Of Epistemic Tools: musical instruments as cognitive extensions

THOR MAGNUSSON

ixi audio, Music Informatics Research Lab, Department of Informatics, University of Sussex, BN1 9RH Brighton
E-mail: thor@ixi-audio.net

This paper explores the differences in the design and performance of acoustic and new digital musical instruments, arguing that with the latter there is an increased encapsulation of musical theory. The point of departure is the phenomenology of musical instruments, which leads to the exploration of designed artefacts as extensions of human cognition – as scaffolding onto which we delegate parts of our cognitive processes. The paper succinctly emphasises the pronounced epistemic dimension of digital instruments when compared to acoustic instruments. Through the analysis of material epistemologies it is possible to describe the digital instrument as an *epistemic tool*: a designed tool with such a high degree of symbolic pertinence that it becomes a system of knowledge and thinking in its own terms. In conclusion, the paper rounds up the phenomenological and epistemological arguments, and points at issues in the design of digital musical instruments that are germane due to their strong aesthetic implications for musical culture.

1. INTRODUCTION

The philosopher Don Ihde is well known for his analysis of how we establish a relationship with the world through tool use (Ihde 1979, 1990). Ihde reports on various phenomenological modalities in our relationship with tools, two of which are relevant to this article. For Ihde, the acoustic musical instrument is an illustrative example of a technology that enables an *embodiment relationship* to the world. The instrument becomes an extension of the body, where trained musicians are able to express themselves through incorporated knowledge that is primarily non-conceptual and tacit. The other phenomenological mode, the *hermeneutic relationship*, differs in the sense that here the instrument is not an extension of the body, but rather a tool external to the body whose information we have to interpret (thus hermeneutic). This instrument can be seen as a text, something we have to *read* in our use of it. Disregarding the perils of dualism, and acknowledging that these distinct relationships can overlap in the same musical instrument, I would like to propose that many digital instruments are to be seen primarily as extensions of the mind rather than the body. This seemingly dichotomous statement will be explored in section 3 below.

Furthermore, and in relation to the above, I will argue that while acoustic instruments afford a strong embodiment relationship with the world (or the *terminus* of our activities – the physical energy of sound), digital instruments increasingly tend to construe us in a hermeneutic relationship with the world. The tangible user interfaces that *apparently* constitute many digital musical instruments are but arbitrary peripherals of the instruments' core – that is, a core that is essentially a symbolic system of computational design. I contend that the primary *body* of the digital instrument is that of symbolic instructions written for the meta-machine, the computer. As opposed to the body of the acoustic instrument, the digital instrument does not resonate; it contains few latent mysteries, or hidden expressive potential that typically can be derived from the materiality of acoustic instruments (Edens 2005). The functionality of the digital instrument is always explicitly designed and determined. Indeed, the digital musical instrument – especially if it makes use of automation or other mappings that are not one-to-one gesture-to-sound – is constituted by generic, prescriptive and normative sets of rules that affect or direct the musician at the high level of musical language (both formal and theoretical).

The focus of this paper are novel digital musical interfaces, in particular those to be found in a research field best represented by the NIME (New Interfaces for Musical Expression) conference series. Although relevant as well, the analysis is not directed at digital pianos or pure studio simulators like ProTools. What is of interest are the computational music systems used to build expressive intelligent instruments, or composed instruments (Schnell and Battier 2002), where the distinction often blurs between instrument and composition on the one hand, and performance and composition on the other. Composed instruments typically contain automation of musical patterns (whether blind or intelligent) that allow the performer to delegate musical actions to the instrument itself, such as playing arpeggios, generating rhythms, expressing spatial dimensions as scales (as opposed to pitches), and so on. These systems are therefore split systems between the physical interface and the programmed sound engine. Typically such engines are programmed in environments like Pure Data, SuperCollider, ChucK,

Organised Sound **14**(2): 168–176 © 2009 Cambridge University Press. Printed in the United Kingdom. doi:10.1017/S1355771809000272

Max/MSP or Kyma. These tools have such advanced algorithmic capabilities that there is no need to limit the instrument to direct one-to-one gesture-to-sound mapping; the instrument can implement various complex (and even adaptive) mapping structures and contain various degrees of automation from simple looping to complex artificial intelligence responses. All these computational techniques are impossible in acoustic instruments and their theoretical implications unavoidably involve an explicit systemic representation of music as a rule-based field or a creative search space (Boden 1990).

I will define the computational music system as an *epistemic tool*, as an instrument (*organon*) whose design, practice and often use are primarily symbolic.[1] The concept of epistemic tools is not intended to define exclusively digital technologies; it includes all tools that work as props for symbolic offloading in our cognitive process. Good examples of symbolic but analogue machines are the *abacus* and the *astrolabe*. In order to clarify this point, this paper proceeds to explore the nature of embodiment as a non-representational or non-symbolic process. It then looks at how human cognition can make use of material supports outside the body, echoing Andy Clark's statement that cognitive processes can 'extend outside the head of an individual' (Clark 1996: 81). The central question then becomes what it means when music is composed and performed with intelligent artefacts that are inscribed with a specific music theoretical outlook.

