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RESEARCH ARTICLE

Hearing Epistemic Sound in Experimental (Music) Systems, 1958–73

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Abstract

From the late 1950s to the mid-1970s, American experimental musicians like Pauline Oliveros, David Tudor, and Gordon Mumma employed complex and idiosyncratic technological systems to produce and capture acoustic resonance for aesthetic appreciation. Although this shared exploration exhibited many of the hallmarks of a genuine research project, scholars of experimental music have long been wary of claims that there is anything particularly scientific about this music, frequently comparing its informality unfavorably with the rigor and empiricism of the individual scientific experiment. However, historian of science Hans-Jörg Rheinberger has long held that the fundamental working unit of scientific research is not the individual experiment, but what he terms the experimental system: The loose coherence of objects, instruments, and technologies through which research questions are materialized over time. I argue that Rheinberger's framework of the experimental system offers a compelling way of understanding the experimentation that catalyzed the emergence of what has come to be known as "resonance aesthetics" in American experimental music. By focusing on the material links of musicians' activities, the experimental system illuminates how knowledge was produced and circulated within and between vastly different musical performances. Rheinberger's characterization of successful research also informs a more nuanced conception of virtuosity in experimental music. Finally, this framework is an opportunity to re-evaluate the status of sound as an object of epistemological inquiry, akin to what Rheinberger describes as an "epistemic thing." In theorizing epistemic sound as both contextual and emergent, I re-evaluate musicians' approaches to spontaneity and improvisation in musical performance.

On the evening of Monday, January 5, 1970, the musicians John Cage, Gordon Mumma, and David Tudor found themselves making sounds in the dark. The occasion was a performance of *Canfield*, one of three dances presented by the Merce Cunningham Dance Company (MCDC) in their season-opening program at the Brooklyn Academy of Music. As the dance progressed, Cage wandered into the audience and through various spaces in the theater with a battery of sound-making implements while Tudor and Mumma, seated at a control table piled with electronics, conversed with him over the public-address system.[1] The three musicians had been charged with determining the resonant frequency of the theater, a task laid out in a musical score by Pauline Oliveros titled *In Memoriam: Nikola Tesla, Cosmic Engineer* (1969). Conceived with the company's rigorous touring schedule in mind, the premise of this work is to investigate the unique acoustic qualities of each venue so as to be able to excite it into cacophonous vibration using electronic tone generators at the conclusion of the performance. As Oliveros explained, "If the search for the resonant frequency has been successful, then the frequency of the generators selected by the musicians can cause the performance space to add its squeaks, groans, and other resonance phenomena to the general sounds."[2]

I am grateful to a number of individuals for their thoughtful and constructive feedback in developing this project, including Claire Bishop, Ryan Dohoney, David Grubbs, Martin Iddon, Hans-Jörg Rheinberger, and two anonymous reviewers.

[1]Clive Barnes, "Dance: New Cunningham," *New York Times*, January 6, 1970, in "Canfield," Merce Cunningham Dance Capsules, Merce Cunningham Trust.

[2]Pauline Oliveros, cited in Heidi Von Gunden, *The Music of Pauline Oliveros* (Metuchen, NJ: Scarecrow Press, 1983), 64.

For all of its novelties, this performance was emblematic of a longstanding preoccupation with resonance among experimental musicians. From the late 1950s to the mid-1970s, American experimental music was saturated with idiosyncratic investigations of resonance by a range of figures including Oliveros, Cage, Mumma, and Tudor, as well as Alvin Lucier, Robert Ashley, and others. Each work in this shared exploration seemed to call for increasingly complex technological arrangements to produce, amplify, sustain, and capture all manner of acoustic resonance for aesthetic appreciation. Nevertheless despite the proliferation of what has come to be known as "resonance aesthetics" during this period, the nature of this heterogeneous activity as a cultural formation confounds typical historical through-lines.[3] It cannot be fully grasped through the performance history of a single composition, yet is most legible in performance; it is rooted in the creation and circulation of specific technologies, yet dependent on none in particular. Likewise, it evades any account organized around a single musician, studio, institution, or location. Even style is an unreliable guide: While aesthetic affinities emerged from time to time, they were fleeting, haphazard, and highly decentralized.

Perhaps most curious of all is the fact that this exploration was taking place both during and between performances. For example, although individual realizations of *Nikola Tesla* modeled a kind of scientific inquiry into the acoustics of a particular venue, the work was also enmeshed within a network of epistemological activity that extended well beyond its own run of performances. In addition to the knowledge and skill Cage, Mumma, and Tudor cultivated over numerous realizations of *Nikola Tesla* as they toured with the MCDC, each musician was also involved in an extraordinary range of activities that might have influenced how they chose to realize Oliveros's composition, including circuit design, computer programming, installation work, instrument building, and performances employing novel configurations of diverse electronic equipment.[4] Through collaboration and conversation, these "hugging old band buddies" (as Mumma has characterized them) were building an epistemic enterprise—an informal research system driven not by a common cause, but rather by individual creative pursuits that freely careened in close proximity for over a decade.[5]

Scholars have long been wary of claims that there is anything particularly scientific about experimental music—its name notwithstanding—frequently comparing its informality unfavorably with the rigor and empiricism of the individual scientific experiment. However, historian of science Hans-Jörg Rheinberger has long held that the fundamental working unit of scientific research is not the individual experiment, but what he terms the experimental system: The loose coherence of objects, instruments, and technologies through which research questions are materialized over time, and within which context individual experiments become meaningful.[6] I argue that Rheinberger's framework of the experimental system offers a compelling mechanism for understanding the experimentation that catalyzed the emergence of resonance aesthetics in American experimental music from about 1958 to 1973. By privileging the materiality of research activity, the experimental system illuminates moments and trajectories within, around, and between performances that might be overlooked in historical accounts organized around conventional musicological continuities, such as an individual composer, work, or performer. In addition to contextualizing the circulation of specific technologies between individuals and works, as a theoretical framework the experimental system is especially sensitive to how the same technology is used in different ways over time, from the earliest experimentations with a novel gadget to its integration into a new system as a familiar and reliable tool.

[3]For more on the phenomenon of "resonance aesthetics," see Adam Tinkle, "The SAG Representative for the West Coast," *American Music Review* XLVII, no. 1 (Fall 2017).

[4]Cage, Mumma, and Tudor appear to have been involved in every performance of *Nikola Tesla*, although they were occasionally joined by others. Jean Rigg, an administrator with the MCDC, is the fourth performer in the only extant recording of *Nikola Tesla*, which is excerpted in the *Music for Merce* box set. David Behrman, who frequently collaborated with the MCDC, also appears to have performed *Nikola Tesla* several times in 1970. While *Canfield* remained in the MCDC repertory from 1969 to 1977, after 1972 it was typically presented as part of Cunningham's Events with different musical accompaniment. Consequently, *Nikola Tesla* was likely performed primarily from 1969 to 1972. (I am not aware of any performance of *Nikola Tesla* separate from a performance of *Canfield*.)

[5]Gordon Mumma, email to the author, April 2, 2021.

[6]Hans-Jörg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford, CA: Stanford University Press, 1997), 28.

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This process of circulation is never straightforward or preordained and often entails unforeseen intersections—what Rheinberger characterizes as "conjunctures"—between different experimental systems, resulting in ensembles of experimental systems and, on a larger scale, what he terms "experimental cultures."[7] Through its own circuitous progress, the emergence of resonance aesthetics is best characterized not as an orderly sequence of well-defined experiments, but rather by the more nebulous qualities that Rheinberger associates with successful scientific research, including "instability, indeterminacy, serendipity, intuition, improvisation, and a measure of 'fuzziness.'"[8] In this view, the individual researcher proceeds primarily through trial and error [*tâtonnement*], guided more definitively by their own skill and knowledge—their "virtuosity," as Rheinberger has put it—than by the rational application of theory.[9] I argue that this characterization is an especially good fit for the development of resonance aesthetics by surveying a number of representative works, including *In Memoriam: Nikola Tesla, Cosmic Engineer* by Pauline Oliveros, and *Rainforest* (1968–73) by David Tudor. The framework of the experimental system is also an opportunity to re-evaluate the status of sound in experimental music as an object of epistemological inquiry, akin to what Rheinberger describes as an "epistemic thing." Furthermore, in theorizing epistemic sound as both contextual and emergent, I re-evaluate musicians' approaches to spontaneity and improvisation in musical performance.

Toward Experimentation

Despite its considerable prevalence in contemporaneous accounts of experimental musicians' work, the scientific analogy has been vigorously contested in more recent reappraisals.[10] Frank X. Mauceri, for instance, has concluded that the purposes of the musical work itself seem to be inescapably "at odds with those of scientific methods."[11] Along similar lines, William Brooks proposed that the scientific experiment is characterized by observations that can be tested, whereas post-Cagean experimental music is, in theory at least, concerned with observation alone.[12] Both Mauceri and Brooks contrast Cage's approach with the more overtly scientific undertakings by Lejaren Hiller in the 1950s and 1960s in testing the ability of the ILLIAC supercomputer to compose music.[13] Nevertheless both writers conclude that even aspects of Hiller's research cannot rightly be termed scientific because they fail to conform to the logical framework of the individual scientific experiment. Consequently, the origins of the term "experimental" as it pertains to music can be traced most directly not to the laboratory, but to Cage's famous definition of an experimental action as one whose outcome is unforeseen, first postulated in the late 1950s.[14]

The unforeseen is also a preoccupation for Rheinberger throughout the historical examples that ground his theoretical framework. One of the most illustrative case studies of an experimental system is his account of mid-century cancer research undertaken at the Massachusetts General Hospital in Boston. In 1945, a team of scientists began their research by focusing on the role of amino acids in

[7]Rheinberger, *Toward a History of Epistemic Things*, 137–38.

