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Embrace the Weirdness: Negotiating Values Inscribed into Music Technology

Abstract: This article explores the ways specific hardware and software technologies influence the design of musical instruments. We present the outcomes of a compositional game in which music technologists created simple instruments using common sensors and the Pure Data programming language. We identify a clustering of stylistic approaches and design patterns, and we discuss these findings in light of the interactions suggested by the materials provided, as well as makers' technomusical backgrounds. We propose that the design of digital instruments entails a situated negotiation between designer and tools, wherein musicians react to suggestions offered by technology based on their previous experience. Likewise, digital tools themselves may have been designed through a similar situated negotiation, producing a recursive process through which musical values are transferred from the workbench to the instrument. Instead of searching for ostensibly neutral and all-powerful technologies, we might instead embrace and even emphasize the embedded values of our tools, acknowledging their influence on the design of new musical artifacts.

Discussions surrounding new audio technologies for the arts tend to promote them as a means of individual achievement and creativity, effortless production, leisure, and immediate gratification (Théberge 1997). Digital music tools are often depicted as pliable vehicles that provide access to audio manipulation at various levels, from primitive operations to predefined musical abstractions, allowing musicians to create a great variety of sonic structures (Zicarelli 2000; McPherson and Lepri 2020; McPherson and Tahıroğlu 2020). This argument has long been prevalent in both academic and nonacademic contexts of music technology (Born 1995, chaps. 7, 11; Sterne 2003, pp. 218, 225).

According to this view, new instruments can be somehow understood as powerful and yet neutral mediators capable of producing "any sound you can imagine" (Théberge 1997). Despite the variety in form of digital musical instruments (DMIs), however, some authors have observed recurrent patterns in the musical language of these instruments (Igoe 2008; Dolan 2012; Snape and Born 2022); regular attendees of electroacoustic concerts will be familiar with flippant comments that a piece of music "sounds like Max" or "sounds like NIME" (the New Interfaces for Musical Expression conference). It is not our intention here to isolate the specific cues that lead to such comments, much less to pass judgment on the artistic quality or variety of works created with DMIs. Instead, we simply highlight the apparent disconnect between the diversity of technology and musical outcomes in early DMI experimentation (Miranda and Wanderley 2006) and the subsequent consolidation of high-level aesthetics, which often (though not always) cluster around a few electroacoustic or postdigital styles (Smalley 1997; Cascone 2000).

In this article we aim to explore whether this clustering is due to cultural dynamics (e.g., pedagogical and aesthetic habits, cf. Marquez-Borbon and Martinez-Avila 2018) or to the standardization and spread of specific tools within interactive art and music technology communities (Teboul 2017). Our investigation attempts to unpack some of the means by which specific music technologies influence the design of DMIs. In line with the research concerns posed by Snape and Born (2022) for the study of the Max audio programming language, we are interested in the "aesthetic situatedness" of the uses made of digital music tools. In particular, we report on a compositional game in which music technologists were asked to sketch musical interfaces with common electronic sensors and the Pure Data (Pd) programming language.

Rather than design a scientific study seeking to isolate general statistical trends from the high variability of human creative decision making, we embrace the "ultimate particulars" (Stolterman 2008) of each creative encounter between instrument designers and their tools, while also watching

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for instances in which several designers independently follow similar paths. We acknowledge that the tools-and-design brief proposed to our participants constrained the outcomes of our research and should not be generalized. Our work introduces a practical approach to the study of the nonneutrality of technology, however, that might inspire other researchers interested in this topic. This approach, we suggest, allows valuing the specificity and diversity of individual musical practices while also providing sets of detailed design examples that can be used to ground comparisons among music technologists active in different subcommunities, pointing toward the digital tools as a common element facilitating the emergence of specific aesthetics and interaction patterns.

After introducing relevant literature on the nonneutrality of technology, we present the results of our study, describing a set of recurrent paradigms related to the interpretation of sensors, data mapping, and sound design. Our analysis takes into account participants' concerns and reflections on both design processes and musical outcomes, and it also considers their musical background. In the final discussion we reflect on how musical values are transferred from one technology to another through recursive and situated processes of negotiation.

Background: The Politics of Technical Artifacts

Madeleine Akrich (1992) claims that "technical objects have political strength" for their ability to modify and stabilize social, economic, and historical courses. She proposes the notion of the "script" to illustrate how artifacts "de-scribe" potential scenarios of uses that were previously "in-scribed" into technical objects. While interacting with a technology, we interpret the script envisaged by the designer. In turn, Michael Horn (2013) argues that the shared practices and cultures evolving around artifacts can be exploited to design new tangible interactions.

On a more fundamental level, Tim Ingold (2010) views materiality as an intrinsic guide for human action: The "grain" of materials influences our practices, as the grain of the wood guides the woodworker's strokes. Melvin Kranzberg (1986, p. 547) famously wrote: "technology is neither good nor bad; nor is it neutral." His axiom captures the way that technological artifacts, far from being unbiased mediators of perception and action, can engender or reinforce particular uses as well as social relationships and shared values.

There is a longstanding stream of scientific and engineering research within the DMI community that decomposes, analyzes, and constructs (or reconstructs) instruments as assemblages of technical components, namely a control interface, a sound synthesizer, and a mapping that connects the two (Chadabe 1977; Paradiso 1997; Miranda and Wanderley 2006). Studies in line with this perspective focus on the choice of sensors to control musical functions (Wanderley et al. 2000), mapping design strategies (Malloch et al. 2019; Blandino and Berdahl 2021), the distribution of control parameters between human and machine (Mathews 1991), and evaluation from the perspectives of different human stakeholders (O'Modhrain 2011) including players (Hunt, Wanderley, and Paradis 2002) and audience (Emerson and Egermann 2018).

A different perspective on DMI research examines new instruments as nonneutral mediators of perception and action (Mudd 2019) and situates them within larger sociomaterial ecologies—as Simon Waters (2021, p. 135) writes: "a musical instrument is not an object but a process; a dynamic system in a constant state of change, seasoning, adjustment, and decay." Researchers adopting this perspective often frame DMIs as active agents inseparable from the ecosystems out of which they emerge (Rodger et al. 2020).

This article approaches these perspectives as two sides of the same coin, aiming to balance them by exploring digital tools and their use in detail, while also considering broader sociocultural dynamics linking the technology under scrutiny, the musicians using them, and their environment. Based on this mindset, we examine instruments as cultural artifacts that reproduce broader discourses (Morreale et al. 2020) and aim to shed light on how specific tools can influence the creative process of instrument design.

Figure 1. Each participant independently sketches simple instruments using common sensors, a Bela board, and Pd.

Figure 2. Setup of the compositional game, one station per participant, facing one another.