The question of epistemic tools can be posed like this: if much of our thinking happens 'in the wild' (Hutchins 1995), external to our body, as a sociocultural process that uses technology as an external scaffolding of cognitive processes, and if our learning is largely a process of incorporating knowledge in a non-symbolic way through an enactive relationship with our tools and environment; how do computers, as necessarily symbolic devices, enable, produce, maintain, support, augment but also constrain and limit our cognitive processes and therefore creative output?

The aim of this paper is to identify two linked distinctions that are becoming increasingly apparent in the design and analysis of modern musical instruments. Firstly, it examines the different embodied experiences available in acoustic and digital instruments (which is primarily a phenomenological investigation); this route has been navigated most often in the NIME community. Secondly, it explores the disparate theoretic and material affordances of acoustic and digital instruments (here seen as an epistemological enquiry); whilst related to and constraining the first area, previous work has largely neglected this perspective. This paper therefore seeks to correct the imbalance between the two identified distinctions in the analysis of digital musical instruments by addressing the epistemological nature of our new musical instruments.

2. THE MASTERY OF A MUSICAL INSTRUMENT: A SUB-SYMBOLIC SKILL ACQUISITION

Twentieth-century cognitivism has not been successful in portraying human intelligence, and various approaches have emerged that propose different views of cognition where typically the body and the environment enter the equation.[2] One of the most musically relevant approaches is enactivism, as developed by Varela, Thompson and Rosch (1991). This theory, with roots in biology but inspired by phenomenology and Eastern thought, depicts the mind as necessarily embodied in an external environment. In enactivism there is no distinction between perception and action; both co-emerge through the agent's active involvement with the world. This involvement is primarily non-representational – in other words, it is at a level where the cognition is subconscious, pre-conceptual, distributive and emergent. Varela et al. define the term:

> We propose the term *enactive* to emphasize the growing conviction that cognition is not the representation of a pregiven world by a pregiven mind but is rather the

[1]As an example we might take Michel Waisvisz's *The Hands* instrument. Every sensor of the complex interface is mapped to a specific parameter in the software-based sound engine. A change in the engine will result in a new (or altered) instrument. Although the interface has not been altered by a change in the mapping algorithm, the instrument behaves differently. For Waisvisz, changing the algorithms that constitute the sound engine means learning a new instrument, which involves the re-incorporation of the conceptual understanding of the engine's functionality into bodily memory (Waisvisz 1999, 2005).

[2]Cognitivism is here used as a term that denotes the trend in cognitive science from the mid twentieth century to view human cognition as primarily symbolic. This resulted in a tradition in Artificial Intelligence now called GOFAI (Good Old Fashioned AI). Arguably, the distinct fields of cognitive science and computer technology symbiotically constituted each other's rise through this period. The new theories criticising cognitivism include: *Connectionism*, where the idea is to build artificial neural networks that perform cognitive tasks through non-representational content (McClelland, Rumelhart and the PDP Research Group 1986); *Enactivism*, which claims that the whole body and the environment becomes part of the cognitive function (Varela et al. 1991); *Dynamic Systems*, a non-representational theory claiming that cognition (and consciousness) arises as epi-phenomena of the process of being in the world (Brooks 1991); *Situated Cognition*, a theory of knowledge acquisition as situated, being in part a product of the activity, context and culture in which it is developed and used (Brown et al. 1989); *Situated Action*, an emphasis on the constitutional context of all action as emergence (Suchman 1987); *Activity Theory*, where the focus is on human tool use and the cultural and technological mediation of human activity (Bertelsen and Bødker 2003); *Embodied Cognition*, where thinking and acting is seen as one process, emphasising our situatedness, and claiming that our cognitive system emerges from interaction with the world (Anderson 2003); and *Distributed Cognition*, where cognition is seen as an interaction between human and artefacts, and emphasis is laid on the social nature of human existence (Hutchins 1995).

> enactment of a world and a mind on the basis of a history of the variety of actions that a being in the world performs. (Varela et al. 1991: 9)

Importantly, this does *not* mean that humans are not symbolic cognisers. That fact is obvious by looking at how humans constantly create and use symbolic systems such as language, mathematics and music, or games such as chess. Stressing that they 'see symbols as a higher-level description of properties that are ultimately embedded in an underlying distributed system' (Varela et al. 1991: 101), Varela et al. find it more appropriate to define symbols (or cognitive representations) as 'approximate macrolevel descriptions of operations whose governing principles reside at a subsymbolic level' (Varela et al. 1991: 102).

