Computation as Mediation in Composition -- From the Technical to the Technological

Michael Hamman
1814 Larch Place
Urbana, Illinois 61801
United States
mhamman@shout.net http://www.shout.net/~mhamman

Abstract

1 Introduction

Philosopher Arthur Danto used the term "post-historical" to refer to a period in art—roughly from the late 1950s to the present—in which "art was no longer possible in terms of a progressive historical narrative" (Danto 1992, 9). For Danto, a work like Andy Warhol's *Brillo Box*—a large packing box for then-ubiquitous brillo pad cleaning items—best captured that moment when art became "philosophical" (ibid.). In order to even begin to *see* a work like *Brillo Box*, one had to understand it within the context of its social and historical framework; the work *was* in fact this very framework. Such a notion of visual art challenged the traditionally held idea that visual artworks present "significant forms" predicated primarily upon "retinal experience" (Foster 1996, 4). Since then, the "content" of visual artworks have increasingly concerned the means by which they are made, both in terms of the social and historical context in which they obtain meaning (their epistemological framework) and of the technical means by which they are produced.

A similar holistic approach has energized advanced music composition. Musical works are viewed not simply as machines for aural experience, exhausted in the listening experience they engender; rather, they are understood as knowledge systems, as sources for analysis, discussion, extrapolation. The sensual experience they elicit is but one aspect of their existence as works of art—they also exist as social, political, and technological agents. Sustained by this overall view is an appreciation for the procedural dimension of music composition—technique has been elevated, not merely as a means toward an end, but as an end in itself. Electronic systems for sound and music composition empower this approach to composition, since the composer's work includes radical reformulation of the very techniques by which material is generated. The technical difficulties encountered within the early electronic music studio, for instance, focused composers' attention toward the dialectical nature of their compositional process, empowering them to see the object of their musical activity (the musical work) as contingent upon the particular manner in which its musical problems were articulated and framed.

The idiosyncratic musical forms and materials produced in these studios testify to a radical interpretive attitude regarding the technical devices employed in their composition. This radical approach to music composition was greatly advanced with the introduction of the computer. The computer provided the kinds of tools that allowed the composer to explore, more deeply, the very conceptual frames in which musical ideas might be imagined and realized. It enabled the composer to critically examine and assess the musical result, the means by which that result came about, and how the two are conceptually and generatively related.

In recent years, compositional technique has been derided, regarded as an "elite" holdover from the experimental days of the 1950's and 60's. This overall derision comes during a time when the computer tools used in music composition have increasingly emphasized ease-of-use over representational flexibility. This has generated, arguably, a more productive composer while, by precisely the same process, transforming the computer from a tool for experimental composition into a tool for musical production.

The aim of this paper is to articulate an approach to understanding music technology that favors its *experimental* imperative over its merely productive capability. Such an approach would focus on technique, understanding technique as the locus of any experimental activity. Toward this end, I begin by discussing technology more generally and, due to its ubiquitous presence in computer technology, the computer interface more particularly. In doing so, I wish to counter *technological determinism* with *technological hermeneutics*. Technological determinism views technology as a deterministic frame, only minimally permeable to social, cultural, and political concerns. By contrast, technological hermeneutics views technology as an *interpretive* frame in which humans model the materials and forms by which domain-specific activity is defined. Viewed as interpretive frame, technology overtly invites and includes the participation of humans in designing the representations through which domain-specific thought and activity is conceived, understood, and realized. In designing the representations through which domain-specific thought and activity is conceived, understood, and realized, humans participate in designing the larger social and political frames according to which artifacts (e.g. works of art) are produced and propagated. In doing so, humans participate in the design of *their own* ontological, cognitive, and epistemological experiences. The computer may therefore find its most compelling use, not in modeling already known historical frameworks, but in positing as-yet unknown models (Laske 1989, __). Viewed in this manner, the computer becomes a valuable tool for composers who view compositional technique itself as an end, not merely a means to an end. Such an interpretive stance regarding the computer acknowledges its subversive potential; as a means for *negating*—in the dialectical sense—the performative principles that otherwise direct technology research and the commercial imperative that drives that research.

2 The Colonization of Technique

2.1 Technological Determinism

Technique—as a notion—is most commonly understood simply as a *means*–conceptual and technical—by which things get produced. Once produced, the thing and the technique by which it is produced are separable. Technique figures importantly only insofar as it contributes to the thing's production: once the thing is finished we need no longer be concerned with its technique. This nominal view of technique is so deeply ingrained that it is scarcely acknowledged, let alone assessed. Ideologically, it is based on the presumption of technological *neutrality*, the premise being that "technologies have an autonomous functional logic that can be explained without reference to society" (Feenberg 1995, 5). Accordingly, technology's social dimension arises only in the purposes it serves and the functionality it satisfies, and never in the presuppositions—social, economic, and cultural—upon which its developments are based.

Recent *constructivist* sociologists challenge this presumption of technological determinism, rejecting the notion that science and technology should be, or even *can be*, exempt from sociological scrutiny (op. cite., 6). In doing so, they take to task the theoretical underpinnings of essentialism, which assumes the existence of objective and intrinsic facts, independent of cultural and linguistic interpretive frames (Rosenau 1992, 111). Constructivism understands facts and categories largely as social "constructions:" in order to understand socially activated phenomena like technology, we must interrogate the cultural framework within which they obtain their meaning and identity. As such, technologies can only be fully accounted for through a larger social inquiry: they are underdetermined by solely technical criteria (Feenberg 1995, 6).

Among its many premises, technological determinism asserts (1) that technology progresses from lower to higher levels of achievement (i.e. it *improves* over time), and (2) that technological development follows a single unified sequence of necessary stages. Constructivists call this set of presumptions into question. For one thing, they point out that any given problem will usually yield a surplus of possible solutions. Moreover, the formulation or definition of a given problem frequently changes during the course of its solution (Feenberg 1995, 8). Technological determinism, however, drives an *immanent* interpretation of history "by projecting the abstract technical logic of the finished object back into the past as a cause of development" (Feenberg 1995, 7). The falseness of this conditioned interpretive response has socially debilitating effects, projecting the view that technical progress follows a purely pragmatic and instrumental course and that there is little that human beings can do to alter that course. As a consequence, blatantly anti-democratic practices—ranging from exclusion of popular participation in the framing of technological decisions to educational systems which teach students that technology is impervious to human interpretive activity—are justified, when and if they are even acknowledged.

