# Entangling Entanglement: A Diffractive Dialogue on HCI and Musical Interactions

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## ABSTRACT

If, as several recent papers claim, we have entered a new wave of "Entanglement HCI," then we are still at a liminal stage prior to consensus around which sources underpin this paradigm shift or how they might inform actionable approaches to design practice. Now is the time to interpret technosocial mediation from a range of disciplinary perspectives, rather than settling on a narrow canon of literature. To this end, our paper enacts a diffractive dialogue between researchers from different disciplines, focusing on digital musical instruments to examine how technical knowledge from design and engineering can be read against the grain of critical theories from music, media, and cultural studies. Drawing on two object lessons—keyboards and step sequencers, plus their remediations in recent musical interaction research—we highlight interdependencies of theory, design, and practice, and we show how the idea of entanglement is itself entangled in a cross-disciplinary web.

## CCS CONCEPTS

• **Applied computing** → **Arts and humanities**; **Sound and music computing**; • **Human-centered computing** → **HCI theory, concepts and models**; **Interaction design theory, concepts and paradigms**.

## KEYWORDS

Entanglement HCI, Diffraction, Musical Interaction, New Materialism, Social Studies of Science, Engineering, Music and Media Studies

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## 1 INTRODUCTION

Several authors have recently argued for the emergence of a fourth wave of HCI research centered on the idea of "entanglement," signaling a move towards a relational posthumanist paradigm based on the co-constitution of subjects and objects in technosocial configurations and other hybrid assemblages [54, 83, 125, 150]. With these authors, we share a general enthusiasm about the renewed focus that entanglement theory brings to cross-disciplinary questions of mediation between humans, technologies, and their surrounding environments.

At the same time, however, we have reservations about how the critical potential of entanglement can get lost in the process of translating theory into actionable methods, raising questions around whether the concept is leading to better design choices or just different ways of talking about design. We are also concerned with how discourse on entanglement in HCI has tended to elevate a few select sources as part of an emerging theoretical canon, rather than make space for messy negotiations around what a relational theoretical approach might look like in practice. With this in mind, we open a dialogue that considers approaches at the edges of the present "Entanglement HCI" paradigm, especially those from adjacent discourses in music, media, and cultural studies, which offer important insights for future work in design.

### 1.1 Writing as Diffractive Dialogue

In this paper, we stage a dialogue by borrowing from the playbook of feminist theorist and physicist Karen Barad, one of the most prominent proponents of entanglement who, in their seminal book on the subject, proposes the optical metaphor of *diffraction* as a method for "reading insights through one another in attending to and responding to the details and specificities of relations of difference and how they matter" [11, p. 71].[1] We have adapted their method here as the basis for what we call a "diffractive dialogue," in which each of us responds to a series of discussion prompts by drawing on our own disciplinary backgrounds.[2] For Landon Morrison (LM), this includes music theory and media studies, while for Andrew McPherson (AM), it includes electrical engineering, music composition and digital musical instrument (DMI) design. Beginning in Section 2, we will split our perspectives as authors, shifting to the use of "I," as we act as delegates for these respective fields in the context of a cross-disciplinary exchange.[3] We do not pretend to speak for everyone – least of all for HCI as a polyglot discipline – and we don't claim to offer a comprehensive review

[1] Elsewhere, in their article "Diffracting Diffraction" [12], Barad demonstrates what a diffractive reading of this sort might look like by juxtaposing and interleaving quotations from multiple sources in an intertextual format. Their work builds on Donna Haraway's original formulation of diffraction [73] as an alternative to the metaphor of reflection and the method of reflexivity.

[2] The dialogue presented in this paper was inspired by a writing game created by Tara Rodgers and Jonathan Sterne for a keynote at the 2023 *Instruments, Interfaces, Infrastructures* conference, where their address developed over a series of back-and-forth responses to alternating prompts. In our case, the game extended over the course of ten daily discussion prompts, through which we posted individual responses of up to one thousand words in length. From there, we engaged in a collaborative process of editing and re-working materials to produce a final document, which is meant to enact diffraction in both form and content.

[3] Splitting authorial voices to emphasise, compare or diffract first-person perspectives has precedent in recent HCI, e.g. [43, 85, 125, 195].



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of existing work on the subject. Nor do we aim for any kind of synthesis or reconciliation of our positions, preferring instead to juxtapose responses, sometimes abruptly, in a way that facilitates their comparison and contrast, leading to productive "science frictions" in the process [49]. With this performative gambit, we offer a sympathetic engagement with those calling for a turn to Entanglement HCI, while also attempting to prolong a window of possibility around what this new paradigm of research might mean for the future of HCI and musical interaction.

In its form, our dialogue resembles an outward spiral, revisiting key themes from several angles while moving forward arguments linked to our own practices and situations. We begin in Section 2 with "conversation starters" to map out the broad contours of entanglement theory, its cross-disciplinary influences (including some not yet prevalent in HCI discourse), and why it matters. Section 3 then engages more closely with our respective disciplinary backgrounds by seeing what can be learned about entanglement from two musical object lessons: the keyboard and the step sequencer, along with their recent remediations in DMI research. A series of provocations in Section 4 puts a sharper edge on lingering questions from Sections 2 and 3, discussing prospects of a "fourth wave," who is being left behind, and how to avoid a creeping sense of nihilism in design practice. Finally, Section 5 looks outward to living with partial perspectives, grappling with the thick tangle of practices that can result from interactions between different "epistemic cultures" [26] in HCI, science and the arts.

## 2 CONVERSATION STARTERS

### 2.1 *Entanglement theory*: what is it and from whence does it come?

**LM:** I think that, until recently, to the extent people even thought about *entanglement* as a technical term of art, it usually evoked the stuff of quantum mechanics, calling to mind subatomic particles acting on each other over "spooky" distances [50, 152]. But thanks to the work of Barad and others, the term's ambit has expanded, and it now figures prominently across a wide range of research domains, such as archaeology [39, 80], ethnography [67, 115], anthropology [97, 177, 183], philosophy [37, 127, 198], management studies [131], and the social sciences [53, 151]. It is generally used to connote a relational ontology, often described in terms of "material-semiotic actors, human and not" [73, p. 298], or as a "web of scientific, social, ethical, and political practices" [11, p. 138]. Because such relations can be found at multiple levels of analysis in any given domain, entanglement easily slips between registers according to the situation. We thus read of "entangled objects" of colonial exchange in the Pacific Islands [171], of the "postcinematic entanglement of time and image" in new media art [28], or of "cross-species entanglements" between people and mushrooms [178]. At this point, the concept has been fitted to many disciplinary contexts, becoming a rich metaphor for thinking through complex interactions in networks of all kinds.

The language of entanglement is also filtering into the musicological sphere. For instance, Clarke [31] adopts an ecological perspective to explore the "various kinds of productive and problematic entanglements that music affords"; Fairbairn [173, p. 22] offers a book-length study of how soundwaves "splice bodies together in mutual, collaborative entanglement"; Cho et al. [27, p. 17] take a historical lens to "German-East Asian musical entanglements of the twentieth and twenty-first centuries"; and Crawley [35] speaks reflexively about the "practice of entanglement" in musically expressing Blackpentecostal and Blackqueer social identities. If this list is extended to include music-related research and practice that remains at the edges of entanglement discourse – i.e., not explicitly invoking the term, but sharing its general emphasis on technosocial relationality – then one encounters a vast amount of material spread across many burgeoning areas of interest, including new organology [144, 176], musical mediation [24, 79], political economies/ ecologies of music [45, 48, 65], and the list goes on. Going back to the New Musicology of the 1980s, there has been intense interest in deconstructing boundaries between musical texts and their surrounding contexts, in showing how musical objects and subjects relate in ways that might be loosely described as entangled. And yet, while this strain of music studies has relevance to the question of entanglement in HCI, it does not necessarily share the same philosophical commitments to posthumanist new materialism and so must be carefully differentiated.