[8]Henk Borgdorff, "Artistic Practices and Epistemic Things," in *Experimental Systems: Future Knowledge in Artistic Research*, ed. Michael Schwab (Leuven: Leuven University Press, 2013), 115.

[9]Rheinberger, *Toward a History of Epistemic Things*, 74. See also Hans-Jörg Rheinberger, "Virtuosité expérimentale," in *Itérations*, trans. Arthur Lochmann (Bienne and Paris: Diaphanes, 2013), 135.

[10]As will be discussed below, these accounts frequently rely on assumptions about what the activity of science is actually like. For example, in describing a 1970 performance of *Nikola Tesla*, the critic Stephen Smoliar wrote, "like scientists, the musicians worked independently in teams on a series of experiments." Reprinted in the liner notes to *Music for Merce*, New World Records 80712, 2010.

[11]Frank X. Mauceri, "From Experimental Music to Musical Experiment," *Perspectives of New Music* 35, no. 1 (Winter 1997): 194. See also Borgdorff, "Artistic Practices and Epistemic Things," 115.

[12]William Brooks, "In Re: 'Experimental Music,'" *Contemporary Music Review* 31, no. 1 (February 2012): 38–40.

[13]See Mauceri, "From Experimental Music to Musical Experiment," 194–97 and Brooks, "In Re: 'Experimental Music,'" 39–40, 54–55.

[14]John Cage, "History of Experimental Music in the United States," in *Silence* (Middletown, CT: Wesleyan University Press, 1961), 69. A version of this definition first appears in Cage's article "Experimental Music: Doctrine," first published in 1955. Michael Nyman's *Experimental Music: Cage and Beyond*, published in 1974, is widely regarded as the first major work of music scholarship to take up Cage's definition systematically.

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protein synthesis, which they surmised were linked to cancer growth. Through numerous individual experiments spanning nearly two decades, each of which resulted in shifts in material focus, theoretical assumptions, and disciplinary boundaries, the scientists identified that protein synthesis could be characterized as a process of the transmission of genetic information.[15] The resulting knowledge, as Rheinberger points out, was not only "within a completely different conceptual horizon," but also completely unforeseeable in the context of the original research framework.[16] Rheinberger also emphasizes the role of serendipity in guiding the course of the research system, describing how a substance initially regarded as a contaminant in one experiment was "transformed from a disturbance into an object of investigation" when it exhibited resistance against removal, and was subsequently used to decipher the genetic code in further investigations.[17] As Rheinberger explains, "experimental systems can be regarded as the structures that make it possible for such turns in the knowledge-gaining process to happen…to make it possible that those kinds of chance events can…lend themselves to being handled in an epistemically productive manner."[18]

In addition to Rheinberger, who has frequently commented on the parallels between scientific and artistic practices himself, a number of scholars have examined creative works, and even experimental music, through the lens of the experimental system.[19] For example, Virginia Anderson concludes her study of experimental music by Cornelius Cardew, Gavin Bryars, and other British composers by asserting that despite certain obvious distinctions, "scientific experimental systems and British experimental music systems differ little in their framework and activity of their methodology."[20] Anderson likens the realization of indeterminate elements of experimental scores to the creative, improvisatory thinking that occupies scientists before the structure of their next experiment has taken shape—what the biologist François Jacob has termed "night science."[21] Although Anderson acknowledges a similarity between the performance of experimental music and the experimental system with respect to their framework and activity, like Brooks and Mauceri—and rightly, in my view—she stops short of suggesting that their aims and results are commensurate. However if experimental music is taken to encompass not only individual performances, but also the activity in between, the epistemological implications become more central and more clearly defined.

For example, one of the earliest sites for the emergence of resonance aesthetics was Gordon Mumma and Robert Ashley's Cooperative Studio for Electronic Music in Ann Arbor, Michigan in the late 1950s. However this studio was not really a place; Thom Holmes describes it as comprising "rooms set aside for electronic music equipment in each of their two homes" stocked with a shared pool of resources that included "about a half-dozen tape recorders between them, as well as oscillators, filters, mixers, and other audio processing circuits, many that they devised and built themselves."[22] Mumma and Ashley performed together at sculptor Milton Cohen's local venue the Space Theater twice weekly for 7 years, during which time Mumma also came to know Oliveros and Tudor. By

[15]Hans-Jörg Rheinberger, "Difference Machines: Time in Experimental Systems," *Configurations* 23, no. 2 (Spring 2015): 171–75. This case study is also presented in *Toward a History of Epistemic Things* at greater length.

[16]Rheinberger, "Difference Machines," 172.

[17]Rheinberger, "Difference Machines," 174–75.

[18]Rheinberger, "Difference Machines," 175.

[19]These scholars include Virginia Anderson, Henk Borgdorff, Paulo de Assis, Olaf Hochherz, and Michael Schwab. I would like to emphasize that what I am proposing diverges from recent scholarship into what has come to be known as "artistic research" by writers including Borgdorff, de Assis, Schwab, and others, in which creative work is explicitly regarded as a form of research. For example, although de Assis is also concerned with a Rheinbergian reading of music, his focus is on a generalizable theory for the production of knowledge in musical performance. See Paulo de Assis, *Logic of Experimentation: Reshaping Music Performance in and through Artistic Research* (Leuven: Leuven University Press, 2018).

[20]Virginia Anderson, "Whatever Remains, However Improbable: British Experimental Music and Experimental Systems," in *Experimental Systems*, 66.

[21]Anderson, "Whatever Remains, However Improbable," 59. Naturally, Jacob positions "night science" opposite "day science," which more closely correlates with how scientists tend to present their ideas publicly: As perfectly logical chains of reasoning and tests. For a summary of Jacob's ideas—and their link to the experimental system—see Hans-Jörg Rheinberger, "Scrips and Scribbles," *MLN* 118, no. 3 (April 2003): 626.

[22]Thom Holmes, *Electronic and Experimental Music: Technology, Music, and Culture*, 3rd edition (New York: Routledge, 2008), 96.

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the time of *Nikola Tesla* in the late 1960s, Mumma, Oliveros, and Tudor had collaborated and performed together numerous times, and in so doing, exchanged a dizzying body of knowledge between them. For example, although Tudor suggested that it was Mumma who first introduced him to the possibilities of musical circuits,[23] Mumma holds up Tudor's late 1950s and early 1960s performances of works by Cage as "a considerable stimulus to experimentation in live-electronic music."[24] Alvin Lucier has likewise posited that Tudor "invented the table of electronics that saved our lives in the Sixties."[25] At the same time, Mumma notes that Tudor and Oliveros's performance of the latter's electroacoustic composition *Applebox Double* in 1965 inaugurated (or at least catalyzed) their shared interest in resonance, which would manifest in works like *Nikola Tesla* and Tudor's *Rainforest* years later.[26] The actual apple box used in this performance had made its first sonic appearance in an earlier work by Oliveros, *Time Perspectives*, which in turn formed at least part of the basis on which Tudor first sought out Oliveros to collaborate in 1963.[27] Furthermore, Adam Tinkle makes the case that, in a symmetrical twist, Mumma and Tudor's Pepsi Pavilion installation at the Osaka World's Fair in 1970—which could "self-sense, self-actuate, and morph its own resonance…with its embedded speakers and microphones"—could itself "be viewed in light of Oliveros's invitation to 'cosmic engineering'" in *Nikola Tesla* the previous year.[28]

This freewheeling, years-long sprawl is not necessarily the kind of formation that would typically be described as a "system," a term that in many cases suggests a fixed, top-down structure. As it turns out, several writers, including Rheinberger himself, have questioned the extent to which the word "system" precisely captures the experimental arrangement he proposes. As the music theorist and philosopher Henk Borgdorff has pointed out:

> In the historical and philosophical literature on science, the interest in experimental systems arose at the point where the theory-dominated view of scientific research began to make way for ideas centering on practice…Now practices generally manifest the same characteristics as Rheinberger's systems…One can therefore just as well speak of "experimental practices" as of "experimental systems," not least because Rheinberger also applies his findings on experimental systems to academic practices outside the laboratory.[29]

Borgdorff continues:

> The term "experimental system" could give the impression of a fixed structure, whose elements relate with one another in clearly ordered, stable arrangements. In using this term, however, Rheinberger does not have a systems theory in mind…He is simply highlighting a loose coherence between the various elements of the experimental system (technical, epistemic, social, institutional elements).[30]

Accordingly, in what follows the term "system" should be understood more accurately in contemporary parlance as a "practice" whose constituent elements are only loosely and temporarily linked through the intervention of the researcher. As Rheinberger and Michael Hagner write in a co-authored

[23]Holmes, *Electronic and Experimental Music*, 290.