2.2 The Tool as Deterministic Frame

One can observe determinism at work in the creation and production of our everyday working and recreational tools. The high volume manufacturing of tools, combined with increased specialization in industrialized society (Buckminster-Fuller), has left us with tools whose interpretive frame is defined according to narrowly constrained performative values. Moreover, due to the processes of mass production, it is often difficult to rework the tool for customization. We are thus forced to accept tools as they are presented to us.

This is particularly true with computer software, even though the very principle of computer software is its customizability. Typically, however, software source code is not distributed, so if the user wishes to tailor a software tool for a particular use, s/he would not be able to. Moreover, software license agreements make it difficult for humans to share software, further alienating them in their ability to interpretively interact with that software (Free Software Foundation) Another factor of course is the very complexity of software development—it can take years to acquire the necessary expertise to intelligently write or extend software, even if one had access to the source code.

As a consequence of these factors, humans are only minimally involved during the formative stages of software design. By the time they are brought in, as beta testers for instance, the formative aspects of the design have already been solidified and are not likely to be changed. This becomes a problem since important design decisions are made at this level which can have a profound influence on how human beings are constrained to act within the domains in which software systems are used. And while there are always future versions of the software, it can take years to incorporate user suggestions into a product release.

The end result of all of this is that software tools carry huge ideological and epistemological payloads that the human user must accept, silently or otherwise. Moreover, and as a consequence of their deterministic operation, those tools give no hint as to the enormous epistemic flexibility of which the computer is capable. Instead, humans are required to force problem formulations in ways that the computer can "understand." Under this rubric, *technique*—nominally defined as that through which work gets done—is reduced to the task of learning how to map one's notional view of a problem, or problem domain, into sequences of steps which have no meaningful relation to the relevant problem domain. Such environments produce little in the way of pleasure—the tool, rather than being a "liberator" of human beings, becomes an agent of repression, forcing the user to succumb to a normalizing view of her/his task environment.

2.3 "User-centered" Interface Design

Beginning in the 1970's, scientists and technologists in the field of human/computer interaction research set about to address the problem of the usability of computers. Toward this end, they formulated various approaches to graphical user interfaces that employed principles involving "direct manipulation" (Hutchins 1986; Johnson 1997, 20-23). Direct manipulation means that the computer user has some feeling that s/he can directly manipulate objects on the computer screen, primarily through use of a pointing device like the mouse.

In addition, a more over-arching "user-centered" design approach was developed. This approach to interface design was emblematized in Donald Norman's *The Psychology of Everyday Things* (1988). In this book, Norman described difficult door passageways and unusable stovetop systems in great detail in order to point out how flaws in the basic design of human "interfaces" degrade our living environments. Norman advocated a notion of interface design that is "goal-oriented" in that it considers what humans are trying to accomplish. Toward this end, it is paramount that devices—from telephones to door handles to airplane cockpits—be designed to leverage personal and cultural experience in order to facilitate execution of particular tasks in a manner that minimizes conscious involvement. One should not, when passing through a doorway for instance, have to think about using the door: its structure and shape should tell us immediately of its use. Similarly, when using a new piece of software on a computer, one should be able to leverage past experience with other software tools in order to use the new one.

Donald Norman and others within the field of human/computer interaction developed a "cognitive engineering" approach to human/computer interaction (Norman 1986). According to this approach, an interaction comprises two participants—the "user" and the "system." Between the user and the system, there are a number of gulfs separating the goals and knowledge encapsulated within one system (the "user") and the presentation of available services and resources of another system (the "system"). The purpose of an interface is to bridge these gulfs. This is done by writing additional software to "translate" the I/O properties of the system into representations that are more easily mapped to particular problem and activity domains.

Computer software whose interface is designed in this manner frees the user's attention for domain-related activities. Rather than having to think in terms of the system s/he is using, the user can remain focused on domain-related concepts, thus freeing attention for domain-centered activities. The user forgets that s/he is using a computer, with its large array of I/O requirements—all of the complexity is under the hood, so to speak. The computer, as such, effectively *disappears* in its use.

2.4 The Thing as "Equipment"

What is gained through such an approach to interface design are tools that are easy to use. Since we no longer have to think about them, we can remain focused on the tasks at hand. Those things, and the structure by which they are organized, quite literally *disappear* in the use-function to which they are consigned

Heidegger coined the term *equipment* to describe this consignment of thing to use-function (Heidegger 1962), while Marx used the term *commodity* to describe a similar consignment (Marx 1967, 36). When hammering a nail, the skilled carpenter appropriates the hammer purely in terms of that which drives the nail. The hammer, as thing—as indeterminate object—succumbs to its appropriated use-function: it becomes a useful piece of equipment. In their appropriation as equipment, things quite literally *disappear*. Using Heidegger's characteristic phrasing of it, "in the indifferent imperturbability of our customary commerce with them, [things] become accessible *precisely with regard to their unobtrusive presence*" (my emphasis) (Heidegger 1988, 309).

While this transformation of things into equipment most often supports human activity, there is a potentially pernicious side to it: for as tools disappear in their use, so too does the possibility of active interpretive involvement by humans. To intercede in something whose use has become "second nature" requires considerable effort—the very thing that our habitual relationship to it would forbid. We—the "user"—become almost as automated as the thing we are using. Whatever cultural practices are built into the tool become our practices, whether we know it or not.

Heidegger used the term ‘circumspection’ to describe the resulting ontological state—a state of being in which conscious, voluntary involvement succumbs to unobtrusive *absorption*. Involvement in everyday activity becomes “a kind of ‘sight’ which does not involve deliberate, thematic awareness” (Dreyfus 1993, 66). An example of such a state of being is what some athletes refer to as “flow.”

> A person in the midst of the flow experience is both keenly aware of his or her own actions and oblivious to that awareness itself. One rock climber remarks, “You are so involved in what you are doing you aren’t thinking of yourself as separate from the immediate activity. . . . You don’t see yourself as separate from what you are doing (Dreyfus 1993, 66).

In describing this kind of “self-less awareness” (Dreyfus 1993, 67), Aron Gurwitsch writes,

> What is imposed on us to do is not determined by us as someone standing outside the situation simply looking on at it; what occurs and is imposed are rather prescribed by the situation and its own structure; and we do more and greater justice to it the more we let ourselves be guided by it, i.e., the less reserved we are in immersing ourselves in it and subordinating ourselves to it ” (Dreyfus 1993, 67).

