Sound Design As Human Matter Interaction

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Abstract
Recently, terms like *material computation* or *natural computing* in foundations of computer science and engineering, and *new materiality* in cultural studies signal a broader turn to conceptions of the world that are not based on solely human categories. While respecting the values of human-centered design, how can we begin to think about the design of responsive environments and computational media while paying as much attention to material qualities like elasticity, density, wear, and tension as to social and cognitive schema? This presumes understanding computation as a potential property of matter in a non-reductionist way that plausibly spans formal divides between symbolic-semiotic, social, and physical processes. We begin this in the concrete practices of computational sound and sound design.

Author Keywords
Materiality, material computation, computational media, computational physics, digital sound synthesis

ACM Classification Keywords
Human-centered computing [Human computer interaction (HCI)]: HCI design and evaluation methodsField studies; Human-centered computing [Human computer interaction (HCI)]: Interaction devicesSound-based input / output; Human-centered computing [Human computer interaction

(HCI)]: HCI theory, concepts and models

General Terms

New Materiality, Phenomenology, Non-anthropocentric design

Introduction: Computational Sound and HCI Design

We start by describing some particular examples of people making music and dancing in a responsive environment, i.e. an environment in which the sound and video is computationally modulated in concert with people's live, contingent activity as well as prior design. The examples come from the Topological Media Lab's work with dancers and musicians, but they have a double valence. From one hand, they are motivated by questions of making realtime systems that can support the most nuanced and expressive action by participants in a social event with aesthetic value. From the other they are motivated from, and by design yield insight into questions about continuous gesture and the processual formation of experience. We have written about these computational environments as experimental apparatuses for philosophical inquiry elsewhere [8] [9]. This paper focuses on implications from the making of such realtime, continuously responsive environments for the design of technical systems for human-computer interaction design.

First we'll introduce three recent installation-performance environments: WYSIWYG sonic weaving, Tabletap sonified kitchen as stage, and a prepared piano coupled to computational sound synthesis. All, but particularly the last application exemplify how sound designers blend computational techniques with qualities of physical materials and human activity to condition and co-create live events. Then we'll contextualize this in a broader discussion about locus of computation in alternative models of what's called material computation, and suggest some implications for design and HCI.

We have always been material(ly computing)

The old analog - digital computation distinction is more useful as distinction between academic disciplines rather than as a distinction in designing material that changes in concert with human activity. But computation, in the sense of a determined and designed set of well-defined transitions as a function of a given state to another state of an event, is always material. Under the fiction of the digital there is always the hiss of electrons and of matter-energy fields in physical, even quantum mechanical transmutation. It just happens to be under the radar as far as HCI is concerned. But as Barad, Bennet, the first author, and many others have argued, physics, suitably understood, figures equally with social field and narrative in modulating our computationally mediated experience. It is true that, to pun on Bruno Latour's critique of the distinction between social and natural categories ([6]), we have never been digital. But this paper rests on the observation that we have always been computational, because matter that is not formed into digital architectures can also carry out computation. (By architecture we will adopt the sense implied in [1].)

WYSIWYG [4]

One legacy of the intense growth of HCI during the invention of the personal computer and office automation is the model of the user experience as a personal and thus solipsistic activity. Considering the medium of sound however, one quickly learns how no object is physically isolate. So acoustic interaction is necessarily distributed, and continuously so. Pursuing this thought in the gestural control of sound, the TML built in collaboration a 6m x

Figure 1: WYSIWYG weaving mapping nearby movement and bodies to sound, Marguerite Bromly, Daviid Gauthier, Elliot Sinyor et al.; TML, XS Labs, IDMIL.

1.2m "tapestry" (Figure 1,) woven of conductive thread made into capacitive sensors. We designed custom electronics and sound processing instruments to map proximate movement to sound. Being much larger than a human body and sensitive to *any* nearby presence, WYSIWYG is an instrument designed to be modulated by not a specific "agent" doing discrete actions, but by *continuous distributions* of activity.

Tabletap [7]
Another legacy is the establishment of gesture sampling and screen refresh in the 30-60Hz range and fragile system architectures that drop frames or gesture samples in times of computational stress. Newer applications such as gaming, music, and those integrating multiple sensory modalities need higher data rates and lower jitter than the legacy standards provide. Encoding gestures in audio [11] has the advantage of leveraging a high reliability signal path into computers (optimized because audio clicks are very noticeable) with high data rates (44.1-198kHz) and low jitter (better than 1nS). As well as transcoding gestures from haptics into acoustic energy sounding objects such as fruit, vegetables, the floor and the human body [3] provide useful computational operations such as band-limiting, resonance and spatial encoding.

