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New Instruments

What does the digital afford to new musical practices? Without diving into an in-depth analysis of "the digital," a topic of considerable complexity, our aim is to study how digital technologies alter the technological conditions of music production, demanding or enabling us (depending on viewpoint) to operate differently in practically all areas of musical practice: from making instruments, composing, and performing to marketing or listening. While new digital musical instruments (DMIs) have become omnipresent in today's music, the focus here is on the *unique qualities* of the digital, as opposed to the digital *simulation* of previous technologies. As an example, many fruitful insights can be gained by analysing the difference between an acoustic, electric, or digital piano, and yet, for the argument put forward here, it is of lesser importance whether Elton John or Herbie Hancock play an acoustic, electric, or digital piano on stage: their playing is what it is, and the nature of the sound generation is irrelevant in this context. Similarly, music recording and production software in the form of digital audio workstations (DAWs) is designed as a simulation of the traditional tape studio, including all its outboard gear, with additional design tropes from the musical score and the piano roll. When the term "digital instruments" is used in this book, I am thinking primarily of computational instruments; digital media are computational media. However, "computational instruments" is an awkward term that perhaps also overly emphasises the computational. While "digital" is not a perfect denominator, it is probably the least bad word. It also references the fingers (digits), the human hand, and thus brings with it the connotation of embodiment, which the computational does not have. In other words, for the argument of this book, it is not of key importance whether a signal is acoustic, analogue, or digital (other work looks into that); what is interesting for us are the affordances, expressive scope, and theoretical potential offered by the instruments – their ergodynamics. Therefore, it is not so riveting for us to study whether someone plays an acoustic or digital piano if "playing the piano" is all they are doing. However, it becomes interesting if suddenly the digital piano responds, changes tuning, morphs between sounds, suggests future paths, or provides an accompaniment to what is played. That is where the digital exhibits its nature as being computational.

As any ethnographer, ethnomethdologist (or better "technomethodologist" – see Button and Dourish 1996), or participatory design researcher would point out, a direct translation of technologies from the analogue to the digital domain is never possible. By moving practices from the real world to the computer, objects, relationships, and work processes are abstracted, quantified, classified, and arranged into an ontology that supports the operational principles of the software. The DAW is a *representation* of the studio, and through subscribing to the work practices laid out by software designers (e.g., their decisions on what appears at the first surface level of the interface versus its back layers), new practices will emerge and others will disappear. What interests me is when the DAW goes beyond its simulative functionality and begins to operate in ways that are uniquely digital, for example by new signal processing techniques, innovations in interface and interaction design, and new AI that enables the software to learn, adopt, suggest, and generally form a dialogue with the musician, where the software becomes more of a partner than a tool. Technical transitions such as those that move from the acoustic, to the electronic, to the digital are transformative *transductive* processes that do not simply change the underlying media functioning: they transform our musical ideas and practices too (Mackenzie 2002).

Instruments and alien objects

In his book *Alien Phenomenology*, Ian Bogost (2012) asks how the world is perceived by things like a bat, a hookah, or a cantaloupe. This is proposed as a new methodology to understand the thing in its context, an object-oriented ontology (Harman 2002). Such an exercise in non-human phenomenology is, of course, impossible, but it is an interesting proposal nevertheless. Let us accept Bogost's challenge and perform an alien phenomenology on musical instruments: acoustic, electronic, and digital. Imagine being an acoustic instrument. You lie on your back in the dark, hoping to be picked up and touched with trained hands that pluck, stroke, and activate your body, exciting sounds from your primary organs. You can feel the room resonate as a result of your own movement and that, in turn, affects how you behave. You feel connected to the room and the performer, as if you, the performer, and the room were one system. You realise how every pair of hands is unique and how every piece of music makes you feel different. But you live a complete existence: you are always there, waiting to be activated, but unlike other artefacts of art, such as an oil painting, it is through human manipulation that you gain a complete existence, pregnant with meaning and function.