Method: Composing Sensors with Pd

To explore the aesthetic influence of specific music technologies, we created a musical game for the composition of DMIs. The activity is conceived as a playful hands-on exercise in which practitioners of music technology are invited to design sonic interactions using the Pd language and a basic hardware interface. We refer to the etymology of the term "compose" to frame our activity (from *com*: "with" or "together" and *ponere*: "put," "place," or "arrange"). We then envisage musical artifacts as multifaceted assemblages resulting from the aggregation of sonic, temporal, corporeal, technological, and social leverages (Born 2005). Based on this mindset, we investigate the design of new DMIs drawing from the perspective of "research through design" (RtD) (Gaver 2012).

Figure 1.

Instrument Making

Our compositional exercise requires two participants at a time. For each game, two instruments are designed and participants work on both instruments. Participants are provided with a breadboard containing three sensors commonly used in DMI design: a pushbutton, a potentiometer (with knob attached), and a force-sensing resistor (FSR). The sensors are prewired to a Bela board (McPherson and Zappi 2015), using a digital input for the button and analog inputs, run through 16-bit DACs, for the other two sensors. The activity workflow involves creating Pd patches on a computer and uploading them to the Bela board where they can be tested. Two workstations are prepared, one for each participant: a computer, a Bela board with three connected sensors, and a pair of headphones (see Figures 1 and 2).

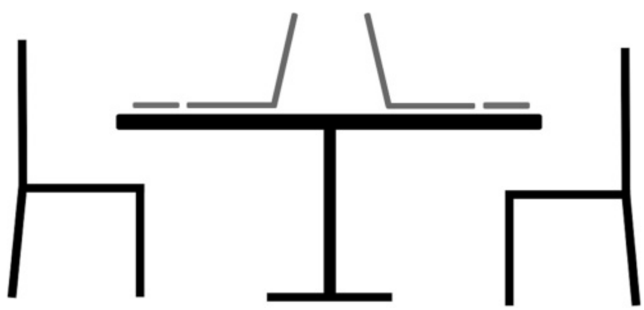


Figure 2.

The making of the instruments is organized in several short steps. First, a facilitator invites both participants to "compose an audio algorithm for one of the available sensors" (the sensor chosen by a simple random process—folded slips of paper lying on a desk each had the name of a sensor on the inside, the participant chose one such slip and opened it before starting). After ten minutes the two participants switch places, moving to the opposite side of the table. They are then are invited to start a second Pd project with a new sound algorithm to be controlled by one of the two remaining sensors available at the workstation (again chosen at random). Afterwards, participants swap places again, and the facilitator asks participants to start a third Pd project, working with the remaining sensor. Finally, participants are invited to make a new Pd patch gathering together the three algorithms saved on their current workstation. During this last step, participants are requested to review the overall instrument, modifying and improving it according to either aesthetic or technical concerns. By the end of the instrument making, each participant is able to play an instrument featuring the three sensors.

We ran two different versions of the study, each following the same structure but with a difference in the first step. In the second version of the game, participants randomly selected two sensors with which to start with. Four pairs of participants played the first version of the game (one sensor at a time), and three pairs played the second version (starting with two sensors).

To emphasize the playful nature of our study, the activity is introduced as a collaborative game, based on our previous work (Lepri and McPherson 2019; Lepri, McPherson, and Bowers 2020; Lepri et al. 2020) where playful group activities proved to be particularly suited to promote creative design practices. Furthermore, participants have a limited amount of time to compose each algorithm: from 10 to 15 minutes for each step. We borrowed this approach from the work of Andersen and Wakkary (2019) on the Magic Machine workshops, in which participants are engaged in short, open-ended activities that encourage them to "think with the hand." Drawing on Andersen and Wakkary's approach, we did not mention terms such as "instrument," "interface," or "design," aiming to sidestep related preconceptions on musical interactions. Our intention was to present participants with short and easily achievable tasks, encouraging making without overthinking, thus promoting spontaneous and intuitive material assemblages.

Although our activity focused on Pd and the three specific sensors, we also ran one session of the game involving two expert users of the SuperCollider language. In later sections of this article, we will occasionally comment on the work of these musicians, mainly to support specific reflections on the instruments designed with Pd. The choice of having two music technologists working with SuperCollider relates to our intention of conducting a preliminary exploration of the analogies and differences between different tools and related practices—that is, comparing different cases meaningfully (Bryman 2016).

Instrument Presentation

Once the instrument making is completed, participants are invited to present their work to the facilitator and perform a short demonstration. Making is here used as a means for speculation and reflection: Participants are invited to unpack their actions, disclose priorities, and examine design processes and outcomes (cf. Sengers et al. 2005). Our intention was to discover participants' values, motivations, and felt experiences through the composed musical artifacts (Lepri and McPherson 2019; Lepri 2020).

Participants were encouraged to elaborate and expand on their work while describing their instruments. The facilitator asked open-ended questions in the form of a semistructured interview, often inviting participants to elaborate on the instruments' functionalities and sonic properties (e.g., what were your musical intentions? how did the making process evolve? what were the relationships between sensors, algorithm, and sound? how should the instrument be played?). As participants are also invited to comment on the work of their teammates, the interview often evolved into small group discussions. We found that the emergence of different interpretations and viewpoints often turned out to be a stimulus for participants to further consider their work.

This concluding stage was audio recorded, manually transcribed, encoded, and analyzed based on an inductive approach (DeCuir-Gunby, Marshall, and McCulloch 2011), looking for patterns, similarities, and diverse degrees of agreement across the participants' reflections (Ryan and Bernard 2003). The results of our analysis were collected in a codebook, which was systematically updated and refined. The various codes were organized by categories: groups of codes that shared specific elements and features. We conducted five iterations of coding, and only once the codebook was established did hypotheses or theories emerge. The method adopted (from open coding to category formation) forced us to look critically at data through different lenses, (cf. Holton 2009), and each concept earned its way into the discussion by repeatedly being present in "raw" data (DeCuir-Gunby, Marshall, and McCulloch 2011).

Table 1. Summary of Participant Backgrounds

	Music Activities	*Music Technology Background*	*Pd Experience*
P1	Electronic music composition and performance, music interface design and research	Electronic music composition, music technology	High
P2	DMI design and research, audio programming, live band performance	Audio engineering, sound and music computing	High
P3	Audio engineering, audiovisual production, sound design	Audio engineering and music production	Low
P4	Sound design, audio programming, modular-synthesizer performance	Sound and music computing	Low
P5	Sound design, collaborative music applications research, live band performance	Sound and music computing	High
P6	Music composition, sound design, teaching music technology	Music technology and composition	Medium
P7	Electronic music composition and performance, DMI design and research	Music and creative practice, film production	Medium
P8	Music performance research, choral and solo singing, live band performance	Sound and music computing	Low
P9	Electronic music composition, live coding, computational creativity research	Music technology, mathematics	Medium
P10	Accessible DMI design and research, live band performance	Music technology, design, electronic engineering	Medium
P11	Music production, sound design, audio engineering research	Electronic engineering, digital signal processing	High
P12	Electronic music composition and performance, live coding, DMI design and research	Music technology, multimedia, design	High
P13	Electronic music composition, modular-synthesizer and live band performance	Mathematics, computer science, music technology	High
P14	Electronic music composition, sound design, live band performance	Computer science, interactive media	Medium

DMI: digital musical instrument.