By sonifying with microphones and realtime sound instruments the utensils and gestures of a chef, Tabletap symbolically charges everyday actions and objects in ways that combine the choreographer's and composer's design with the performer's contingent nuance. Tabletap replaces the design of interaction as discrete action-response by the composition of time-based media that can recalibrate themselves on the fly (within 30 frames, i.e. 0.6 ms under ordinary load), according to contingent action. Also there is no "non-grammatical" action; any movement at all may potentially be made by the performer or the objects. The meaning comes from the context established in the moment of performance together with the theatrical apparatus of expectation.

One way we have designed the continuous richness of potential computational response to non-schematized gesture is via an architecture that implements physical models coupled via acoustic sensing. (See the architecture diagram of one example system which incorporates many fairly sophisticated sound analysis, mapping, and synthesis systems such as [5]: Figure 2)

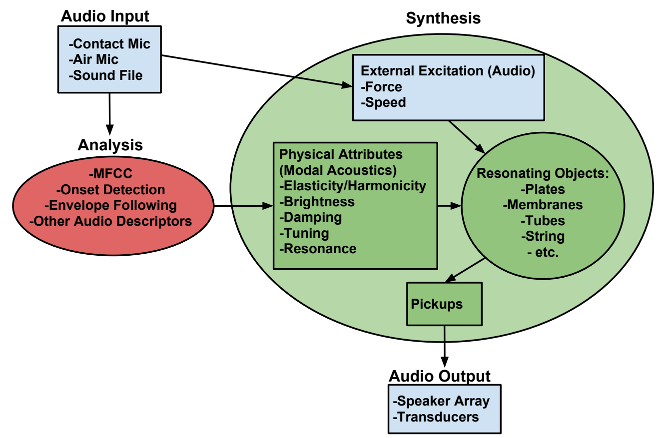

Figure 2: System for sonifying matter using physical modeling.

Acoustic Conditioning, Material Computing
Acoustic and sound processing present concrete examples of material computing in analog media as well as electrical or computational media. For example, for *Ancient Voices of Children*, composed for an ensemble of analog folk, toy, and prepared classical western musical instruments, George Crumb instructed the mezzo-soprano Jan

Figure 3: Whole-body movement workshop, TML, December 2012.

DeGaetani to cluck-sing into a prepared piano, which acted as a complex realtime filter and extension of her voice.

In a recent workshop at the TML on whole-body movement and realtime media, the second author hybridized computational and physical techniques to prepare the entire room as an instrument. (Figure 3) In the preparations, we encountered the very common problem that the chosen space, a dance teaching and rehearsal studio, was poorly suited for the sound aspects of the interactivity. The shape was a typical rectangular prism with sound reflective windows on one side and mirrors opposite. The remaining walls were concrete. The floor was optimized for dancers and therefor acoustically reflective. We are able to employ mid-weight curtains around the space to absorb most of the difficult flutter echos and other artifacts that interfere with speech intelligibility and sound quality. The price to pay for this choice was a "deadening" of the room requiring some kind of amplified support. We couldn't address this by employing the usual "Public Address" approach because we wanted the performers: actors, dancers, musicians and casual visitors to move in the space unimpeded and unencumbered by microphones. An elegant solution is typified by the Meyer Sound Constellation system: an array of microphones and small speakers spread throughout the space that engage the room and an array of processed signal streams into a recursive network of acoustic and digital convolution calculations.

The time and budget didn't allow for the installation of a Constellation system so we employed another programmable convolution engine that can be found in most dance studios: an upright piano. (Figure 4) Sound sources from contact microphones on the floor, air microphones in the space and synthesized sound sources from the media computing systems were sent to an array of bending mode transducers attached to the wooden sound board of the piano. These excited the sound board and strings of the piano but typically at sound levels that were barely audible in the room. Sound from an array of piezoelectric contact microphones in the piano were amplified and sent to a ring of 8 loudspeakers in the room. Sound engineers will recognize this approach as similar to the plate reverberators common in the late 1950's that were an important shaper of the sound recordings of the Beatles and Pink Floyd in the 1960's. Actually this approach is closer to the sympathetic resonating strings found commonly in Indian musical instruments. The most similar historical antecedent though is the Ondes Martenot an early sound synthesizer system designed in the 1930's that included a loudspeaker with attached sympathetic vibrating strings.