As an electronic instrument, you typically lie dormant – half dead – perhaps never to become fully alive again, because without electricity feeding your body, you are nothing. With electrons flowing through your wire-veins, you become functional even if there is no sound. Unlike acoustic instruments that need to be activated for every sound, you fulfil your nature with the injection of electricity, even if the volume is down or there are no speakers in the room. This orgasm of electricity is tantamount to a junkie getting a fix, and when you are up and working, you perform perfectly. The hands of your performer do not really play you, they control your functionality – which keys to press, knobs to turn, and sliders to move; which jacks to plug into which sockets. The player's physical energy is not proportional to the sonic energy you express. This sound is generated by electrons and output as a voltage-current boosted by an amplifier that drives the speaker cone movement – in and out. Analogous to the movement of a tuning fork – in and out. The difference is that the sound does not come from you; it emerges from another location in the room, but there is a clear trace and translation of your movements to the movements of the speaker.

Incarnated as a digital instrument, you might seem of the same nature as the electronic instrument, say a synthesizer, but there is a big difference. All your behaviour can be redefined using a language of algorithms that can be written and rewritten to change your nature. Indeed, you might not feel that you have a nature as such, as a new software upgrade might change your behaviour so completely that it does not remind you of anything you've done before. You turn schizophrenic, polyfunctional, and meta-dimensional. The coupling between the user's touch and what you output depends on the program applied at the particular moment, so you don't really know your user's touch. Unlike the acoustic instrument that knows its user very well, your user behaves differently every time you are played, and that is possibly because you are never the same either! You like being mysterious, conversational, definable, and yet you direct the user in what is possible. What makes you really excited is when you are given the opportunity to learn about your user and establish a relationship. You memorise what has been played, you analyse their performance, and you can respond, suggest, adapt, reject, serve, or tease as you like. This is where you find meaning in your existence.

This playful thought experiment in the alien phenomenology of musical instruments could, of course, be much longer and more detailed, involving all the actors ranging from the instrument maker to the listener, but suffice it to mention that I have previously analysed the qualities of the three types of instruments – acoustic, electronic, digital – in more detail in a journal article (Magnusson 2009). In that text also I exaggerated, for the sake of argumentation, the differences over similarities and continuities, in order to tease out what the ergodynamic character of each type of instrument holds, and acknowledged as much in the conclusion: "This paper has focused on differences at the cost of similarities, and divided into distinct groups phenomena that are best placed on a continuum" (Magnusson 2009: 175). The second-person accounts above are clearly written in jest, but there may be grains of truth in there that relate to the distinct ontological conditions of each instrumental type and the reader is encouraged to meditate further, applying Bogost's methodology, by conducting an in-depth imaginative exploration of how it feels to be acoustic, electronic, or digital.[1]

Interfacing sound

The most obvious difference between the acoustic instrument and its electric and digital counterparts involves the concept of the *interface,* a topic that is of key importance in the design and critique of digital technologies (Galloway 2012; Andersen and Pold 2018). Electronic instruments have designed interfaces that connect to the black box of their functionality. The instrument designer has decided to "expose" certain sound parameters through user control; others lie fixed in the darkness of the box. In general, we can state that the electronic or digital instrument *has* an interface, whereas the acoustic instrument *is* the interface. The term "interface" is not used much

