pardue and Bin 2022). Despite these culturally specific assumptions, MIDI and the tools which use it have travelled around the world, reconfiguring musical practices in their image (Magnusson 2021).

This paper will not rehash the various technical arguments for or against MIDI. In any case, a great many digital instruments and interactive systems manipulate audio and other signals without the use of MIDI, preferring alternative communication protocols such as OSC or employing abstract implicit representations such as the latent spaces of machine learning models (Caillon and Esling 2021; Tahiroğlu and Wyse 2024). Audio analysis tools have also long been used in composition without turning to MIDI, for example, in

[4]This is not to say that an entanglement perspective on billiard balls couldn't exist: it might have more to do with what makes the objects identified as billiard balls at all, the various socioeconomic dependencies of 'billiards' as an activity, the contestable boundaries between a billiards player and their sporting equipment, and so forth.

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spectralist scores which repurpose conventional notation to prioritise timbre over harmony or rhythm (Fineberg 2000). Nonetheless, without overstating the universality of MIDI as a specific technical protocol, I want to call attention to how a more abstract concept of *note* (and its constituent properties) is deeply embedded in music technology discourse.[5] Notes exist within, and give meaning to, a system of notation, but no notation system is ever universal. Magnusson describes designing notation systems as 'a process of selective abstraction and classification'. They 'define which parameters are "valued", and these get abstracted out and assigned a symbol' (Magnusson 2019, 123–24). Notation is thus premised on representationalism, something made explicit in the title of the TENOR conference ('Technologies for Music Notation and Representation'), which has run annually for over a decade. What are the implications of this situation?

3.1. Reification and additive representations

I advocate for a greater awareness amongst designers of how building tools with notation (of any sort) acts as a reification: not a descriptive representation of what was already there so much as an inscription (Akrich 1992) of which parameters will *become* valued, which then serves to shape future practice through the things it makes easier or harder to do (McPherson et al. 2020). Arguably, this is the idea behind a number of digital instruments which self-consciously merge the concepts of 'instrument' and 'score': composed instruments (Schnell and Battier 2002; Murray-Browne et al. 2011), tangible scores (Tomás and Kaltenbrunner 2014), magnetic scores (Privato et al. 2023), agential scores (Armitage and Magnusson 2023) and so forth. Here, the ideological non-neutrality of the notational system itself becomes part of the give-and-take between performer and instrument, and I suspect that few of these designers would suggest that the notation bound up in their instrument should be used as a representation of a broad swathe of other musical practices.

However, it remains common across DAWs and music programming languages alike to propose that music should be generated using one or more systems of symbolic notation. These notation systems might encode relatively specific conventions (such as MIDI or shorthand names for specific sounds found in live coding languages like Tidal Cycles or Sonic Pi (McLean and Wiggins 2010; Aaron 2016)), or they might be more abstract (such as OSC or the programmer-defined parameter values that follow the time fields in a Csound score). In practice, systems with strong conventions are rarely completely restrictive (e.g., many keyboard-like conventions can be challenged with the careful use of MIDI Pitch Wheel or Control Change messages), while supposedly open-ended systems are often still used in conventional ways (McPherson and Tahıroğlu 2020).[6] But we see in all of these systems either an additive property, where music is produced through combinations of smaller encapsulated elements, or a factorial property, where musical elements can be described by their position within a mathematical space which encourages the deployment of geometric metaphors (McPherson et al. 2024). Even textural music without conventional 'notes' can be generated from additive processes such as granular or concatenative synthesis (Schwarz 2007), while spatial audio might be produced from an accumulation of sound objects given discrete locations and radiation patterns (Wolstanholme et al. 2023).

To be clear, I do not claim that any of these tools, languages or notation systems are better or worse than any other. But any assumption that the individual quasi-atomic or factorial elements of notation are a 'real' representation of pre-existing musical phenomena risks inverting cause and effect. To further explore this point, I will turn to my experience in the highly traditional, notated music practice of classical string playing.