[24]Gordon Mumma, *Cybersonic Arts: Adventures in American New Music* (Champaign: University of Illinois Press, 1999), 83.

[25]Alvin Lucier, *Music 109: Notes on Experimental Music* (Middletown: Wesleyan University Press, 2012), 61.

[26]Mumma, *Cybersonic Arts*, 153. See also You Nakai, *Reminded by the Instruments: David Tudor's Music* (New York: Oxford University Press, 2021), 155–56.

[27]Tudor and Oliveros's first collaboration, *Duo for Accordion and Bandoneon with Possible Mynah Bird Obbligato*, is documented in Nakai, *Reminded by the Instruments*, 143–51.

[28]Tinkle, "The SAG Representative for the West Coast," 16–17. Mumma and Tudor were lead artists on the installation, which was a collaborative endeavor with the group Experiments in Art and Technology (E.A.T.). For an account of some of the farther-reaching points in this network—including Iggy Pop, John Cale, and the MC5—see the epilogue of Benjamin Piekut, *Experimentalism Otherwise: The New York Avant-Garde and Its Limits* (Berkeley: University of California Press, 2011), 177–98.

[29]Borgdorff, "Artistic Practices and Epistemic Things," 116.

[30]Borgdorff, "Artistic Practices and Epistemic Things," 116.

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essay, "[t]he concept of experimental system appears to be justified only if a 'system' is allowed to encompass heterogeneous elements that can be recombined at any time; and, moreover, if it is seen as remaining open in the course of its history for discarding old components and for incorporating new ones."[31] Consequently, understanding experimental music through Rheinberger's framework will require close attention to the objects at hand, and how their use by practitioners both binds the experimental system and drives it forward.

Epistemic Objects

Oliveros's score for *Nikola Tesla*, commissioned by Cunningham in 1968, employs no musical notation —just two typewritten pages of verbal instructions that roughly indicate how the search is to proceed. Oliveros composed the work with Cage, Mumma, and Tudor in mind (as they were the resident touring musicians with the MCDC), identifying the latter two by name in the score. Each performance is divided into three parts, beginning with a period of discussion among the musicians to plan their approach, followed by the execution of "simple practical experiments" throughout the theater.[32] The score provides for handheld acoustic sound-making objects including cap pistols, "a metal slide whistle for David" (Tudor was known for using whistles in performances of Cage's works since the early 1950s), and "a bugle for Gordon" (Mumma is known as a hornist as well as a technologist).[33] The score also specifies the use of audio equipment including microphones, tape recorders, playback devices, and an amplification system. As the musicians make test sounds and listen to their resonance, walkie-talkies or wireless microphones allow them to direct one another in different parts of the theater and share their discoveries. This process, which is audible to the audience during the entire performance through the public-address system, is inevitably marked by moments of improvisation, negotiation, disagreement, and uncertainty. In the recording of the work included in the *Music for Merce* compilation, in which MCDC administrator Jean Rigg joins Cage, Tudor, and Mumma as a performer, one hears numerous such moments.[34] For example, at one point Mumma describes to the others the instruments he has available; at another, Cage explains to Tudor the nature of a musical "tattoo" after asking Mumma to play one on his bugle. Still later, Rigg narrates her position to Tudor as she moves across the space with the slide whistle. Tudor listens, asking clarifying questions, and eventually asks Rigg to return to the center of the space and change the quality of the test sounds she is making.[35]

The findings from this exploration are collated in the third part of the composition, in which the musicians estimate the resonant frequencies of the space and set amplified tone generators to those frequencies, causing the space to vibrate. Mumma describes the "earth-shaking" finale vividly:

> The third section began in silence, from which an ambience of low-frequency sound emerged, tuned to the predominant resonances of the space. They gradually swelled in volume to a sea of oscillating pressure, analogous to Tesla's famous experiment in which a building was made to vibrate at its own resonant frequencies.[36]

According to the logic of the individual experiment, if the wrong frequency were chosen, the space might not vibrate, or would vibrate less, and the performance would be unsuccessful. This is the logical framework in which both Mauceri and Brooks root their dismissals. Mauceri, for instance, describes as unscientific musical "experiments" that do not conform to a model of "theory testing and

[31]Michael Hagner and Hans-Jörg Rheinberger, "Experimental Systems, Objects of Investigation, and Spaces of Representation," in *Experimental Essays*, eds. Michael Heidelberger and Friedrich Steinle (Baden-Baden: Nomos, 1998), 359–60.

[32]Pauline Oliveros, *In Memoriam: Nikola Tesla, Cosmic Engineer* (musical score) in "Canfield," Merce Cunningham Dance Capsules, Merce Cunningham Trust.

[33]For more on Tudor's use of whistles, see Nakai, *Reminded by the Instruments*, 89–92. See also Martin Iddon, *John Cage and David Tudor: Correspondence on Interpretation and Performance* (New York: Cambridge University Press, 2013), 91.

[34]Pauline Oliveros, "In Memoriam: Nikola Tesla, Cosmic Engineer," *Music for Merce*, Disc 3, New World Records 80712, 2010, compact disc.

[35]The moments described begin at 2:38, 2:18, and 3:23 in the recording, respectively.

[36]Mumma, *Cybersonic Arts*, 123–24.

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confirmation."[37] Nevertheless even though Oliveros does not provide a direct means of confirmation in the score, the performance is unmistakably oriented toward the production of new knowledge.[38] Rheinberger explains that experimental systems are "designed to give unknown answers to questions that the experimenters themselves are not yet able clearly to ask."[39] Simply put, they are "vehicles for materializing questions," and this is precisely what Oliveros's composition achieves.[40] One can imagine sitting in the dark theater toward the end of the performance as a 25-foot-tall beam, standing upright, pans back and forth across the lip of the stage like a search light, illuminating the dancers upstage in narrow slices.[41] The musicians stop talking and return to the control table. There is silence, and the sound of the dancers' feet becomes audible, followed by a vibration in the metal and wood of the floor, seats, and railings. Low sustained tones become audible and, gradually, louder. The metal rigging in the fly space clatters; fixtures buzz unidentifiably. The ear may be drawn to any number of these sounds to explore further—in another performance of *Nikola Tesla*, or as the basis for another composition altogether. Despite a lack of experimental confirmation, in some form or another, unexpected knowledge has emerged.

One of Rheinberger's central contributions has been problematizing the notion that the individual experiment, with its tight epistemological focus around a single question—a "sharp procedure for testing a sharp idea," in his words—is particularly significant.[42] Where experiments are regarded as discrete, self-contained entities, the experimental system offers a framework that reaches outward to trace how the contours of a given performance are rooted in knowledge produced elsewhere. As the artistic researcher Michael Schwab has written, "experimental systems are designed to be open, so that the deployed knowledge results in ruptures from which unexpected new objects relevant to knowledge emerge, which Rheinberger calls 'epistemic things.'"[43] Epistemic things are "hybrid objects" whose status is determined simultaneously by their materiality and their uncertain function within the system.[44] They can be contrasted with technical objects, which are familiar to the researcher and have a clear role in the system. As Borgdorff summarizes, if an epistemic object is what we "want to know," technical objects are those "through which we can know."[45]

To the extent that the resonant qualities of the venue are the focus of the musicians' inquiry in *Nikola Tesla*, it would seem that the venue, through its acoustic response and vibration, becomes a kind of epistemic object in each performance. By the same logic, the sound-making implements used for testing and the tone generators used in the third section are technical objects: Tools or instruments through which knowledge about something else can be ascertained. Nevertheless each object, over the preceding years, had become familiar to each musician through an open-ended process of experimentation. In his 1967 composition *Hornpipe*, Mumma had exhaustively explored the resonant characteristics of the French horn using microphones and amplification to generate an acoustical feedback loop with which to improvise. Tudor, likewise, explored experimental juxtapositions of a slide whistle with electronic sounds in his 1959 recording of Cage's *Indeterminacy* with the composer. Meanwhile in earlier works like the *Mnemonics* series, Oliveros had at first similarly approached electronic tone generation through the highly unconventional technique of heterodyning analog oscillators, in which two or more oscillators are set to frequencies beyond the range of human hearing

[37]Mauceri, "From Experimental Music to Musical Experiment," 195.

[38]Presumably, if multiple performances were held in the same venue the musicians could test different frequencies, but this is beyond Oliveros's direct control. It is instructive to compare Oliveros's take on scientific research with the contemporaneous "research activities" of the Scratch Orchestra, including the *Nature Study Notes* and *Schooltime Compositions*, as described in Anderson, "Whatever Remains, However Improbable."

[39]Rheinberger, *Toward a History of Epistemic Things*, 28.

[40]Rheinberger, *Toward a History of Epistemic Things*, 28.

[41]This beam, part of the set for *Canfield*, was designed by the artist Robert Morris.