In the case of Entanglement HCI, authors have been clear about their sources of inspiration, with Barad's work often cited [54, 83, 150]. Barad's philosophy of *agential realism* seeks to foreground the "entanglement of matters of being, knowing, and doing, of ontology, epistemology, and ethics, of fact and value" [11, p. 3], and it does so through the prism of a contemporary "philosophy-physics" that prioritises hard matters of fact over issues of language and representation. But Barad is not the only driving force behind this wave of research, and Frauenberger helpfully identifies three additional sources as belonging to a group of what he calls "entanglement theories" [54, p. 23]; these include actor-network theory [98], object-oriented ontology [76], and post-phenomenology [87]. Frauenberger is not alone in noting the proximity of these theoretical orientations to the formation of Entanglement HCI,[4] but this big-tent grouping risks eliding important differences between these approaches. For instance, feminist science scholars like Barad and Haraway have critiqued Bruno Latour and others in Science and Technology Studies for having "too narrow a concept of the 'collective,' one built up out of only machines and scientists, who are considered in a very narrow time and space frame," and also for drawing "a suspicious line around what gets to count as 'practice.' They *never* ask how the *practices* of masculine supremacy, or many other systems of structured inequality, get *built* into and out of working machines" [73, p. 332].[5] Likewise, Barad's relational ontology does not mesh well with the object-oriented ontology of philosophers like Graham Harman, who has been dismissive of entanglement in his calls to "recover the autonomy of things occluded

[4] Frauenberger cites a similar grouping of relational theories found in an earlier management research article by Orlikowski [131]. In an interesting parallel with Frauenberger's own work in HCI, Orlikowski argues that "entanglement in practice" marks a fourth wave in perspectives on technology in management research.

[5] From the other side, STS scholar Trevor Pinch penned a review of Barad's book, questioning their need to substantiate theories of technosocial relations with the logic of quantum physics, warning that "using science... to bolster a view in science studies is a dangerous game" [136, p. 440].

by the recent relational turn across the humanities" [75, p. 43].[6] And finally, the decentring of humans in Barad's philosophy seems rather remote from Don Ihde's post-phenomenological analysis of different types of human-technology use relations (i.e., embodied, hermeneutic, alterity, background), which centre human bodies and perceptions even as they account for technological mediations [87]. If, as seems to be the case, a fourth wave of HCI has been influenced by these diverse strains of thought, then contributions from each need to be assessed on their own terms and not subsumed in an overly broad category.

**AM:** Entanglement theories, in their various and sometimes contradictory forms, attempt to articulate in words an intuitively felt sense of the interconnectedness of humans, things, social and ecological systems. Musical performers are deeply familiar with this sense of interconnectedness. Instrumentalists will frequently describe the experience that the instrument has become a part of the body, receding from conscious attention [88, 126].[7] This is post-phenomenology's *embodiment relation* [87], which builds on Merleau-Ponty's philosophy of mediated perception [116, 167].

Cognitive science and neuroscience have provided tools to study the origins of these experiences in sensorimotor learning and imagery [196]. For an instrumentalist, though, entangled experience precedes any theoretical vocabulary. I have experienced it firsthand: as a violist I played the same instrument for over 20 years. When a few years ago I bought a new viola, I tried dozens of instruments. I found it was insufficient to think of an instrument in terms of intrinsic sound quality or playability; rather, with each one, I became a different player, and my choice was driven by the kind of musician I wanted to be.

For these reasons I think musical performance and instrument design, in addition to musicology, have much to offer the emerging Entanglement HCI discourse. For example, Waters [191] takes an ecosystemic view of musical practice based partly on Small's *musicking* [155], destabilising some familiar concepts: "a musical instrument is not an object but a process; a dynamic system in a constant state of change, seasoning, adjustment and decay." *Instrumentality* (in the sense of what makes something a musical instrument) has been discussed as a relational and social phenomenon [14, 19, 74]. Other seeds of entanglement thinking in digital musical instrument research might include: considering wide networks of (mainly human) stakeholders [130], the fluidity of roles and identities [68, 169], the influence of political and economic infrastructures [78, 120], the mutual dependency of different loci and scales of practice [158].

## 2.2 So what, why does it matter?

**AM:** Call to action, or fancy words about the status quo? That's the question that I'm currently grappling with. Does subscribing to an entanglement worldview have clear, actionable implications for the processes of design or research, beyond what third-wave HCI would already suggest? The recent literature shows that many HCI researchers share the same essential motivation: how to turn inspiring theory into concrete design practices. Thus we see ideas like diffraction-*in-action* [150], *doing* postphenomenology [77] and more-than-human theories that aim to reconfigure design practices [60, 125, 184]. Barad's *diffraction* seems to be the concept with the most detailed engagement in the recent HCI literature, with a number of papers proposing diffractive methodologies for design, data collection or analysis [100, 128, 150, 153, 186]. Sanches et al. propose some principles for using diffraction to design with data, including engaging with data as "open-ended and undefined process... resist[ing] the impulse for actionable insights early on"; focusing on efforts to "surface, articulate and explore practices around data"; and "hold[ing] space for messy, ambiguous data that requires active interpretation, resisting the impulse for clean and tidy data." This work sits within an ecosystem of sympathetic ideas, including slow technology [129], felt meaning [135], lived experience [41, 142], questioning HCI (non-)contributions [44] and alternate modes of dissemination [42, 57]. Skepticism of received notions of scientific positivism and resistance to easy answers seem to be the name of the game.

HCI is a pragmatic discipline, happy to borrow useful ideas wherever it finds them, with or without accepting all the underlying philosophical premises of its sources: see, for example, Frauenberger's borrowing of methodologies from object-oriented ontology [76] while maintaining distance from its ontological principles [54]. Along similar lines, we can find plenty of work which is methodologically aligned with Entanglement HCI without adopting its explicit theoretical grounding. Howell et al.'s *retrospective trioethnography* [85] is presented as "asynchronous and synchronous dialogues that delved into each of our individual experiences and juxtaposed them to highlight differences", which resonates with many diffractive methods in HCI. Soma design, with its overlapping narratives and agenda of breaking down dichotomies (inside/outside, individual/social, body/technology) [84], is grounded in Bennett's *vital materialism* [17] but intersects in many ways with other theories under the entanglement umbrella. Ståhl et al. [160] also develop a detailed encounter between soma methods and Baradian concepts of the *apparatus* and *intra-action*.

I revisit this pastiche tendency of HCI in Section 4.1 with a deliberately skeptical stance as one of several provocations. My nagging doubt stems from a sense that many design methods and artefacts (and musical practices) attributed to entanglement theories seem comfortably in the same landscape as previous work which doesn't make such an attribution. The theory is a radical break, but is the practice a modest evolution?

Ultimately, I'll cast my lot with the entanglists. I identify with Agre's account [2] of seeking out "strange disciplinary languages"

[6] Though it is worth noting a supportive review of Barad's book by OOO theorist Timothy Morton (see [55]), as well as an early embrace of their work by OOO theorists Levi R. Bryant and Ian Bogost who, in a 2010 online exchange, propose entanglement as "a nice candidate to replace the terms 'network' and 'assemblage,"' which they believe "suffer from less than felicitous connotations at the level of language"–network because of its association with a "homogeneous set of entities," and assemblage because it "suggests something that is rather static, that is already assembled, that is already there... [and because it] is extremely difficult to escape thoughts of an assembler." By contrast, Bryant finds that "entanglement seems to hit exactly the right note... [it] avoids the anthropocentric and ontotheological connotations of references to the agency of Demiurge Minor (man, mind, or subject) and Demiurge Major (God, the big Other, or language)."

[7] For instance, anthropologist Tim Ingold writes of the moment where his cello transforms in the moment of playing: "what had been a recognisable, coherent entity becomes something more like a bundle of affects: a meeting of bow hair, rosin, metallic strings, wood and fingers, coupled with resonant air. Bundle them together and sound erupts as through a fissure." [88, p. 111]

to express long-held but vaguely-felt discontent with a prevailing discourse, in my case the discourse of digital musical instrument (DMI) research. That it has taken me more than ten years to find a theoretical framework to express that discontent suggests that a designer's intuitive actions could run years ahead of their ability to articulate those intuitions in words. As a result, if a designer's practice appears not to change before and after adopting an entanglement frame, perhaps the words just took time to catch up.

However, I want to suggest a cruelly ironic risk of a canonisation of entanglement theories. As we accumulate snappy terms like *relationality*, *performativity*, *intra-action*, *ethico-onto-epistemology* (!), do we risk reifying these concepts into fixed and prescriptive formulas for design? Is the seductiveness of some of Barad's anti-representationalist writing going to rejuvenate the power of language amongst an otherwise skeptical HCI (sub-)community? As someone trained in engineering, I'm acutely aware of the risk of "translating these strange disciplinary languages into technical schemata" [2]. Entanglement theory ought to matter, but it's also not a specification. So what is it?

**LM:** As someone from the arts and humanities, rather than sciences, my interest in this question hinges less on entanglement's capacity for producing actionable design methods and more on how the concept might lead to new ways of analysing, theorising, and historicising musical interactions. I find cause for inspiration in the ecological focus of Barad's entanglement theory, especially its potential to promote a sense of accountability and responsibility that extends beyond humans to include animals, plants, and other non-human agents, one hopes in ways that lead towards environmental sustainability. I am equally interested by their diffractive methodology for reading sources and whole disciplinary discourses through and against one another, as well as for writing in polyvocal formats, such as we have adopted in the present dialogue. Attending to differences in this way has the potential to decentre normative tropes and create openings for a greater plurality of voices to emerge, not just in crosstalk among disciplines, but outside of academic discourse too, bridging theoretical trends with broader social and political movements. This is perhaps close to Haraway's description of diffraction as an "optical device" for composing "*interference* patterns, not reflecting images," as a mode of "critical, deconstructive relationality," and as a vehicle for "rainbow political semiology, for wily transnational technoscience studies as cultural studies" [73, pp. 299 and 329].