Participant Backgrounds

Our research involved seven pairs of music technologists, comprising ten male and four female participants aged 23–37 years. We recruited our participants mainly through an academic institution (Queen Mary University of London). After recruitment, information on each musician was collected through an online survey (see Table 1). All participants reported to have studied music, be it self-taught or through formal or informal training. All participants play at least one instrument (including seven playing guitar or electric bass, six using electronics or laptops, and one vocalist). All participants self-identified as music practitioners, and eleven participants have been active as musicians for more than 15 years. Eight participants identified as professional musicians and six as amateur musicians. At the time, the majority of our participants (13 out of 14) were working as doctoral or postdoctoral researchers in different fields, for instance, in sound and music computing, DMI design and NIME, cognitive science, and human–computer interaction.

Twelve participants reported having at least basic training in electronics, programming, and mathematics, and nine of these encountered those subjects through music technology programs (undergraduate and master's level), such as audio engineering or electronic music composition. Six participants received formal training in the fields of humanities, and four of them hold a graduate or postgraduate degree in music performance or composition. The musical activities of our participants are quite diverse. Most of them are active in multiple musical contexts (e.g., audio engineering and live band performance), dealing with different sets of practices and genres. We were able to gather some information on the aesthetic and stylistic preferences of our participants (e.g., favorite genres and influential musicians or ensembles). Again, they showed interest in a large and diverse set of musical styles: Some of the most-cited genres were experimental electronic, techno, ambient, experimental pop, rock, funk, and jazz.

We were also able to get a sense of participants' level of expertise with computer music languages, and, more generally, on their previous experience in sound design. All participants had worked with Pd in the past, some on a regular basis and others for short-term projects (e.g., university assignments). Eight participants had formal training in Pd and seven had experience with other music programming languages such as Max, ChucK, Csound, SuperCollider, or TidalCycles. Participants self-rated their level of Pd proficiency, and based on this evaluation and on our own data analysis (i.e., patches and interview analysis) we categorized three groups of Pd expertise: low, medium, and high.

Findings: A Polyphony of Sources

Our findings are organized as follows. First, we describe participants' engagement with tools (i.e., Pd patching and use of sensors). We then integrate these observations with a summary of musical and technical concerns expressed by participants while reflecting on their work. Finally, we examine the sonic interactions and aesthetic qualities of the various instruments. In this section, we often contextualize our findings in reference to participants' musical and technical backgrounds.

Patching and Workflow

In a previous paper (McPherson and Lepri 2020) we focused on an initial examination of the control strategies and Pd sound-production techniques from this exercise. Here we expand our findings, integrating them with the insights that emerged from the interview data. It is important to note that our research is not a focused study of a mapping toolkit, investigating a limited set of predefined relationships between sensors and sound. Rather, we kept our exercise open-ended, with no indication on how to use the sensors or how to generate sound. In principle, nearly any relationship could have been expressed in Pd using the sensors provided. Of course, even with an open-ended language, the types of sensor–sound relationships created by participants will be limited by time, expertise, and musical ideology. Our intention in this study is precisely to call attention to these limitations and the way that the tools steer designers toward particular outcomes and away from others.

Despite the theoretically unconstrained nature of Pd, we found that most control relationships fell into just a few categories of sensors manipulating fundamental sonic parameters (e.g., frequency or amplitude), usually in a linear, time-invariant, one-to-one manner. Indeed, out of 50 patches, only three Pd objects were responsible for the original sound in every case: `osc~` (sine wave oscillator); `phasor~` (simple 0–1 sawtooth oscillator with no antialiasing); and `noise~` (white noise). Surprisingly, the findings reported in this section were common to all participants, regardless of their musical backgrounds or level of Pd expertise.

Equally important is what we did not see in the final instruments. None of the instruments involve the quantization of pitch to a musical scale, and none involve rhythmic patterns (other than constant regular interval metronomes), sample playback, or looping mechanisms. Similarly, we could not find step sequencers or other pattern sequencing of control parameters, other than two instruments' use of the button to step through fixed-frequency values (e.g., harmonics of a given fundamental). Only one participant made use of conditional statements (if constructs), and none of the instruments include logic resembling loops (while or for constructs). Dynamic instantiation of synthesis processes—for example, increasing or decreasing the number of oscillators on the fly—is also not present in the patches reviewed. By convention, the control data from each sensor is normalized between 0 and 1 at the input from the Bela board. With the exception of some amplitude controls, almost all instruments rescaled this range in some way. Linear relationships between sensor and sound parameter were by far the most common, even though both amplitude and frequency are typically perceived on logarithmic scales; only one participant explicitly commented on the implementation of a logarithmic input scaling using the `log~` object, and one other participant rescaled the FSR input with the `mtof` MIDI-to-frequency object to control the cutoff frequency of a filter.

Participants made use of only a small number of Pd functions and control strategies. During the final group discussions, five participants highlighted the structural similarities between their designed patches. In the case of P11 (a researcher in machine learning and music working in the private sector) and P12 (a musician and technologist with a experience in NIME research and live-coding performance), these comments relate to both patching techniques and musical outputs:

> P12: That's funny, we kind of did the same thing!
>
> Facilitator: In terms of sonic output and aesthetics?
>
> P12: Yes, like beating saw waves.
>
> P11: We are both using Step 1 to modulate what each other did in Step 2. I modulated what P12 did and P12 modulated what I did.

Similarly, P5 and P6 agreed on the fact they implemented the same Pd algorithm with the FSR sensor:

> P6: You know, I think you did a similar thing with the FSR as I did. It's a sawtooth that's just going up in pitch by an octave, and the volume increases at the same time.

In line with the ethnography of Snape and Born (2022), we found that Pd patching often manifested itself as an "open-ended and unpremeditated compositional process" in which short "bursts of coding" are hesitantly combined together without necessarily knowing what the result would be. Indeed, half of participants acknowledged that while patching they were not always fully in control of their work. This intuitive, exploratory, and permissive coding approach often led to the emergence of unexpected results that were embraced even if resulting from unintentional or misinterpreted patching. Two PhD students in sound and music computing and audio engineering with low Pd experience, P3 and P4, provide a good example:

> P4: I've just routed the phasor to really random places. I just sent to [somewhere] to see what happened, which is also being controlled by this knob. . . . Maybe it's just controlling the frequency of one of the phasers?
>
> P3: I have no idea what [the knob] is, but it's cool! It's randomly generated, like multiple oscillators.