[42]Hans-Jörg Rheinberger, "Experimental Systems: Difference, Graphematicity, Conjuncture," in *Intellectual Birdhouse: Artistic Practice as Research*, trans. Burke Barrett and edited by Florian Dombois, Ute Meta Bauer, Claudia Mareis, and Michael Schwab (London: Koenig Books, 2012), 92.

[43]Michael Schwab, "Experiment! Towards an Artistic Epistemology," *Journal of Visual Art Practice* 14, no. 2 (2015): 122.

[44]Borgdorff, "Artistic Practices and Epistemic Things," 114, 117.

[45]Borgdorff, "Artistic Practices and Epistemic Things," 114.

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and mixed together to produce what are known as difference or combination tones within the audible range. The subtlety and sophistication of this technique, as compared with the rather rudimentary use of oscillators in *Nikola Tesla* as a source of vibration, belies their shifting role—as with each of the instruments—from a genuine object of epistemic inquiry to a technical object that could be used, in turn, to reveal new epistemic objects, and materialize new questions.

The experimental system is characterized by a constant play between these two functions, a state that is well illustrated by the phenomenon of tinkering. Tinkering is defined by an intimate material engagement and trial-and-error approach that points beyond a particular task, such as a mechanical repair, and toward creative exploration. All of the musicians involved in resonance aesthetics were committed tinkerers, members of what Thom Holmes has called "the Radio Shack school of electronic music."[46] This practice largely facilitated the intensely personal and idiosyncratic sonic results that came to be associated with individuals, rather than notations, in experimental music circles. It also aligns closely with Rheinberger's conception of the researcher. In order to truly tinker, one must exhibit technical skill, but must also be willing not to let the technical aspects overwhelm more creative exploration. As Rheinberger writes, productive experimentation is characterized by an "interaction between scientific object and technical conditions [that] is eminently nontechnical in its character. Scientists are, first and foremost, *bricoleurs* (tinkerers), not engineers."[47] Instead of working systematically toward a solution to a well-defined problem, tinkering is characterized by an ongoing process of destabilization that produces moments of uncertainty, which in turn allow for the exchange of epistemic and technical functions among objects.

The Limits of Experimentation

As a rule, experimental systems tend to stabilize over the long term. In the sciences, this process occurs when a research system fails to produce new knowledge, and instead becomes focused around answering an increasingly narrow set of questions in more or less predictable fashion. Frequently, formerly productive research systems are integrated into new experimental research systems as stable sub-units. As Rheinberger writes, "There is a life cycle to experimental systems. They are brought into being as research devices, become transformed into kits, and finally are replaced."[48] This cycle is illustrated by another work from the same period as *Nikola Tesla*: David Tudor's *Rainforest*, composed for another of Cunningham's dances in 1968.[49] Although Tudor created several versions of *Rainforest*, common to all is the use of an audio signal played into an object through a transducer, which causes the object to audibly vibrate. The overarching impetus seems to have been Tudor's desire to find "a means of making objects reveal their own resonant characteristics rather than using them as instruments to be played manually," suggesting a strong affinity with *Nikola Tesla*, in which sound is also employed to reveal the resonant qualities of objects.[50] The first version of *Rainforest* was performed with Cunningham's dance *RainForest*, while later versions were used for Cunningham's *Events* and for live performance as concert works or sound installations. Since the 1970s, the group Composers Inside Electronics (CIE) has continued to present the work in various forms.

The sounds heard in *Rainforest* are dependent primarily on two factors: The acoustic characteristics of the object and the audio signal used to excite the object. The objects are not specified in any of the

[46]Holmes, *Electronic and Experimental Music*, 288.

[47]Rheinberger, *Toward a History of Epistemic Things*, 32. The significance of an individual researcher's personal experience with their material is central to Rheinberger's framework. Elsewhere Rheinberger describes how this experience results in "acquired intuition" and "embodied reasoning," which he compares with Michael Polanyi's notion of "tacit knowledge." See Rheinberger, *Toward a History of Epistemic Things*, 77–79.

[48]Rheinberger, *Toward a History of Epistemic Things*, 81.

[49]*Rainforest* was premiered on March 9, 1968 at SUNY Buffalo in New York, but continued to evolve over many years. See Nakai, *Reminded by the Instruments*, 635; and Matt Rogalsky, "Idea and Community: The Growth of David Tudor's *Rainforest*, 1965–2006" (PhD diss., City University London, 2006).

[50]John Driscoll and Matt Rogalsky, "David Tudor's *Rainforest*: An Evolving Exploration of Resonance," *Leonardo Music Journal* 14 (2004): 26. See also You Nakai, "Hear After: Matters of Life and Death in David Tudor's Electronic Music," *Communication +1* 3, no. 1 (September 2014): 28.

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versions and, by design, vary widely with each performance. Examples of objects previously used include "a metal bedspring, a huge wine barrel, toilet floats, cast-iron wagon wheel rims, a stainless-steel milk container lid, lawn sprinklers, a copper still, a Styrofoam box, and a large metal cable."[51] What distinguished the first three versions of *Rainforest*, however, were the types of sound sources used to excite the objects. Certain details regarding the different versions remain ambiguous, but according to CIE member Matt Rogalsky, sound sources to *Rainforest I* were limited to tone generators, *Rainforest II* used live vocal input, and *Rainforest III* used various taped sounds derived from a library assembled by Tudor and others.[52] Nevertheless even with the sound source stabilized, in performance new questions are inevitably materialized. As Rogalsky points out:

> The use of contact microphones on the transduced speaker-objects…raises the question of exactly where the sonic identity of a *Rainforest* object is to be found; the (in)fidelity of *Rainforest* objects depends not only on the objects themselves, but also and as much on the frequency response of the object in each stage of transduction.[53]

The ambiguity of the object's "sonic identity" recalls the contingency of the resonant qualities of the theater in Oliveros's composition. The multiplicity of variables and their attending uncertainty, like the questions that they raise, are not possible without the object. On the contrary, these questions are literally "materialized" through the objects of the system. At the same time, it is possible to trace these objects and their uses to earlier instances. *Rainforest* was based on ideas and circuitry Tudor had been developing since at least 1965, and almost certainly influenced by even earlier performances with Cage using contact microphones and other transducers to amplify quiet sounds. The most famous example is Cage's *Cartridge Music* (1960), in which a record player needle is removed from its cartridge and replaced with other materials with which to make (amplified) contact with assorted objects.[54] Just as *Nikola Tesla* employed familiar tools to new ends, Tudor's experience amplifying small sounds meant that a variety of transducers could now be integrated into his *Rainforest* setup as technical components and directed toward uncovering the resonant qualities of new objects of inquiry.

The instability of epistemic things is directly related to the functioning of the experimental system through a process that Rheinberger calls differential reproduction. As Rheinberger writes, "[i]n order to remain productive, experimental systems must be arranged and carried on in such a way that the generation of differences becomes the reproductive driving force of the whole machinery."[55] For Rheinberger, these differences are inextricably linked with the production of knowledge, whether in a scientific or artistic context. For example, he explains that:

> I have the impression that an artist like Cézanne, who painted hundreds of apples in his countless later still lifes, must have been caught in a kind of experimental system. It was all about tiny changes and iterations—doing it again and again and always with a small differential gesture. I am interested in the creation of differences through such processes of iteration, be it in the sciences or in the arts. Holding these small differences against each other produces knowledge effects."[56]

[51]Driscoll and Rogalsky, "David Tudor's *Rainforest*," 29.

[52]Driscoll and Rogalsky, "David Tudor's *Rainforest*," 27. As Rogalsky points out, "Tudor was himself at times apparently indecisive about how to number the series," and in the absence of a definitive answer, being "too obsessive about getting the versions right is to risk losing sight of the broader picture." See Driscoll and Rogalsky, "David Tudor's *Rainforest*," 28. See also Nakai, *Reminded by the Instruments*, 339, 419.

[53]Driscoll and Rogalsky, "David Tudor's *Rainforest*," 26.

[54]Driscoll and Rogalsky, "David Tudor's *Rainforest*," 25–26. Rogalsky traces the origins of this technique even further back to Tudor's 1959 realization of Cage's *Solo for Piano* from the *Concert for Piano and Orchestra* (1958). See Rogalsky, "Idea and Community," 39.

[55]Hans-Jörg Rheinberger, "Consistency from the Perspective of an Experimental Systems Approach to the Sciences and their Epistemic Objects," *Manuscrito* 34, no. 1 (January/June 2011): 314.

[56]Hans-Jörg Rheinberger, "Forming and Being Informed" in *Experimental Systems: Future Knowledge*, ed. Michael Schwab (Leuven: Leuven University Press, 2013), 216.