3.2. Why are MIDI string synths so disappointing?

Like many classically trained string players, I have a poor opinion of most MIDI bowed string synths, especially solo strings (as opposed to orchestral sections). Why, to my ears anyway, do so many of these systems sound like a pale imitation of good string technique? In early MIDI synthesis, the situation might have been attributed to the challenges of producing a realistic audio facsimile of a violin using the synthesis methods of the time (e.g., FM, subtractive or low-bandwidth sampling). Audio recording is clearly no longer the driving limitation in modern sample libraries. Later, in my own DMI design (McPherson et al. 2013), I attributed it to a lack of sufficient real-time 'expressive' control over parameters such as vibrato (often relegated to mechanical-sounding LFOs) or dynamics (often chopped up into note-level modulations rather than unfolding naturally over a phrase). I thought that putting those parameters under the fingertips of the DMI player might yield a more realistic emulation.

I now believe the problem speaks to a deeper incompatibility between assuming MIDI messages to be the generative substrate of music, versus what I do when I play the viola. As an orchestral and chamber player, almost all of my playing is from notation. However, as musicians have known for centuries but technologists still sometimes forget, standard Western notation acts as more of a culturally and historically situated *aide-mémoire* than a literal description of precisely what acoustic events will take place.[7] Notwithstanding Magnusson's description of notation as choosing what is valued (Magnusson 2019), there are many aspects of string playing that are highly valued but not assigned symbols.

One of these aspects is *articulation*, the complex acoustic-tactile transients that occur between (and sometimes within) notated events. Contrary to the MIDI worldview, these are neither instantaneous events (e.g., note velocity), nor are they amenable to manipulation at a 'control rate' suitable for human fingers turning plastic knobs. Sample libraries sometimes attempt to classify articulation into discrete linguistic categories (*legato*, *staccato*, *spiccato*, *martélé*, etc.) as if these words have stable, well-defined meanings across different instruments and players (or even across a single performance). The MIDI 2.0 specification even includes a *Note On with Orchestral Articulation* message[8] featuring an 8-bit classification for articulation type and various subclasses covering commonly used words about string playing, including bowing, left-hand techniques and which string a note should be played on. It might be a step forward from mere note number and velocity, but the proliferation of sub-categories and attributes also suggests an

[5]Notes also loom large in the popular imagination, to the point that symbols from Western music notation are an omnipresent visual icon to suggest music itself, something that Figure 1 alludes to.

[6]Even when systems are very tightly restrictive, in some conditions this can be a creative enabler (Magnusson 2010; Gurevich et al. 2012).

[7]Not all notation describes sonic or musical qualities: many twentieth-and twenty-first-century composers employ *prescriptive notation* which specifies physical execution techniques rather than resulting sounds (Kanno 2007). This raises questions of whether those notated techniques are any more or less 'real' than the musical qualities in traditional notation.

[8]See MIDI Association document M2-123-UM. https://amei-music.github.io/midi2.0-docs/amei-pdf/M2-123-UM_v1-0_Note-On_Orchestral_Articulation_Profile.pdf

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attempt to shoehorn string playing into a protocol that fundamentally is not suited for it.

Ultimately, the practice of bowed string playing isn't additive from small atomic units, nor is auditory–motor imagery a linguistic or conceptual process. Its musical language is both bigger (phrasing) and smaller (articulation) than notes, and it emerges from a process of 4E cognition[9] deep and reciprocal enough to challenge the very notion of the separation of 'performer' and 'instrument' into well-defined entities (Nijs 2017). Notation can guide this process, and it can be transcribed *post hoc* from a performance, but to think of it as the 'real' generative basis of the practice will always leave the technologist playing catch-up.

4. Pitch isn't real

MIDI proposes music to be composed of discrete events with deterministic pitch, loudness and timing. If the previous section made a case against discreteness, this section makes a more provocative claim: that *pitch doesn't inherently exist*, except through an entanglement with a specific apparatus of measurement. *Apparatus* carries specific meaning in Barad's agential realism (Barad 2007), which I unpack in more detail elsewhere (Reed et al. 2024). Niels Bohr's theory of quantum indeterminacy proposes that the existence of a quantity depends on the specific apparatus used to measure it: for example, 'position' as a property of a particle only carries meaning in relation to a particle detector with rigid parts, while 'momentum' only carries meaning in relation to a detector with movable parts. The two configurations are mutually incompatible, and so too are the theoretical concepts that they measure. According to Bohr and Barad, it is not merely that the two measurements cannot be simultaneously conducted, it is that making one concept determinate excludes the existence of the other. Hence, Barad's statement is that 'concepts are specific material configurations' (Juelskjær and Schwennesen 2012).