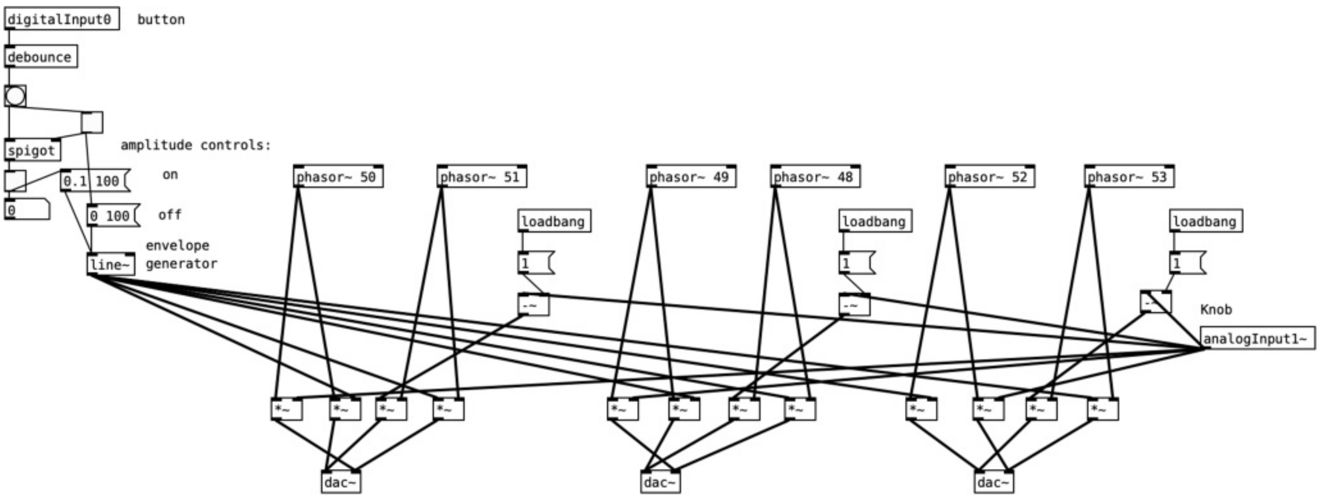
Another prominent workflow relates to combining existing patches, copying and pasting snippets of code. Figure 3 shows an example of such a procedure, in which P11 duplicated the same combination of objects multiple times:

> P11: I also think at some point I was not one hundred percent in control of what I was patching, because when I was duplicating and inverting everything and then duplicating again and inverting. . . I lost track of what it really is doing.

We particularly noticed this procedure in the last step of our game, as participants were required to gather the code from the previous steps into a single patch. Although we were not surprised to see an increase of copy-and-paste routines in the final step, we observed that all participants rapidly combined the various patches with almost no adjustments. Ten participants mentioned how they combined existing Pd patches simply merging their outputs. Typically, multiple oscillators were either summed in basic additive synthesis or multiplied together in a form of amplitude modulation.

By comparison, the two musicians who played the game using SuperCollider lamented a lack of time for the final step, as they had to address a number of technical issues to be able to gather and run the previous code (e.g., renaming of variables and modification of synthesis methods). Despite being expert users, both musicians spent most of

Figure 3. An example of a copy-and-paste routine in which the same combination of objects is reiterated multiple times. Visual layout of the patches is participants' original wherever possible, with minor adjustments for space.



the final session trying to adapt their work in order to be able to simultaneously play all three sensors. It was as if SuperCollider would "fight against" a certain kind of assemblage procedure, and these two participants had to focus on finding suitable workarounds that could allow them to perform and listen to the complete instruments.

These reflections resonate with the observations of Snape and Born (2022, p. 239) on how Max practitioners tend to use "ready-assembled groups of objects so as to accelerate patching and make it as musically seamless an experience as possible." Snape and Born highlight how such practices, shared within the Max culture of copying-and-pasting code and reuse of abstractions, are partially a consequence of users' appropriation (or *détournement*) of Cycling '74 help files and documentation. It is possible to argue that such a culture of use is common to programming practices and tools that extend far beyond music programming languages (cf. Haefliger, von Krogh, and Spaeth 2008). Our point, however, is that specific music technologies, such as Max or Pd, clearly facilitate a copy-and-paste approach by default, whereas with other tools this might be more challenging and laborious. Our musicians then often embraced this Pd feature to meet their goals. This can be related to Mackay's notion of "coadaptive" interactions, in which users are influenced by technology and at the same time they appropriate the technology, adapting it to their needs (Mackay 1990).

Sensor Thinking

The constraints provided by sensors were also often mentioned as driving factors by participants:

> P10: The main thing that was influencing what I wanted to do in each stage was the sensor that I was using.

We were intrigued by a comment from P7, a professional musician active in the context of experimental electro-pop pursuing a PhD on musical interface design. She noticed how, having two sensors to start with, she directly went for the combination of the two, instead of designing two different sounds to be controlled separately by each sensor:

> You have a button and a knob, so what can they do? Obviously they'll do something better if I combine them, like "Oh! I'll make one affect the other!" But we didn't have to do it that way.

Indeed, all participants that played the second version of the game (i.e., having two sensors to compose in the first step) took the same approach. Having two sensors to start with strongly encouraged their combination.

The most frequent uses of sensors we found while analyzing the finished instruments were: use of the FSR to control pitch (eight instruments), use of the knob to control either pitch (eight instruments) or volume (four instruments), and use of the button as an on/off switch (six instruments) or event trigger (seven instruments). Both knob and FSR were mainly mapped through memoryless control relationships, in which the current value of the sensor manipulated a current parameter value. Participants interpreted the FSR as requiring constant finger pressure, thus emphasizing tangible and performative aspects of interaction. Instead, the knob was mainly used as a "tuning device" for the control of parameters constrained within specific ranges (e.g., to set the cutoff frequency of a filter). These approaches reflect the "inherent" continuous character of these devices, as both FSR and knob produce a continuous electrical signal. Buttons, on the other hand, were extensively used to either trigger random events (mainly frequency values using the `random` object) or to switch an audio signal on and off (i.e., activating and deactivating sound processes by triggering the `line~` object to generate envelopes or by simply multiplying a signal alternately by 1 or 0). We thus observed how the use of the button would indicate a "digital" understanding of the device, as its output is restricted to two discrete electrical values.

These interpretations of sensors were often described as "obvious" by the musicians themselves:

> P3: That's the cutoff frequency. You would definitely use the knob, because it gives you that control. [demonstrating how to manipulate the knob] Okay, I can stop here!

Certainly, such "sensor thinking" is rather common within the music technology community, and it is possible to trace its multiple origins back across both engineering and musical practice (Medeiros and Wanderley 2014). Indeed, we could observe how these compositional approaches follow the "grain" of the sensor technologies not only in regard to their functional and material qualities, but also thanks to the shared representations depicted by the majority of our participants:

> P4: With the pressure sensor, the thing I immediately thought of controlling was pitch, because that's just obvious.