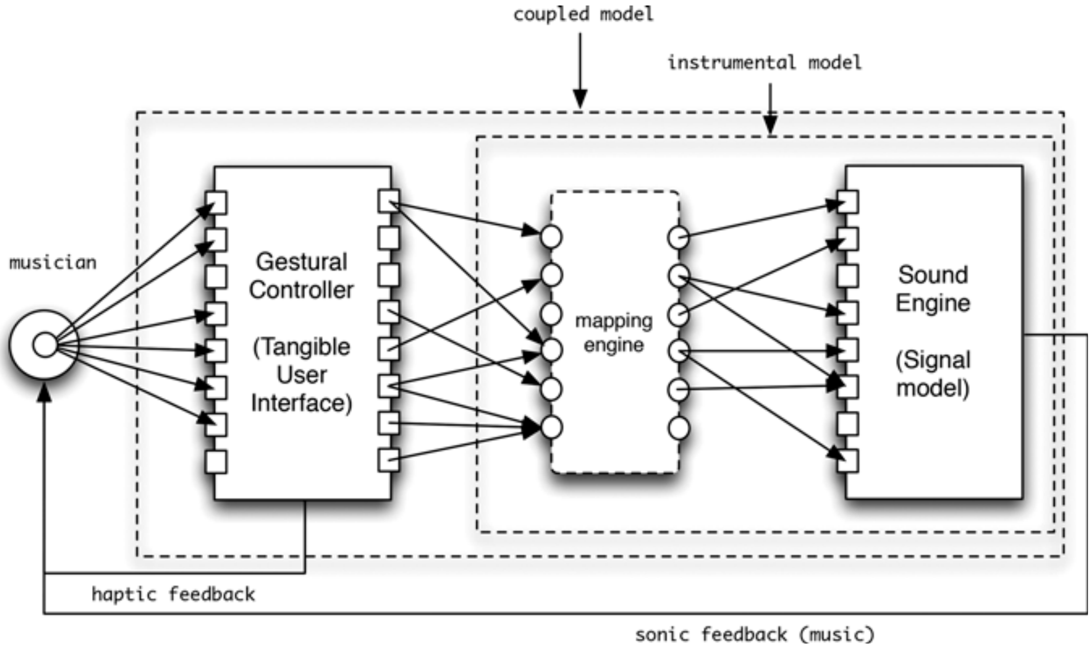

Figure 2.1 A typical explanatory model of an electronic musical instrument (see Wanderley 2000; Leman 2008; Wessel and Wright 2001). New musical instruments typically consist of these three elements. © Thor Magnusson.

in the musical education involving acoustic instruments. Most of Hugh Davis's electroacoustic musical instruments (Mooney 2017), for example, do not *have* interfaces: they are their sound source, even if amplified and processed electronically. This is because there is nothing that is out of our control when playing acoustic instruments, nothing that does not respond to the energy we put into the instrument, albeit with some exceptions, such as the church organ. This applies to many electronic instruments too. The typical instrumental model, explaining how interface relates to the innards of digital instruments, is often presented with diagrams as in Figure 2.1.

We notice how the instrument in its totality can be seen as a designed and direct coupling between the physical interface, the mapping engine, and the sound engine. Any of these could be swapped out for another design at any point, and yet it would be considered the same instrument.[2] This has been termed the "mapping problem" in the NIME literature (see, for example, Maes et al. 2010), one that is crucial to our understanding of digital instruments, and necessarily belongs to the domain of HCI (Human–Computer Interaction), where instrument designers have attempted to come up with principles (Cook 2001) or criteria (Fels 2004) for the design and evaluation (O'Modhrain 2011) of new musical instruments.

Again, what does the digital bring to the domain of instrument design? Which features and practices are carried over (via the process of ergomimesis) and which are left behind? The long history of digital instruments extends over half a century, but we might take Michel Waisvisz's instrument, "The Hands," as an example of a well-known instrument with a body of musical work written and performed. The Hands were developed in 1984 at STEIM (Studio for Electro-Instrumental Music) in Amsterdam,[3] just after the MIDI protocol specification had been released, and implemented in the Yamaha DX7 synthesizer. Waisvisz and colleagues built a controller that would afford gestural hand movements, moving about on the stage, and dance. The controller had ultrasound sensors (sensing the distance between hands), buttons, switches, bend-sensors, and accelerometers. The controller itself is not an instrument; it is only when coupled to a sound engine that we get the instrumental quality, and it is appropriate here to reference the instrumental model presented above, where the digital instrument is thought of as consisting of an interface, a mapping layer, and a sound engine. The assembled totality of the three elements makes it an instrument. However, the distinction between a musical composition, a mapping, and a sound engine blurs here, which is why some authors have recommended focusing on "mak[ing] a piece, not an instrument or a controller" (Cook 2001). Waisvisz was adamant in not changing the mapping and sound engine when he had hit upon an instrumental configuration that he liked. He wanted to develop a deep relationship with the instrument, in ways similar to the relationship acoustic instrumentalists have with their instruments. Waisvisz merged the notions of an instrument and a composition, typically "freezing" the instrument for a couple of years, in order to practise and perform the piece. Most

Figure 2.2 Michel Waisvisz performing his Hands instrument, originally built in 1984. The instrument is highly expressive, affording a variety of musical gestures. © Michel Waisvisz Archive.

performers of electronic and digital systems know how tempting it is to change parameters, fix, and develop further, but Waisvisz's approach was unique in that he was able to restrain himself, and not continually change the settings in the attempt to improve the piece just minutes before going on stage, like many of us are guilty of.