We are aware of what we are doing, but there is no “self-awareness” in doing it—there is, in otherwords, no self-referential involvement. Subject and object are joined as though they were a single entity.

2.5 The Interface as Ideology

The piece of equipment cannot exist in isolation: it is what it is “only insofar as it refers to other equipment and so fits in a certain way into an ‘equipment whole’” ” (Dreyfus 1993, 62). The equipmental appropriation of things thus includes a wide circle of cultural use-practices with which a single piece of equipment ontologically resonates. For instance, hammering exists only with reference to a larger use practice collectively referred to as “carpentry,” while preparing documents using a tool such as Microsoft Word® occurs in a similarly equipmental whole. The apparent ease-of-use of a program like Word® stems, however, not from an innate ability of the human to apprehend its particular language of interaction. Rather it stems from a process of inculcation, with which the interface is designed to cognitively resonate and which enables a human to more readily grasp the proper forms of behavior and expectation appropriate to that language.

Pierre Bourdieu uses the term *habitus* to describe the “practical sense” that “inclines agents to act and react in specific situations” in a socially acceptable and appropriate manner (Bourdieu 1993, 5). Being “the result of a long process of inculcation, beginning in early childhood,” the habitus “is a set of dispositions which generates practices and perceptions” (Bourdieu 1993, 5). Within the habitus, a human is perfectly equipped to enter into and sustain her/himself in a potentially limitless number of "performative utterances." Performative utterances are utterances appropriate to the particular "field" of activity in which they are performed and with respect to which they obtain meaningful status. Performative utterances are, however, "not ways of reporting or describing a state of affairs, but rather ways of acting or participating in a ritual" (Bourdieu 1993, 8).

> This implies, according to Bourdieu, that the efficacy of performative utterances is inseparable from the existence of an *institution* which defines the conditions (such as the place, the time, the agent) that must be fulfilled in order for the utterance to be effective (Bourdieu 1993, 5).

The interface constitutes a fulfillment mechanism for the production of performative utterances. It presumes a singular, totalizing view of the activity domain in which it is applied. The human's role is consigned to that of "User"—one whose range of activity is already given by the interface. This normative view of computing experience understands humans as little more than consumers of "computer goods," their participation registered solely in terms of the NASDAQ. Defined as "non-specialists," consumers contribute little if anything to research and development of the computer tools that ultimately shape their lives. Research and development is left to the "specialists," whose concerns have their own performative requirements, frequently determined by institutional and, more recently, commercial imperatives. Has this focus on the interface, obsessed as it is with human factors, psychological models, and "usable systems" given us a richer experience of computation? As interface design theorist Liam Bannon observes,

> The need is not simply for more detailed psychological models of how people think and communicate, although such models are of course fundamental to the building of more usable systems, but for a more comprehensive, more enlightened view of people that recognizes their need for variety and challenge in the tasks that they perform (Bannon 1986, 11).

3 Technology as Interpretive Frame

3.1 Engineering a "Breakdown" in Circumspective Being

That interfaces encapsulate culturally mediated notional views of a domain is not unique to electronic media (though the exploding profusion of interfaces is carried by the rapid increase in production of electronic media). This is a more general property of the tool. Tools—in their equipmental fit to the specific tasks for which they are fashioned—produce human production. The principle of "ease-of-use" facilitates this production and is, as such, as old as the tool itself. Ease-of-use is a byproduct of the imperative for the efficacy of production—humans are less likely to make mistakes when their engagement is automated, requiring little direct thought and attention. What is gained through such an approach to interface design is increased facility and efficacy in production. What is lost, however, is the power of *mediation*, of interpretive participation.

Once an activity becomes habitual—"circumspective"—the only way it can be interrupted is if something "breaks down." When this occurs—the hammer breaks, or the nail bends—one is no longer a mere "user:" one is quite suddenly thrust to the fore into an interpretive context (Dreyfus 1993, 72). The thing suddenly becomes "unfamiliar"—it becomes foreign to that with which one normally comports oneself circumspectively. In this aspect, the properties and structures of the thing—previously subsumed under the imperative of their comportment *as equipment*—suddenly become apparent, available for inspection and interpretive involvement. One becomes, suddenly, attuned to the properties of the things one is using and to a range of possibilities for interaction that were previously foreclosed through habitual and circumspective involvement.

Creating art is one domain of human activity in which such a form of interpretive involvement is desired. Toward this end, art frequently generates situations in which breakdowns are intentionally engineered. Breakdowns of this sort are engendered as much at the *technical* level (the making of artworks) as they are at the *esthesic* level (observing artworks). At the technical level, artists are concerned not merely with obtaining skill and known-how in the use of tools and the manipulation of materials, but frequently in conceiving ways in which that know-how might be subverted and disrupted in order to arrive at an *originary* view of those tools and materials. Technique itself becomes the object of investigation "where order is not sought in *a priori* systems of mental logic but in the 'tendencies' inherent in a materials/process interaction" (Morris 1970, 63).

Consider for instance Jackson Pollock's method of painting. Pollock made a series of paintings in which he would lay the canvas on the ground and apply paint by dripping, pouring, and flinging it across its surface. Such technique brought to bare entirely new principles for paint application. For one thing, the painter now had to take into account the effects of gravity on paints of different viscosities—thick paint falls differently than does thin paint, for example. In addition, the painter employed movement of the body in an entirely different manner than is possible with easel or wall painting. In developing this technique, Pollock effectively restructured the domain of interaction available to him and in doing so, brought about the re-appearance of otherwise standard materials and of the working process. Such *idiosyncratic* technique occasioned a different interpretation of materiality, the very physicality of which constituted the gestural "aura" of the resulting paintings.

3.2 Compositional Technique

Throughout the last 50 years, composers have been similarly engaged. The so-called "formalist" approach of composers, for instance, is profoundly based in the empirical, not the theoretical—it is occasioned by a desire to fashion a conceptualization of materials and the possibility for their combination and interaction rather than a desire to explain music in any large sense. Even Milton Babbitt's holistic twelve-tone systems are intended primarily as empirical means—their invention was understood "to be part of the creative resource of composition, rather than its invariant context" (Boretz et. al. 1972, ix).