4.1. Frequency doesn't (inherently) exist

To put the argument into clearer relief, I will leave aside the complexities of human pitch perception; my argument here is not that frequency is objective but pitch is subjective. Instead, I will take fundamental frequency (periodicity) as a direct correlate to pitch and argue that *frequency doesn't exist* as an inherent and independent entity. Rather, the phenomenon of frequency only comes to exist in context through an entanglement with the apparatus of measurement, the frequency detector. Fourier theory tells us that a basic prerequisite for any frequency detector is a time window long enough to cover at least one period of the signal, and that precision in the frequency domain comes at the direct cost of imprecision in the time domain (i.e., longer time windows are needed to resolve finer details in frequency). The most obvious implication, as is well known in audio engineering, is that frequency detection on real-time signals necessarily incurs a significant latency, and that the lower the frequency to be detected, the longer this latency becomes.

Frequency is a useful analytical frame, especially for offline or latency-insensitive applications. But does that make it a fundamental, context-independent basis for musical sounds? Even leaving aside inharmonic ('unpitched') instruments like drums and noise-based musical practices, audio signals that we take to have well-defined pitch often exhibit significant regions of ambiguous periodicity or non-periodicity. This is particularly true for transients, where establishing regularity of oscillation after an input of energy can take tens or hundreds of milliseconds. Frequency detectors are easily stymied by this behaviour, such that designers often resort to waiting for even longer time periods to elapse before taking measurements of the frequency – even as they purport that frequency is a fundamental generative property of the audio signal. Put another way, instantaneous temporal onsets and deterministic frequency depend on mutually incompatible apparatuses.

Of course, myriad digital and analogue instruments feature frequency generators (oscillators) alongside some means of producing transient signals (envelope generators). Practically, even a simple oscillator and voltage-controlled amplifier can avoid the latency problem that afflicts more complex instruments (like MIDI guitars) which use audio feature analysis to control synthesis processes. Analytically, every audio system faces the same mathematical constraints around frequency measurement and window sizes. Does this mean frequency and onset should indeed be considered inherent properties of musical audio, independent of any representation?

Reconciliation can be found once again in Barad's statement that 'concepts are specific material configurations' (Juelskjær and Schwennesen 2012). They continue: 'the details of the apparatus – like the bolts fixing one part of the apparatus to another, or springs that enable parts of the apparatus to move and be responsive – are of fundamental importance'. Here, both the oscillator and the frequency detector are specific material configurations that enact a concept of 'frequency', but despite the shared word, the two concepts are not necessarily identical. To examine the implications in more detail, I will return to the case of viola playing.

4.2. Where is 'pitch' located on the viola?

This sounds like the set-up to a bad viola joke, but I intend it as a serious question. What are the material properties I should inspect on a viola to discover the pitch it produces? The obvious answer from musical acoustics is to examine the length, tension and mass density of the strings to calculate their resonant modes. In this idealised account, the rest of the instrument (bow, bridge, body, air, any part of the player's body other than the immediate contact point with the string) might alter the spectrum or dynamics of the sound, but to a close approximation will be irrelevant to determining frequency.

However, when I begin to draw the bow on the string, 'frequency' doesn't immediately jump out. Rather, patterns of stick-slip friction emerge at the region of bow-string contact and propagate in both directions along the string, chaotically at first, and eventually (with the right playing technique) reinforcing one another in a periodic process known as *Helmholtz motion*. Acousticians have shown the establishment of Helmholtz motion on a bowed string to have chaotic properties, dependent on particular combinations and micro-details of bow speed and pressure (Woodhouse 1993). In my own playing – largely as a result of my imperfect technique – some transients unpredictably settle into other vibration regimes such as *multiple flyback* (a harsh, buzzy sound) or *multiple slip* (producing airy, *flautando* sounds or harmonics). Acoustically, there is no *a priori* physical manifestation of pitch within the instrument, only complex spatial-temporal phenomena that *mostly* resolve into periodic oscillation in between periods of instability.