Waisvisz was the director of STEIM, a Dutch institute with decades of history in conducting and supporting research on musical performance technologies, offering spaces for artists to work, hosting workshops, and welcoming artists for residencies. One of the artists who has collaborated intensively with STEIM is Laetitia Sonami, whose "Ladygloves" performance system has been an inspiration for a generation of musicians. Sonami works with concrete sounds which she eloquently shapes through the performance with her gloves. The body is extended but there is a direct connection between the performer's movements and the piece itself, as if the sounds are touched and shaped with the hands. However, the lack of physical objects to manipulate does not remove the need for careful mapping and design. Indeed, it is perhaps harder to play non-physical instruments, such as the theremin, the Ladyglove, or motion capture instruments (e.g., made with the Kinect), because they lack the tactile and often haptic feedback of the physical device. In interfaces, the designed affordances, such as pads or knobs, have a dual function in that they serve as a control channel, as well as a reminder of what is possible through visual and tactile cues. The Ladygloves have inspired various projects, such as Imogen Heap's "Mimi gloves," a technology that reached popular awareness during a recent concert tour by pop singer Ariana Grande. The Mimi gloves are currently developed for commercial release; and there is an undercurrent in popular culture of using new instruments, as innovatory gadgets to liven up stage performances. Examples include pop band Coldplay's recent use of the Reactable – an instrument used by Björk on her world tour in 2007 – almost exclusively for visual effect (see Tomás 2016).

The question has been posed: will new digital instruments become part of the current musico-industrial framework with composers, publishers, producers, sound engineers, performers, concert halls, media, critics, audience, etc., or do they herald a new age of distinct musical practice? This is a straightforward question with very complex answers that deserve to be analysed at diverse tiers of musical practice. The availability of new programming languages for audio (such as SuperCollider, Max/MSP, Pure Data or Kyma) and cheap hardware (Arduino, Raspberry Pi, or Bela) has resulted in cultures of new instrument designers in hack labs, conservatories, and universities. These new instruments are used in club gigs and concert halls, are written about in the media and in conference papers, and shared on social media and online video channels, where links spread very fast. Some of these instruments become subject to more comprehensive innovation processes, where the instrument is developed, user tested, branded, and marketed. The innovation of new instruments has been studied, for example, in the field of Social Construction of Technology (Pinch and Bijsterveld 2004). With the increased documentation and data, introduced by new media behaviours, we gain further information about how an instrument emerges in public consciousness. Consider, for example, the difference between the innovation of the saxophone, the Theremin, and the Reactable table synthesizer. What emerges when looking at this field from an innovation perspective is that there is a problem with identity in new digital instruments, perhaps even a crisis. What is a new digital instrument? How do we play it? Who composes for it? Where does it fit in our culture? And is it a sustainable thing? Below I provide two case studies for discussion: the Karlax, and the LinnStrument. Both are marketed, mass-produced, and readily available for buyers.[4] Their inventors operate in a manner that resembles any established technology manufacturer, with publication materials, logos, sales office, customer relations, and a website with user accounts, technical specs, and more.

The Karlax

The Karlax is an apposite case study for a new digital instrument. It was launched in 2010 and promoted as an instrument of high expressivity, with fifty-five independent sensor parameters which can be used for triggering musical events (e.g., playing notes) or controlling a synthesis engine. The instrument is beautifully made, of aluminium and strong plastic, shipped in a leather case, but the price is high: about 3,500 euros. Compared with acoustic instruments, this is in the price range of a good guitar or a clarinet, but the key difference is the instrument's lack of establishment – its individuation and concretisation as part of our musical culture. For an instrument to become established, a variety of factors must conjoin, for example, composers and performers using the instrument, the production becoming streamlined, affordable price of the instrument, the market being responsive, and so on. Remi Dury, the inventor of the Karlax and founder of the Da Fact company that produces it, engaged in commercial promotion of the instrument between 2010 and 2014, but as a busy professor at the Conservatory of Music in Bourges, his focus is now on the educational aspects of new musical interfaces and the company is developing two new instruments – Zil and Bop – which are, together with the Karlax, integrated into the education at the conservatory. This need for an educational infrastructure to support the instrument is also reflected in Karlax workshops given to ten- to eighteen-year-old pupils at the Conservatoire de Vincennes.[5] Indeed, there is a parallel here with how Adolphe Sax considered conservatory tuition of the saxophone as an essential element in establishing his instrument as part of general musical culture. For Sax, it was critical that composers would begin to write for the saxophone, something both Debussy and Berlioz did and which established the reputation of the instrument (see Liley 1998; Horwood 1983).