In many respects, Cage embodied this empirical approach to the systematization of technique. In his appropriation of so-called "chance" operations into music composition, Cage sought to *re*-present the possibility of sonic materials and their combination—to structure a particular "materials/process interaction." For instance, his use of charts in works of the early 1950's—as in *Music of Changes*—insured "combinations [of sonic elements] that Cage would never have considered himself" (Pritchett 1993, 79]. Compositional procedure focused not so much on the production of particular musical artifacts (musical works, etc.), but rather on the process by which such a production might itself be composed. Such a notion of compositional activity, while not bound exclusively to the imperative of the particular musical artifact, is nevertheless informed by it. The output is not simply random, freely interpretable "raw data"—rather, it constitutes a notion of a material that is prefigured in the design of the system through which it is produced.

One can generalize this principle somewhat by saying that the means and ends of compositional production arose together, each determining the unfolding of the other. This principle constitutes one of the most important empirical insights generated by early electroacoustic music: that the relationship between the particularity of a technology and the means by which musical structures might be conceived and realized were understood to be mutually determinative (Eimert 1959, 3). The radical approach to musical form and material that emerged from the electroacoustic music studio could only have occurred within a studio interpreted hermeneutically, wherein technique is mediated by compositional thought, and vice verse. The attitude reflected an interpretive stance regarding the possibilities of electroacoustic music that was not present in earlier electronic technologies like the Theremin (which still preserved instrumental music notional views). Interpreted hermeneutically, technical difficulties encountered in the studio were not something to be "overcome" in order to insure preservation of older musical traditions. Rather, those difficulties were themselves understood musically inasmuch as they both framed—and were framed by—musical thought. Musical thought was no longer bound solely to a *transcendental* musical object—the musical object *per se* arose as a consequence of the particularity of the investigations and experiments under which acoustical material, and the techniques for its production, were produced.

3.3 The Computer and the Construction of Representations

The computer expands the hermeneutic interpretability of musical task environments since it gives composers "a chance to choose, rather than suffer, their processes" (Laske 1991, 236). The primary device by which this interpretive agency is achieved is the computer program. The computer program is built from the construction of representations (Winograd et. al. 1987, 84). Theoretically, the computer ought to facilitate an arbitrarily large number of musical and sonic representations (Moore , p27). However, implementing a representation means first producing a logically correct algorithm and a correct though efficient set of data structures, and then implementing these correctly as program code. Either of these tasks is nontrivial while the two together require enormous effort. As a result, relatively few composers have been deeply involved (at the level of design and implementation) in developing systems for music and sound composition outside the large institutions (IRCAM, CCRMA, etc.). However, these institutions have their own social organizations that strongly effect the nature of technology development (Born 1995) and, as a consequence, of the representations expressed by the tools they produce.

Herbert Simon observes that "solving a problem simply means representing it so as to make the solution transparent" (Simon 1969, 77). Computer music systems that understand composition merely as a form of problem-solving encapsulate representations that are bound to a nominal view of the problem domain. In using such a system, the composer appropriates that view in the very activity of composing. Consider, for instance, two different approaches to modeling the computation of a plucked string sound. The first example is written in CSound (Vercoe 1988):

```
ar pluck 10000, 440, 440, 0, 1
```

The **`pluck`** unit generator has 6 parameters. The first parameter defines the overall amplitude of the signal; the second and third parameters define its frequency. The third parameter declares an index to a table which initializes the data cycled during the decay of the pluck, while the last parameter defines the method of decay.

The second example is taken from *Modalys*, a software synthesis and music composition system based on modal synthesis (Morrison et. al. 1993):

```
(define my-pluck (make-object ‘mono-string
                   (modes 20) (length 2) (tension 120)
                   (density 720) (radius 0.002) (young 2.1e9)
                   (freq-loss .3) (const-loss 1)
                 )
)
```

Modalys structures are written in the Scheme programming language (a Lisp-like language). This example defines a Scheme function called "my-pluck" which instantiates a *mono-string* object, a type of plucked string generator defined within *Modalys*. Since *Modalys* is based on modal synthesis, its model of the plucked string constitutes parameters such as string length, tension, density, radius, and loss of energy.

The CSound implementation is admittedly more "user-friendly"—it resonates familiar task environmental features such as loudness and frequency in a direct manner. In this regard, it assists the composer in mapping familiar musical concepts into this relatively unfamiliar computer representation. By contrast, the Modalys implementation introduces concepts which, though familiar to physicists, are problematic for the composer who is looking for a way to map familiar musical concepts. How do concepts such as "length", "tension", and "density" map to the more familiar musical concepts such as frequency and amplitude?

Yet it is by virtue of the more problematized interface that the Modalys representation provides a potentially richer interpretive frame for discovering principles according to which a variety of sounds might be composed. It is not that the CSound implementation specifically *disallows* such interpretive play. To do so, however, requires greater knowledge of the inner workings of CSound—something which the more "habitual" mode of interpretation induced would more readily foreclose than is the case with the more representationally rich interface provided by *Modalys*.

3.4 From the Construction of Representations to Semiotic Play

Yet a third example is from Herbert Brün's *Sawdust* (Blum 1979):

```
e1 = ELEMENT(100,200)
e2 = ELEMENT(70, -18000)
e3 = ELEMENT(10, 16000)
e4 = ELEMENT(300, -40)
L1 = LINK(e1,e2,e3)
L2 = LINK(e4,e1)

M1 = MINGLE4(L1,L2)
L3 = MERGE(L1,L2)
```

Here 4 elements (e1 – e4) each define a sequence of impulse samples. e1 defines a stream of 100 samples, all with an amplitude value of 200 (in signed 16-bit integer range of {-32768, 32767}). e2 defines a stream of 70 samples, all with an amplitude value of –18000. And so on for the other elements. A waveform is generated when two or more elements are linked using the LINK operation. The MINGLE is a cycling operation that takes an ordered sequence of links (in this case just two) "and forms a new set in which the original collection is repeated *n* times" (Blum 1979, p. 7). MERGE takes two links and produces a new link by interspersing each of the elements from the original links. Thus, the L3 link would comprise the following sequence of elements: e1-e4-e2-e1-e3.

Another operation from *Sawdust* (not shown in the example) is VARY. VARY transmutates one link into another over the course of a specified duration and according to the degree of a polynomial, whose degree is also specified by the composer. Each element in the initial link will then vary according to the curve defined by the polynomial until it winds up at the corresponding element of the destiny link.

The first thing to be noticed is that there is no *a priori* acoustical model referenced. Rather, the composer constructs waveforms from the ground up, and then specifies their combinations and transformations. In this way, higher-level musical structure is immanent in the specification of the structures through which waveforms are composed and by which they are transformed. As was the case with Brün's *Infraudibles*, "by substituting sequences of different single periods for the modulation of simultaneous frequencies, the composer is able to control the infrastructures of the event, forming sounds just as precisely as the macro events of his (sic) composition" (Brün 1969, 117). The musical idea is not bound to a particular material realization: rather, the musical idea "functions as the generator of a system so structured that the sequence of its states could be called 'musical composition' by its composer. . . ." (Brün 1969, 119).