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Both *Rainforest* and *Nikola Tesla* are designed so that new materials enter the system with each performance: New objects and sound sources in the former, and new spaces in the latter. In *Rainforest*, as Rogalsky observed, the means of transduction and amplification *into*, *through*, and *from* the objects are also points at which differences may be generated between performances. In fact, the work is defined by the perpetual rearrangement of these materials. As Rogalsky summarizes, *Rainforest* is above all "a musical practice based on constant modification and innovation."[57] Yet I would argue that this process of differential reproduction is significantly attenuated in the fourth version of *Rainforest*, marking a shift in priorities from the production of new knowledge through difference toward the reproduction of specific kinds of sounds. Unlike the previous versions, *Rainforest IV*, completed in 1973, begins with a preliminary workshop in which various freely selected objects and sound sources are tested for musically interesting results.[58] This culminates in the public presentation of the objects as a sound installation. Tudor apparently utilized a highly systematic testing process in the workshops he led. As Cathy van Eck describes, Tudor would use a sine tone generator to test the resonant frequencies of an object, sweeping through the entire range of frequencies while listening for complex, nonlinear, and otherwise interesting responses.[59] CIE co-founder John Driscoll has led a number of workshops over the past few decades, and describes the process as follows:

> The choice of sound materials is motivated by the unique set of resonant characteristics that each sculptural speaker [i.e. object] presents. After investigation, the composer creates material that will tease the speaker's resonant nodes into strong vibration, creating responses that are highly nonlinear. It is the equivalent of tickling someone—a little input at just the right spot creates great output.[60]

The focus here moves beyond the "materialization" of questions, and toward useful, reproducible results. The participant works to achieve the best—that is, the most interesting—sonic results, and only upon the stabilization of the system is it presented to the public. This is not a differential reproduction, but a repetition ideally without difference, in which the desired sound whose arrival marked the end of the workshop phase can be reliably generated again. The object itself has gained "sharp contours" and transformed into a technical object.[61] This process illustrates Rheinberger's distinction between experimental systems that are oriented toward research and those that are oriented toward what he characterizes as technological ends. A research system remains open to the production of unknown things and new knowledge, whereas a technological system is characterized by a sharper point of inquiry, a complementary foreclosure of scope, and movement toward greater efficiency, stability, and reproducibility of results.[62] The two types of systems can be understood as occupying opposing positions on a spectrum, distinguished not by material, but rather by purpose and time. Consequently, the changes that took place between the first and fourth versions of *Rainforest* illustrate movement across this spectrum, from a research system to a technological system.

Experimental Virtuosity

The performances envisioned by Oliveros and Tudor illuminate a fundamental tension in the experimental music of the 1960s and 1970s. Performers were expected to produce the recognizable sounds of "experimental music," while at the same time remaining nominally open to unexpected sonic results. Judy Lochhead was one of the first scholars to articulate this paradox by comparing recordings

[57]Driscoll and Rogalsky, "David Tudor's *Rainforest*," 28.

[58]See Nakai, *Reminded by the Instruments*, 302–3.

[59]Cathy Van Eck, *Between Air and Electricity: Microphones and Loudspeakers as Musical Instruments* (New York: Bloomsbury, 2017), 118.

[60]Driscoll and Rogalsky, "David Tudor's *Rainforest*," 29.

[61]Rheinberger writes that, "within a particular research process, former epistemic things can gain sharp contours and become transformed into technical objects, thus becoming part of the technical conditions of the system." Rheinberger, "Consistency," 312.

[62]Rheinberger, *Toward a History of Epistemic Things*, 79–81.

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of indeterminate compositions by Tudor and Cage that exhibited similar sonic features.[63] More recently, analyses of realizations of works by composers such as Morton Feldman and Earle Brown have identified consistent sonic qualities that came to be regarded as crucial to the successful performance of experimental music, despite being unnotated.[64] As Lochhead has written, the experimental music community functioned collectively as a kind of "aesthetic arbiter" for a shared "sound ideal or style" that formed "a tacit backdrop for the composition and performance of music within this community."[65] Although individual composers' sonic preferences varied to some extent, what is clear is that performances of experimental music were rarely as open as they seemed to be on paper.

This conflict played out in a number of different ways. For example, practitioners frequently sought to emphasize the natural or autonomous quality of the sounds they produced—often framing the production of sound in performance as an act of discovery, rather than expression—even as they carved out distinctive aesthetic niches within the experimental music scene.[66] Similarly, many experimental musicians emphasized the spontaneous nature of their performances. In fact, the close personal friendships and shared experiences within the community may have perpetuated a sense of aesthetic serendipity that might have been better attributed to sonic preferences and standards of performance practice that were no less in force for being informal and primarily unspoken. For example, in his account of the rehearsals prior to the first concert performance of *Rainforest* with Tudor in 1969, Mumma stresses how little advance planning was actually needed. As he writes, "just before we started Tudor said to me: 'We will end at the right time.' Knowing one another as we did, that was all that was needed."[67] To the extent that Mumma's remarks highlight the spontaneity of a particular performance, they underscore the importance of the musicians' familiarity with one another over the long term in equal measure.

This familiarity frequently appeared in the guise of what is commonly described as the performers' "musical personalities": sonic qualities consistently associated with a particular performer. As Benjamin Piekut points out, musical personality was of paramount importance in MCDC performances during this era on account of the emergence of the "composer–performer," whose work was increasingly defined by improvisation and a lack of reliance on notation.[68] Many of the musicians in the MCDC roster became associated with particular techniques, stylistic elements, and sonic qualities that were consistent between performances. For example, Mumma seems to allude to familiar qualities when he writes that, despite the lack of coordination with Tudor prior to the aforementioned performance of *Rainforest*, "for me the lyrical gentleness still predominated, even with Tudor's occasional celebrated sound-bursts."[69] In this context, it is clear that Oliveros's inclusion of Mumma and Tudor's names in the score of *Nikola Tesla*, along with specific instruments appropriate to each, was intended as an invocation of their musical personalities aimed at securing a particular kind of musical result.[70]

[63]See Judy Lochhead, "Performance Practice in the Indeterminate Works of John Cage," *Performance Practice Review* 7, no. 2 (Fall 1994): 233–41; and Judy Lochhead, "Controlling Liberation: David Tudor and the 'Experimental' Sound Ideal" (paper presented at "The Art of David Tudor: Indeterminacy and Performance in Postwar Culture," Getty Research Institute Symposium, Los Angeles, May 17–19, 2001).

[64]See Lochhead, "Performance Practice," 237. For a detailed discussion of Feldman's sonic preferences in the realization of his graph works, see David Cline, *The Graph Music of Morton Feldman* (New York: Cambridge University Press, 2016), 243–63. Likewise, Rebecca Y. Kim illustrates how Brown sought to influence performers' "spontaneous" realizations of his indeterminate graphic notations by interspersing them with fully notated passages. Rebecca Y. Kim, "Four Musicians at Work and Earle Brown's *Indices*," in *Beyond Notation: The Music of Earle Brown,* ed. Rebecca Y. Kim (Ann Arbor: University of Michigan Press, 2017), 139–41.

[65]Lochhead, "Performance Practice," 235–37.

[66]See You Nakai, "How to Imitate Nature in Her Manner of Operation: Between What John Cage Did and What He Said He Did," *Perspectives of New Music* 52, no. 3 (Autumn 2014): 141–60 for more on this phenomenon.

[67]Mumma, *Cybersonic Arts*, 154.

[68]Benjamin Piekut, "Not So Much a Program of Music as the Experience of Music," in *Merce Cunningham: Common Time*, ed. Fionn Meade and Joan Rothfuss (Minneapolis: Walker Art Center, 2017), 116–19.

[69]Mumma, *Cybersonic Arts*, 154.

[70]At least as far as Tudor was concerned, this practice had direct precedent in Sylvano Bussotti's 1959 composition *Five Piano Pieces for David Tudor*, in which the inclusion of Tudor's name was intended by the composer not as a dedication, but as an indication of instrumentation. See Nakai, *Reminded by the Instruments*, 74–82.

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Nevertheless I would argue that personal identification with particular sonic preferences was not a violation of indeterminacy as practiced within the experimental music community: it was actually integral. For example, Piekut has described Cage and James Tenney's infamous performance of *Atlas Eclipticalis* (1961–62) and *Winter Music* (1957) with the New York Philharmonic in 1964 as an "improvisation" on the grounds that they were not aiming for the unforeseen, but rather a sonic ideal that was already quite familiar. As Piekut has written:

> I would contend that Cage improvised at the mixing board because he (and Tenney) had lived with and in the sound-world of indeterminacy for many years. He knew how it usually sounded; he understood its peculiar rhythms, surprising interruptions, and stochastic texture. Indeed, he had created indeterminacy—controlled it and served as its primary discursive gatekeeper.[71]

Beyond the characterization of his activity as improvisation, it is worth emphasizing that Cage could never have anticipated what ultimately took place in this performance, yet he unequivocally regarded it as a failure. I would propose that despite the undeniably unforeseen (and therefore indeterminate) nature of this performance, Cage was disappointed because he had failed to maintain the sonic standards of indeterminacy. In other words, despite his commitment to remaining open to any eventuality, Cage's conception of a successful performance of indeterminate music entailed the presence of certain stylistic features.