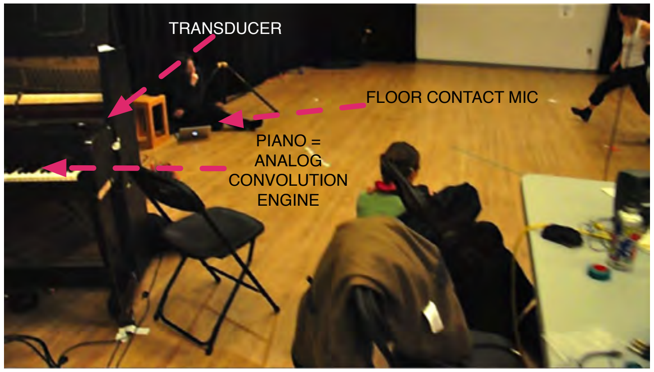

Figure 4: Using piano as convolution engine, transducers, microphones, speakers and live sound processing to acoustically condition the entire room.

With care in the design and choice of materials, connections, electronics and signal processing implementation, each component of this reverberation system can be made linear enough to be modeled using the same powerful Liner Time-Invariant system theory (LTI). We view this as a general model of computation where a large number of signals are continuously delayed by varying amounts and summed with varying weights. Such systems can be characterized completely by an impulse response which can be viewed as the program for such a computer and this is in fact the most popular approach for digital reverberators now, where room reverberation can be simulated by convolving recorded impulse responses.

Material convolvers such as the room, soundboard and strings have some special advantages over digital computations that were important in our whole body interaction workshop. The first one is latency. Although latency minimization is an important research area in convolution reverberators [2] practical implementations still add many milliseconds of delay. More important than this is the dimensionality of the signal flows. Digital systems model the acoustics as if they are propagating in a one-dimensional medium. The piano sound board allows us to diffuse and collect information from a large array (88) of strings. Each string supports primarily two independent lateral modes of vibration and the propagation in the sound board is multi-dimensional. The sonic impact of this richer dimensionality is much easier to experience and evaluate in the room itself than in by verbal description. The impact from an interactivity perspective on the other hand is readily apparent when we look at how we tuned the piano/room/floor/loudspeaker systems. We did this by directly generating sounds with percussive interactions between our bodies and the bodies of the room and instrument thereby injecting sound into the system at various points while listening to the outputs. Tuning was achieved by moving the transducers in space and indeed the entire piano in the room. The piano had a particularly interesting affordance in that we could individually enable the dampers on each string. It was also useful during some of the whole body interaction experiments to perform with the piano - both conventionally and by direct access to the strings and soundboard.

(Such acoustic design is by no means restricted to art applications. Public PA systems in cavernous noisy spaces are now orders of magnitude more intelligible than they were 40 years ago. Acoustic engineers can treat the entire building interiors as complex resonators with many points of excitation and damping. Some are fixed – e.g. speakers or walls, some are moving – e.g. walking people, bodies as dampers.)

"Matter matters": Designing Material Computation

HCI has tended to regard the computer as a machine for (human-human) communication. It is equally a machine for calculating - a machine for physics. (In a sense this mirrors the historical branches of LISP vs FORTRAN). The turn from the symbolic / semiotic to the material can be summed up in Karan Barad's motto "matter matters." In the context of user interface design – it matters whether the user places a finger on a piece of hard plastic, or manipulates something soft and plushy. (This is the materials analog to understanding that prosody matters as much as the lexical in the meaning and experience of speech.)

But how can HCI, which recently has turned to using some conventional tools of late 20c social sciences and psychology designed to pick up conventionally human-sized subjects and social phenomena, such as ethnography, capture enough of, and the right aspects of people's experience that matter in their material computational design? How can HCI synthesize such observations into insights that designers can use to create computational media and environments?

New materiality
To help stimulate fresh insight for design, it's useful to avoid certain "ism's" that can dog what is called new materiality.

Physicalism: To be material does not merely mean made of steel or silicon. It may be useful to lift, however, some characteristics of physical matter, such as being subject to degeneration, irreversible processes, mortality, thermodynamics, and phase. (To do this robustly requires a careful generalization of physics such as Rene Thom's re-reading of Aristotle's Physics in the second part of *Semiophysics*, which develops a generalized notion of potential versus actual. But this is out of scope of our paper.)

Physiologism: Just as being material is not just to be made of metal or water, being embodied does not necessarily reduce to measuring physiological data from humans. In a related way, being vital or autopoietic does not devolve to hacking dishes of neurons, or other types of cells, or of higher order complexes, such as individual organisms or collections of organisms.

Naive notions of experience: The very term,"embodied interaction" encodes dualisms which are helpful to analyze and perhaps sidestep in design theory. When does experience *not* involve your body? Why must interaction be "inter"? Making relations (the arcs in a diagram) the primitive unit of analysis entails the question of what are their end points, which may be a confusing question (ungrammatical in Wittgenstein's sense). Why must there formally always be two terms to a relation? More fundamentally, such a view of relation (vs. field, for example) entails compact entities like "agents."