[9]4E cognition is shorthand for *embodied, embedded, enactive and extended*, a set of perspectives challenging classical information processing models of the mind by examining how cognition is intimately connected to bodily and worldly processes; see Van Der Schyff et al. (2018) for some implications for music research.

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Lest this seem like so much (bow)hair-splitting, there is a further wrinkle. My viola, like many larger violin-family instruments, has a *wolf tone*, a high-Q resonant mode within the instrument body. Vibrations in acoustic instruments are bidirectionally coupled: string vibrations couple through the bridge to the body of the instrument, and the same is true in reverse. Wolf tones occur when the back-propagated energy from a resonance in the instrument's body interferes with the establishment of Helmholtz motion on the string (Gourc et al. 2022). On my instrument, the resonance occurs near the pitch notated as F above middle C (349Hz). As a result, under certain playing conditions – quiet dynamics, light bow pressure, high up the lowest (C) string – it is nearly impossible to get the instrument to speak at this pitch at all. Instead of clear periodicity that would match an analytical concept of frequency, I get a strange warbling, with concomitant changes in tone quality and tactile sensations through the bow. If 'frequency' is actually a material configuration, it is an idiosyncratic one, and those idiosyncrasies become part of my playing.

4.3. Virtual violas: seeking refuge in physics

None of the aforementioned properties of my viola, even its idiosyncratic wolf tone, are inherently impossible to model numerically. Physical modelling of acoustic instruments, including string instruments (Bilbao and Ducceschi 2023), is a mature enough technique to feature in high-quality commercial audio plug-ins.[10] This research extends to how such simulations might be musically controlled (Demoucron and Rasamimanana 2009; Carrillo et al. 2011) and what kinds of sensors might capture the necessary physical measurements (Néill et al. 2025). In an important way, physical modelling offers a refuge from prescriptive musical concepts: for many forms of numerical simulation, nothing in the mathematics assumes the prior existence of stable concepts of 'frequency', 'note onset' or any other musical idea. Rather, these concepts gain meaning through contextual interpretation of what the models do, analogous to how musicians interpret acoustic instrument behaviours. Hypothetically, given a sufficiently comprehensive model of an instrument and acoustic space, one could produce a credible enough facsimile that a human listener couldn't tell the difference, even as the computation would remain agnostic to any concept of 'notes'.

But can such a simulation really *remain* note-agnostic? With physical modelling, one can easily produce an immaculate ship in a tightly sealed bottle, impervious to human manipulation. To render a numerical simulation playable, the problem of physics quickly shifts to the problem of human interfacing – or more controversially, simulating humans. Interfaces used to control bowed string simulations, such as graphics tablets (Demoucron and Rasamimanana 2009), load cells (Néill et al. 2025) or 3D motion capture (Carrillo et al. 2011), are each in their own way distinct from the high-bandwidth intercoupled audio-tactile dynamics of acoustic bowing. Invariably, assumptions must be encoded to render the numerical simulation useful to a performer. These might include MIDI control of pitch or, more expansively, machine interpretation of scores (Demoucron and Rasamimanana 2009), or the classification of bowing technique (Maestre et al. 2010) into discrete categories similar to those found in MIDI 2.0 (Section 3.2). The musical assumptions haven't gone away, and they have just moved upstream from the numerical simulation.

[10]See, for example, Modartt Pianoteq (https://modartt.com) and the Physical Audio suite of plug-ins (https://physicalaudio.co.uk).

5. Accounting for intentionality

> *The cello is not just a transducer. In one sense it is, as it converts my manual gesture into a line of sound. But in another sense – at the moment I begin to play – the cello seems to explode. What had been a recognisable, coherent entity becomes something more like a bundle of affects, a meeting of bowhair, rosin, metallic strings, wood and fingers, coupled with resonant air. Bundle them together and sound erupts as through a fissure. – Tim Ingold (2017, p. 111)*

The discussion thus far has been primarily object-focused. But the term 'musical instrument' is also not a representation of some inherent, pre-existing category of objects. Continuing with Barad's framing, instruments are enacted together with instrumentalists, gaining their *instrumentality* through intentional use in a musical context (Alperson 2008; Sergeant 2016; Nijs 2017). One consequence of this relational framing is that, like Ingold's quote above, it is not always determinate where the player ends and the instrument begins – for example, are the trumpeter's lips part of the player, the instrument or both (Alperson 2008)? Another consequence is that we should draw the boundaries of musical concepts widely enough to account for their entanglement with the intentions of the performer.