Varela et al. describe embodiment as an enactive stance towards the world where we create *our* (not 'the') world through an active engagement with it. Enactivism is resourceful in explanations of embodiment, something we should bear in mind when analysing how acoustic musicians incorporate knowledge of their instruments through repeated practice. It also explains how symbolic systems are higher-level descriptions of phenomena understood by the agent through bodily perceptions. There is a general consensus in cognitive science that musicians (or athletes for that matter) learn their skills gradually through persistent practice and a minimum of verbal instructions (Dreyfus and Dreyfus 1986). Such bodily incorporation transforms our tools into ready-at-hand phenomena (Heidegger 1962) that are not based on symbolic or theoretical relations any more. The focus becomes the act and not the object, or, as Winograd and Flores explain in a Heideggerian manner, '[m]y ability to act comes from my familiarity with *hammering*, not my knowledge of a *hammer*' (Winograd and Flores 1986: 33).

According to the enactive view, the skill acquisition related to learning an acoustic instrument is highly embodied, non-symbolic and perceptuo-motor based.[3] It explains how Ihde's 'embodiment relations' to the world are established, and provides a description of this process of incorporation[4] from the level of biology. An important research question here becomes to explore, together with the enquiry into the epistemological or music theoretical nature of digital tools, how the digital musical instrument manifests a different relationship between the human body and the body of the instrument itself through its characteristic split between the interface and the sound engine.

3. THE EXTENDED MIND

In the 1990s, working in another strand of cognitive science from that of Varela et al., Andy Clark developed his theory of the 'extended mind'. Clark illustrates how people use props in the environment to extend their cognitive capacity and ease cognitive load. Sticky notes, notebooks, diagrams, models, and so on all serve as scaffoldings onto which we 'offload' our cognition. It should be noted that this is not some kind of mystical panpsychism, as Clark and Chalmers adamantly point out that they do not equate the cognitive process with consciousness (Clark and Chalmers 1998). The cognitive process happens both inside and outside the skull, an observation reminiscent of Wittgenstein's account of thinking as physical activity (Wittgenstein 1969: 6).

> [In certain conditions, t]he human organism is linked with an external entity in a two-way interaction, creating a *coupled system* that can be seen as a cognitive system in its own right. All the components in the system play an active causal role, and they jointly govern behavior in the same sort of way that cognition usually does. If we remove the external component the system's behavioral competence will drop, just as it would if we removed part of its brain. Our thesis is that this sort of coupled process counts equally well as a cognitive process, whether or not it is wholly in the head. (Clark and Chalmers 1998: 7)

Objects and artefacts serve as an external playground for thinking. We calculate on paper, draw graphs, build models, make reminders of all kinds, and, as Clark illustrates, we reorganise the pieces when playing Scrabble. According to this view, it does not matter whether information is stored and processed in the brain or outside in the environment, what matters is how the data is retrieved and taken into use (Clark 2003).

While the theory of extended mind has much potential for interesting discussions in cognitive science, it is pertinent, in the context of musical technology, to probe deeper. Indeed, the picture is more intricate since we are surrounded by objects and technologies (or 'thrown' into world of equipment as Heidegger would describe it) that contain complex material properties, scripts of their usage (Latour 1994), and even politics (Winner 1980). The objects around us – the technologies that serve as props in our thinking and music making – are stuffed with people and their ideas; in them we find programmes of action, manuals of behaviour, and political and sociocultural constructions, including aesthetic tendencies. Technological objects are therefore never neutral, they contain scripts that we subscribe to or reject according to our ideological constitution. The problem is that the scripts are often well hidden and concealed, which can result in an uncritical use of

[3]Useful accounts of the non-symbolic nature of learning are David Sudnow's ethnographic account of learning to play the jazz piano (Sudnow 2001) or Dreyfus and Dreyfus' analysis of the five stages of skill acquisition (Dreyfus and Dreyfus 1986).

[4]On the process of incorporation in the context of embodiment, see Hayles (1999).

creative technologies – technologies inherent with ideological content.

To illustrate this point in the field of musical instruments, we see that the piano keyboard 'tells us' that microtonality is of little importance (and much Western music theory has wholly subscribed to that script); the drum-sequencer that 4/4 rhythms and semiquavers are more natural than other types; and the digital audio workstation, through its affordances of copying, pasting and looping, assures us that it is perfectly normal to repeat the same short performance over and over in the same track. It is therefore germane to ask ourselves how much theory is inscribed into our new tools, particularly with regard to how automated, structurally complex and aiding (in composition and performance) our new musical instruments have become.

4. MATERIAL EPISTEMOLOGIES

Things are impregnated with thoughts; they are embedded with ideologies that have ethical, political and aesthetical implications. Furthermore, we use those artefacts in our daily tasks as extensions of our cognitive mechanism. But how do things 'contain' knowledge? How do we *write* our knowledge into artefacts, and how do we *read* that knowledge from them? By the same token, how does this relate to digital musical instruments?