But even as I am interested in how diffraction supports and extends the development of critical methodologies, I am concerned with how arguments for diffraction are often tied to a rejection of reflexivity, with the two being framed as mutually exclusive. Barad, for instance, claims that "reflexivity is nothing more than iterative mimesis... mirrors upon mirrors, reflexivity entails the same old geometrical optics of reflections" [10, p. 88]. Likewise, they dismiss constructivism as a naive form of representationalism, which assumes fixed subject-object boundaries and is confused about whether "psychic and sociohistorical forces alone could account for the production of matter" [10, p. 810]. This is not fair to the diverse range of scholarship engaged in constructivism, or in representation for that matter (e.g. Stuart Hall's encoding-decoding model [70, 71]), much of which has been aimed at perturbing neat distinctions between nature and culture, humans and machines, matter and signification. It also seems to fit a larger pattern of new-materialist criticism which, according to feminist theorist Sara Ahmed, is "offering a caricature of 'the turns' in recent theory," and which paradoxically reifies matter into a "pure theoretical object ... [that] reintroduces the binarism between materiality and culture that much work in science studies has helped to challenge" [4, p. 35]. Similar objections can be found in STS literature; for instance, in Paxson and Helmreich, which cautions that "new materialist tactics often veer toward universalizing metaphysical claims about the nature of 'matter' as such" [134, p. 169], and in Hollin et al., which notes that "Barad does not seem to be attentive to difference where reflexivity is concerned" [82, p. 927], arguing the concept has generated numerous interpretations that subscribe to a more complex view of materiality than what Barad suggests.

In the same way that, within Barad's own disciplinary context of science studies, the theory of entanglement is framed as a critique of reflexivity and constructivism, one finds in Entanglement HCI a move away from the anthropocentric third wave of "situated actions" [165], away from "interaction that is situated in the social and bodily complexities of a messy, real world" [54, p. 22]. The third-wave focus on "bodies" – itself marking a push toward pluralism against a second-wave focus on the ideal "body" and first-wave focus on the "user" – is being decentred in the move to "more-than-human bodies" [83]. But it's still unclear whether the critical methodologies around gender, race, and disability that were associated with third-wave research will find similar support in the new posthumanist paradigm. As Eva Haifa Giraud argues in her 2019 book, *What Comes After Entanglement*, insights gained through entangled perspectives need to be balanced against what she calls an "ethics of exclusion, which pays attention to the entities, practices, and ways of being that are foreclosed when other entangled realities are materialised" [61, p. 2]. This is helpful advice for researchers looking to adopt new-materialist language and conceptual frameworks, as it allows entanglement to be situated as part of an ongoing discourse, diffracted through adjacent lines of thought in sociology, psychoanalysis, Marxism, post-structuralism, feminist and other standpoint theories, as well as a host of fellow travellers in science and technology studies (STS), sociology of scientific knowledge (SSK), and history of science and technology (HST), not to mention those in the more loosely defined subdisciplines that make up music, media, and cultural studies. All of this work provides relevant context for understanding how posthumanist theories of entanglement might be applied in practice; without it, appeals to Entanglement HCI risk losing their critical orientation to questions of knowledge, power, and technology.

## 3 MUSICAL OBJECT LESSONS

We now move from abstract theory in the preceding section to a consideration of how this theory applies in analysis of concrete examples. We engage with two familiar musical objects, the keyboard and the step sequencer, partly at a theoretical level to reflect on the enduring power of these mundane forms, but also through a consideration of several specific design artefacts. In the centre (Section

3.2), McPherson turns the lens on his own past keyboard-related design practice, not to propose his work as a solution to conundrums of turning theory into practice, but rather because Entanglement HCI suggests productive ways of unpacking and learning from past failures and limitations. Just as diffraction patterns can produce alternating bands of reinforcement and cancellation, here our two disciplinary backgrounds align and misalign through a shared focus on and interest in particular musical interfaces.

## 3.1 Keyboards and step sequencers: the perpetual future of mainstream DMI design?

**AM:** Digital musical instrument research has a love-hate relationship with the keyboard. The best-known textbook in the field [117] is entitled *New Digital Musical Instruments: Control and Interaction Beyond the Keyboard*; it argues that relying on a keyboard paradigm (and to a lesser extent, any acoustic instrument paradigm) represents a needless constriction of the creative possibilities afforded by digital technology. Still, seventeen years later, keyboards remain ubiquitous not only in commercial practice, but in DMI research as well. Dolan [47] noted a "poignant" tendency in maker practice to use boards like MaKey MaKey to fashion rudimentary keyboards from random bits of fruit; the *bananapiano* even finds its way into HCI research in the wild [147]. And otherwise outside-the-box design projects like the "Chromochord" – a bio-instrument that links sound generation to the photo-synthesis of specially engineered proteins – get hemmed in by a compulsion to outfit musical instruments with a keyboard interface, reducing the sonic universe to 12 vials of protein mapped to twelve pitch classes [168].

Perhaps it was ever thus: Pinch and Trocco [137] describe how in the 1960's, Buchla steadfastly avoided conventional keyboards for his synths, believing that new interfaces were needed for new music, while Moog took a pragmatic approach to leveraging musicians' familiarity with the keyboard. The *ondes Martenot*, which dates to the 1920's, originally used a sliding ring to control pitch but acquired a keyboard in its later revisions [9], perhaps in a similar pragmatic nod. There's nothing surprising about building new instruments that connect to existing skills. As Perry Cook put it: "Copying an instrument is dumb, leveraging expert technique is smart" [33]. But something deeper is going on. Dolan [47] proposes that Western music itself exists "as a species of keyboard" (p. 12), while outlining how throughout its centuries of history, the keyboard as both literal interface and metaphor has been associated with values of complete control.

The keyboard, then, is a rich entanglement. Like all instruments, it is deeply entangled with human musicians; viewed through Ihde's post-phenomenology [87], the keyboard shifts easily between an embodiment relationship (the player need not think consciously or symbolically about the keys to play it) and a hermeneutic one (consider piano roll notation or using the keyboard to teach music theory). The keyboard is also a material-discursive practice [11] – a dynamic mutual dependency between matter and discourse. The familiar geometric form of seven white notes and five black notes per octave is the materialisation of a specific musical discourse, but many things can be keyboards that don't look like that. The key ingredients, so to speak, include:

- Spatial distribution of pitch into discrete and static categories (often called "notes" in a reverse-engineering of notation);
- Discreteness of activation, in which keys are either on or off (though variations are possible within the "on" state, such as onset velocity or aftertouch);
- Typically, though not always, an inter-coupling of pitch selection and sound activation (the ondes Martenot being a counterexample);
- A prevailing discourse of control, precision and virtuosity [47].

My definition of "keyboard" thus includes many isomorphic controllers that propose new and ostensibly more efficient layouts of pitch space (e.g. according to principles of Western tonal harmony) [104, 133, 148]; it includes instruments like the LinnStrument[8] which, though nominally inspired by a guitar fingerboard, ticks all four boxes above. My definition also includes recent work in virtual and mixed reality musical instruments where the prevailing paradigm is of spatial pitch distribution (e.g. [66, 189]).

Like all material-discursive practices, the keyboard is performative: not just in the musical sense, but in the sense that an active decision is made to imbue an object with *keyboardness* (to borrow from Dolan once more). The bananapiano is a vivid example, but so too is a set of tuned bottles or wine glasses. Conversely, even a literal 7+5-note keyboard can be stripped of main ingredients of keyboardness, as in artist Ken Butler's 1983 K-Board[9], where a 55-key organ manual is used as a mechanical fretting device for a monochord instrument, disrupting both familiar pitch relationships and prevailing discourse. Certain digital instruments, including the Haken Continuum [69], the Expressive-E Osmose[10] and – I'd like to think – my own magnetic resonator piano [114], also destabilise the ideology of the keyboard through making continuous what was discrete and occasionally injecting elements of surprise and negotiation into the discourse of control, even as the last of these is literally still a piano!

Obviously there exist common instrumental paradigms other than the keyboard, but my sense is that keyboardness will remain a major stream of future DMI design as long as the discourse stays where it is, even as we invent new (virtual-)material configurations – high-tech sensors, smartphone apps, online game universes – to enact that discourse. Meanwhile, the discourse will remain as long as we continue to exist in a world of materials and sensorimotor skills that lead us to see certain objects as natural vehicles for music making. As Barad notes, neither matter nor discourse precedes the other.