Such an approach reflects what Otto Laske termed *rule-based* composition. Laske differentiated rule-based and *example-based* composition. With rule-based composition, composers explicitly design the rules and procedures according to which musical materials and structures are to be generated and endowed with musical meaning.

By contrast, with example-based composition, composers construct materials and musical processes from past "examples" obtained through experience and practice (Laske 1991, 238). In truth, however, rule-based approaches to composition frequently are based, at least in part, on previous models or "examples" of music, even if it is music which the composer themselves composed (Laske 1991, 238-9). However, what distinguishes rule-based approaches is that there is an effort to represent otherwise internal processes externally; to *objectify* them so that, as observable objects and processes, they may be consciously molded and manipulated (Hamman 1999a, 50).

Consider, as another example, Gottfried-Michael Koenig's *Project I. Project 1* allows the composer to stipulate, as input, a set of "structure formulae" whose stochastic structural characteristics range from *order* to *disorder* (Koenig 1969; Laske 1981; Koenig 1991). These structure formulae are applied to a repertory of parametric materials (such as pitch, duration, instrumentation, etc). The program generates a list of events, each event defining a potential musical event. The task of the composer is to interpret and analyze this list in order to come to some understanding of its structural potential. The composer then begins to design a composition based on her/his understanding of the output.

As Laske perceptively observes, the process induced by a program like *Project 1*, "exposes the transition from analysis to design" (Laske 1989, 51). It presents the composer with data that, taken together as well as in its details, presents an "interface" that is at first unfamiliar and foreign. In working with the data, however, the composer learns to integrate her analytical observations of the output with the ideas and plans that led to the initial input in an evolving design model, leading at times to reformulating the input and at other times to reformulating the analysis of the data. The notion of musical form is *emergent*; immanent in the particularity of the composer's interpretive activity.

More recently, Arun Chandra has developed a method of synthesis, reminiscent of Herbert Brün's *Sawdust* system, in which a waveform is not merely a data element, but an object upon which operations can by applied (Chandra 1999). The *state* of the waveform constitutes a tiny "piece" of that waveform (1 to 2 milliseconds in duration) that is defined by: (1) the number of segments; (2) the "type" of each segment; (3) the sequence of segments; and (4) the number of iterations of the state. A *segment* is a sequence of samples having some discretely defined behavior, or *type* (all the same, moving in a particular direction, etc). A sequence of segments, and the number of iterations of that segment define the state of the waveform and determine the acoustical behavior of the resulting sounds. For each iteration of the waveform, the results of an algorithm are applied to selected segments within that waveform. Changes in segments yield changes in the acoustical structure in the resulting waveform. Each segment is given maxima and minima which determine maximum and minimum growth of the length of the segment, as well as increment values, which determine the amount of change per iteration of the waveform.

With such a system, the composer must synthesize an emergent comprehension of the behavior of the system with a similar emergent model of musical material: a synthesis which allows the composer to find descriptions and criteria that arise, once again, from the particularity of her activity, rather than from a fixed historical model. For instance, as Chandra points out, experimental observations can be made regarding the relationships among minima/maxima and cycle lengths for algorithms operating on the different segments, yielding very different acoustical behaviors.

Along similar lines, Agostino Di Scipio has pointed out the computer's capacity to assist composers in challenging the dualistic paradigm according to which musical material and musical form are traditionally separated (Di Scipio 1994). Di Scipio posits a theory of sonological emergence in which a composer "imagines and explores possible links between the patterning of atomic details—a ground level process (glp)—and the sound forms which emerge from them—a meta-level process (mlp)" (Di Scipio 1994, 206). Di Scipio and Prignano (1994) developed an approach to granular synthesis called functional iterative synthesis that involves iterated application of difference equations in the generation of sonic material (see also Di Scipio 2000). Such applications have the interesting property of propagating acoustical behavior upwards from the lowest level of sound to higher level patterns of sounds and sound environments. Of particular interest in the approach taken here is that the algorithm not be treated as just another "unit generator" for generating discrete and disembodied sound events (as is the case with more traditional approaches to sound synthesis and the use of MIDI-based synthesizers), but that it be treated as a holistic approach within a more general model of acoustical design (both music *and* sound) (Di Scipio 1994, 203).

Each of these projects articulate a model of materials and composition process—a *task environment*—for constructing musical compositions. Each system defines models with a high degree of systemic integrity: while any one of these systems pose an initial challenge to the composer, the composer is rewarded, after some initial work and experimentation, with a highly principled presentation regarding possible musical representations. Each forms a novel view of musical and compositional procedure while nevertheless presenting the user with an inarguably "musical" problem and task domain.

The computer is thus transformed from a tool for constructing symbolic representations, in which the referend is a historical acoustical model existing prior to and independent of individual thought, to an instrument for "semiotic play," in which the referend is correlated to the particularity of the referent (Hamman 1999B, 94). A system constitutes a reflection of an inner world projected outwardly, not as something fixed or immutable, but as an indeterminate unfolding. Composition is as much concerned with the construction of systems of production as it is with the production of specific artifacts. The system presents an 'environment' in which otherwise familiar patterns of thinking and action are *problematized*, forcing the composer to formulate, for her/himself, models of musical materials and form from a myriad of possible models.

Such a process is *semiotic* in Kristeva's sense of the term (Kristeva 1986). The semiotic seeks after a model of experiential and articulative involvement in a world such that the particular contours of the world are *emergent* rather than fixed—correlated to the particularity of interpretive activity. Of such a process, Julia Kristeva writes that "the site of semiotics, where models and theories are developed, is a place of dispute and self-questioning, a 'circle' that remains open" (Kristeva 1986, 78).

4.1 Artificial Intelligence

Such a blatantly interpretive understanding of the role of computer systems in human activity acknowledges the *particularity* of labor as central to that activity. Precisely *how* one goes about doing things greatly determines the outcome. In problematising the appearance of otherwise familiar things, one constructs an environment in which those things, once mediated through cultural representation, become available for interpretive activity. Anything that productively results from that activity, can be traced to the particularity of that activity—it's properties and function come about as a consequence of the very particularity of that activity. Pollock's canvases could not likely have been made by any other technique than that which he adopted to make them. Similarly, Brün's "Dust" pieces (*Dust*, *More Dust*, *I toLD YOU so!*) could only have been produced through the particular techniques enabled through *Sawdust*.