Davis Baird (2004) shows how material objects can have a different epistemological status to statements of language. Technological objects may contain functions which their users understand, but would not be able to describe in language as '[t]he material products are constitutive of scientific knowledge in a manner different from theory, and not simply "instrumental to" theory' (Baird 2004: 1). Much like Heidegger and Ihde, Baird shows that technological objects can *precede* science, and afford scientific discoveries through their physical structure and functionality. The point here is not what precedes what, but rather that the instrument becomes an *expression* in itself, an externalisation of knowledge in a form that is not symbolic but material. Additionally, it is not only designed objects that inhere knowledge, but natural objects as well, by means of the physical and mechanistic properties of their material.

> Knowledge can be expressed in many ways. Theories express knowledge through the descriptive and argumentative functions of language. Instruments express knowledge both through the representational possibilities that materials offer and through the instrumental functions they deploy. (Baird 2004: 131)

Baird is well aware of Bruno Latour's ideas of concretisation: namely, that when many elements combine into one actor and start to operate as a unity (with either human or non-human agency), they gradually become a black box. When the black box works, its origins are forgotten and thus 'paradoxically, the more science and technology succeed, the more opaque and obscure they become' (Latour 1999: 304). Baird agrees with Latour on the nature of scientific blackboxing, but highlights another and perhaps more epistemologically active function of the black box itself: while talking about a particular instrument, called Spectromet, Baird says

> [t]he knowledge used in this context is tacit in the sense that those using the instrument (typically) could not articulate the understanding of spectrochemestry they deploy in doing so. Nonetheless, they can use it. This spectrochemical knowledge has become detached. It has gone inside – inside the instrument – and can now tacitly serve other technical and scientific purposes. (Baird 2004: 163)

Here (and spectacularly exemplified in the digital musical system) we see how the blackboxed instrument contains the knowledge of its inventors, which means that the users of the instrument do not need to have a deep knowledge of its internal functions. If we assume that both the designers and the users of the instrument have an understanding of it, this understanding is very different and attained from distinct origins. The former creates the instrument from a conceptual understanding of the domain encapsulated by it, whereas the latter gains operational knowledge that emerges through use (or habituation) and not from abstract understanding of the internal functionality. This picture is particularly complex in today's new musical interfaces as typically their designers are also the performers. This implies a continuous oscillation between a mode of conceptual (system design) engagement with the instrument and embodied (performative) relationship with it. Again, we are reminded of Waisvisz's stance introduced above, where we might talk of two modes: that of the instrument designer and the instrument player.

5. THE ACOUSTIC, THE ELECTRIC AND THE DIGITAL: INTERFACES OF A DIFFERENT KIND

When the technological artefact is made of material substrata (as opposed to symbolic), it can contain knowledge that precedes the scientific understanding of its functioning. The acoustic instrument is a good example. The sophisticated sound of the clarinet or the cello was developed over an extended period of time, but this sound was mature long before Fourier or Helmholtz brought forth their theories of sinusoidal functions and timbre. Strings, wood and brass tacitly encompass the theories of sound in their materiality. The observation here is that acoustic instruments inhere knowledge that has to be explicitly understood and stated in the design of digital instruments; without this explicit knowledge no code could ever be written. We explore and discover the sonic properties of wood and strings, but a solid theoretical knowledge of sound is required in order to create digital musical systems.

Let us briefly explore some main differences in the design of acoustic, electric and digital instruments. The *acoustic instrument* builders will acquire their skills through the embodied practice of making the instruments. These skills, including the intuition of material properties and sound physics, are largely in the form of tacit knowledge (Polanyi 1966) acquired through apprenticeship. It is a predominantly embodied and non-theoretical knowledge derived from discovery, exploration and refinement. The development of the acoustic instrument involves iterations of designing, building and testing. The instrument makers work with what physical materials afford in terms of acoustics; a change in curve, in width, or in material means a change in sonic timbre. The interface is necessarily conditioned by the properties of the materials used, and various solutions are therefore introduced to adapt to or extend the scope of the human body with the use of levers, keys and other mechanisms. Acoustic instruments are therefore firmly grounded and conditioned by human physique in their design.

The makers of *electronic instruments*, such as the early synthesisers, work with different materials. Instead of millennia of tradition, they start with exploring the material properties of electricity, magnetic waves, oscillators, capacitors, inductors and transistors. As with the acoustic instrument, the creative process is one of designing, building and testing through a cycle of iterations, actively working with the materials. However, the materials of the electronic instrument makers come with instructions and schematic diagrams that describe their behaviour. There is an increased logic of calculation, science and engineering. Fourier's and Helmholtz' theories are now well known, and the instrument makers can draw from that knowledge in their designs of oscillators and filters. However, some of the characteristic sound in electronic instruments depends on the chaotic or entropic properties of the materials used.[5] The user interfaces in electronic musical instruments can be built in any shape and form. In terms of ergonomics, we are still constrained by physical mapping, so when the instrument has been wired up, its fundamental functionality is not easily changed. This gives the machine an instrumental quality, a character that affords in-depth explorations.