On the viola, pitch may be an idiosyncratic spatio-temporal phenomenon rather than an idealised concept made manifest in physical materials, but when I play, pitch is also an intention. Prior to making any sound, my playing (like all instrumentalists) is guided by auditory–motor imagery of what sound should emerge and how it will feel to produce that sound. The neuroscience of auditory–motor imagery is not fully settled, but there appears to be substantial overlap in the brain pathways for perceiving a sensory stimulus or moving muscles versus imagining the same thing (Gelding et al. 2019). This imagery is also surely enculturated through years of listening and playing. As such, I may well imagine musical events through the structures of Western classical music and its notational systems (and, conversely, struggle to imagine sounds of other musics I am less familiar with, even if they could be played on the same instrument).[11]

To avoid a romanticised notion of human intentionality, two caveats are important. First, this imagery is predominantly non-linguistic, more amenable to study through (micro-)phenomenology (Reed et al. 2022) than discourse analysis. Second, the imagery is strongly conditioned by the instrument in my hands, which guides and constrains my imagination (Tuuri et al. 2017). In this way, the reciprocity between human and material agency often proposed in digital instrument research (Stapleton and Davis 2021; Mudd 2023; Tahiroğlu 2024) is a property of *any* instrument – perhaps even one of the core aspects that turns an inert 'thing' into an instrument in the first place.

5.1. Notes are enacted, not extracted

The upshot of a relational framing of instrument identity is that the Baradian apparatuses which give meaning to concepts like notes and frequencies must be drawn widely enough to incorporate (more-than-)human cognition and cultural systems. This view presents severe challenges to the digital instrument designer. We have no technical means to observe the intentions or sensorimotor imagery of a performer, nor any robust way for a digital instrument

[11]This appears to be a common phenomenon amongst performers; a study of violinists playing quarter-tones found that both pitch accuracy and response time suffered in comparison to playing familiar semitones, even though there is no intrinsically greater mechanical difficulty in playing them (Guidi et al. 2020).

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to be aware of and adapt to the cultural situation of its use. Even worse for the designer, intentions and cultural situations are never fixed or stable enough to underpin a design specification without changing in the process. As a result, the technical 'solution' comes to define the problem rather than the other way around: relying on narrow mathematical or engineering-driven definitions of concepts ends up reconfiguring both human thinking and musical cultures around those definitions. As Morreale et al. (2025) put it, 'epistemology (our knowledge about music) determines ontology (what music is)'.

Consider a practical example: guitar-to-MIDI converters (Section 4.1) will typically take audio as input (possibly with separate channels per string) and produce MIDI note messages as output. The converter encodes rules about what constitutes a 'note' and how the pitch and velocity of the symbolic message will be derived from a set of signal processing elements. As Reed et al. (2024) argue, the device becomes a locus of knowledge about music which will inevitably diverge from the human musician's own knowledge of the same musical situation. One result is a set of frictions. Reed et al. describe as an 'ambiguity shift', in which the performer experiences these competing loci of knowledge as glitches or technical failures. Indeed, online reviews of guitar-to-MIDI converters sometimes discuss challenges with perceived tracking accuracy.

However, the actual situation is more insidious than discussions of tracking accuracy let on. As Nijs (2017) and Ingold's firsthand account attest, the boundary between player and instrument is fluid and contingent. A guitar-to-MIDI converter is thus better analysed as a *guitarist*-to-MIDI converter, accounting for the reciprocal effects of the guitar on the guitarist's ideation, perception and action. The guitarist, playing without such a device, would have had a certain set of sounds and techniques in mind. They could choose to hold firm to those ideas when playing with the MIDI converter, which will bring all of the aforementioned frictions to the fore. Instead, what is far more likely to happen is that the guitarist will change their expectations and techniques to match what the MIDI system wants to produce. The effect of players adapting their techniques to the affordances of an instrument is well established (Tuuri et al. 2017; Jack et al. 2017). By adapting to think in terms of note onsets, the distance between the two loci of knowledge is reduced and the player experiences greater conformance with their expectations, with more satisfying results. This, too, can be seen in online reviews and discussions of such technologies.[12]