Such an approach to the interpretive use of technical things understands their outputs as *artificial*—that is, they are solely the product of particular human planning and design (Laske 1992; Simon 1969). As artificial, those outputs result from the choices made by a human. Whether they are *intelligently* artificial depends on whether the choices made were genuine choices made by a human or were built into the system and thus invisible to the human (and thus not the result of choice). A system of interactions that empowers its user to make real choices bares witness to an explicit involvement of human thought. Systems that block explicit interpretive involvement—by invoking circumspective engagement—yield only minimal traces of particular human planning and design.

> For anything to be of relevance to something, to be of significance to someone, a system has to be created; an artificially limited and conditioned system has to be imagined and then defined. *Only artificial systems will clearly show that they have been elected by choice* . . . . (Brün 1969, 119, my emphasis].

Whether the system is "limited" or "conditioned" is not the issue—all systems are, by their construction, both limited and conditioned. The issue is whether the limitations and conditions are the traces of individual human choice or of cultural appropriation.

G. M. Koenig responds similarly to the computer, and technology more generally. He expresses a need to react "functionally" to new technology, which for Koenig "means not only to refrain from stylistic imitation, but also to refrain from imitation of a particular production mode in another medium" (Koenig 1983, 28). Along similar lines, Paul Berg writes that the fundamental contribution of the computer to music is that it empowers the composer to "hear that which could not be heard without the computer, to think that which could not be thought without the computer, and to learn that which would not be learned without the computer" (Berg 1987, 161).

4 From *Interpretation* to *Mediation*

4.1 Music and Technology

Artificial systems index human involvement—to understand them is to comprehend the interpretive activity with respect to which they structure the human productive impulse. Their admittance into human activity relies upon the utter interpretability of technology. For the composer, technology, understood as an interpretive framework, becomes a means for designing models according to which musical materials and formal criteria might be imagined and realized. Approached in this manner, technical devices—from equipment in the studio to computer software for sound synthesis—occur within the context of a discursive frame. The discursive frame is as much the subject of compositional investigation as are the materials and formal criteria which emanate from that frame. Composition becomes a form of "system design" and musical artifacts become *traces* of that design (Brün 1969, p. 119). The musical work, *per se*, includes the acoustical trace (the acoustical "artifact") plus the technical means by which that artifact is imagined, realized, and conceived.

Such a notion of the musical work negates the cultural imperative by which musical works—and more generally artworks—are understood as technically autonomous artifacts whose function is constituted by their utter functionality (bourgeois enjoyment, affirmation of church, state, or corporate organization, etc.). As technological forms—and therefore interpretive— musical works constitute knowledge systems: they are, as Adorno argued for artworks more generally, *cognitive* (Adorno 1997). A musical work can no longer be accounted for purely through examination of the acoustical experience it engenders or the formal structure it may exhibit. As technological, the work constitutes both the result and the technological forms by which the result was realized. These include the particular technical tools plus the attitude of the subject under whose unfolding those tools were taken up and applied. To equate music solely with the results of its productive activity is to disembody the result from its technique—it is to fetishize the musical work, converting it from a catalyst for experience into a commodity to be traded within an economy, either financial or ideological.

4.2 Technology as Mediation

A more fully developed hermeneutic approach to technology would conclude that technology "be a subject of interpretation like any other cultural artifact" (Feenberg 1995, 6). Rather than something that is separate fom social and interpretive concerns, the very essence of technology lies in its hermeneutic interpretability. To explicitly stake one's claim to involvement in that interpretive activity is to move against the tide of technological determinism. Under this claim to explicit interpretive participation, technology becomes a context for challenging cultural use-practices by which domain-specific activity is frequently constrained. It contextualizes the activity by which humans, as for instance composers, come to understand, design, and model the materials and forms that frame their view of the world in which those activities occur and in which things are produced.

To participate in the interpretive unfolding of technical devices is to explicitly mediate their very appearance. The device—as independent of thought—has an *indeterminate* unfolding. In committing itself to the device as an indeterminate unfolding—over and above the concept by which the device is culturally bound—thought understands its involvement with device as that which brings about the particular appearance by which the device obtains functional meaning. The functional meaning of the device (i.e. how it is to be used, etc.) is not given exclusively *a priori*; rather, it is predicated on the particularity with which thought apprehends it.

And yet, through the very same interpretive involvement that brings about the use-function of the device, so too does thought generate the circumstances for *its own* unfolding. Thought "shape[s] itself to the contours of the object—not as an irreducible given but as something with its own tensions and contradictions, *which include those of the thought that tries to comprehend it*" (Adorno 1993, xv, my emphasis). Just as thought is capable, through mediation, of freeing the object from the concept that binds it to cultural use-practice, so too is thought capable, through its interpretive interaction with the object, of freeing itself (the "I") from the concept that binds it to its own histories and "use-practices." In its very *labor* over the discernment of the object's "qualitative movements" (Adorno 1995, 45), the subject brings about its own unfolding—it brings about its own appearance—it's *self—as other to itself*. Self appears as an active and dynamically unfolding subjectivity correlated to the indeterminate unfolding of an object. The general "I" becomes a particularized "I", thus constituting the empirical dimension of the subject wherein speculation becomes an "experiential content."

4.3 Negation

Technical devices, in reflecting the structure of thought that mediates them, for this very reason are tools for self-reflection—for observing the objectification of the self as other. The assumption that technical devices are culturally neutral and deterministically framed forecloses their dialectical capacity, thus blocking direct human intervention. This is an issue of particular import to artists. Nowadays, all art is 'technological'—all music is technological (Mauceri 1996, 26)—it cannot escape the interpretive attitude that frames its application in the production and dissemination of artworks. Just as individual *techne* outwardly projects thought and activity, reflecting itself in the models of materials and forms which individuals generate, so to does techne reflect, in aggregate, the thought and activity—otherwise unrevealed—of a society at large (Heidegger 1977).