For all their differences, many performances of resonance aesthetics shared sonic and stylistic qualities as well. As Adam Tinkle has pointed out, the amplified conversation in *Nikola Tesla* can be traced back to Oliveros's experience with Robert Ashley's music, while the exploratory quality of the second part of the performance has a strong affinity with Alvin Lucier's *Vespers* (1969).[72] Further confluences can be discerned by analyzing recordings. For example, Gordon Mumma's recording of *Hornpipe*, a 1967 work for solo hornist and live electronics, exhibits many sonic qualities that can also be heard in *Nikola Tesla*.[73] The first half of the performance comprises short, improvisatory sounds the hornist makes while testing the acoustics of the venue (in this case, the Rose Art Museum at Brandeis University), and the second half is dominated by sustained electronic sounds. The gradual shift from fragmentary gestures of widely varying character to the drone-like texture of the electronics evokes not only *Nikola Tesla*. In fact, I regard the entire performance as an idealized expression of acoustic resonance, which is typically characterized by a brief, noisy onset and a longer, more consonant period of decay.

About halfway through the recording, Mumma plays a shrill, sustained tone using a double-reed in place of the horn's mouthpiece.[74] After 10 seconds, the electronics fade in for the first time, seemingly blending and harmonizing with Mumma. At first, the electronic timbre recalls the pure tones of an oscillator, like the ones Mumma would have used in the third section of *Nikola Tesla*. However, the texture quickly becomes more complex and inharmonic as the sound rises in volume like peals of feedback from an amplifier. Although there is no extant recording of Oliveros's "earth-shattering" finale, it is not much of a stretch to imagine that it might have sounded something like the climax of this recording of *Hornpipe*: a gradually rising flood of chaotic vibrations and raw, unpolished electronic sound.

Hornpipe is typical of works of resonance aesthetics in that the performer largely dictated the sonic content of the work through improvisation. It is also typical in that the technology employed was deeply familiar to its performer (Mumma had designed and assembled the electronics himself). For Rheinberger, a scientist's familiarity with their tools and instruments is a crucial prerequisite for the successful functioning of the experimental system. As he writes, "the more familiar a scientist is

[71]Piekut, *Experimentalism Otherwise*, 48.

[72]Tinkle, "The SAG Representative for the West Coast," 15.

[73]Gordon Mumma, "Hornpipe," *Live-Electronic Music*, Tzadik 7074, 2002. Mumma provides a detailed account of the work, and this recording in particular, in Mumma, *Cybersonic Arts*, 55–61.

[74]This occurs at about 7:39 in the recording.

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with his experimental set-up, the more effectively its inherent possibilities open up."[75] This dynamic might appear paradoxical at first glance, as it would seem that experimental musicians' familiarity with their setups would be more likely to constrain the possibilities than multiply them. For example, even though Mumma writes that *Hornpipe* "was improvised in response to the acoustical properties of each distinctive performance space," he also relied on "diverse instrumental idioms and materials that I collected and prepared over the course of several years."[76] As Mumma acknowledged a commitment to "specific kinds of sounds and theatrical effects" in his performances of *Nikola Tesla*—which occurred contemporaneously with his performances of *Hornpipe*, and which shared a similar open premise—it remains an open question as to how much each performance of *Hornpipe* actually varied.[77] Along similar lines, as Mumma, Cage, and Tudor became increasingly comfortable with their setup for *Nikola Tesla* while touring with *Canfield*, it seems likely that they would have become more efficient at reliably producing certain kinds of musical results, should they have desired.[78] Consequently, the openness of a composition like *Nikola Tesla*, in which performers are encouraged to record "particularly interesting" sounds and broadcast them over the public-address system (or the focus on "interesting" sounds in *Rainforest*, for that matter) actually reinforces whatever preexisting notions the musicians might hold regarding interesting sounds. In other words, the performers' skill was predicated not only on their ability to produce interesting sounds, but also to recognize them.

This rethinking of skill as a performer was aligned with larger priorities within the experimental music network. Many experimental musicians sought to distinguish themselves from both mainstream musical practices and the European avant-garde through a skeptical reframing of technical skill or virtuosity. By the late 1960s, dismissals of conventional displays of virtuosic technique were commonplace for experimental musicians, especially in overtly improvisational contexts.[79] In the early 1970s, Michael Nyman wrote that the "apparently routine tasks" called for in some experimental works require a "heroic virtuosity on the part of the performer" that is "unsung" and "unnoticed."[80] This understanding of virtuosity as encompassing skills that may not be culturally legible contrasts sharply with contemporary perspectives on virtuosity as a fundamentally social performance.[81] In a 1974 essay, Mumma writes that "everyone can be a virtuoso with the resources to which they have access," elsewhere alluding the "unique virtuosities" of individuals.[82] In another text, Mumma muses of his work alongside Cage and Tudor with the MCDC that "our 'virtuosity' really showed *after* the performance, when we could strike the musical parts of the set and load it into the shipping containers in less than two hours."[83] In Mumma's experience, the virtuosity of experimental music performance was not only

[75]Rheinberger, "Experimental Systems: Difference, Graphematicity, Conjuncture," 89.

[76]Mumma, *Cybersonic Arts*, 59.

[77]Mumma, *Cybersonic Arts*, 123. In fact this is true of all three works discussed, but perhaps especially so for *Hornpipe* and *Nikola Tesla*, as there is only one extant recording of either. (A shorter version of *Hornpipe* is also in circulation, but is actually excerpted from the same recording.) John Driscoll's description of *Rainforest IV* as "an improvisational coordination of the sound materials…that has become extremely familiar and ingrained in the performers" likewise suggests a similar trend. See Driscoll and Rogalsky, "David Tudor's *Rainforest*," 29.

[78]Given all of the evidence above, there is reason to suspect that performances of *Nikola Tesla* would have become more uniform over time—not less. Remarks by Oliveros (apparently contemporaneous with the work's run of performances) seem to suggest as much: "The musicians have mastered the materials of a very difficult situation and very much go their own ways. Their performance could exist independently of the dancers." Reprinted in *Music for Merce* liner notes, n.p.

[79]For example, in a passage taking aim at what he called "empty" virtuosity, the improviser Derek Bailey wrote that "although some improvisers employ a high level of technical skill in their playing, to speak of 'mastering' the instrument in improvisation is misleading." Derek Bailey, *Improvisation* (New York: Da Capo Press, 1993), 99–100. Along similar lines, the trumpeter and composer Wadada Leo Smith, in his 1973 collection on creative music *notes (8 pieces)*, argues that "to improvise, a display of flawless standardized technique is not enough: an improviser must be creative." Wadada Leo Smith, *notes (8 pieces) source a new world music: creative music* (1973; repr., Chicago: Renaissance Society, [1973] 2015), n.p.

[80]Michael Nyman, *Experimental Music: Cage and Beyond*, 2nd edition (New York: Cambridge University Press, 1999), 15.

[81]For example, David Vanderhamm defines virtuosity as "skill made apparent and socially meaningful" in David Vanderhamm, "'I'm Just an Armless Guitarist': Tony Melendez, Disability, and the Social Construction of Virtuosity," *Journal of the Society for American Music* 14, no. 3 (2020): 282.

[82]Mumma, *Cybersonic Arts*, 97.

[83]Mumma, *Cybersonic Arts*, 171.

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"unsung" and "unnoticed," it could also take place outside of the time of performance. It was also highly subjective—defined individually, rather than externally—a view that seems to accord with Cage's interest in performers' "spirit," and of what he called "spiritual virtuosity."[84]

For Rheinberger, virtuosity is synonymous with the skill cultivated by a researcher that permits the experimental system to generate new, unexpected knowledge. As Rheinberger puts it, emphasizing the embedded contradiction, "Formulated paradoxically, the more an experimental system is tied to the skill and experience of the researcher, the more independently it develops."[85] More precisely, it is the experimental researcher's deep familiarity with the tools and objects of their system that allows them to introduce the differences through which new knowledge is produced. Consequently, familiarity engenders not increasing certainty of outcome, but rather the continued production of difference—and therefore, knowledge—albeit within increasingly precise bands. At least on the surface, this rapport between familiarity and uncertainty is incongruous with the way the experimental system of resonance aesthetics has been described so far, in which familiarity and skill seem to allow for greater control and focus, rather than unpredictability and difference. The case of *Rainforest IV* illustrates this dynamic clearly: To the extent that practitioners' familiarity with the process means that specific musical results are prioritized over the possibility of the unexpected, it would seem that the research system is no longer in operation.