This shift of technique and intention might go unremarked in the majority of cases. The vagueness of the words and concepts we use to talk about music could easily sustain the fiction that nothing substantial changed with the introduction of MIDI conversion. Guitar playing was already about notes, we might tell ourselves – just look at tablature! We've merely built a machine that understands our notes! But this elides the fundamentally different role of the 'note' as an (incomplete) cue for performance versus a generative element of the instrument itself. Concepts, humans, materials and discourses are still entangled, but technology-led decision-making ends up enacting what Barad calls an *agential cut*, giving meaning to the boundaries between entities and opening up certain possibilities while foreclosing others (Barad 2003). Notes *become* real through our own designerly actions, and we believe they were there all along.

5.2. Is it still okay to like notes?

There exists a considerable body of DMI literature on instruments as co-creative agents and performance as exploration of the material properties of instruments (Mudd 2023; Melbye 2023; Stapleton and Davis 2021; Tahiroğlu 2024; Redhead 2025). That literature is helpful in unsticking ossified conventional wisdom and narrow historical discourses of what good music ought to be. This paper shares with that literature some degree of revolutionary fist-shaking against the real or imagined hegemony of Western tonal music with its normative ideas of expressivity and virtuosity (see Gurevich and Treviño (2007) on the latter point) or against mass-market popular music with its tightly circumscribed musical conventions. Battle lines (or maybe just taxonomies?) are drawn, with contrasts thrown into sharp relief: Mudd (2019) distinguishes between communication-oriented interaction (traditional music) versus material-oriented interaction (experimental music); Magnusson (2009) distinguishes instruments into extensions of the body (acoustic) or extensions of the mind (digital/live coding).

It's important to acknowledge the very real power imbalances between large corporate interests ingrained in every part of the popular music ecosystem, the major institutional support and conservatoire education system supporting Western art music, versus the limited scale and resource of experimental practices (though as Hayes and Marquez-Borbon (2020) show, institutional support has its own influences on DMI research). But I would be cautious of any effort to canonise experimental practices by codifying their essential elements, assigning them new words and symbols, and then using those words and symbols to guide future design processes, or relatedly, to enact new rigid binaries (even with respect to 'old' ways of doing things) when their avoidance is one of the very things entanglement theories try to teach us.

Many otherwise inspiring and well-conceived new instruments would liberate us from the hegemony of certain musical concepts by precluding their existence in the first place. Plenty of new DMIs which are capable of vast abstract timbral palettes or complex generative behaviour are also entirely unsuitable for playing 'Happy Birthday', even if the player was so inclined. This is neither good nor bad in any absolute sense, but it represents a different agential cut and calls for careful attention to what practices are excluded by it and why (Giraud 2019).

So, what happens if I intend to play notes? Is that forbidden?[13] As a classically trained acoustic instrumentalist, am I stuck between accepting reductive and caricatured representations of music in mass-market digital tools (Pardue and Astrid Bin 2022), parting ways with core elements of my musical language or rejecting the use of digital technology entirely to stay within my comfort zone? The problems begin when such a decision has to be categorical rather than nuanced. Musical intentions enact concepts and categories rather than simply following them, but intentions are also technologically mediated (holding a viola, I think of certain musical ideas far more readily than others; sitting at a piano, a

[12]For example, the reviews of the Roland GK-55 on the online outlet Sweetwater are revealing https://www.sweetwater.com/store/detail/GR55BK–roland-gr-55-guitar-synth-with-gk-3-pickup/reviews. Example comments: 'little disappointed in the tracking for the fiddle and banjo, but I think I can tweak the pickup and change the sensitivity and nuance'; and another user: 'You have to adapt to it, for reasons that become obvious, quickly. You can't play a 'piano' the way you play a guitar' (accessed 29 September 2025).

[13]A colleague was once accused by a NIME music reviewer of 'borrowing legitimacy' for proposing to play a piece by Bach on a new instrument (presumably instead of a new experimental piece). This raises many sticky questions. Why does Bach have legitimacy (at NIME!) that experimental music does not? Is the legitimacy voluntarily lent, and by whom? Do you have to give it back when you're done?