Similarly, composers of electronic music have embraced the Karlax as an exciting new instrument with strong potential. In a NIME 2014 paper, Tom Mays and Francis Faber discuss their compositional strategies as well as the development of new notations for the Karlax in order to establish a repertoire for the instrument (Mays and Faber 2014). They write that with the Karlax, they see "an opportunity to go beyond the composer/performer/programmer model and start to write pieces for DMIs that could be performed by others – repeatable and shareable" (Mays and Faber 2014: 553). For them, composing for the Karlax involves creating a stable software environment

Figure 2.3 The Karlax. A new instrument with fifty-five individual parameter controls, manufactured by the Da Fact company in France.

(presumably technically consistent and sustainable for future use), coherent mapping strategies, and a bespoke system of musical notation. More importantly, this also means establishing certain performance practices and methods of training. During a symposium on composing for the Karlax, a participant expressed the view that when designing an instrumental mapping for the instrument, the composition has to be kept in mind ("En construisant l'instrument, il a déjà la composition en tête"), reflecting Perry Cook's (2001) imperative of composing a piece, not an instrument. Regarding notation, the discussions included whether to write in the form of tablature (where gestural mapping is depicted) or sonic end-result notation of some sort (not necessarily depicting pitch and note lengths as in traditional notation, as the controller is so diverse in function). Mays and Faber's paper describes their Karlax notation system in good detail and they claim that their system is "functional, expressive and readable," albeit there is room for improvement – as in any system of musical notation. They do, however, project that if a standard repertoire of expressive instrumental pieces for the instrument exists (e.g., Max/MSP patches), and if this repertoire is expressed through an idiomatic system of notation, attractive conditions arise for the establishment of a repertoire for the Karlax controller.[6]

The LinnStrument

The LinnStrument is an excellent example of a new musical controller that offers novel modes of expression. Developed by a veteran inventor of influential music technologies, Roger Linn, the interface has a grid of 200 note pads (twenty-five pads on the horizontal axis, and eight on the vertical). The controller's output uses the MIDI protocol by default, but it can be programmed in different ways on the software side and the firmware is open source, so any microtonal or alternative tuning system can be written for it, for example, in the OSC format. Adjacent pads increase by a halftone, but the row above is tuned up a fourth, like on the guitar or the bass, which makes it easy for players to apply their skills and embodied knowledge of chords, scales, and arpeggios on the LinnStrument. This makes the instrument attractive to a large range of performers, and Linn points out on his website that this layout of fourths is becoming a standard for grid button controllers like Ableton Push, Roli Blocks, and diverse mobile apps. The LinnStrument pads have lights (variable degrees of red, green, and blue), they are touch sensitive, a feature which is typically mapped to the amplitude of the note played, and then fingers can be moved on the horizontal and vertical axes, from the key pressed over to the adjacent keys, for example in mapped gestures that control pitch and timbre.

Above, I called the LinnStrument a controller, as it does not have a sound engine or a clear mapping between gesture and sound, but one understands why Linn is adamant in calling his invention an instrument. The LinnStrument is a fine musical object, beautiful in design, feel, and touch. It offers depth and space for exploration, enticing the performer into dimensions of possibilities that can be practised and embodied. Multi-touch, the instrument allows for chords and melodies to be played simultaneously, just as a pianist would play, but with more sophisticated control over each note. The lights in the pads offer ways in which the instrument can begin to communicate back to the performer, suggesting possibilities, or tracing past actions. This is an instrument to learn from. From a sociological and marketing perspective vis-à-vis innovation, it is interesting to observe how the LinnStrument is being introduced to the popular music culture, as opposed to the classical context in which the Karlax controller operates. The musical background of the inventors can partially explain the perceived markets of the instruments, as Linn is a rock guitarist and the inventor of the LinnDrum drum machine, whilst Dury is a conservatory-trained composer working in academia. Such things matter, as any sociologist of music would confirm. And in terms of the longevity of the instrument, from the perspective of marketing and business, the popular culture of a NAMM instrument trade show, where Linn