Nevertheless, the researcher's skill should not be mischaracterized. The experimental system is not sustained by one's ability to *make* certain things happen, but rather by the ability to *let* them happen, and, perhaps more importantly, to be able to recognize them when they do. As Rheinberger writes, experimentation "is a question of obtaining new knowledge, but precisely this knowledge cannot be achieved in the precise sense of the term, it can only happen. The virtuosity of the experimenter consists in perceiving the event—'on the fringes of the expected discourse,' as Dagognet says."[86] In short, familiarity is exactly what allows the researcher to recognize what is unexpected in the system. This conclusion reinforces the fundamental purpose of the experimental system—namely that it is organized so as to permit the unexpected to occur—but also helps to redefine what "unexpected" might mean in the context of the experimental system of resonance aesthetics. Experimental musicians' familiarity with their setups may not have always led them to new, unexpected sounds, but it did allow them to newly "discover" the familiar sounds of experimental music in novel electronic configurations. Whatever the nature and extent of these familiar sounds, accounts of both *Nikola Tesla* and *Rainforest* make clear that the performers were invested in certain sonic results, at least to some degree. The fact that the same sounds were revisited not only across multiple performances, but also in different works with different technological setups, suggests an almost theatrical conceit in which musicians reveal their virtuosity by drawing compelling sound from sources that were not only unexpected, but frequently also unexpectedly mundane.[87] From this perspective, once again taking up the scientific metaphor, the experimental sonic ideal actually functions less like an unforeseen discovery and more like a model substance, whose qualities and reactions are well known to researchers, and which is

[84]Fluxus artist Dick Higgins recalled John Cage discussing "spiritual virtuosity"—as opposed to physical or technical virtuosity—with George Brecht when they were classmates in Cage's Experimental Composition course at the New School for Social Research in the late 1950s. Quoted in Larry Austin et al., "Is the Composer Anonymous?," in *Source: Music of the Avant-Garde, 1966–1973*, eds. Larry Austin, Douglas Kahn, and Nilendra Gurusighe (Berkeley: University of California Press, 2011), 51. Cage would later describe being fascinated by Tudor's "extraordinary virtuosity, and his competence," but acknowledged that "what made him what he is for me is his spirit, or his personality—I don't know what word is appropriate here." See John Cage, *For the Birds* (London: Marion Boyars Publishing, 2009), 178.

[85]Rheinberger, "Experimental Systems: Difference, Graphematicity, Conjuncture," 89.

[86]This is the author's translation; the original is as follows: "Il s'agit d'obtenir de nouveaux savoirs, mais ces savoirs précisément ne peuvent être atteints au sens précis du terme, ils ne peuvent qu'advenir. La virtuosité de l'expérimentateur consiste à percevoir l'événement—«en marge du discours attendu», comme dit Dagognet." Rheinberger, "Virtuosité expérimentale," 134.

[87]A sense of competition and one-upmanship has always been a critical part of the reception history of experimental music, even if the musicians themselves rarely discussed their work in these terms. Richard Taruskin is alluding to this when he describes Cage as a composer who "always managed to seem so effortlessly farther-out-than-thou." See Richard Taruskin, "No Ear for Music: The Scary Purity of John Cage," in *The Danger of Music: And Other Anti-Utopian Essays* (Berkeley: University of California Press, 2009), 263.

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consequently used to calibrate or test other unfamiliar aspects of the research system. As I will illustrate below, it is the inevitable deviation from this ideal that ultimately aligns the activity of experimental music with the production of knowledge.

Epistemic Sound

If the experimental systems described above genuinely produce knowledge, as I argue that they do, it remains to be addressed how to characterize that knowledge, especially in comparison with the well-defined knowledge that results from an experiment. For example, with respect to a performance of *Nikola Tesla*, it must be acknowledged that theaters are complex spaces, encompassing multiple isolated acoustic areas and many different objects distributed in unpredictable ways, each of which has unique acoustic qualities of its own. Consequently, it is likely that a theater will vibrate at many different frequencies given sufficient amplification, especially in the relatively low range proposed by Oliveros (up to 100 cycles per second, corresponding to the sub-bass and bass ranges of human hearing). The choice of sound-making tools is also a source of unpredictability. Therefore, the knowledge produced through this process must be framed in terms of the variables at play: Something like, the theater vibrates in *this* way given *these* frequencies, *this* level of amplification, and *such and such* distribution of loudspeakers, bodies, and objects. The contingencies cascade and multiply the further one attempts to simplify the system in pursuit of the isolation of any individual variable.

Despite this complexity, what is clear is that Oliveros's composition, like Tudor's, embodies an epistemic process through which sound is put forward as a way of knowing about a space or object. The uncertain quality of this knowledge—propositional, embodied, or aesthetic—is immaterial: More significant than concrete answers is the materialization of further questions that keep the system in operation through differential reproduction. The confirmation yielded within the framework of the individual experiment reflects, by contrast, "the degeneration of an elementarily complex experimental situation," an observation that lends weight to other Rheinbergian readings of artistic practice, such as Michael Schwab's interpretation of Marcel Duchamp's *Three Standard Stoppages* as an experimental system.[88] Schwab's argument emerges through a critique of Herbert Molderings' characterization of Duchamp's work as a "pseudo-experiment."[89] As Schwab writes, "by focusing on the status of the experiment," Molderings' interpretation "runs the risk of undoing at least part of Duchamp's epistemic enterprise," while also "[failing] to perceive how the experimental system operates."[90] The same critique could be extended to the readings of experimental music put forward by Brooks and Mauceri. By resisting the simplification characteristic of the individual experiment through a complex and indeterminate arrangement of materials, interactions, and procedures, Oliveros's composition shifts the production of knowledge away from a single moment of confirmation, and toward other unpredictable, unforeseen places and objects within the system. If *Nikola Tesla* is not an experiment, it is not because it tells us too little, as the critiques discussed earlier imply. On the contrary: If anything, it tells us too much.

The same thinking can be applied to Tudor's work. Let us imagine the trajectory of a transducer such as a contact microphone during the workshop preceding a public presentation of *Rainforest IV*. Picture a workshop participant sitting at a table in front of a sheet of aluminum and a tone generator, testing which of a handful of different contact microphones to use to connect the two. During one of these tests, a particularly idiosyncratic frequency response is observed, in which certain frequencies are passed through and others attenuated in a highly idiosyncratic pattern. After having tested several contact microphones using the same sound source with the metal sheet, it seems clear that this frequency response is a unique property of the microphone; consequently, the microphone comes to the foreground as an object of interest. The participant reaches across the table for another previously wired-up object and replaces an old contact microphone with this new one. The new sound is completely unlike either the sound of the old microphone or the sound of the metal sheet with the new

[88]Rheinberger, *Toward a History of Epistemic Things*, 28.
[89]Schwab, "Experiment! Towards an Artistic Epistemology," 127–28.
[90]Schwab, "Experiment! Towards an Artistic Epistemology," 128.

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microphone. The participant then considers whether to use a glue gun or a clamp. On the workbench cluttered with objects, it can become difficult to distinguish the technical from the epistemic quite quickly. In fact, Tudor's objects could be said to embody the epistemic and the technical simultaneously through the internal conflation of the sound source and the vibration of the object. More pressing than the isolation of these two functions—epistemic objects are inevitably hybrids of one sort or another—is the answer to another question that is especially significant within the realm of music: In this experimental system, what precisely is the role of sound?

Rheinberger has devoted great attention to the representation of knowledge in his scholarship, maintaining that epistemic objects hold the status of a trace: A Derridean form of generalized writing.[91] My aim in these final paragraphs is not to contribute any broader claim of my own, but rather to focus on the role of sound within the particular epistemological context of a sub-genre of experimental music. In short, I aim to examine the sense in which sound can be regarded as a way of knowing. This belief is latent (and frequently made explicit) in a wide range of mid-century experimental musics. For example, throughout her life, Oliveros was fond of observing that even in the ocular-centric North American culture in which she lived, it is the ear that tells the eye where to look. This seems like a particularly apt way of describing the activity of a performance of *Nikola Tesla*, in which the musicians are guided throughout the theater and its adjoining spaces by sound. In fact, at virtually every point at which there is some degree of indeterminacy in the performance, the next course of action is determined by the ear. The performance begins with an amplified conversation regarding the acoustics of the space, a conversation likely informed by the amplified sounds of the musicians' own voices as they speak. This sonic knowledge informs the way the sound-making instruments are used during the exploration of the space, which, in turn, determines the sounds deemed most interesting for recording. In the final section, the frequency to which the tone generators will be set is contingent upon all that is heard in the preceding performance. As the musicians turn up the volume, two different sounds are heard to occur simultaneously: The vibration of the space, in all its unpredictable and exciting cacophony; and the sound of the tone generators, blasted at high amplification through the sound system, which excites these vibrations. Just as with Tudor's objects, sound appears concurrently in two guises: As a technology for hearing resonance or vibration, and in the audible resonance itself. The resonance, though nominally aesthetic, exhibits an epistemic quality insofar as the musicians hear it and, consciously or not, allow it to shape the future operation of the experimental system.

Just as the experimental system is driven by the emergence of epistemic objects, I propose that the experimentation that resulted in what came to be known as resonance aesthetics was oriented toward the production of epistemic sound. Epistemic sounds suggest new knowledge, or ways of knowing, interrupting the stability of the system and drawing attention to themselves, thereby extending the experimental system into the future. Through their very unexpectedness, they demand the musician's attention, and a reorientation of the system that places themselves at the center, albeit temporarily. Without such sounds and such moments, the activity of experimental music—from afternoons spent tinkering to evenings spent performing—would quickly dissipate. Epistemic sounds do not have a characteristic material or perceptual quality; they do not correlate with a certain range, loudness, or timbre. Like epistemic objects, they are defined by their function—whether or not they represent knowledge to their beholder—and in this way, exist only in relation to the researchers themselves.

Yet the fit is not a perfect one. So far I have not challenged the assumption that "unexpected" sounds are equivalent to "unfamiliar" ones. However, I would propose that what most vividly distinguishes this experimental system from Rheinberger's model is a peculiar correspondence between the familiar and the unexpected when it comes to sound. What truly interrupts and destabilizes the noisy, cacophonous sounds of a performance of *Nikola Tesla*—or *Rainforest*, or any work of resonance aesthetics—is not another new sound, but a familiar one that emerges unexpectedly from the din. Tudor was known for rarely intervening or interacting with his system once it was turned on.[92] How else to

[91]Rheinberger, *Toward a History of Epistemic Things*, 110. See 102–13 for more.