The *digital instrument* makers are in a different world altogether. The 'workshop' is the meta-machine of the computer, and inspecting them at work might not suggest any associations with musical activities.[6] Code as material is not musical; it does not vibrate; it is merely a set of instructions turned into binary information converted to an analogue electronic current in the computer's soundcard. The materials of the digital instrument are many: a computer, a monitor, a sound card, an amplifier, speakers, and tangible user interfaces. Behind this material surface lie other materials: audio programming languages, digital signal processing, operating systems, mapping mechanisms between gestures and sound engines, and so on. From the perspective of Latour's actor-network theory, the networks enrolled in the production of digital instruments are practically infinite. There is an impenetrable increase in complexity, which means that the inventors have to constantly rely on black boxes. Furthermore, the materials used in the digital instrument originate from technoscientific knowledge. There are relatively few physical material properties at play (although of course at the machine level we find matter) compared to the amount of code that constitutes its internal (and symbolic) machinery. The inventors have knowledge about digital signal processing, sound physics, audio synthesis, gesture recognition, human–machine interaction, and the culture of musical performance. In general, the digital instrument is based on the knowledge of symbolic systems and their essence in the form of code. From a design perspective, any interface can be designed for any sound. There is no natural mapping between gesture and sound in digital systems. In acoustic instruments the performer yields physical force to drive the instrument, whereas in electric instruments there can be mixture of both physical and electric force. In digital instruments, the physical force becomes virtual force; it can be mapped from force-sensitive input devices to parameters in the sound engine, but that mapping is always arbitrary (and on a continuous scale of complexity), as opposed to what happens in physical mechanisms.

Therefore, from the perspective of embodiment relations, there is a characteristic diversity in the way we work with the materials that constitute our musical instruments. Digital music systems, whose foundations are essentially of a symbolic nature, are more likely to establish hermeneutic relations to the world than acoustic instruments, where understanding of expressive

[5]A good example is how the oscillators in the Moog synthesisers detune, resulting in a full and pleasant chorus-like sound. In later synthesisers, like the ARP, it was discovered that by placing the oscillators on the same material, next to each other, they would have the same temperature and therefore not go out of tune as much as in the Moog (Pinch and Trocco 2002).

[6]There might not be any keyboards, notes or indeed sounds in the air – a fact that apparently prompted Bob Moog to attach a keyboard to his analogue synths, as, when he was photographed in his studio, people would be more likely to relate this new technology of knobs and wires to music (Pinch and Trocco 2002).

affordances are incorporated into the performer's motor memory. To work with symbolic tools means that one has to continually switch modes from focusing on the world to focusing on the tool with regular intervals and to a more pronounced degree than in acoustic instruments. This detachment from the terminus of our activities could be paraphrased as a disruption in flow and is present in the majority of existing digital music systems.

6. EPISTEMIC TOOLS

Anyone who speaks more than one language, in particular if those languages are of different linguistic families, knows how differently each language portrays the world. A language is a world-view. This observation is the basis of a theory called the Sapir–Whorf hypothesis, which states that different languages portray both space and time differently.[7] The Sapir–Whorf hypothesis claims that grammatical categories of the language determine the speaker's behaviour: 'We cut nature up, organize it into concepts, and ascribe significances as we do, largely because we are parties to an agreement to organize it in this way – an agreement that holds throughout our speech community and is codified in the patterns of our language' (Whorf 1956: 213). Seventy years earlier, Nietzsche had argued that physics were an *interpretation* of the world and not its explanation. The sciences reject phenomenological experience in favour of objective language and they 'do this by means of the pale, cool, gray, conceptual nets which they threw over the colourful confusion of sense, the rabble of the senses' (Nietzsche 2004: §14). Rather more recently, Bowker and Star (2000) have argued that there are certain problems in the design of computer systems that relate to the act of classification. When we classify and categorise our external world, in order to represent it through the machinery of information technology, we are inevitably performing acts of reduction. Such reductions are bound to be contingent and messy, with abundance of ethical and political implications. Human actions are displaced into representation, thus establishing strata of complexities and interdependencies that limit the agent.

This nature of categorisation and abstraction of human knowledge (both know-that and know-how) and actions is the essence of computer software, a fact that is vividly apparent in the realm of musical software tools. Software is, as Bowker and Star point out, a 'contingent' and 'messy' classification that has diverse implications and, in our case, aesthetic, cultural and culture-political effects. As Latour (1987) so elegantly demonstrates, objects establish themselves as black boxes through repeated use, and in that process their origins disappear. The object is naturalised[8] through heavy use, a fact that makes Bowker and Star observe that '[t]he more naturalized the object becomes, the more unquestioning the relationship of the community to it; the more invisible the contingent and historical circumstances of its birth, the more it sinks into the community's routinely forgotten memory' (Bowker and Star 2000: 299).