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different set of ideas is ready to hand). This situation puts the instrument designer in a position of considerable responsibility.

6. Conclusion

Notes may not be 'real' in any universal, representationalist sense, but bringing the concept of *note* into existence in specific musical contexts may still be useful. Plenty of compelling music remains to be made with MIDI and other familiar systems. However, uncritical adoption of any system as a true and neutral substrate for music-making can coax a designer through a series of decisions that lead to familiar DMI clichés (McPherson et al. 2020; Snape and Born 2022) or to tools unwittingly inscribed with cultural values that then reconfigure other musical practices (McPherson and Tahıroğlu 2020; Magnusson 2021).

This paper has proposed entanglement theory, and specifically Karen Barad's agential realism (2007), as a way of destabilising concepts that seem too obvious to be worth questioning. Similar arguments could be explored around many other familiar words in the music technology canon: *onset*, *gesture*, *interface*, *control*, *mapping* and so forth (McPherson et al. 2024). Inverting the usual language of HCI, I proposed these explorations as a kind of *anti-framework*, in that even a reader who vehemently rejects my particular choice of frame might be led to reconsider existing musical discourses and either alter or reaffirm them as a deliberate and responsible choice.

What are some implications of such an anti-framework? First, it requires acknowledging that we as designers and researchers don't stand outside of the entanglements we create or analyse; we are entangled with them. Second, it suggests moving away from a world of stable objects with properties towards a dynamically unfolding world of situated practices (Waters 2021); Small's (1998) expansive verb 'to music' is a healthy rejoinder to present-day music informatics discourse on disentangling the true generative factors of data (Morrison and McPherson 2026). Third, it requires attention to phenomena and experiences that don't have a ready name: we can insist on the importance of hard-to-articulate or ineffable qualities of musical experience without assigning them transcendental status.

Norman et al. (2025) emphasise the importance of Joel Ryan's idea of 'knowing when' as something that stands outside of conceptual or propositional knowledge but is nonetheless 'as articulate as language'. As a quality of live improvisation, knowing-when can't be learned from a textbook or a research paper any more than viola playing or bicycle riding could be. But knowing-when might equally be a design skill: knowing when to accept someone else's definition of a concept, to formulate one's own definition, or to abandon the concept entirely; knowing when to accept a given design or iterate it (as Michel Waisvisz reportedly grappled with in fixing the mappings in *The Hands*); knowing when to switch from a goal-directed engineering mode of thinking to an exploratory artistic one in a process of 'technical practice research' (Pelinski et al. 2024); or knowing when to shift the focus of attention between theory, design, analysis or deployment, a 'productive oscillation' that Lindley et al. (2025) argue is crucial to conducting design research in conversation with entanglement theories.

Like Norman et al. (2025), this paper deliberately avoids authoritative (and authoritarian) answers on how these problems *should* be approached. As a consequence, the paper also stubbornly refuses to call out specific instruments as getting it right or wrong, since the goal is to raise awareness of ingrained ways of thinking rather than to suggest that one direction of travel is appropriate for all designers. This contrarian stance is offered in Latour's spirit of critique as being 'associated with *more*, not with *less*, with *multiplication*, not *subtraction*' (Latour (2004); italics in original). An anti-framework does not cede too much ground to language (Barad 2003) and remains cognisant that 'nothing comes without its world' (Haraway 1997). The content of those worlds lurking behind familiar concepts should remain a matter of great curiosity.

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Ethical standards. Referencing conspiracy theories, however facetiously, runs the risk of misinterpretation. All conspiracy theories described in this paper are fake. I do not endorse *Birds Aren't Real* nor any actions of its founder or fans, and *Notes Aren't Real* is intended as a productive challenge rather than a suggestion of nefarious activity on the part of any person or entity.

This paper attempts to bring instrument design practices into conversation with entanglement theories, advocating against oversimplified reliance on either the elements of musical notation or of caricatures of those theories. However, my own perspective is no more universal than the perspectives that I critique, and the paper could run the risk of promoting its own narrowly prescriptive approach to musical practice. Ultimately my hope is that a greater awareness of these issues will lead to productive new ideas in DMI design, even when diametrically opposed to the perspective in this article. As a theoretical paper, no human participants or datasets were used in the research, so no institutional ethics board review was deemed necessary.

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