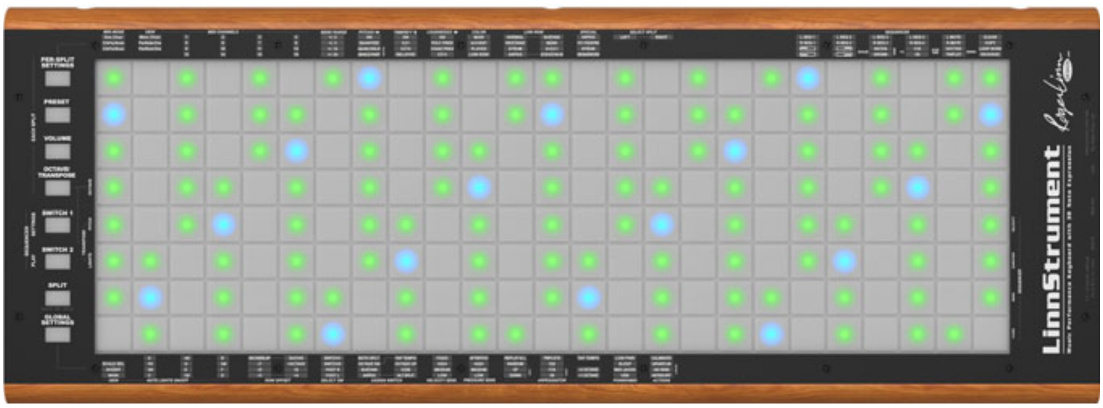

Figure 2.4 The LinnStrument, by Roger Linn. Relating to the tuning of string instruments, and offering the affordances of pressing, sliding, vibrating through finger movements on a 3D sensor (x, y, and pressure). © Roger Linn.

can typically be found, is clearly a better place for business than attending the NIME conference, where people tend to make their own instruments as opposed to buying them.

Resonating acoustic instruments

A different approach is taken by Andrew McPherson and Halldór Úlfarsson, the respective creators of the Magnetic Resonator Piano (MRP) (McPherson 2012) and the halldorophone (Ulfarsson 2018). Not wanting to sacrifice the sonic expressiveness of the acoustic instrument or the trained skills of performers, the MRP constitutes a modification of the grand piano, by adding controlled electromagnets into the body of the instrument above the strings, giving it new expressive possibilities, for example the sounding of a string without an attack. The string slowly comes to life through magnetic activation, with a smooth dynamic envelope, as opposed to the hard attack of the piano hammer, thereby giving the MRP an additional feature that makes it a separate instrument from the regular grand piano. In terms of further compositional opportunities, the angle of the pressed key is also used to emphasise different harmonics of the string, through a delicate tremolo on the key surface. The string's timbre can be changed by pressing into the base of the keys (aftertouch), and pitch bend is achieved by holding one key while lightly touching a neighbouring key. The instrument is augmented; there are no speakers, no microphones, but simply actuators that create a magnetic field that excites the piano string, like a magnet pulling its opposite pole, which is a technique we know from a guitarist eBow. The magnetic actuator of each string has the frequency of that string, or its harmonics (multiples of whole numbers). This enables the performer to "tune into" different harmonic qualities of the string.

Similarly, the halldorophone is an actuated resonating instrument, based on feedback as an integral ergodynamic feature. The halldorophone is modelled on the cello, although it looks slightly different in its modernist design. The instrument has a speaker cone at the back of the sound box that feeds vibrations into its body, typically the sound of its own strings. The feedback emerges when the vibrating body yields a resonating action on the strings, only to be fed back into the instrument's body by the individual pickups. Each string has its unique pickup whose gain can be controlled by sliders and this gives the performer further control in shaping the feedback, unlike the electric guitar where the sound of each string comes from the same pickup. There is a space for electronic and digital manipulation of the signal between the pickup and the speaker cone fixed to the instrument, and Úlfarsson is currently studying the different use in how an electronically fitted halldorophone differs in use and character from a digitally equipped halldorophone. Since the instrument borrows its design from the cello, performers can recycle their knowledge of the cello for performance, although the understanding and control of feedback is a new area of learning. This "recycling" of skills in new instruments is a notion that interests both McPherson and Úlfarsson. Recently, other resonating string instruments have appeared with auxiliary equipment added onto the stringed instrument, such as Alice Eldridge and Chris Kiefer's "Feedback

Cellos" (Eldridge and Kiefer 2017), Tom Davis's "Feral Cello" (Davis 2017), and Thanos Polymeneas-Liontiris's "Feedback Double Bass" (2018).