There's an important technical loose end here, which is the protocol – that perpetual bugbear of DMI designers, the MIDI (Musical Instrument Digital Interface) protocol. Formalised in 1982 by a self-appointed consortium of mainly North American and Japanese companies, and constrained by the limited computational capability of the time, MIDI encodes music through a set of simplifications reflecting what Diduck [46] calls *claviocentrism*: "the centuries-in-the-making cultural logic that places the piano keyboard in the middle of the musical instrument ecosystem." These simplifications

[8] LinnStrument: https://www.rogerlinndesign.com/linnstrument (released 2016).
[9] Ken Butler: see https://kenbutler.squarespace.com/ and https://www.youtube.com/watch?v=grrjrE42ScY.
[10] Osmose: https://www.expressivee.com/ (released 2019).

include: that music is composed of "notes" which have integer numbers 12 to the octave; note events have discrete onsets and releases; onsets are characterised by a single "velocity" value which correlates with dynamics, etc. But MIDI often gets credit, especially in the popular press, for a musical universality that no protocol deserves, and complaining about MIDI has been a sport for most of its existence [119]. Suffice it to say that the inscribed values in MIDI provide a deep reservoir of claviocentric ideology even as digital music hardware and software attempt to move in new directions.

**LM:** Next to keyboards, step sequencers stand as another *instrument par excellence* in electronic and digital music. In a general sense, sequencers do for time what keyboards do for pitch – that is, they divide a continuous stretch of musical time into a series of discrete units ("steps") that can be organised into rhythmic patterns, much in the same way that keyboards carve out a discrete series of pitches that can organised into various modes, collections, and scales. A crucial difference, however, is that step sequencers make it possible to program patterns one "step" at a time, store them, and automatically replay them on command. In practice, the approach is used to program to melodies, bass lines, rhythms, and other musical parameters, producing patterns that can be manipulated in different ways (e.g., adjusting tempo or filtering). These patterns can also be combined with polyphonic and multi-track technologies for layering voices, making step sequencers a versatile instrument that can facilitate the organization of elaborate compositions, while also supporting improvisation during live performance.

Many readers will be familiar with step sequencing in music software, such as one finds in digital audio workstations (DAWs) like Ableton Live, where a grid-based division of time in the x-axis is conjoined with the skeuomorphic representation of a keyboard marking the division of pitch in the y-axis. This visualisation, which has been around since at least the mid-eighties (e.g. see Passport Master Tracks Pro [51]), remains the same regardless of instrument, attesting to the dominance of this conceptual metaphor for sequencing in screen-based interfaces. But prior to what Pinch and Bijker [138] would describe as "closure" around this particular mode of presentation, step sequencers were subject to a long period of "interpretive flexibility," during which they were reconfigured many times over in relation to an evolving apparatus that can be traced back to player pianos, music boxes, and other curious examples of automated digital sequencing *avant la lettre*. This history is well documented, both in scholarly literature [7, 62] and in popular media outlets [156], so I won't rehearse the details here, except to highlight the articulation of digital step sequencers to two dominant interface paradigms: the first is step sequencers using a keyboard layout, and the second is step-entry drum machines using a row of buttons. Together, these interfaces illustrate how step sequencers are entangled with a constellation of music theories, material instruments, performance techniques, and surrounding discourses.

The mid-eighties introduction of MIDI unleashed a wave of standalone digital sequencers like the Roland MSQ-700 Multitrack Digital Keyboard Recorder. Here already we find the keyboard tethered to a MIDI sequencer in a common hardware configuration that loosely mirrors that of software sequencers today. This convergence also mirrors the integration of keyboards in earlier analogue sequencers and even in mechanical player pianos, but interestingly, it departs from the model of pre-MIDI digital sequencers like the 1977 Roland MC-8 Micro-Composer, which was advertised as doing "for the musician what the pocket calculator has done for the schoolboy," making composition more accessible so that "the writer needn't even touch a musical keyboard." [11] Note here the distancing from "musical keyboards" and the refiguring of the musician into a "writer" who makes use of a "calculator" for programming, storing, and playing musical sequences. Roland uses the rationalisation of creative activity in these informatic terms–or rather, in what Ihde might describe in terms of a *hermeneutic relation* [87, p.179]–to support claims that the MC-8 offers the user not just a new instrument, but rather "a new concept of control for a new era in electronic music composition." Here, too, it's important to note the gendered language that assumes a "schoolboy" as the target audience, playing to the norms of what Tara Rodgers describes as "audio-technical discourse," which is built on masculinist narratives of control over soundwaves and "contributes to rendering women – who are ever-present as composers, inventors, and electronics tinkerers – ever out of place as subjects of critical and historical accounts" [146, p. 10]. In this sense, the programmer-musician envisioned by the Roland ads was only the latest iteration of a sexist trope previously used to market analogue synthesisers, hi-fi sound systems, and other technologies [157, 163], and it's a trope that persists today in online sound technology forums [15].

Alongside the keyboard-sequencer pairing in the 1970s-80s, the development of step-entry drum machines offered an interface for sequencers where time is represented as a series of discrete units, each assigned its own button marking subdivisions of a musical measure (e.g., sixteen buttons for sixteenth-note subdivisions of a 4/4 time signature). In this way, machines like the Roland TR-808 and Roger Linn's LM-1 Drum Computer encoded a hierarchical model of musical metre based on metronomically uniform beats. The crystallisation of this model in a wide range of styles imparted a cookie-cutter crispness to drum tracks on Top-40 songs by artists like Prince and Madonna, while at the same time lending a motoric drive to underground techno tracks by artists like Cybotron and Drexciya. The model also extended to live performance through the use of rhythm quantisation, which raised the possibility of "correcting" human timing by mapping micro-rhythmic "errors" to the closest beat available in a predefined metric grid. This practice bridges the gap between the automation of sequential programming and the liveness of real-time performance by embedding distinctions between structural and expressive timing in music technologies, bringing users into contact with theories of rhythm and metre that are historically and culturally contingent, despite being presented as neutral tools [121]. The effect is similar to Auto-Tune in the pitch domain, where studio producers use frequency quantisation to "correct" a singer's intonation, mapping it to a keyboard-like division of pitch space [141]. But in both time and pitch quantisation, one finds non-normative applications of the technique, such as the robotically stepwise vocal melismas of T-Pain's neo-soul ballads, or the warped, "off-the-grid" beats of J Dilla's hip hop tracks [40].

[11] These advertising blurbs appear in a two-page ad in the Fall 1978 issue of International Musician and Recording World Magazine. Accessed online, http://retrosynthads.blogspot.com/2012/08/roland-mc-8-micro-composer-if-you-can.html.

By "de-scripting" the intended function of these technologies [5], these artists have invented creative ways to subvert strict tonal and temporal constraints in their music, redefining the terms of what counts as authenticity. And yet, even so, the mass production and distribution of sequencers and drum machines, along with the normative music-theoretical systems they encode, raises questions about the balance of cross-cultural exchanges of style and technique in the age of digital media. In practice, a handful of actors exert enormous influence over the global market, and even tools meant to subvert the uniformity of quantised music–such as producer James Holden's Group Humanizer software, which claims to reinject programmed beats with the "unfakeable magic of live performance" using an algorithm based on recent neuroscience experiments [81]–can ultimately reinforce a universalising and essentialising perspective on what it means to have "human" timing, without reflecting on how such meanings are historically and culturally constituted.

## 3.2 Instrument design research as inverted analysis: a personal reflection

**AM:** I spent many years with a vague feeling that something was backwards about the way DMI design is typically explained in the research literature, and I've only recently begun to formulate why. There is an essentialising quality to DMI discourse. Many papers begin with statements like "a DMI consists of a gestural controller, a sound generator and a mapping layer between them." Such statements build on seminal work by Marcelo Wanderley and colleagues (e.g. [86, 149, 188]) which remains insightful and productive. But is the controller-mapping-synth topology really the *definition* or *essence* of a DMI? I would argue it's often better as a post hoc analytical frame rather than a paint-by-numbers template. To declare this topology, or any other, to be a universal starting point for DMI design practice risks reifying conceptual descriptors about music into prescriptive ingredients of music itself. Dylan Van der Schyff [182] observes this tendency in music education, where reification "assumes music to be an objective 'thing' rather than an interactive, relational, multi-modal activity; and it creates a rather fixed boundary between some notion of what the music is on one hand, and the environments in which it is created and experienced on the other." The resonance with entanglement theory, and particularly Waters, is obvious. Tuuri and Koskela [180] extend Van der Schyff's critique to smartphone music apps, but the same could be said about nearly any instrument, and also music notation [105, 107].