Under the "integrative trend" imposed by the increased industrialization of cultural activity (Horkheimer et. al. 1972), however, the expected role of art is that of legitimizer of the cultural framework from which it obtains its institutional and monetary support. In this regard, its reflective position is to be that of *affirmation*. Nowhere does this seem to be more true than with technological art (or so-called "media" art), whose very system of education, dissemination, and performance is greatly influenced by the positivistic ideology that underlies most scientific and technical research. As that which is already outside the quantifying energy by which social and economic systems are structured, technological art is placed in trusteeship—its existence is that of a benefactor and thus indebted. Under this arrangement, the creation of technological art becomes just another form of production—it's segregating tendencies brought under control in order to render its artifacts integrally whole with the society from which it procures its survival (Horkheimer et. al. 1972, 120-167).

Adorno articulated quite a different relation of art to the cultural whole which it reflects. He saw the function of art not as that which *affirms* the cultural whole but as that which *negates* it .

> What is social about art is its intrinsic movement against society, not its manifest statement . . . . Insofar as a social function can be ascribed to art, it is its functionlessness (Adorno quoted in Bürger 1984, p. 10)

As Burger reminds us, "Adorno obviously uses the term *function* here with different meanings: first as neutral category of description, then with negative connotations. . ." (Bürger 1984, p 10). The functionless that Adorno ascribes to art is not a lack of reflective activity *vis* society—rather it is an indication of a purposive negation of the very imperative that demands of art a functional relation to society. As a socially functional entity, the artwork becomes little other than that which is bound by the criteria and qualifications by which it obtains its social meaning. It becomes a thing mediated solely by its social value. As that whose function arises from its functionlessness, however, art "imitates what does not yet exist" (Jarvis 1998, 100)—it "gives the lie to production for its own sake and opts for a situation of practice beyond the spell of work" (Adorno 1997, 12).

As concerned with the technological, art counters its synthesizing trend, foregrounding its interpretive agency. As a context for interpretive mediation, and in transgressing its allegiance to the positivistic frame by which it is commonly defined, technology occasions the reintroduction of the subject. The tools and concepts that define technology's realization are no longer disembodied from the particular questions and inquiries in whose service they are brought to bare. Rather, the very structure and meaning which technical objects are accorded arise as much as a consequence of those very particular questions and inquiries as they do from the transcendental concept by which the history of those objects are reified. As such, the subject so-introduced is not the ethereal concept-less subject imputed by positivism's rebellion against idealism. Rather, the subject is immanent in the particular manner in which technical objects are interpreted and implemented.

In re-introducing the subject, technological art enacts a form of *subversive rationalism*—a form of resistance against the totalizing agency with which technology is reified, socially and politically. Such an approach to technology "challenge[s] the horizon of rationality under which technology is currently designed" (Feenberg 1995, 18), dismissing the deterministic framework typically accorded it. Art, just like science, strives for "mastery over its material" (Jarvis 1998, 106). However, art, in so striving, includes in its domination a "critique" of that domination—a negation of the techniques by which that domination is historically propagated (Jarvis 1998, 106).

5 Conclusion

As Mark Sullivan notes, a standard strategy in computer music software development is to adopt a problem-solving methodology and then apply it to the musical domain (Punch et. al. 1994, 45): “attempts to force the domain, of music composition in this case, to fit a particular problem-solving approach *instead* of having the problem itself dictate what approach is useful all too often leads to demos and toy systems” (Punch et. al. 1994, 45). This is because the methodology leaves little room for technique. Consequently, the musical results tend more readily to reflect the methodology rather than the technique.

Nevertheless, those who understand composition as an experimental endeavor, take a radical approach to the use of computers in composition: they understand that “different problem-solving *tasks* (diagnosis, composition, design, etc.) might require significantly different problem-solving methods and representations” (Punch et. al. 1994, 47). As such, they focus their effort on formulating compositional problems and on designing systems whose representational expressivity permit experimental latitude in interpreting and, eventually, solving those problems. However, the predominant computing paradigm is unkind to this approach to computing, forcing composers into extremely difficult and time-consuming software engineering enterprises in order to realize their projects. Some systems currently exist which assist the composer in this endeavor. The most flexible of these permit the composer to extend already existing systems or frameworks to fulfill their own research interests with relative ease (Hamman et. al 2000).

These are problems that have yet to be fully addressed. In this paper, I have merely laid some theoretical groundwork in order to dispel the myth of technological determinism and to counter the predominantly positivist interpretation of technology—which affirms its dominant modes of use—with one which understands its relation to technology as one of mediation—which *negates* its dominant modes of use. Many composers and artists (as well as poets, writers, and many others) view technology as that by which problems are framed and that, by changing the frame, one changes the presentation of a problem. Composers have, as a consequence of this attitude, contributed significantly to computation and human/computer interaction research in designing and implementing systems for experimental composition. It yet remains for computer science and engineering to take these efforts as serious research and invest some of its resources into research in computing and human factors that favor the kinds of problem-posing and idea-generational domains in which composers are experts. In embracing the technological concerns of advanced art, the fields concerned with technology would begin to gain a greater foothold in addressing the difficulties encountered by humans in formulating and solving problems more generally.

I would argue that it is here that a “rapprochement” between society and art, between scientific methodology and art-making technique, is most compelling and not in art’s forcible acquiescence to the positivist imperative imposed upon it by society and in its association with science and technology.

6 References

Adorno, T. W., 1993. *Hegel: Three Studies*, transl. S. W. Nicholsen, Cambridge, Mass: The M.I.T. Press.

Adorno, T. W., 1995. *Negative Dialectics*, transl. E. B. Ashton. New York: Continuum.

Adorno, T. W., 1997. *Aesthetic Theory*, ed. G. Adorno and R. Tiedemann, transl. R. Hullot-Kentor. Minneapolis: University of Minnesota Press.

Bannon, L. J., 1986. “Issues in Design: Some Notes.” in *User Centered System Design: New Perspectives on Human-Computer Interaction*, ed. D. A. Norman and S. W. Draper. Hillsdale, N. J.: Lawrence Erlbaum Associates.

Berg, P., 1987. “PILE—A Language for Sound Synthesis,” in *Foundations of Computer Music*, ed. C. Roads and J. Strawn. Cambridge, Mass.: The M.I.T. Press.

Blum, T., 1979. “Herbert Brün: Project Sawdust.” *Computer Music Journal* 3(1): 6-7.

Boretz, B., and Cone, E. T., 1972. “Preface,” in *Perspectives on Contemporary Music Theory*, ed. B. Boretz, and E. T. Cone. New York: W. W. Norton & Company.

Born, R., 1995. *Rationalizing Culture: IRCAM, Boulez, and the Institutionalization of the Musical Avant-Garde*. Berkeley: University of California Press.