We suggest that an extended notion of materiality (looking to Deleuze, Barad, Simondon, and [9]), coupled with a span of technical practice that includes electrical engineering, mechanical engineering, and condensed matter physics, for example, together with emerging models of material computation, would remove certain design problems, and point to a way to design humanely for dense built environments inhabited by arbitrary numbers of people doing arbitrary things. We suggest that such approaches may be conceptually cleaner for the theory of dense responsive environments, and practically simplify their design and engineering.

This abstract suggests that (1) matter can sometimes be a computational substrate, and (2) refined design and disciplined practice are possible as demonstrated by the domain of computational sound concerted with expressive corporeal movement.

More General Material Computation
The arguments for non-standard computation such as material computation, or natural computing hinge on the depth, speed, robustness, cheapness, energy-efficiency, and density of ordinary matter. But we believe simply imposing digital models onto material substrates, whether biological or not, is not the way to go. As S. Stepney has observed: "[Computation using biological substrates such as DNA or proteins] is interesting and productive, but does it tell us anything deeper about computation? I would submit not. There are two main reasons for this. Firstly,

the applications chosen are usually classical and digital, and not naturally suited to the analogue substrates. Secondly, and more profoundly, the biological substrate is extremely complex and complicated, having evolved over billions of years to exploit specific properties. In some sense, biological substrate is as far (or further!) removed from a primitive substrate as are our own designed abstract digital computational media" ([10], 1159) Also, in a chapter describing computing with liquids hosting reactiondiffusion processes, Adamatzky and Costello write: "So far, most known experimental prototypes of reactiondiffusion processors exploit the interaction of wave fronts in a geometrically constrained chemical medium. The computation is based on a stationary architecture of the mediums inhomogeneities. Constrained by stationary wires and gates, reactiondiffusion chemical universal processors provide little computational novelty and no dynamical reconfiguration ability because they simply imitate the architectures of conventional silicon computing devices. To appreciate in full the inherent massive-parallelism of thin-layer chemical media and to free the chemical processors from the imposed limitations of fixed computing architectures, an unconventional paradigm of architecture- less, or collision-based, computing has been adopted. An architecture-based, or stationary, computation implies that a logical circuit is embedded into the system in such a manner that all elements of the circuit are represented by the systems stationary states. The architecture is static. If there is any kind of artificial or natural compartmentalization, the medium is classified as an architecture-based computing device. Personal computers, living neural networks, cells, and networks of chemical reactors are typical examples of architecture-based computers." ([1], 1915).

Generality of Material Computation

Let's compare the claimed generality of materially embedded acoustic convolution computations with the claim that modern digital CPU's are "general purpose." Are we talking about the same sort of generality? How is this related to claims of Universality of Computation as explored by Turing and others? We first have to clarify a common confusion that it was the invention of the stored-program in digital computers that gave them generality of application. Digital stored programs provide a high level of precision and repeatability but the question of generality is contingent on what the computational components are that the stored program mediates data flows among. Analog computers and our acoustical computer store their programs in a spatial, non-digital form which we would admit is not as precise as a digital representation because, for example, all the parameter stored are temperature dependent. The inherent two dimensionality of the parameters gives the acoustic system an advantage in accuracy. A rather important practical advantage is that pianos and rooms tend to outlive digital systems so the parameter storage of the mechanical systems has a longer potential lifetime.

If we look carefully at the history of digital computer systems architectures we see regular shifts in the kinds of processing components reflecting the changing application domains of computers. Early digital computers, the DEC PDP-8 for example had no multiplication units - multiplication was achieved by repeated addition. As applications requiring computations expressed in terms of linear algebra have expanded the number and performance of multiplication hardware components has increased. The GPU, DSP, array processors all reflect different choices of processing units to reflect the expected requirements of their specific application domains. So even in so called "general purpose" computers, material choices in the implementations have a strong influence of what specifically is computed.

References and Citations

How to build such systems for material computation

So, how could we design some material computation systems?

One account that describes the architecture uses the narrative fiction of a stimulus response processing loop (Figure 5).