My objection isn't that every instrument inscribes an ideology about music. Musical neutrality doesn't exist, and if it did, it would surely be dreadfully dull. It's that too much DMI research seems to adopt reification as a design method. If you organise your design thinking around numerical mapping, the other pieces tend to fall into place through a particular process.

I want to illustrate this design-by-analysis process with a cautionary tale from my own design practice. In the spirit of Howell et al.'s "cracks in the success narrative" [85], I hope to learn from a project I've since come to regard as a failure in certain respects. In 2010, following a different piano-related design project that in retrospect has been more artistically enduring [109, 114], I set my sights on "transforming the keyboard into an expressive multi-touch control surface" (my phrase at the time). My technical vehicle was capacitive touch sensing, and the engineering challenge was how to integrate touch sensing onto the surface of a physical keyboard to measure the location of the pianist's fingers on each key.[12] The result was TouchKeys [110].

After designing a workable sensor system (and not so much beforehand), I turned to the question of what to do with its data. The answer seemed straightforward: make a Cartesian coordinate system (horizontal and vertical position, plus touch size) and delegate the parameter mappings to the pianist "user" – a linguistic import from HCI to DMI design which has attracted some controversy [145]. Almost all digital keyboards are MIDI controllers, so the flexibility was in drawing (mostly linear) relationships between spatial dimensions and different MIDI parameters.

The ergonomic non-viability of simple mappings was obvious from day one: playing the keyboard is already complex, and demanding additional spatial precision on where the pianist touches the keys would make it unplayable. Thus I undertook an empirical user study, grounded in first- and second-wave HCI principles of ergonomics and task performance, to shape the design of mappings that attempted to distinguish intentional from unintentional movements [113]. The result works pretty well, though like all instruments it comes with a learning curve. In 2013 I launched the instrument on Kickstarter [111] and I continued to make and sell it for the next few years.

Despite uptake by some talented musicians, I've remained ambivalent about the project, and entanglement theories have helped me formulate why. An instrument acquires its instrumentality in relation to players, communities, musical contexts and discourses [74, 88, 145, 191]. My data mapping engine attempted to be context-free aside from general principles of keyboard ergonomics, foregrounding analytical dimensions of gesture (finger placement) and music theory (MIDI synthesis parameters). Tasking the player with making musical sense of it was cast as a beneficial flexibility. However, far from being a blank canvas, the ideology of the mapping engine is pre-inscribed by how the dimension spaces are organised and the supposition that static linear relationships are the natural way of connecting them. Meanwhile, sound is addressed only implicitly, relying instead on the musician's existing collection of synthesis software.

In Barad's vocabulary [11], the instrument is an *apparatus* which co-produces musical phenomena from within an entangled state rather than measuring something pre-existing. Ihde [87] might describe it as a non-neutral mediator of musical perception and action. TouchKeys reliably elicited certain mapping configurations and playing techniques from many different players. Like all instrument designers, I was engaging in a form of *instrumentalist design*, while remaining overly preoccupied with numerical representations rather than situated musical experiences. Following Section 3.1, TouchKeys is also a material-discursive practice, and in creating it I imagined that my sensor technology was liberating the keyboard from some of its historical limitations, including discreteness of notes. In actuality, the value of complete multiparametric

[12] I knew this was not a novel idea: Robert Moog had built a one-off prototype like this in the 1980's [118], but the increasing performance and decreasing cost of capacitive sensing in the early 2000's made the idea newly viable.

control by a virtuosic performer is an intensification of keyboard discourse. Looking back, I'd trade most of it for one or two really captivating sonic behaviours, discovered and cultivated in a specific musical context.

### 3.3 Ideological interfaces and the limits of creative agency

**LM:** Building a control interface is a routine part of designing DMIs. Interactions between bodies, musical tasks, and digital technologies must be mapped in some way, and by definition, the choices a designer makes regarding things like hardware materials, sensors for collecting gestural phenomena, feedback mechanisms, and how control signals get mapped to sonic parameters will have real implications for how an instrument can be controlled in performance, and thus the level of creative agency granted to the performer.

Related to these technical concerns over user control are questions about how interfaces exert control over users. An early touchstone for this idea – albeit couched in a critique of commercial interests in the popular music industry – is Theodor Adorno's concept of *pseudo-individualisation*, which refers to the process of "endowing cultural mass production with the halo of free choice or open market on the basis of standardisation itself" [1, p. 25]. Transposed to the study of interfaces, this angle has been explored in critical media theory by authors like Alexander Galloway [56] and Wendy Hui Kyong Chun [29], who frame software and digital interfaces as an allegory or analogue of ideological control because of the way they interpellate users and obfuscate their own functionality and effects. Drawing on post-Marxist notions of ideology as that which produces an "imagined relationship of individuals to their real conditions of existence" [6], a prominent theme for both Galloway and Chun is the way interfaces simulate such relationships between users and a virtual world, the way their mappings simultaneously result in a "being-mapped" for the subject,[13] and the way promises of transparency, direct manipulation, and real-time interaction create the illusion of control by concealing the effects of technosocial mediation.

Particularly useful for DMIs is Galloway's framing of what he calls the "intra-face" not as a *thing*, but rather as a threshold between states that can be interrogated, subjected to close historical and cultural analysis, and described in terms of politics and aesthetics in different "regimes of signification."[14] Thus, the deterministic impulse evident in Adorno's early writings is counterposed against the idea that intra-faces are not just ideological, but rather, can be reframed as a way of critiquing ideology and drawing users' attention to the effects of mediation that are usually concealed. The take-away is that design choices and formalist descriptions of digital interfaces need to be considered alongside their enactment of ideological relationships (or negation thereof) between users and underlying systems of control, musical or otherwise. We need to consider how interfaces "concretize our relation to invisible (or barely visible) sources and substructures" [29, p. 59]. Or rather, in the context of DMIs, we need to consider which kinds of interactive musical phenomena are collectible, which sonic parameters are accessible, which modes of expression are communicable, which kinds of knowledge are sensible, and why.

**AM:** Whatever one's position on Adorno, *pseudo-individualisation* seems germane to at least the marketing that surrounds new commercial musical instruments [112]: "Anyone can make music!" "Make any sound you can imagine!" "Make music anywhere!" What is the music that anyone is now ostensibly empowered to play? As with music apps [154, 180], it's often a small sandbox of familiar musical tropes, presenting a set of limited possibilities that can be purchased and then navigated, and where accessibility is often defined as the inability to play a "wrong" note.

The interesting question of who controls whom in the musician-instrument relationship is tackled from a phenomenological angle by Tuuri et al. [181]. The resulting process of mutual negotiation has been explored from many different perspectives [38, 89, 90, 106, 123]. But although there is an awareness of the subtlety of this agential relationship, a lot of DMI research still falls into two clusters. The first promotes values of control, virtuosity and expression, in ways that vaguely suggest the Romantic ideal of the heroic performer, even as terms like *expression* are only loosely defined. The evergreen alternative in communities like NIME[15] is the deliberate ceding of (partial) control to a digital system, typically coupled with reflections on technological agency, and most often within a prevailing aesthetic of post-Cage free improvisation. The *alterity relation* in Ihde's post-phenomenology [87] is ascendant: the instrument often acts as a collaborator or creative foil [161, 170]. Technologically, such instruments often incorporate generative behaviours, AI algorithms, randomness, or (more interesting than randomness) chaos (e.g. [124]).

My reductive framing of NIME discourse isn't intended to diminish nor homogenise the inspiring music and scholarship that emerges from the community. Rather, my problem with this state of affairs is that the debate easily settles into a battle of clichés where two camps with different aesthetic priorities talk past each other. I don't propose to resolve that with a further split-the-difference cliché: like Frauenberger's critique of treating positivism and constructivism as ends of a spectrum in HCI [54], the middle space may lack a firm theoretical (and aesthetic) grounding. But I would advocate for ceasing to treat digital instruments as somehow *sui generis*. Comfortable dualities of "acoustic instruments this, digital instruments that" tend to obscure the fact that *all* instruments act in many ways and engender many different relationships, and that present-day designers expressing their creative impulses through digital circuits and software would almost certainly recognise similar motivations in previous generations working with analog electronics, metal, wood, string and skin.

### 3.4 If not claviocentrism, then what?

**AM:** *Claviocentrism* [46] goes beyond piano-like instruments. It's broader than twelve-tone equal temperament, instantaneous onsets, or the problems of the MIDI protocol. Claviocentrism is bound up

[13] Note here the inversional affinity with Frederic Jameson's notions of "false consciousness" and "cognitive mapping" [93].