Both McPherson and Úlfarsson have created opportunities for composers to write for their instruments. They have lent their instruments to performers, sold a few copies, and run workshops where composers have supervised access to the instrument over a period of time, often involving performers too.[7] Both instrument makers have refrained from suggesting a musical notation system for their instruments, as they are interested in musicians exploring the instrument from a neutral mindset; to discover what they find interesting to play with, and eventually to come up with their own idiosyncratic notation. The danger of defining a language for the instrument through symbolic notation is that this would concretisise certain compositional ideas and performer actions; arguably this should be the realm of individual composers who compose their pieces in their own notation, based on what they have discovered through exploring the ergodynamics of the instrument.

Digital affordances

The above examples involve lab productions that require skill, knowledge, and financial means. However, with programmable mobile devices, such as the ubiquitous mobile phone or tablet, musical instruments can be built in the form of apps that exploit the technology of the device itself. This was the approach taken by Ge Wang and collaborators when they created the "Ocarina" instrument in 2004. At the time, when inspecting the recently released iPhone, Wang thought that it would be interesting to design an instrument that would make use of all the interface affordances of the phone: the multi-touch screen, the microphone, the speaker, the gyroscope, the GPS, and so on. The result was the Ocarina, an instrument based on the traditional Mesoamerican clay flute, but with the digital platform affording the design of new features such as embedded musical scores, recording of songs, and communication with other players of the Ocarina around the world (Wang 2014). The instrument sports ergomimetic design features from the real flute, where the sound is controlled by blowing into the phone's microphone (translating the microphone noise into a control signal), and the keys are pressed on the multitouch screen. The Ocarina is a good example of an instrument that has shipped thousands of copies, used by laypeople and professional performers alike, and generally serving as an enjoyable, fun and uplifting musical object that exists in people's pockets, available whenever the urge to play music crops up. The instrument itself supports the knowledge and expertise that people have gained on this age-old instrument, yet offers engaging and novice-friendly entry for new players. It is indeed an excellent example of how learning can be supported by alternative means, such as embedded scores in tablature notation and its game-like functionality. The community aspect is important too, where users share compositions and videos of their work. The Ocarina is amongst the top 20 downloaded apps of all time, which indicates how powerfully it connects with people's general love of music and experimentation. The app is also a good example of how digital instruments can democratise music-making by enabling simpler entry levels. A good source of information for exploring this and related work is Ge Wang's *Artful Design* book (Wang 2018).

Instrument or controller?

In this chapter we have discussed how the digital instrument *has* an interface, whereas the acoustic instrument *is* an interface. We do not typically use the term "interface" when describing acoustic instruments, and the term was not used much until the advent of electronic technologies; it was certainly not a concept used by instrument makers of acoustic instruments.[8] We can, of course, talk about an interface in acoustic instruments – for example, the church organ has quite a sophisticated and complex interface. However, like the piano, the organ has an interface that is mechanically coupled to the instrumental functionality via physical law. In digital instruments, their computational nature and arbitrarily mapped control elements result in technologies that feel thin, yet powerful. Unlike acoustic instruments, whose bodies and play are thick, there is nothing that *necessitates* the design of the digital instrument: it is all a matter of design. The difference between an instrument and a controller also reflects this: we expect controllers to be easy, like a button on a coffee machine, a car radio, or a train ticket kiosk. Instruments, on the other hand, have depth, character, resistance, and individuality. We don't want them to be controller-interfaces: we want mystery and magic, discoverability and surprise. The notion of ergodynamics unveils how the first encounter of a digital musical instrument typically involves exploring its affordances and then a further study in the instrument's constraints. For this reason, digital luthiers often make use of complexity and non-linearity to make the instrument perceptually interesting to play.