In reviewing the interview data, we observed how previous experience with the sensors influenced musicians' design choices. Electronic instruments and interfaces (e.g., modular synthesizers and studio equipment) were often mentioned as precedent for design choices. A live-coding musician and researcher in computational creativity, P9, commented on the ways she encountered the sensors:

> P9: I worked with hardware before, you see a knob and that implies . . . if I think about how I would want to implement a center frequency, I'll just [go] straight to a knob.

A PhD student working on collaborative music making with digital musical instruments, P5, instead referred to his experience as a student in a physical computing class while discussing the work of his partner:

> P5: I find really interesting that you used the button to control the output of everything, while I used the FSR. And the reason was that when I took the [Media and Arts Technology] course here, we usually used the FSR to control the main volume. So I never thought "Oh, maybe I can use the button for that." You approached that in a different way, and you've got a really different result. And I love it!

Participants' previous experiences thus turned out to be influential for the interpretation of the sensors provided in our game, an understanding of musical devices that is both technical and cultural. These findings are in line with Donald Norman's (1999) notion of perceived affordances: A design provides clues. But "affordances can go unnoticed if they do not fit with real-world experience and cultural knowledge" (Hornecker 2012, p. 179).

We also identified a group of experienced Pd practitioners (P1, P2, and P12) who challenged the more common interpretations of sensors we often found in the work of our participants. These three musicians declared longstanding experience in the design of new musical interfaces for both artistic and research purposes. Moreover, they are affiliated with the same research group, which focuses on the

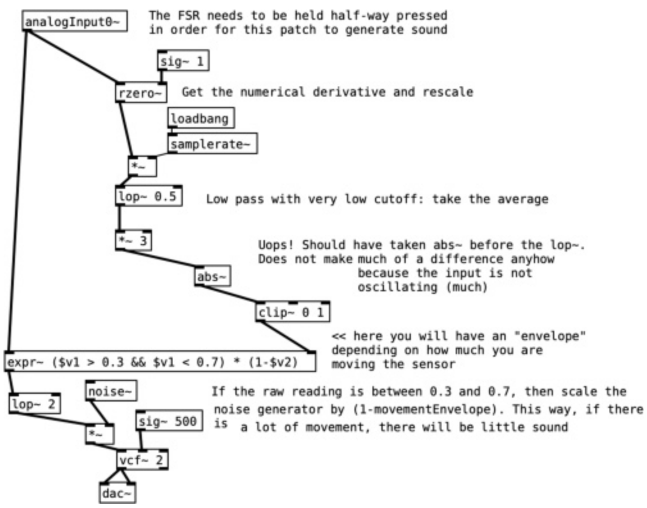


Figure 4. Implementation of a "hidden" sound control: The force-sensing resistor (FSR) needs to be held pressed half-way for the patch to generate sound.

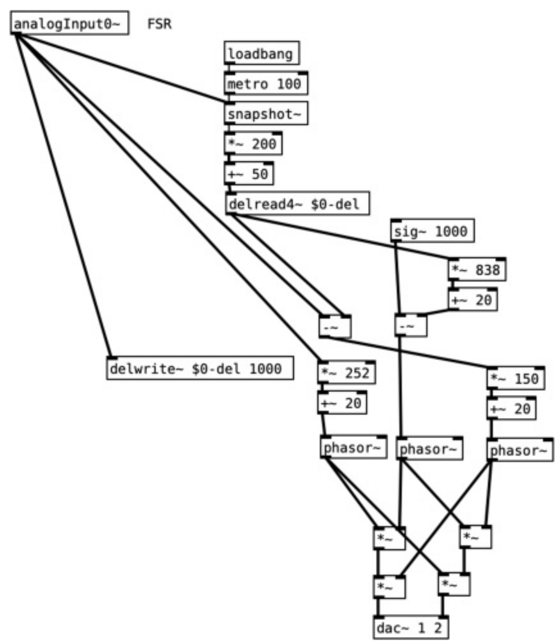


Figure 5. One-to-many mapping strategy: The FSR data is delayed and differentiated to obtain three different control values.

study and development of novel musical interfaces. An example of such sensor approaches relates to P2's idea of filtering and thresholding the FSR signal so that only a certain amount of constant pressure would activate a sound (see Figure 4). This "hidden" control strategy requires fine sensorimotor skills to be discovered, as P2 noted:

> P2: You need to find it! So you're supposed to press it halfway through and hold still.

He also implemented a basic memory-like algorithm for the button, in which the user must repeatedly press the sensor to increase the volume of a sound:

> If I press it once, I just get a tiny bit; but if I press multiple times, I can keep it higher.

In this way P2 considered the activity of the performer within a specific time window of a few seconds and used this information to operate the instrument, a strategy that expands the temporal frame of the interaction in contrast to the immediate and linear gesture–sound response that the sensor apparently suggested to most participants. This temporally expanded approach is well-known to instrument designers, as it has been described various times in the literature (e.g., Hunt, Wanderley, and Paradis 2002).

An alternative approach was taken by P12, who processed the continuous signal of the FSR based on different timescales to extract three different streams of data, assigning the streams to different frequency values (see Figure 5). This result was achieved using the `delwrite~` and `delread4~` objects.

> P12: I had the original signal, I had the delayed signal, and then I had the signal that was the first two subtracted. The delay is variable, based on how much you're acting on the sensor.

The intention was to implement an algorithm that could take into account past interactions and obtain several rich (i.e., performatively meaningful) control signals.

A one-to-many mapping strategy was also employed by P1 to manipulate a multidimensional feature such as timbre:

> P1: I just started with a sine wave and the FSR controlling the volume, but that was too simple. Then I had the FSR also decide the incidence of this ring modulator, so I can control the richness of the timbre and the volume.

Thresholding the continuous data, implementing time-dependent memory-like algorithms, or obtaining multiple signals out of a single input value can be understood as attempts to escape idiomatic patterns suggested by the materials (McPherson and Tahıroğlu 2020).

Original and Unconventional Making

While examining participants' reflections on the composition of the instruments, we identified a set of recurrent design concerns and values. Of the 14 participants, 9 declared the intention of exploring creative and unusual solutions while composing the instruments. For instance, P3 explained that his main thought was, "how can I make it sound stranger and cooler?" We could, however, identify different attitudes towards the formulation of what participants actually considered to be "original" and "unconventional."

Audio algorithms generating noisy, distorted, and out-of-tune sonorities were often considered peculiar and engaging. A musician and technologist working as a postdoctoral researcher on the design of accessible musical instruments, P10, comments on his aesthetic choices:

> P10: I was trying to come up with a melody, but then I realized it sounded cooler to have it slightly out of tune. I just went for this weirdly out-of-tune sound.