Writing digital musical interfaces therefore necessarily entails the encapsulation of a specific musical outlook. It is a (sub-)culturally conditioned systematisation of musical material. Musical patterns, musical styles and musical aesthetics become black-boxed in software. Most people do not know why the standards, implementations, patterns or solutions in musical software are there. At times, they manifestly limit the musical expression, but at other times limitations are concealed by the rhetoric, streamlined functionality and slick interface design of the software tool. Here we encounter yet another difference between the worlds of acoustic and digital instrument making. The acoustic instrument maker can freely re-invent or improve the instrument at any time with new materials, changing structures or adding/deleting features (Eldredge and Temkin 2007). The software instrument maker is limited by the complex infrastructure of operating systems, programming languages, protocols and interface limitations. In digital instruments, systems of classification form an organisation of musical language, a clarification and explicit elucidation of the musical language and its rules. However, and well known since Wittgenstein's later writings, languages are not easily formalised as systems. At the core of all languages are dynamic, emergent and adaptive sets of rules that change through time and differ in geographical locations or in sub-cultures. The act of formalising is therefore always an act of fossilisation. As opposed to the acoustic instrument maker, the designer of the composed digital instrument frames affordances through symbolic design, thereby creating a snapshot of musical theory, freezing musical culture in time. The digital instrument is thus more likely to contain an expressive closure as contrasted with the explorative openings of the acoustic instrument.

From our analysis of the epistemic tools, we can now crudely generalise (and therefore exaggerate for the sake of an argument) a core difference between the acoustic and the digital. The *acoustic instrument* is material and developed from bottom-up exploration of the acoustic properties of the materials used. Here, the sound generation (and the required knowledge

[7]This hypothesis has many followers and critics. A notable criticism was voiced by Stephen Pinker (1994), who, in a Chomskyan manner, argues for a universal underlying structure of language.

[8]Or 'concretisised' or 'pointilised' in actor-network theory lingo.

of it) is given to us for free by nature. We had complex instruments in the form of lutes, flutes and organs long before we ever had a mathematical understanding of sound. The physics of wood, strings and vibrating membranes were there to be *explored* and not invented. However, *using* the acoustic instrument we develop an intuitive understanding of the instrument, the music theory, and the tradition in which we are playing. As the interaction with the instrument is primarily embodied, we have to train our body to be in rhythm with the instrument – in other words to incorporate the musical knowledge *in sync* (or mutual resonance) with the particular instrument of choice. As opposed to the generic explicitness of the digital instrument, the acoustic instrument contains a boundless scope for exploration as its material character contains a myriad ways for instrumental entropy, or 'chaotic', non-linear behaviour that cannot be mapped and often differs even in the same type (brand and model) of instruments.

The *digital instrument* is theoretical and developed from a largely top-down methodology. In order to *make* the instrument, we need to know precisely the programming language, the DSP theory, the synthesis theory, generative algorithms and musical theory, and have a good knowledge of Human Computer Interaction. To *use* the instrument, on the other hand, we learn the tool through working with it and habituate ourselves with its functions, progressively building an understanding of its workings. As users we often do not need to know as much about synthesis or music theory, as the black box is intended to be used through its simple and user-friendly interface. Ergonomically, the interaction happens primarily through a symbolic channel, which gradually teaches the user to operate with technical terms (such as 'low-pass'), but this happens from the habituation of the model (what we call the epistemic tool). The predefined quality of the digital instrument means that its functionality can be exhaustively described in a user manual; all is supposed to be explicit, nothing covert. Where the digital instrument exhibits any chaotic or entropical behaviour, it tends to be due to a failure in design, a bug in the code or loose wiring in the hardware.

Let us now reverse out of the epistemological investigations and revisit the phenomenological point: it has been explored above how people learn acoustic instruments through an enactive and embodied practice. Digital music systems or instruments (such as Logic, Pure Data, The Hands, or the reacTable) pose a difficulty here. They do, of course, provide for a certain *virtual embodiment*, but the locus of their real nature is fundamentally in the symbolic realm. Although we interact in an embodied manner with the computer using physical interfaces (moving our mouse on a two-dimensional plane, touching screens, or swinging Wiimotes) the interaction always takes place through symbolic channels of varied bandwidths. The interaction is primarily with *graphical* representations such as words, menus, cables or icons on the one hand, or *abstract* representations such as variables, parameters and functions on the other. This symbolic communication is based on a designed construction, which is inherently an approximation and an ad hoc representation of the task/world/music. What characterises the player of the digital instrument is a mental representation of the instrument's parameters, and a strong awareness of how easily and arbitrarily those can be changed. As such, the digital instrumentalist is always a luthier (Jordà 2005) as well, someone that consciously engages with the instrument as a dynamic and fluid tool of a contingent nature.