Bourdieu P., 1993. *The Field of Cultural Production: Essays on Art and Literature*, ed. R. B. Johnson: NY: Columbia University Press.

Bourdieu P., 1991, *Language and Symbolic Power*, ed. J. B. Johnson, transl G Raymond M. Adamson. Cambridge, Mass: Harvard University Press.

Brün, H., 1969. “Infraudibles,” in *Music by Computer*, ed. H. Von Foester and J. Beauchamp. New York: John Wiley and Sons.

Bürger, P., 1984. *Theory of the Avant-Garde*, transl. M. Shaw. Minneapolis: University of Minnesota Press.

Chandra, A., 1999. http://grace.evergreen/edu/~arunc.

Danto, A. C., 1992. *Beyond the Brillo Box: The Visual Arts in Post-Historical Perspective*. Berkeley: University of California Press.

Di Scipio, A., 1994. “Formal Processes of Timbre Composition: Challenging the Dualistic Paradigm of Computer Music,” *Proceedings of the 1994 International Computer Music Conference*. San Francisco: International Computer Music Association. pp. 202-208.

Di Scipio, A., and Prignano, I., 1994. "Sintesi per Iterazioni Funzionali," *LMS Technical Report*.

Di Scipio, A., 2000. "Ecological Modeling of Textural Sound Events by Iterated Nonlinear Functions," in *Proceedings of the XII Colloquium on Musical Informatics*, pp. 33-36.

Dreyfus, H. L., 1991. *Being-in-the-World: A Commentary on Heidegger's Being and Time, Division I*. Cambridge, MA: The MIT Press.

Feenberg, A., 1995. "Subversive Rationalization: Technology, Power, and Democracy," in *Technology and the Politics of Knowledge*, ed. A. Feenberg and A. Hannay. Bloomington: Indiana University Press.

Foster, H., 1996. *The Return of the Real: The Avant-Garde at the End of the Century*. Cambridge, MA: The MIT Press.

Free Software Foundation, "What is Free Software?", http://www.fsf.org/philosophy/free-sw.html

Hamman, M., 1999B. "From Symbol to Semiotic: Representation, Signification and the Composition of Music Interaction," *Journal of New Music Research* 28. pp. 90 - 104.

Hamman, M., 1999. "Structure as Performance: Cognitive Musicology and the Objectification of Compositional Procedure," in *Otto Laske: Navigating New Musical Horizons*, ed. J. Tabor. Westport: Greenwood Press.

Hamman, M., and Pamment, S., 2000. "A C++ Framework for Generic Programming and Composition," *Proceedings of the XII Colloquium on Musical Informatics*, pp. 81-84.

Hediegger, M., 1962. *Being and Time*, transl. J. Macqarrie and E. Robinson. San Francisco: Harper & Row.

Heidegger, M., 1977. "The Question Concerning Technology," in *Basic Writings*. transl. D. F. Krell. New York: Harper & Row.

Heidegger, M., 1988. *Basic Problems of Phenomenology*. transl. A. Hofstadter. Bloomington: Indian University Press.

Horkheimer, M., and Adorno, T. W., 1972. *Dialectic of Enlightenment*, transl J. Cumming. New York: Continuum.

Hutchins, E. L., Holland, J. D., Norman, D. A., 1986. "Direct Manipulation Interfaces," in *User Centered System Design: New Perspectives on Human-Computer Interaction*, ed. D. A. Norman and S. W. Draper. Lawrence Erlbaum Associates.

Jarvis, S., 1998. *Adorno: A Critical Introduction*. New York: Routledge.

Koenig, G. M., 1969. “PROJECT 1,” *Electronic Music Reports*, 1(2).

Koenig, G.-M., 1983. “Aesthetic Integration of Computer-Composed Scores,” *Computer Music Journal* 7(4), pp. 27-34.

Koenig, G.-M., 1991. “Working with ‘Project 1’: My Experiences with Computer Composition,” *Interface*, 20, pp. 175-180.

Laske, O. E., 1981. “Composition Theory in Koenig’s Project One and Project Two,” *Computer Music Journal*, 5(4), pp. 54-65.

Laske, O. E., 1989. “Composition Theory: An Enrichment of Music Theory,” *Interface* (18), 45-59.

Laske, O. E., 1991. “Toward an Epistemology of Composition,” *Interface* (20), 235-269.

Laske, O. E., 1992. “The Humanities as Sciences of the Artificial,” *Interface* 21(3-4), pp. 239-255.

Marx, F., 1967. *Capital: A Critique of Political Economy* Vol 1, ed. F. Engels, transl. S. Moore and E. Aveling. NY: International Publishers.

Mauceri, F. X., 1996. *From Experimental Music to Musical Experiment* and *Listening to Technology: Musical Response in the Age of Digital Technique*. D.M.A. diss., University of Illinois at Urbana-Champaign.

Moore, F. R., 1990. *Elements of Computer Music*. Englewood Cliffs: Prentice Hall.

Morris, R., 1970. “Some Notes on the Phenomenology of Making: The Search for the Motivated,” *Artforum* 8, 62-66.

Morrison, J. D., and Adrien, J.-M., 1993. “MOSAIC: A Framework for Modal Synthesis.” *Computer Music Journal* 17(1), p. 45-56.

Norman, D. A., 1986. “Cognitive Engineering,” in *User Centered System Design: New Perspectives on Human-Computer Interaction*, ed. D. A. Norman and S. W. Draper. Lawrence Erlbaum Associates.

Norman D., 1988. *Psychology of Everyday Things*. New York: Basic Books.

Pritchett, J., 1993. *The music of John Cage*. Cambridge: Cambridge University Press.

Punch, B., Sullivan, M., Koehler, R., 1994. “An Algorithmic Approach to Composition based on Dynamic Hierarchical Assembly,” *Proceedings of the 1994 International*

Computer Music Conference. San Francisco: International Computer Music Association, pp. 45-52.

Rosenau, P. M., 1992. *Post-Modernism and the Social Sciences: Insights, Inroads, and Intrusions*. Princeton: Princeton University Press.

Simon, H. A., 1969. *The Sciences of the Artificial*. Cambridge, Mass: The M.I.T. Press.

Vercoe, B., 1988. *CSOUND: a Manual for the Audio Processing System and Supporting Programs.* Cambridge, Mass: The Media Laboratory, M.I.T.

Winograd, T., Flores, F., 1987. *Understanding Computers and Cognition: A New Foundation for Design*. Reading, Mass: Addison-Wesley Publishing Company.