Similarly, P13, a computer scientist and multi-instrumentalist with a passion for modular synthesizers, commented:

> P13: I started by trying to do FM between [audio signals in the patch], I wanted to make a noisy thing with weird harmonics.

Musicians self-identifying as beginners or intermediate Pd users often saw a lack of control as interesting and exceptional—for example, in designing and playing random and unpredictable sound processes. The comments by P3 on the sonic interaction developed by her teammate for the knob sensor is representative of such a perspective:

> P3: I think there is no way for you to control it—which is really cool! That's something you won't be able to control that well. At the same time, it's a fun way of using the pressure sensor in an unconventional context.

By contrast, other participants believed that building chaotic and uncontrollable processes was not particularly compelling. For instance, when P1 considered what he could have done differently for his sound design, he reflected:

> P1: I would probably have had some type of random process. But again, by having a random process generating pitches, it wouldn't have been so interesting, maybe boring.

Indeed, some experienced Pd users (P1, P2, and P12) exhibited interest in developing subtle and nuanced musical interactions. For example, P1 noted:

> P1: It's not really [changing] the pitch and that's why I kept this idea. Because if this interaction would have resulted in a random pitch that was clearly audible, I would probably delete the connection. But the fact that [it] wasn't really perceivable but still had a certain effect—that was good for me!

The intention of designing hidden interactions that could be identified only through careful exploration was clearly a driving force. This manifests itself in the work of P12 and P2, who sought to compose the FSR in enigmatic ways in which sounds should be discovered almost like "Easter eggs" in a video game:

> P12: I thought to try to use the FSR, like pressing it, and then it wouldn't do anything until a delay had happened.
>
> Or trying to find a way for the FSR to be a bit more mysterious.
>
> P2: You have to find [the sound]! . . We're looking for the offset to be between 0.3 and 0.7. Then, if there's no variation you, get the sound.

Based on the data we collected from participants, the self-conscious avoidance of perceived clichés exhibited by P1, P2, and P12 can be considered in light of two main factors: their high level of Pd proficiency and their long-term affiliation with music technology communities, including an academic lab active in the context of NIME research. These two circumstances might explain the presence of shared musical aesthetics, musical values, and intentions towards the design of musical interactions. Indeed, we could not find approaches similar to those of P1, P2, and P12 in participants who did not share both conditions. We also recruited musicians with high levels of Pd expertise but not affiliated with the aforementioned lab (P5, P11, and P13) and members of the same research group (P7, P8, and P10) who, although having similar experience in the design of new musical interfaces, identified as beginners or intermediate Pd users.

Participants often recognized as valuable what the assemblage of Pd and sensors makes easy to design. For instance, we observed how the implementation of chaotic sonorities often emerged as a consequence of intricate snippets of code. Indeed, one participant commented on Pd's visual immediacy, highlighting how the language promotes the design of convoluted patches.

> P12: There is this visual suggestion . . . it's kind of screaming at you: "Connect everything to everything!"

Another example of such an easy-to-make procedure is the use of the button to trigger the `random` function and change the frequency of the `phasor~` and `osc~` objects. This approach, found in the work of six participants, allows the programmer to easily achieve some degree of musical variation without the need to implement particularly sophisticated sound algorithms.

Aesthetic Considerations

The most recurrent aesthetic comments provided by participants focus on the pitches produced by the instrument. Musicians mainly composed musical artifacts able to play pitches one after another, often selecting random frequencies within specific ranges:

> P6: I wanted it to go up to the fifth or the tenth harmonic, then come back down, and keep on cycling back and forth.

> P7: What I originally aimed to do was to confine it to about five different bass notes, so that it could at least become some kind of melody. I figured out the interval between these tones, so that the thing that goes up and down always has the same intervals.

Amplitude was the other parameter most often considered while designing the interactions:

> P6: I was just trying to get all the volumes balanced right at the end. Because we had this really quiet, then this really loud, and then this one was in between.

If pitch and volume were often mentioned by beginners and intermediate users, expert Pd users tended to comment on diverse aesthetic matters. These include sound synthesis and effects such as timbre morphing, low-frequency modulation, nonlinear feedback, saturation, and panning:

> P13: I wanted to do something more interesting, just not to make another pitch with an FSR.

> P11: I was trying for a kind of a panning modulation, so when you press the sensor it switches the channel.

> P2: I modulated the amplitude on the two channels separately in positional phase, so you get some movement. And I added a soft saturation here.

> P12: [I am] controlling the frequency of two detuned saw oscillators, so they're roughly the same. Then, when you hit the button, it randomizes—to a degree—the frequencies. And then this is also controlling two [low-frequency oscillators]. They are all slightly detuned from each other, so that's why you get beating.

Interestingly, we could also appreciate a similar aggregation of aesthetic concerns for the two musicians using SuperCollider. Indeed, compared with most Pd instruments (including some of those made by expert users), these instruments combine a greater assortment of audio processes, for instance, comb filtering, phase modulation, compression, and stochastic sequencing of note triggers. On the other hand, the sonic processes implemented in SuperCollider are characterized by a rather high degree of autonomy (i.e., the outputs of the instruments might change over time, even without the intervention of the performer).

To get a better sense of the instruments designed by our participants, we spent some time playing them, thus exploring their interactive and aesthetic properties in detail. The most prevailing modality of interaction embedded into the artifacts relates to activation and deactivation of unsynchronized sound processes. It follows that the amount of agency allowed to the performer is considerably constrained, as the majority of interactions are reduced to the possibility of triggering or modulating different sounds. This feature also affects how musical events can be organized in time. The instruments collected are indeed bounded by an implicit temporal notion that facilitates immediate and linear gesture–sound interactions. Similar findings have been reported by Snape and Born (2022): Max users have little or even "minimal" influence while performing their patches. The impossibility of encoding sonic structures evolving through an extended period of time also recalls the notion of time identified by the "kind of time that Max is more readily configured to offer: a temporality in which musical events simply do or don't happen, without a coded sense of a musical past that can be recalled or a musical future that can be fast-forwarded to" (p. 243).

Once activated, the sonorities produced by the instruments can be categorized according to the three sound sources exploited by participants. The artifacts using the `phasor~` object are generally distinguished by the production of continuous tones with distinctly perceivable noisy components. The instruments based on the `osc~` object tend to produce sonorities associated with additive synthesis techniques. The instruments based on the `noise~` object instead tend to produce constant noise textures obtained through subtractive synthesis procedures. The noise instruments are characterized by different bands of resonance due to the filtering of the noise source. These instruments allow continuous control of either the cutoff frequency of the filter (the pitch of resonance) or the noise amplitude.