The constraints in acoustic instruments are of a different kind: they have naturally inbuilt affordances, but those are mechanistic and physical (typically the domain of frequency range and timbre), not musicotheoretical and symbolic (typically the domain of notes and form). The acoustic instrument presents itself as a coherent whole where the interface and the sound engine are one and the same. Although the digital instrument can be conceived of as an integrated whole (Bongers 2000; Jordà 2005), this is often done for the sake of practicality and is not the only approach that should be taken when they are analysed. Particularly in intelligent instruments we find that the expressive design and the determinant of performance experience is to be located at the symbolic computational level. This area, abounding with culture-specific models of music, has been largely neglected in the analysis of digital musical systems.

The abstract characteristic of all system design constitutes the epistemic nature of digital tools. The tool is designed, its affordances and constraints are outlined, and the user's actions are predicted and delineated into the instrument's interface and interaction design. It is the designer who decides with clear rational arguments what is revealed and what is concealed in the use of the system. Whereas the *body* of the acoustic instrument is physical, the body of the digital musical instrument is intrinsically theoretical. Skill acquisition, the path to mastery, and the nature of virtuosity are all features that are transformed with the digital musical instrument. From this perspective, when computers are seen as mediation, the role of the system designer is that of outlining a system that directs the energy from the physical interface to the work (or the *terminus* – the music) through the symbolic engine of the epistemic tool. This activity of blackboxing, of creating abstractions of activities where bodily movements *and* thoughts are represented as discrete chunks in time, grounds the complexity and the non-transparency of digital tools. Therefore, if there is a normative message in this paper, it would be an encouragement to acknowledge the theoretical, cultural and social context in which all tools are designed – and this implies an awareness by designers of the responsibilities they have in terms of aesthetic and cultural influence.

7. CONCLUSION

The journey from the phenomenology to the epistemology of musical instruments took the following form in this paper: first it introduced Ihde's phenomenological modalities of tools. It was proposed that we could define, with some rough generalisations, the acoustic instrument as a channel for *embodiment* relation with the world, and the digital instrument as medium for a *hermeneutic* relation. Through the analysis of enactivism, the highly embodied nature of skill acquisition and performance of acoustic instruments was identified, but that thread was abruptly deferred in order to introduce the epistemological fundament of designed artefacts. An exploration of the extended mind helped to clarify how things external to the body can become part of its cognitive mechanism, thus rendering technology as integral element in musical creativity. The thread of embodiment was picked up again by exploring the different phenomenological relationship we have with acoustic and digital instruments, due to the distinct nature of their interfaces, and this divergence was described with regards to the conceptual and system design complexity integral to all digital systems.

Consequently, the digital instrument was defined as an *epistemic tool* (a conveyor of knowledge used by an extended mind) and its symbolic nature was described as a designed artefact that affords cognitive offloading by the thinker or the performer. Although acoustic instruments may contain epistemic dimensions as well, a diverging factor in acoustic and digital instruments is the difference in mapping between a gesture that affects real vibrating material, on the one hand, and an action that is arbitrarily mapped to a symbolic system, on the other. I pointed at a fundamental difference of the acoustic versus the digital in that, although both inhere knowledge of acoustics, the latter is typically designed from the top-down activity of classifications (of sounds, gestures and musical patterns), where nothing is given for free by nature. The digital instrument is an artefact primarily based on rational foundations, and, as a tool yielding hermeneutic relations, it is characterised by its origins in a specific culture. This portrayal highlights the strengthened responsibilities on the designers of digital tools, in terms of aesthetics and cultural influence, as they are more symbolic and of compositional pertinence than our physical tools.

This paper has focused on differences at the cost of similarities, and divided into distinct groups phenomena that are best placed on a continuum. This has been done, not in order to claim preference for one type or the other, but for the sake of creating an awareness, as creators and users of instruments, of how much intelligence our instruments contain; from where this knowledge derives, and at what level it resides. The project of exploring music technologies in this manner thus becomes a truly philosophical, aesthetic and ergonomic investigation that can benefit from the use of a historical genealogy (as proposed by Nietzsche and practised by Foucault) as method. The question 'why does a particular music sound like it does?' can this way be transposed into a questioning of the conditions in which musicians make music, which instruments are used, and the complex origins of those. When music making has become a process largely taking place through digital tools, we should bear in mind that software has agency and necessarily inheres more cultural specifications than any acoustic instrument.

8. ACKNOWLEDGEMENTS

The author would like to thank Enrike Hurtado Mendieta for collaborating in the generation of these ideas over the years. Nick Collins, Chris Thornton, Alex McLean and Tom Ottway read the paper and made important suggestions. Finally, the author expresses his gratitude to the three anonymous reviewers and the editors of *Organised Sound* whose comments made this text much better than it otherwise would have been.

REFERENCES

Anderson, M. L. 2003. Embodied Cognition: A Field Guide. *Artificial Intelligence* **149**: 91–130.

Baird, D. 2004. *Thing Knowledge: A Philosophy of Scientific Instruments*. Berkeley: University of California Press.

Bertelsen, O. and Bødker, S. 2003. Activity Theory. In John Carroll (ed.) *HCI Models, Theories and Frameworks*. San Francisco: Morgan Kaufmann, 291–324.