[14] See [56], p. 45; Galloway identifies four regimes as part of this analytical framework, including ideological (coherent aesthetics and politics); ethics (incoherent aesthetics, coherent politics); poetic (coherent aesthetics, incoherent politics); and truth (incoherent aesthetics and politics).

[15] The International Conference on New Interfaces for Musical Expression; see Section 4.3.

with notions of control and virtuosity and the instrument as a materialisation of music theory.

In an era of embedded technological "intelligence"– AI algorithms, smart devices, IoT technologies – I propose that an antidote to claviocentrism is precisely to have instruments be *less* intelligent in a conceptual or theoretical sense. That doesn't mean instruments will become less laden with theory (nothing is neutral), but that the digital system need not and in fact *should not* be preoccupied with encoding a neat conceptual representation of what the player is doing. In this view, so-called "intelligent" or "smart" instruments, which use sensors and computing to try to codify and then react to an explicit representation of musical activity [94, 140, 179], are actually a move in the wrong direction.

Barad [10] returns regularly to Niels Bohr's quantum philosophy-physics, including Heisenberg's famous *uncertainty principle* (which Bohr argued was better expressed as an ontological indeterminacy). The premise is that it is impossible to simultaneously determine the exact position and momentum of a particle because the apparatus of observation that gives one quantity a measurable identity necessarily obscures the other. Like a game of quantum Whac-a-mole, resolving indeterminacy in one area only causes it to pop up somewhere else.

Digital musical instruments create two competing loci of meaning. One is the meaning attributed to the instrument by human musicians, while the other is the symbolic representation within the instrument itself (i.e. does the digital system "know" what music it is playing?). To demand more specificity in one locus might entail greater vagueness in the other. Thus, when we demand our "smart" instruments encode explicit, inspectable music-theoretic models of concepts like onsets, pitch, rhythm and meter, musicians are left with the unenviable choice of either redefining their musical practice to fit the machine's representation or experiencing a frustrating sloppiness when the instrument gets certain musical judgments "wrong" – e.g. the missed notes and octave errors familiar to the user of any audio-to-MIDI converter.

Framed in this way, the HCI design literature on ambiguity [23, 58, 185] offers a path forward. I'll also point to one arbitrary "ultimate particular" [164] which strikes a subtle blow against claviocentrism. Dahlstedt's *Living Strings* project [36] works with a MIDI keyboard (a Nord Stage piano and my own TouchKeys (Section 3.2)), but the basis of sonic excitation isn't just the MIDI data but the literal mechanical noises of the object. Slapping the case becomes acoustically functional; hitting a key is only functional if it makes a sound against the key bed. The spring-loaded pitch wheel takes on an entirely different meaning when what matters is the *sproing*! noise it makes when you suddenly release it: the numerical abstraction is shattered and physicality reclaims centre stage. But, critically, neither the Nord Stage nor the digital resonator attempt to infer any symbolic meaning from these actions. Instead, the locus of meaning making remains with human musicians within a surrounding ecology.

Finally, an anti-claviocentric design methodology might work upward from sonic phenomena rather than downward from concepts and dimension spaces. Working upward is not toolkit design; it's not about interconnectable blocks or languages that recombine familiar sanitised concepts. I'm more interested in the early musicians who discovered the effect of blowing through blades of grass or plucking a tensioned string, then harnessed those phenomena into objects suitable for expressing familiar musical ideas. Perhaps the contemporary circuit benders who turn Speak & Spell toys into bizarre alien drum machines [59], or the Japanese group Electronicos Fantasticos who make instruments out of CRT televisions,[16] barcode scanners and fans, are following a similar impulse. Here again: the instruments don't know anything about the musical meaning of their use. There's no special window to peer into to discover a neat music-theoretic representation of what's happening. Meaning emerges only through the social and embodied act of musicking [155, 191]. That seems to nicely fit the ethos of entanglement theory.

# 4 PROVOCATIONS

In this section, we move from a practical focus on musical object lessons to a series of deliberate provocations meant to throw the theoretical stakes of Entanglement HCI into sharper relief. We begin in 4.1 by revisiting the question of whether entanglement theory is leading to a new wave of HCI research, before shifting to a consideration of who may be left behind by this wave in subsections 4.2 and 4.3. The final two subsections examine the creeping nihilism that can set in for designers faced with the ethical ramifications of their own entanglements, as well as the possibility of hope to be found in a more situated perspective.

## 4.1 Is entanglement theory really HCI's much-anticipated fourth wave?

**AM:** Susanne Bødker reports being asked in 2015 "if a fourth wave is coming." [21] She answered: "HCI is in the middle of a chaos of multiplicity in terms of technologies, use situations, methods, and concepts. Hopefully something lies beyond that horizon, but for now, I'll leave it to others to identify it." The question mark in the title of Frauenberger's paper ("Entanglement HCI The Next Wave?") dangles a tantalising possibility while withholding judgement on it. He writes [54]: "I aim to test the waters for a paradigm shift that seems to be in the making, particularly within the more design oriented corners of the field." The hundreds of citations amassed since then – and the fact that our own research project is explicitly organised around entanglement – shows that this proposed wave has touched a nerve. I'm enthusiastic about the prospect. But are we there yet? Is now the time to seek order amidst the chaos of multiplicity?

In HCI waves as in so much else, hindsight is easier than foresight. In recent years other ideas have been proposed for HCI's fourth wave, including Transdisciplinary Design HCI [20], African HCI [122], Activist HCI [8] and Post-Interaction HCI [32]. The specifics are interesting: these other proposals seem to share with Entanglement HCI concerns with ethics, local and global politics, epistemologies and fuzzy boundaries between humans and technology, though not every proposed wave deals with all of them. Like the concurrent emergence of entanglement across many disciplines (Section 2.1), that could be evidence for an emerging paradigm.

[16] CRT television drums by Electronicos Fantasticos: https://www.youtube.com/watch?v=QAoyes6VCrQ

It could also mean that entanglement fits comfortably within the gamut of third-wave HCI, perhaps as a radicalisation of discourse rather than a wholesale reconstitution of current practice. Critiquing user-centred design and user experience, part of the proposed entanglement shift, is hardly new (e.g. [143]), and participation in numerous forms has been the backbone of HCI for decades, long enough to give rise to a variety of critiques [22], including tokenistic participation [16, 159, 197], *participationism* that reduces the designer to a mute facilitator [108], or virtue signalling in work with marginalised communities [132]. When does a critique serve as a premonition of a new paradigm rather than simply an indicator of a healthy evolving discourse?

Post-humanism might be one of the foundational shifts in Entanglement HCI, though when philosophy filters through to research practice, there may still be more continuity than rupture with Bardzell and Bardzell's "Humanistic HCI" [13] or Bødker's 2015 account of third-wave HCI [21].

## 4.2 Who is excluded from the turn to posthumanist new materialism?

**LM:** The concept of entanglement is so broad that it might seem like nothing is excluded from the scope of posthumanist new materialism. Indeed, a common motivating force of posthumanist discourse is the need for humans and nonhumans to come together to avoid ecological disasters in the Anthropocene, giving the impression of total inclusivity.

Amplifying this impression, researchers in HCI have begun to design for "more-than-human bodies," which Homewood et al. peg to a "relational ontology and a focus on the agency of more-than-human objects and entities such as things, spaces, people, and materials" [83, p. 7]. Along similar lines, Ron Wakkary [184] proposes a theory of design for "more than human-centred worlds," building out a "nomadic practice of designing things," as a "designing-with" that recognises the "unique intentionalities and agentic capacities" of nonhumans. The focus here is on how technologies gather "constituencies" around them, which entails a "political structure ... that convenes humans and nonhumans" [184, p. 201]. An intriguing ambiguity arises in this flat ontology, however, as Wakkary's concept of a "speaking subject puts the human designer in the heart of the political ecology of things" (p. 238), such that a human is still the "convener that assembles and maintains the collective," and is still the one who "speaks on behalf of and ensures the participation of nonhumans" (p. 239). In my reading, this kind of ambiguity is positive and productive, as it registers the undecidability of subject-object agencies in entangled situations prior to any "agential cut," and because it reflects the influence of a sociological and even constructivist strain of thought at play in more-than-human discourses.[17] Leaving the door open to a critique of political asymmetries within constituencies is preferable to the adoption of a purist program of posthumanist new materialism, which would raise doubts about how inclusivity is supposed to work in the context of such gatherings. The fear is that significant cultural differences might collapse down to the lowest common denominator of matter, reinforcing the very problem of universalism that is often the target of posthumanist calls to move past Enlightenment ideals of the human as an autonomous subject.