The above argument might contradict the ideology of musicians affiliated with what is often called "controllerism" (as in "turntablism"), but here DJs and music producers focus on the performative and expressive use of their software controllers. "Controllerism is the art of manipulating sounds and creating music live, using controllers and software" (Moldover in Golden 2007). Typically using MIDI controllers with rubber pads, plastic buttons, knobs and sliders, this approach attempts to frame the performance on a controller like that of a musical instrument. Although the differences are many and profound, it is impressive to see the expertise and ingenuity demonstrated by controllerists. This is further supported by music software houses such as Ableton and Native Instruments, and equipment manufacturers like Akai or Roland, who are increasingly beginning to present their music technology products as something that equally belongs to the stage as well as the recording studio.

A question arises: how does controllerism differ from the development of new DMIs as we see in the NIME research community? The most prominent difference is the status of a user versus designer of technology. Controllerists are creative users of hardware and software, but their primary focus is working within established musical genres, often with clear criteria for the music's functionality, such as getting people onto the dance floor. In contrast, NIME researchers tend to think more critically about the technology, often designing the instrument from scratch, and questioning what it does, how it works, and what kind of music it encapsulates, to the degree that the distinction between the instrument and the musical piece disappears. Here, building a musical instrument becomes indistinguishable from designing a music-theoretical framework; the musical instrument is a theory of music, and it equally contributes to genres, styles, and musical scenes. Another profound difference is the conception people have of their performance: the controllerist performs their music via an interface, whereas in the NIME performance the instrument itself constitutes the music: without the particular instrument the music would be different.

It is unwise to generalise too much here, as NIME is a broad field of investigation and practice, an inordinately interdisciplinary community populated by engineers, computer scientists, psychologists, musicologists, composers, performers, philosophers, tech innovators, and more. Research topics range from usability (how can this technology best support creative work, is the experience of using it good?), ergonomics (is the technology well designed for the human body, does it support learning and mastery?), human–computer interaction (is the device understandable, well set up, does it communicate its function?), and design (how does it function, what are the materials, is it sustainable?), to aesthetics (how does it look, is it an inspiring object?), music theory (what kind of musical knowledge is inscribed into the instrument, what musicality does it contain?), performance studies (how does it work in live situations, is it open and flexible, fast and controllable?), and audience studies (is the instrument understandable, does it communicate human intention?). This interdisciplinarity is what makes the field so interesting and rewarding: it operates at the most immediate and intense interface, or meeting point, between humans and technology, in one of the most ancient and popular cultural domains: music. Musical instruments present a tech-intense area of interface design for real-time performance, and the design of ergodynamic objects serve as boundary objects (Star and Griesemer 1989), due to the diverse expert knowledge required to build these objects. Other such design areas include the design of interfaces for flying, sailing, driving; surgery or dentistry; playing computer games, martial arts, cooking, or sports. Many of these interfaces are not crucially dependent on the real-time performance aspect, as most are not about the performance itself but about the product, where the critical focus is more likely to be on the aesthetics than strictly technical skill.

Conclusion

From the perspective of innovation and design, as well as composition and performance, the key difference in acoustic and digital organology is that digital musical instruments develop at the speed of general computer technologies. This is a multidimensional field that moves faster than music, so music is borne along by our new technologies. That is a very different situation from what we are used to with acoustic instruments where we have a more considered, slow, and grounded dialogue between the instrument maker, the composer, and the performer in what might be a useful addition or change to an acoustic instrument. The new technologies bring with them practices, ideas and ideologies, and methods and methodologies that enframe how we conceive of the instrument. By applying technology such as a game controller, a sensor of some sort, a network protocol, an FFT or deep learning library, we typically incorporate into our instruments much of the ergodynamics and ideas embedded in those technical elements. Considering the speed of development and the competition in the respective areas of high tech, whose products we integrate in our new instruments, we can question whether it is realistic to expect our instruments to stabilise, or concretisise in the Simondonian terms (Simondon 2017). The technology moves faster than musical practices and what we are getting are snapshots of technics applied in musical composition and performance, technics whose materialities will be quickly replaced with new ones, but whose ergomimetic structures continue and become re-implemented in later technical objects. For us, researching in the domain of musical performance, it is therefore the *ergomimetic gesture* that becomes concretisised, not the technological object. The next two chapters explore the epistemic structure embedded in new instruments, how musical movement and technological objects relate, and further study what a digital organology might entail.