Despite the variety of musical backgrounds and interests of our participants, the output of the various instruments exhibited a relatively narrow range of musical aesthetics. In general, the presence of noise is pivotal and rather constant. Despite considerable variation in the finer details of sound design, we found that the instruments are clustered around a few musical aesthetics that relate to experimental, noise, and glitch music. The predominance of "raw" and "noisy" materials is certainly related to the limited amount of time our participants had to compose the artifacts. Nevertheless, we suggest that Pd actively supports particular musical aesthetics precisely because those aesthetics "organically" emerge after a few minutes of coding. We endorse the reflection posed by Snape and Born (2022, p. 246) while discussing the musical outcomes facilitated by the Max language: "in a double bind, the technology that makes it possible for artists to forge unusual musical practices also locates those practices within familiar and consolidated technical-and-aesthetic universes." In fact, these programming languages come from specific musical communities that are particularly concerned with electroacoustic experimentation and "postdigital" aesthetics (Cascone 2000; Puckette 2014).

Discussion: On Technomusical Mediation

Our discussion focuses on two main elements: (1) the technomusical backgrounds of the instrument makers and (2) the patterns tacitly promoted by the musical tools. First, we suggest that the design of a DMI entails an in situ negotiation between its designer and the tools used to construct the DMI, arguing that musicians react to suggestions offered by tools based on their previous experiences and personal knowledge. We then consider how the artifacts resulting from such negotiation often repurpose the musical values inscribed into the tools used in the design process, proposing that musical inscriptions can be regarded as highly recursive processes.

DMI Design as Cultural Negotiation

Digital instrument design relies upon a vast set of emotional, cognitive, and material processes that cannot be fully reduced to a few individual elements, such as the cultural aspects examined in this article. Our analysis suggests, however, that musical ideologies inherited from specific communities and contexts are likely to affect the assembly of a new DMI. Examples of such "cultural translations" were provided by P1, P2, and P12. Aside from being part of the same NIME-related research group, these music technologists have broad experience in the design of musical interfaces in both academic and private sectors. Their approaches might be partly explained by considering their academic affiliation and previous professional experience as long-lasting involvement with communities of practice, implying "ways of learning—of both absorbing and being absorbed in—the culture" (Lave and Wenger 1991, p. 169).

These considerations are supported by findings of similar research on DMI evaluation. In particular, the influence of designers' knowledge and cultural background has been highlighted by West et al. (2021), who examined the strategies musicians chose for the implementation of initial DMI ideas over a limited period of time, although this work is focused on mapping only. In line with that study, we wish to highlight how DMI design criteria are inherently context dependent, and that DMI frameworks and evaluations should be crafted in light of the specific ecology out of which the instrument emerges—including design intentions and perspectives, contexts of use, and musicians' previous experience.

On the other hand, rather than aiming for specific musical ideas, various participants focused on the design of musical interactions that were easily achievable with the Pd language. Often participants had to simplify (if not abandon) more challenging compositional ideas in order to prioritize basic yet functional instruments. For:

> P6: My priority was to build an instrument that would definitely work first of all, then to give it some character.

After having explained his original plans, P12 commented:

> P12: I couldn't think of a very immediate way to program that, so I just used [the knob] as a kind of trigger to create some randomness instead.

Having encountered some difficulties while implementing a complex FM synthesizer, P13 decided to simply multiply carrier and modulator signals:

> P13: It just was a bit more complicated to do the FM stuff, so I just ring-modulated both [signals].

The difficulties encountered while implementing a given idea in a very short period of time might be, in part, related to participants' skills in programming with Pd. Nonetheless, our findings also suggest that the musical notions embedded into a given technology inevitably condition the work of the designers. Pd seems to promote an exploratory programming style, the reuse of previously made code blocks, the composition of rather convoluted patches, as well as direct, memoryless strategies to activate and deactivate unsynchronized sound processes.

This observation is supported by reflections from Pd creator Miller Puckette, who acknowledges that Max and Pd are fundamentally systems "for scheduling real-time tasks," as their architecture is inspired by a "piano model" of music performance: "A collection of tasks running in parallel" whose timing is controlled by "wait functions and triggers" (Puckette 2002, p. 32). Puckette acknowledges how these assumptions condition the musical interactions promoted by Pd: "The prevalence of over-reactive and over-obviously reactive pieces of live electronic music in today's repertory can be partly blamed, perhaps, on the fact that Max's and Pd's designs make it so easy to code up that sort of knee-jerk behavior" (Puckette 2014, p. 7).

Each instrument composed in our game offered a particular combination of musical qualities, whereby some can be associated with the technical and cultural background of the designer and others are instead promoted by the technologies used to assemble the artifacts. We suggest that the design of a new digital instrument is best viewed as a negotiation between designer and tools, a dialogue by virtue of which, to get something each party sacrifices something else (Lepri 2020; McPherson and Lepri 2020). Despite providing participants with the same tools, the negotiation that occurred while composing the instruments resulted in different outcomes, even though they clustered around a few interactive and stylistic approaches. Each musician had a particular set of predispositions, which emphasized or downplayed aspects of the technologies used in our research. Participants with different technomusical backgrounds (including DMI design expertise and Pd proficiency) also offered opposite views on some of the musical interactions made more accessible by the tools. For instance, processes based on randomness were interpreted either as eccentric and engaging (e.g., P10 and P13) or as rather obvious and boring (e.g., P1 and P2). From this perspective, we might then say that we do not use a given music technology, but it is rather the instrument that uses the resources available in each of us, including our musical values and previous experience with musical tools and the cultures around them.

Recursive Musical Inscriptions

In summarizing the most salient traits we found in the work of participants, we do not aim to propose a general model of how the chosen technologies influence the design of musical interactions. We also acknowledge that our sample of 14 musicians is likely not representative of music technology practice as a whole. The artifacts composed in our game give us the opportunity, however, to reflect on how musical notions travel from the workbench to the instrument. In media studies, the "formal logic" through which a new technology refashions prior media forms has been described as a process of remediation (Bolter and Grusin 2000). This phenomenon implies that characteristics typical of an existing technology (whether technical or sociocultural) are transferred into the new design. In the domain of music technology, long-standing musical ideas might be remediated by new designs and therefore tacitly influence the production of new music. The piano-style keyboard can be regarded as one of the most remediated musical interfaces, a design that has greatly shaped the Western conception of music itself (Dolan 2012).

The instruments examined in this article can be regarded as remediating musical values coming from preexisting musical cultures. For example, participants often interpreted sensors as either "continuous" or "discrete," and incoming data would then be interpreted accordingly. The comments by P3 and P9 on the use of the knob as a precision controller for fine-tuning are representative of the knob's cultural load, which might relate to its previous uses in telecommunication. Most participants intended the return-to-zero sensor (FSR) as requiring constant interactions, for example, to control pitch in a melodic fashion. A few exceptions occurred, however: For instance, one participant experimented with the FSR to control the cutoff frequency of a high-pass filter that, once pressed, mutes a sound that was otherwise constantly present.