Concerns of this sort have been raised in a number of fields,[18] including critical race and decolonial studies, where writers like Zakiyyah Iman Jackson have linked more-than-human theories to attempts to "move beyond race, and in particular blackness, a subject that I argue cannot be escaped but only be disavowed or dissimulated in prevailing articulations of movement 'beyond the human.' " [91, p. 216]. Alexander Weheliye makes a similar critique when he observes that "questions of humanity... which in critical discourses in the humanities and social sciences have relied heavily on the concepts of the cyborg and the posthuman, largely do not take into account race as a constitutive category in thinking about the parameters of humanity" [193, p. 8]. This is so despite the fact that race has historically been used to classify people as either "full humans, not-quite-humans, and nonhuman" (p. 4), and also despite persistent inequalities around race that have produced an uneven distribution of precarity in the Anthropocene epoch. In light of this history, the insistence of posthumanist new materialism on ontological sameness can result in what Axelle Karera describes as an "All Lives Matter" mentality which, while cloaked in the ostensible rhetoric of inclusivity, elides fundamental differences and denies key social context for understanding how the "Black Lives Matter" movement emerged out of necessity because the "juxtaposition of blackness and life continues to be ferociously contested as oxymoronic" [96, p. 52].

In music studies, one might imagine there is an easy tie-in between sound and the common emphasis on vibration found in new materialist philosophy (e.g., Bennett's "vibrant matter"). This is the assumption behind the suggestion in Goodman that "vibrational rhythm shoots right to the core of an ontology of things" [64, pp. 83-84] and behind calls by Cox for a sonic materialism that "avoids the pitfalls encountered in theories of representation and signification" [34, p. 146]. But elsewhere, reception has been mixed, with Chung expressing doubt about "the celebratory nonhuman turn in new materialism toward vibration, things, and objects and their ubiquity," reminding readers that "notions of vibrationality shared between humans and earthen materialities were – long before the ontological turn of recent years – once the seat of a non-ethics that regarded some humans, essentially, as dirt" [30, p. 230]. At issue are the homogenising tendencies of new materialism, which risk treating cultural differences as illusory and secondary to the idea that, at base, everything is made of the same vibrating stuff. Vibration here acts as a flattening device, an equaliser, placing everything from planets to atoms on the same level playing field. But as musicologist Robin James has argued, it may be wise to retain some skepticism of theories that "posit acoustic resonance as the fundamental structure of reality and argue that this structure is a more accurate, more equitable and just foundation for philosophical practice" [92, p. 93]. This is because the appeal to vibration is not inherently emancipatory or necessarily inclusive, and as a critical tool, it can be wielded in arguments on both left and right of the political spectrum. And yet, so can constructivist theories, which

[17] For instance, Wakkary builds on work by Susan Leigh Star in his discussion of infrastructuring and its relation to participatory design and the construction of public constituencies [184, p. 214].

[18] E.g., for critical engagements with questions of posthumanist new materialism in Indigenous studies, see Watts [192] and Todd [172]; and in feminist studies, see Ahmed [4], Sullivan [166], Willey [194], Tompkins [175], Braunmühl [25], and Goh [63].

are often articulated to progressive politics, but can just as well be employed by conservatives when it suits their interests.[19] What matters, regardless of theoretical orientation, is that researchers pay attention to what is getting cut from their accounts – i.e., heed Giraud's call for an "ethics of exclusion" [61] by not taking constituencies for granted or letting universal narratives of sameness override cultural and historical specificities.

To be clear, the authors cited above in the area of MTHD do not engage in any kind of discrimination in their research, much of which is in fact geared to the important work of reorienting HCI design practice around more sustainable ecological frameworks. Likewise, outside of HCI, more-than-human theories are often operating on the basis that human-centredness has been the source of imbalances and may paradoxically lead to human extinction, in which case, what is needed is a radical solidarity across all forms of matter. These critical pursuits should not be abandoned or threatened by the need to take critical stock of the philosophical and historical resonances of more-than-human rhetoric that centres objects and things.

## 4.3 Get back in your silo! Who is invited to entanglement HCI's new commons?

**AM:** In my years publishing music-related work at CHI, I've become accustomed to the reviews asking if I was familiar with a conference called NIME, and wouldn't that be a better place for this submission? Meanwhile, NIME has its own origin story which is oft-repeated but wrong: "New Interfaces for Musical Expression" was the title of a CHI 2001 workshop [139] which spun out into an annual conference from 2002 onward. To many observers, this establishes the lineage of NIME as a subfield of HCI, but Wanderley who was present for the "founding", argues otherwise [187]. The acronym might date to CHI 2001, but the community, ideology and aesthetics of NIME are more closely associated with prior gatherings like the International Computer Music Conference and established music technology institutions whose work extended to 1980's or even earlier.

Curiously, then, NIME attendees and "get ye back to NIME!" CHI reviewers seem to share an interest in defining NIME as the true and proper place for music-related HCI to take place. Given the size of NIME (fewer than 500 people participate each year) relative to the breadth of HCI and the centrality of music as a human activity, this seems like a missed opportunity. There is also a music-related CHI literature not directly aligned to the concerns of DMI research, for example Benford and colleagues' ethnographies of Irish session musicians [174] and DJs [3] or Rogers et al. promoting creativity with technology amongst retirees through designing simple keyboards [147] (more on that in Section 3.1). The late great Trevor Pinch, who famously brought an STS perspective to the Moog and Buchla synthesisers [137], co-wrote a CHI paper on art-based enquiry [95] as one of his last published works. Other creative and performing arts have carved out their own subspaces within HCI, as discussed in a CHI 2023 panel [103].

That brings me back to Entanglement HCI. The preponderance of work which explicitly identifies with entanglement seems to come from research through design, practice-based research and similar areas. Does Entanglement HCI "belong" to these communities in any sense of the word? If "paradigm shifts begin in many different corners" [54], which corners get to decide how the paradigm shapes up and what practices are considered relevant? Is orientation towards a particular literature (whether philosophical or design-oriented) the price of admission? Perhaps paradigm shifts can emerge as many disparate local conversations rather than one global one, but part of the methodological rethinking of Entanglement HCI might include more attempts to find boundary objects [101] and foster conversations across silos.

## 4.4 Facing nihilism in design practice

**AM:** This is a major issue I'm grappling with in my instrument design practice. Agre [2] writes: "A critical technical practice will, at least for the foreseeable future, require a split identity – one foot planted in the craft work of design and the other foot planted in the reflexive work of critique." An inspiring sentiment, but how should this split identity work?

The challenge is that it's easier to tear down ideas than to unapologetically stand behind them (echoes of my graduate school in composition). Musical neutrality and value-free tools don't exist [102], and trying to even approximate neutrality seems doomed to failure, more likely to obfuscate the inscribed values of a tool than to mitigate them. Building a digital instrument starts with a coherent set of musical ideas, and it entails writing code, designing circuits, building physical objects. Beyond the familiar engineering challenges, every action is open to criticism: too clichéd, too Eurocentric, too obscure, too complicated, too reductionist, too self-referential. Bringing in outside collaborators shifts the problems but doesn't eliminate them, and I don't intend to use other artists as a credibility shield. "Don't do it *that* way" is a valid precaution, but it doesn't say much about what to do instead. How should a designer know when to say, "this is flawed but I still stand behind it?"

**LM:** If nihilism is the ideology that "nothing matters," then I'm not so sure that what we are talking about here is nihilism. In fact, it's almost the opposite, as entanglist designers seem to be suffering from a general sense that "everything matters," that every person, idea, or object is connected with every other element in a thick, irreducible web. From this perspective, the feeling of nihilism may have more to do with an overwhelming hyper-vigilance, with a helplessness that sets in knowing that it is impossible to fully anticipate or account for all the ethical parts in play in technological innovation. Even more so because, for many, no doubt, there is a clear commitment to design justice (again, an indication that "something matters" and that values have not been abandoned), but no clear road map for how to get there.

To the extent nihilism is the right word, I'm not sure it's always altogether a bad thing to be avoided. Instead, it might be understood as a rejoinder to the unchecked optimism of popular media outlets like WIRED, where an endless stream of gadgets promises to solve the world's problems and unlock better futures. But for who? And at what cost to the planet and society? These gadgets are out of financial reach for many people, and some of them have been proven to be discriminatory, further entrenching and automating the biases and asymmetries of power that already define the status

[19] Sterne and Leach [162] make this point in the introduction to a special issue of Social Epistemology on the theme "After Social Construction."

quo (e.g., apps for face-recognition, speaker identification, predictive policing). From this perspective, the promises of technological solutions to the world's problems can be read as a form of what Lauren Berlant calls "cruel optimism" [18] – i.e., when hope becomes abusive because the thing hoped for is perpetually deferred, and often by design, resides outside the realm of possibility. In response, writers like Calvin Warren have taken up the mantle of nihilism—in his case "black nihilism" – as a defence against the cruelty of technosolutionism, arguing for its utility as part of a "demythifying practice, in the Nietzschean vein" [190, p. 221].