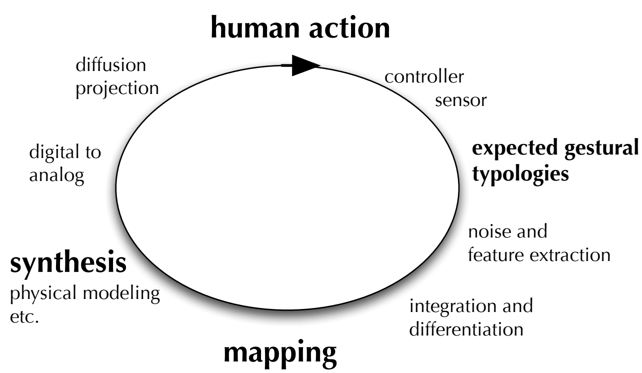

Figure 5: The stimulus response processing loop.

But we can see a problem with design thinking using such a stimulus response loop account.

In "event-loop" programs, the design logic focusses attention on one discrete user action at a discrete time, which triggers a cascade of computer actions in response. The two agents in this design fiction, computer system and user, wait for each other at what we'll call the meso scale of a human act, paradigmatically that of making a selection among a small, discrete set of choices.

However in realtime systems like our time-based computational media environments, the flow of processing happens continuously, and as far as the human is concerned, concurrently with his or her continuous gesture. There is no turn taking. One symptom of applying a turn-taking approach to the design of a sound-processing application with live audio is feedback. This is an elementary "mistake" that novice sound designer/programmers quickly learn to avoid. But it reveals a deep and persistent conceit in design logic inherited from the event-loop, turn-taking conversational paradigm.

But at what, for the sake of argument, we will call a macro scale of activity, "system" designers conceive of computers as mediating humans communicating with other humans.

This raises three deep conceptual problems: (1) locally unidimensional narrative structure, (2) locus of computation, and (3) formal separation of functionality. Particular narrating user experience in ordinary language necessarily inherits a locally unidimensional structure from the very syntax of verbal language. For lack of space, we refer to Brian Rotman for an extensive critique. Our point here is that the full thickness and boundlessly open set of experiences of a responsive environment cannot be adequately modeled by any small finite number of experiential "trajectories through" that environment. Secondly, where computation "happens" is not as obvious as it may seem. (Nor is the locus of human thought any more obvious. As Wittgenstein asked in the *Philosophical Investigations*, "The chair thinks. Where?") A growing literature in the fields of material computing point to the non-digital processes of computation that happen in physical materials that do not follow the architecture or logic of a finite state machine. We emphasize here that we do *not* refer to isomorphic embeddings of FSM logic or digital computing architecures into some biological or physical substrate. Thirdly, in Simondonian terms, the formal separation of a technical object's functions into components, each of which fulfills the function independently of the other components, is an abstraction of how machines actually work in their physical, material operation. In his work in the philosophy of technology based on the history of recent technology, Gilbert Simondon considered in detail the co-evolution of technical objects and technical know-how of their communities of maker-users. We can see a historically continuous process of concretization in which some separate functions become jointly fulfilled as their components come to be designed and manufactured as one physical component. Separating the design of human interaction as a "symbolic" communication problem from the design of the plastic material – e.g. the heft, grip, bulkiness, stretchiness, or persistence of the physical materials encountered by human in the course of a computationally modulated event – is an abstracting separation that we claim introduces as many problems as it may solve.

Implications for Designers

So if everything happens concurrently and densely from the point of view of the human, it helps to have ready at hand some design metaphors adequate for manipulating computational media and instruments of expression that have a richness analogous to that of musical instruments and organized sound. In our past work designing responsive media environments, we often compare our computational media to how analog media are articulated.

We suggest a set of issues that we designers of "human-matter interaction" given material computation may consider. We can artfully and judiciously use analog together with digital materials. But this will demand a shift in attitude about computation that takes into account qualities extending material qualities like weight, elasticity, endurance (battery life), brittleness, stiffness, and so forth. This can include found-technologies like a piano, or no-tech (like an eggplant). We need to sidestep seriality, and sequential processing thinking, or multi-sequential, graph-analytic thinking, toward thinking spatially or topologically. By topology we do not intend the relatively trivial sense of graphs, but general point set topology.

We close this abstract with an open question: If we accept that the material medium manipulated by a human is a site of (analog) computation, and that consequently its physical qualities which can be modulated by contemporary production techniques are part of the human-computer interaction designer's responsibility, then a deep challenge opens up: What sorts of observational and instrumental or experimental techniques, and what sorts of conceptual frames do HCI researchers and designers need in order to understand a user's experience in such material manipulations? What sorts of modes of articulation can HCI develop that would be adequate to such material qualities, not only macroscopic social qualities say of communication acts (time, speaker, geographic location, social class, etc.), but also micro-gestural or physical qualities (e.g. rubberiness, elasticity, material memory, heat capacity, friability, resistivity, etc.) that deeply condition the user experience?

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