Far from being absolute and a priori assumptions, these approaches to a sensor's possible interactions can be regarded as "received notions of what technology can and should do" (Pigrem and McPherson 2018, p. 382). Indeed, the understanding of a sensor as either continuous or discrete can be linked to specific technological and musical discourses—for instance, Bill Verplank (in unpublished lecture notes for a course at Stanford University) reflects on the "handle" and "button" control strategies, and there are the mapping paradigms frequently adopted in NIME contexts (cf. Hunt and Wanderley 2002).

The participants' tendency to compose and perform unpredictable noise-based interactions reflects many contemporary musical practices, including post-Cageian and algorithmic composition legacies. These stylistic features are also in line with the cultural contexts from which Pd emerged: experimental, electroacoustic, and contemporary music. Indeed, Puckette (2002) acknowledged that, throughout the years, the research environments he found at the MIT Experimental Music Studio, IRCAM, and the International Computer Music Conference strongly influenced many underlying ideas behind Max and Pd. Michael Horn (2013, p. 117) describes how the overall experience around an interactive artifact can influence the design process as "individuals appropriate cultural forms and restructure them to serve new functions in light of shifting goals and expectations."

The instruments created in our compositional game repurpose musical assumptions linked to the technologies provided, sometimes also drawing on participants' own musical values. In the case of Pd, while composing the artifacts, our participants indirectly engaged with Puckette's approach to the scheduling of real-time musical tasks. Puckette's approach was in turn influenced by the work of Max Mathews on the "Music N" and RTSKED programs and Barry Vercoe's work on the Csound language (Puckette 2002). We can thus see how the identity of an instrument emerges from a process of "recursive inscription" from successive generations of musicians and technologists.

It is not our intention to propose a rigorous scientific theory that predicts design decisions as a function of technological and cultural factors. We suggest the idea of recursive inscription, however, as a possible way to frame and interpret new musical interfaces. We could apply this rationale to discover the cultural values inscribed into a given digital tool as it results from previous sociotechnical negotiations and assemblages, not only recovering the technical and musical influences of Pd, but also the influences of those earlier technologists and musicians, and so forth.

This recursive inscription is not unique to digital tools, but we suggest that digital technology enables the process to proceed exceedingly quickly owing to the countless sociotechnical components assembled into every digital artifact. Each element introduces a set of preexisting scripts that will tacitly inform future uses of the instrument (Akrich 1992). Due to this cultural load, digital music technologies will inevitably influence future users, which will renegotiate the notions embedded into the instrument based on their own embodied practices, subjective perspectives, and cultural affiliations. Richard Grusin (2015 p. 141) notes that "mediation is always a form of premediation, of generating a multiplicity of potential but never fully formed futures which will have real impacts on life or action in the present whether those futures actualize themselves or not." According to this perspective, the creators (and contributors) of widely used music hardware and software tools might indirectly turn out to be some of the most influential musicians of our time.

Conclusion: Embrace the Weirdness

Rather than offering extensible and quantifiable knowledge, our research provides a possible interpretation on the ways music technologists engage with their tools. Our contribution is based on in-depth observations and reflections limited to a small set of computer music practices and instruments. Furthermore, far from being a neutral tool for musical expression, the Bela platform used in our game introduces a further technological influence that is not the focus of our analysis. As authors, we also cannot claim cultural neutrality in our analysis, though we present in previous sections an analytical process that seeks to minimize bias. We are linked to the same academic groups as some of our participants, and we are closely involved in the NIME research community. Instead of claiming detachment, we suggest our situated outlook might enable a deeper understanding of the practices considered, but it will also color our reflections.

Owing to the short length of our exercise, the instruments created by participants may not reflect their ideal musical statement, but it does reflect what is easily achievable with Pd and the three sensors provided in a limited time frame. We suggest that even with a longer development time, the idiomatic patterns of the language and sensors will continue to exert an aesthetic influence on the creative process. At a minimum, our observations provide an interesting take on the idea that "a computer music language should provide a set of abstractions that makes expressing compositional and signal processing ideas as easy and direct as possible" (McCartney 2002). Because many creators of languages explicitly focus on giving users "rapid experimentation in computer music" (Wang, Cook, and Salazar 2015), they inevitably endorse certain procedures and techniques. By making specific routines more accessible (more immediate or easier), musical tools might also implicitly block (i.e., make more difficult) a great number of alternative methods and techniques.

While reflecting on Max and Pd, Puckette (2002) often insists on his intention to "avoid imposing a stylistic bias on the musician's outputs" (p. 39) but rather "empowering" a broad community of artists. Despite Puckette's honorable goals, he also foresees the impossibility of such a proposition, as "this reasonable-sounding goal seems always to recede as we try to approach it. . . . Soon we will learn that, no matter how general and powerful we believe today's software to be, it was in fact steeped in tacit assumptions about music making that restrict the field of musical possibility" (Puckette 2014, p. 8). This observation resonates with the philosophical argument of Günther Anders (1986) that the uses and purposes of a technology are nothing other than the possibilities made available by the technology itself. As musical aims are already inscribed into a given technology, perhaps the means define their own ends and not vice versa. Certainly, artists and musicians often subvert and creatively misuse technology (Zappi and McPherson 2018). Reflecting on musical ends inscribed into our tools, however, and acknowledging their nonneutrality, we might support the work of designers and engineers, providing them with better conceptual tools and frameworks.

The idea that a musical instrument imposes constraints on the composer or performer has been widely recognized and even celebrated within music technology research (Gurevich, Stapleton, and Marquez-Borbon 2010; Magnusson 2010). Consider the history of electronic (analog and digital) pianos, which have become progressively closer to the "sound and feel" of the acoustic original, yet still fall short of the original in the eyes of professional musicians. Over the years, the few keyboards that have had a lasting impact on musical culture are not the best emulations, but rather instruments, like the Fender Rhodes, that present distinctive and sometimes odd qualities that make them remarkable; instruments succeed for what they are rather than what they emulate.

Similarly, the past decades have seen the appearance of successive generations of hardware and software for designing audio and music systems. Lasting success of any widely used tool might be partly explained by its idiosyncratic qualities, including its constraints and stylistic assumptions. As with instruments themselves, digital tools for creating instruments are not interesting for the extent to which they approach a mythical ideal of a neutral canvas. Instead, tools might be compelling precisely for their inherent traits and the specific ways in which they influence the thinking of the designer. We might then reverse the discussion on the stylistic "bias" of music technology and, rather than pursuing neutrality, we should embrace or even emphasize the idiosyncrasies and weirdness of our tools. Such a mindset, we suggest, might hold benefits in avoiding unrealistic design trajectories, gaining awareness and intimacy with our tools, and critically engaging with the aesthetic outcomes of our work.

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