Boden, M. A. 1990. *The Creative Mind: Myths and Mechanisms*. London: Wiedenfeld & Nicolson.

Bongers, B. 2000. Physical Interfaces in the Electronic Arts. Interaction Theory and Interfacing Techniques for Real-time Performance. In M. Wanderley and M. Battier (eds.) *Trends in Gestural Control of Music*. Paris: IRCAM – Centre Pompidou.

Bowker, G. C. and Star, S. L. 2000. *Sorting Things Out: Classification and its Consequences*. Cambridge, MA: MIT Press.

Brooks, R. A. 1991. Intelligence Without Representation. *Artificial Intelligence Journal* **47**: 139–59.

Brown, J. S., Collins, A. and Duguid, P. 1989. Situated Cognition and the Culture of Learning. *Educational Researcher* **18**(1): 32–42.

Clark, A. 1996. *Being There*. Cambridge, MA: MIT Press.

Clark, A. 2003. *Natural-Born Cyborgs: Minds, Technologies, and the Future of Human Intelligence*. Oxford: Oxford University Press.

Clark, A. and Chalmers, D. 1998. The Extended Mind. *Analysis* **58**(1): 7–19.
Dreyfus, H. L. and Dreyfus, S. 1986. *Mind over Machine: The Power of Human Intuition and Expertise in the Era of the Computer*. New York: Free Press.
Edens, A. 2005. *Sound Ideas: Music, Machines, and Experience*. Minneapolis: University of Minnesota Press.
Eldredge, N. and Temkin, I. 2007. Phylogenetics and Material Cultural Evolution. *Current Anthropology* **48**(11): 146–53.
Hayles, N. K. 1999. *How We Became Posthuman*. Chicago: University of Chicago Press.
Heidegger, M. 1962. *Being and Time*. Oxford: Blackwell Publishers.
Hutchins, E. 1995. *Cognition in the Wild*. Cambridge, MA: MIT Press.
Ihde, D. 1979. *Technics and Praxis*. Dordrech: D. Reidel Publishing Company.
Ihde, D. 1990. *Technology and the Lifeworld: From Garden to Earth*. Bloomington: Indiana University Press.
Jordà, S. 2005. *Digital Lutherie: Crafting Musical Computers for New Musics' Performance and Improvisation*. PhD thesis, University of Pompeu Fabra, Barcelona.
Latour, B. 1987. *Science in Action: How to Follow Scientists and Engineers Through Society*. Cambridge, MA: Harvard University Press.
Latour, B. 1994. On Technical Mediation – Philosophy, Sociology, Genealogy. *Common Knowledge* **3**(2): 29–64.
Latour, B. 1999. *Pandora's Hope. Essays on the Reality of Science Studies*. Cambridge, MA: Harvard University Press.
McClelland, J. L., Rumelhart, D. E. and the PDP Research Group. 1986. *Parallel Distributed Processing: Explorations in the Microstructure of Cognition*. Volume 1 and 2: Foundations. Cambridge, MA: MIT Press.
Nietzsche, F. 2004. *Beyond Good and Evil: Prelude to the Philosophy of the Future*. Cambridge: Cambridge University Press.
Pinch, T. and Trocco, F. 2002. *Analog Days: The Invention and Impact of the Moog Synthesizer*. Cambridge, MA: Harvard University Press.
Pinker, S. 1994. *The Language Instinct*. Penguin: London.
Polanyi, M. 1966. *The Tacit Dimension*. Garden City, NY: Doubleday & Company.
Schnell, N. and Battier, M. 2002. Introducing Composed Instruments, Technical and Musicological Implications. *NIME 2002 Proceedings*. Limerick: University of Limerick, Department of Computer Science and Information Systems.
Suchman, L. A. 1987. *Plans and Situated Actions: The Problem of Human–Machine Communication*. Cambridge: Cambridge University Press.
Sudnow, D. 2001. *Ways of the Hands*. Cambridge, MA: MIT Press.
Varela, F., Thompson, E. and Rosch, E. 1991. *The Embodied Mind*. Cambridge, MA: MIT Press.
Waisvisz, M. 1999. Gestural Round Table. *STEIM Writings*. http://www.steim.org/steim/texts.php?id=4 (accessed December 2008).
Waisvisz, M. 2005. Personal Communication whilst artist-in-resident at STEIM.
Whorf, B. 1956. *Language, Thought, and Reality: Selected Writings of Benjamin Lee Whorf*, ed. John Carroll. Cambridge, MA: MIT Press.
Winner, L. 1980. Do Artifacts Have Politics? *Dædalus: Journal of the American Academy of Arts and Sciences* **109**(1) (Winter): 121–36.
Winograd, T. and Flores, F. 1986. *Understanding Computers and Cognition*. Norwood NJ: Ablex.
Wittgenstein, L. 1969. *The Blue and Brown Books*. Oxford: Blackwell Publishers.