But for designers who want to make things, adopting nihilism as an affective response may be less desirable than turning to something like Philip Agre's "critical technical practice," which opens space for a hermeneutics of values underlying technical work, as well as for constructive engagement with others in fields different than one's own, and for finding a "middle path" where designers are neither stifled by the internal assumptions of their field nor delegitimised by outsider philosophies. With this proposal, Agre sought to legitimise "moral and ethical discussions", and he argued that building things shouldn't be the only acceptable mode of evaluation for HCI research [2, p. 11-12]. He also held onto more than a little ambivalence, perhaps bordering nihilism, about the fact that his interventions against dominant paradigms would likely be assimilated into the reproduction of that very same paradigm at a higher level. And he was reflexively aware of his own entanglement in a web of AI research that emanated from MIT and included financial support from the Hertz Foundation Fellowship with its close ties to military interests. These are all ways of channelling would-be nihilism into a more constructive path that takes account of one's own positionality.

### 4.5 Something, somewhere, in a gradual fashion – or, how to avoid the "god trick"

**LM:** In the 2022 film *Everything, Everywhere, All At Once*, the main characters get sucked into the vortex of an everything bagel, a black hole of nihilism from which no light can escape. Ironically, in a world where everything is possible, nothing matters, and when someone can be everywhere all at once, they exist nowhere in the unfolding present. The emptiness of this omniscient perspective is finally resolved when the protagonist chooses to embrace finitude, taking responsibility for her own positionality within the wider network of all possible worlds.

I want to draw a parallel between this plot and the plight of researchers working to find a way out of the dual traps of absolute objectivity on the one hand (i.e., hard scientific positivism) and total relativism on the other (i.e., strong social constructivism). Both views lapse into what Donna Haraway calls the "god trick," albeit from opposite directions, as they make claims of "seeing everything from nowhere" [72, p. 581]. So, how might we avoid this "god trick" in the context of HCI and music research, instead seeking "partial, locatable, critical knowledges" (p. 584)?

Recognizing the material affordances of different instrument designs, while at the same time acknowledging the historical specificity and cultural contingency of the musical values they encode, is a good place to start. As we've seen with keyboards and step sequencers, a lot can be learned by reverse-engineering the material makeups and implicit values of existing instruments, which not only sheds light on the historical dimension of DMIs, but also provides insights to help guide future innovation and facilitate greater awareness around the cultural impact of new instruments. But here too, in looking backward and forward simultaneously, it is important to recognize the limits of one's own perspective, as hindsight is already compromised by selective memories and partial records, while foresight can never fully anticipate the lives that instruments lead and the ways their intended scripts get deferred and de-scripted as they meet with different cultures of use.

Beyond instruments, it is important to recognize the positionality of researchers themselves. How can we reflexively account for ourselves, our social identities, disciplinary backgrounds with their attendant modes of evaluation (and thus disciplining of what can be claimed), and embeddedness within particular institutions? How does our situatedness impact our access to and production of knowledge, how does it inflect relationships between researchers and study participants, and how do we reconcile it with asymmetrical power structures that tilt the field, promising researchers a privileged "view from above"? And finally, how is our research inflected by its entanglement in a mesh of financial support systems, of academic-corporate partnerships, of global trade geared toward the cheap manufacture and distribution of technological goods? Accounting for the sprawling situations in which we find ourselves surely requires a heavy dose of cultural reflexivity, not just diffraction.

What is necessary is a pairing of reflexive and diffractive modes of thinking, where turning attention to our own positionalities and accounting for how these affect the research at hand is complemented by careful attention to the "intra-actions" of diverse materialities, bodies, ideas, and practices across different scenes and sites of study. In practical terms, this might be accomplished using a variety of methods, including (auto)ethnography, participatory design, and artistic research, which help to decentre the institution and foreground the perspectives of different stakeholders, especially those who may have been historically marginalised, thus offering a countervailing "view from below." The goal would be to compare and contrast these perspectives, attending to their local specificities and partial claims to knowledge without collapsing them into a homogeneous whole. But here too, Haraway reminds us, there is a "serious danger of romanticising and/or appropriating the vision of the less powerful while claiming to see from their positions" [72, p. 584]. So, there are no ready-made, wholesale solutions, only tailored approaches that must grapple in good faith with the multiple mediations of voices, tools, techniques, and materials encompassed within the scope of any given project.

## 5 CONCLUSION: ENTANGLED DESIGN AS CRITICAL TECHNICAL PRACTICE

The preceding dialogue has been an exercise in partial perspectives, diffracting our two backgrounds as authors, without making claims to authority or suggesting that our views should supplant or supersede any of the lively discussion already taking place within

HCI. This kind of collaborative project can be difficult, and throughout the writing process we faced challenges working across disciplinary boundaries and translating between our own specialised skill sets and technical vocabularies. But through these interactions, we learned more about our respective fields and found areas where their interests overlap, engaging in a process that ultimately caused us both to reassess our own theoretical positions and keep an open mind.

As the HCI community gradually unpacks the meaning of entanglement and its implications for design, our dialogue suggests two somewhat contradictory guardrails: first, that we should avoid premature closure around a limited canon of primary theoretical sources, and second, that entanglement should also not be so broadly construed as to be a synonym for all relational theories and hence lose its specific articulation to posthumanist new materialism. The first rail speaks to the need for a plurality of perspectives on entanglement, including critiques, and in this respect, the fields of music, media, and cultural studies can offer HCI a rich literature on questions of technosocial mediation. Meanwhile, the second is meant to ensure the language of entanglement doesn't overshadow important humanist interventions in HCI over the last few decades, including work in feminist, decolonial, and disability studies, much of which can be classified as third wave research. There is no reason that reflexive and diffractive methodologies can't both be part of a critical orientation in HCI research.

We are optimistic about the critical potential of entanglement theories, while at the same time cautious about how they might be translated into actionable design methods. In particular, we share with other Entanglement HCI authors the idea that such theories ought to be assessed for their capacity to connect with social movements and to foster critiques of technology, not just evaluated according to the traditional norms of science engineering, where repeatable and generalisable results are prioritised. This is especially true of research involving artistic practice, such as ours on musical interactions, where a distribution of creative agency across humans and nonhumans, across time scales, and across cultural, political, and geographic boundaries short circuits any attempt to explain mediation in a clear-cut manner, let alone harness that explanation as a ready-made protocol. With this in mind, as we seek to re-configure relations otherwise, it will be important to let go of the illusion of a quick reconciliation or neat mapping of theory to design activities.

Music has been the main focus of our dialogue. And even where domain-specific details, like those in our Section 3, may not always be pertinent to a general HCI readership, we suggest that there is value in their inclusion to show the process of turning theory into practice in different situations, rather than staying focused on abstract principles that translate more easily across domains but blur some of the sharper contrasts that entanglement theories can provide. We have deliberately written in personal voices and acknowledge and expect that some of our positions are open to challenge. To this end, we invite thoughts and responses to the present article, and we look forward to hearing from other specialist perspectives across different subfields within HCI. Healthy discourse on a topic of this magnitude requires an embrace of the "messiness" of technosocial innovation [99] and a patient engagement with science as an "anarchic enterprise" [52]. Following HCI's best traditions, we need to hear from many disciplinary perspectives with their own specific concerns and interests.

This paper aims at more than an escapade through a bunch of theories, and in our dialogue, we have touched on why and how attitudes towards design practices should change to account for situatedness and positionality. We do not intend to pass final judgement on whether it's time to declare a "fourth wave" or if "entanglement" is the right label. Nor has it been our goal to forge a new connection of Science and Humanities, given that they are already connected. Instead, we hope to expand the scope of conversation around entanglement by looking at both resonance and interference patterns between different theories and discourses, some of which may be closer or more germane to the task of developing a critical technical practice that, as Agre puts it, keeps "one foot planted in the craft work of design and the other foot planted in the reflexive work of critique" [2].

Entanglement design is really entangled design. It should be clear by now that no one person or discipline can claim ownership of these concepts, and (following Haraway) nobody sits completely outside of entanglements. We are all caught in one web or another, depending where one chooses to make the cut. The trick, then, is not to disentangle oneself, but to acknowledge that one is always already entangled and to reconfigure relations toward better futures whenever and wherever possible. It is to this end that our paper offers a sympathetic engagement with the new wave of Entanglement HCI, while also airing critical perspectives that have been overlooked thus far, in hopes they will further enrich a vibrant conversation taking shape between the areas of design research and creative practice.

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