[92]Driscoll and Rogalsky, "David Tudor's *Rainforest*," 27. See also Ron Kuivila, "Open Sources: Words, Circuits and the Notation-Realization Relation in the Music of David Tudor," *Leonardo Music Journal* 14 (2004): 21.

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account for his extraordinary patience? We might venture that he was waiting for an aporic moment of serendipitous perception, or unexpected recognition.

Conclusion

Employing one of his favorite metaphors for scientific research, Rheinberger describes the experimental system as a "labyrinth, whose walls, in the course of being erected, in one and the same movement, blind and guide the experimenter."[93] He adds that an analogous process guides creative experimentation as well, insofar as artists and musicians are guided by the subterranean tunnels and shafts of earlier work as they pursue the unknown. So far I have argued that many experimental musicians were not driven by a pursuit of unknown sounds per se, but rather by unprecedented means with which to achieve the sounds of a familiar aesthetic sound world. Although the experimental system describes much of the activity of experimental music, a final, signal difference can be illuminated through this metaphor of the labyrinth. The scientific researcher hopes to explore as deep within the labyrinth as possible, slowly moving forward while being both guided and increasingly directed by previous work. By contrast, experimental musicians find themselves within the labyrinth to begin with, and seek a way out. In other words, the uncertainties of performing (or rehearsing or tinkering, for that matter) cannot be regarded as an end goal, but rather as a deep point within a labyrinthine system of research from which musicians return, again and again, to the same sound world. The performance of works like *Rainforest*, *Hornpipe*, and *Nikola Tesla* thematize—we might even say dramatize—this return, from points of increasing depth and remoteness.

It is curious to note that Frederic Rzewski's 1967 experimental composition *Spacecraft*, comprising several pages of verbal instructions for guided improvisation, employs the same metaphor, plainly stating that "the object of the music-making is to escape from the labyrinth."[94] Just as the researcher might return toward the entrance to pursue a new inquiry bifurcating from previous steps, the experimental musician ventures deeper in a subsequent performance or work only to make the return—the escape—more meaningful. Whether Rzewski's metaphor precisely matches the confluence I am describing between experimental music and the experimental system or not, he is nonetheless similarly sensitive to the existing sonic ideals that a "virtuosic" musician can draw from:

> His mind is like a complicated organ with many keys: an "inspiration" key, a "composition" key, a "communication with God" key, a "Beethoven" key, a "Stockhausen" and a "Cage" key: one for every myth…. He knows that if one thing does not satisfy him he can immediately flip a switch and turn on something else. This is his virtuosity.[95]

Rzewski goes on to suggest that the use of this virtuosity constitutes a kind of artistic failure: "he has done nothing to escape from his labyrinth."[96] Although Rzewski was not directly involved in the mainstream of resonance aesthetics, he would have been a familiar figure nonetheless.[97] His critical perspective on virtuosity, meanwhile, once again raises the issue of the relationship between the experimenter's skill and the independence with which the experimental system develops. In experimental music, it seems that the independence of the system facilitates new starting points and paths of return from within the labyrinth, but not new exits. This observation, in turn, brings experimental music into dialogue with other musical cultures: The idea that it is aesthetically interesting to follow

[93]Rheinberger, *Toward a History of Epistemic Things*, 74.

[94]Frederic Rzewski, "Plan for Spacecraft," reprinted in *Source: Music of the Avant Garde*, eds. Larry Austin, Douglas Kahn, and Nilendra Gurusinghe (Berkeley: University of California Press, 2011), 131.

[95]Rzewski, "Plan for Spacecraft," 131.

[96]Rzewski, "Plan for Spacecraft," 131.

[97]Rzewski was heavily involved in live electronic performance through his group Musica Elettronica Viva in the late 1960s and early 1970s. It is also worth noting that contributions by Mumma, Oliveros, and Robert Ashley appear in the same 1968 issue of *Source* as "Spacecraft."

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how a performer will plot a musical "return" from an uncertain starting point is a recurring theme in many traditions of improvised music.[98]

This application of Rheinberger's model prompts a reconsideration of spontaneity in musical performance more generally. For example, many writers appear eager to characterize every facet of performance as an expression of individuals' will and preparation, whether consciously or through frameworks such as embodied knowledge or distributed cognition. Yet it is possible to agree that the improviser is "always making choices," as Vijay Iyer writes, without necessarily attributing everything that occurs in performance to musicians' intentionality.[99] In fact, this point of view actually underestimates the spontaneity of performance by bracketing out the possibility of anything truly unexpected taking place, as if all possible contingencies were latent in (or between) the performers. The truth is, no musical performance ever proceeds entirely as intended: The slip of a finger may decisively guide an individual's actions, or an ensemble member's signal may be misinterpreted or missed altogether. What Rheinberger's approach illustrates is that like experimental researchers, performing musicians' skill is not merely a matter of avoiding the unexpected to the extent possible through superior coordination or preparation, but of coping successfully when it inevitably intervenes—indeed, of thriving in it. In this context, accounting for spontaneity through networks of causation, intention, or interaction is beside the point. Just as sound takes on an epistemic character because the listener recognizes knowledge in it and not because of any intrinsic quality, the unexpected is entirely a function of individual perception.

At the same time, the musical context proposes further nuance to the contours of the experimental system. Virtuosic musicians—and especially improvisers—are highly skilled at establishing conditions congenial to the production of felicitous events, even if these events are genuinely spontaneous on an individual basis. However, in musical performance these conditions are frequently collaborative and socially mediated. If Rheinberger's vision of experimental virtuosity is centered around intimacy between the scientist and the materiality of their setup, musical performance proposes an arena for experimentation in which intimacy is conceived as both distributed and reciprocal. Consider the familiarity the members of a chamber ensemble might come to share over the course of a decade or two of playing together, or the sheer number of miniscule adjustments made in and between hundreds of rehearsals and performances. Each performer grapples with their own instrument, but also with their collaborators and their instruments who, though constantly present, nevertheless always remain just out of reach. It remains to be seen how the framework of the experimental system might be extended to sufficiently describe an analogous multiplicity within a collaborative experimental research setting.

Perhaps it is unsurprising that the practitioners of resonance aesthetics seemed to prefer that their own instruments dwell beyond their reach as well. Oliveros wrote that the space "performs in sympathy with the musicians," while Tudor often expressed that his electronic systems appeared to take on a life of their own.[100] One might be tempted to see in these characterizations an echo of the Cagean experiment in which the composer represented himself as "a scientist who does nothing more than create the conditions in which the natural realm can speak for itself," as Piekut puts it.[101] Nevertheless there is clearly an important role for performers to take on in mediating between the familiar and unfamiliar, even if their activities do not appear to be particularly skillful or expressive at first glance. As Mumma writes of *Hornpipe*, even though the "cybernetic console" seems to exhibit intelligence, it pales in comparison with the capacities of the hornist, whose musical choices "involve a history of vastly complex habits, performance virtuosity skills, and interactively responsive experiences."[102] That Mumma, designer of *Hornpipe*'s electronics, was also the only performer to ever realize the composition seems to clinch the argument.

[98]For more on this phenomenon, see Drake Andersen, "(Per)forming Open Form: A Case Study with Earle Brown's *Novara*," *Music Theory Online* 26, no. 3 (September 2020): Section 7.6.

[99]Vijay Iyer, "Embodied Mind, Situated Cognition, and Expressive Microtiming in African-American Music," *Music Perception: An Interdisciplinary Journal* 19, no. 3 (Spring 2002): 408.

[100]Von Gunden, *The Music of Pauline Oliveros*, 64; and Nakai, "Hear After," 5.

[101]Piekut, "Sound's Modest Witness: Notes on Cage and Modernism," *Contemporary Music Review* 31, no. 1 (February 2012): 4.

[102]Mumma, *Cybersonic Arts*, 61.

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Although Rheinberger has written that, in an experimental system, "the better one knows one's object, the subtler it resists one's wishes," the performances and practices of resonance aesthetics make clear that the objects still resist.[103] By foregrounding this tension between the performer and the materiality of the system, Mumma, Tudor, and Oliveros avoided the essentializing and ventriloquizing tendencies of Cage's project. Cage got to know his system well enough that he could predict its results: It became a technology for hearing the voice of nature, at least as he understood it, and was soon discarded. Whereas Cage's works in the 1970s seemed to inaugurate a very different kind of research project, the material links of resonance aesthetics forged in the experimentation of the previous decade persist to the present in unexpected ways, especially in the discipline of sound art. The framework of the experimental system suggests one possible explanation for this longevity: The pursuit of the uniquely uncertain conditions under which epistemic sound could emerge continually extended the practice into the future. This trajectory seems to illustrate something fundamental about the pursuit of knowledge itself—namely that it is characterized not by increasing certainty, but rather by flux and doubt.

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[103]Rheinberger, "Difference Machines," 170.

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