

20 On Sound and Artificial Neural Networks

Florian Hecker and Robin Mackay

From the 1980s onward Erkki Kurenniemi involved himself in-depth with tuning systems, musico-mathematical relations, and concepts of artificial neural networks. The following conversation between philosopher Robin Mackay and artist Florian Hecker takes the latter as a point of departure, discussing Hecker's sound piece "Untitled (F.A.N.N.)" (2006–2013), which dramatizes the use of such a network as its core. "Untitled (F.A.N.N.)" was first produced as a contribution to the artist Cerith Wyn Evans's commission in the A. A. Hijmans van den Berghbuilding on the campus of the Utrecht University. The sound piece was designed in collaboration with Tommi Keränen, a Finnish artist and programmer, with whom Hecker has been working on software instruments for over a decade. In the following conversation, Hecker and Mackay discuss the role of artificial neural networks in electronic music in relation to Kurenniemi's research and also in relation to American composer David Tudor, whose groundbreaking work and polymath approach to performance, instrument design, and composition echo Kurenniemi's heterogeneous interests and inventions. The dialogue then turns to the cultural figure of the network in relation to concepts of identity, autonomous simulation, and the shifting frontiers between performer, composer, and instrument—themes that resonate with Kurenniemi's life and work.

Robin Mackay: How did you come to make use of artificial neural network synthesis in "Untitled (F.A.N.N.)"?

Florian Hecker: In 2006, Cerith Wyn Evans invited me to participate in a commission to be staged throughout the A. Hijmans van den Berghbuilding on the campus of the University of Utrecht. The commission was "Kunst am Bau"—pieces that were to remain on the campus for an extended period—and the other commissions across the campus were mostly sculptural, made of materials with that durational aspect in mind. Upon the invitation to realize a sound piece in this constellation with Cerith's works, and thinking about how to structure it, David Tudor's *Neural Synthesis*¹ came to mind as a possible point of departure.

RM: This is a piece related to *Neural Network Plus*, originally conceived as part of Merce Cunningham's *Enter*, which premiered at the Opera Garnier in Paris?

FH: In 1992, yes. Central to the technical setup of Tudor's piece was a neural-network synthesizer designed by Forrest Warthman, Mark Thorson, and Mark Holler² that would cocompose/coperform along with Tudor and his setup of feedback boxes and chaotic circuits.

RM: Why did this come to mind in particular? Because of the possibility of the piece's being left to "compose" itself?

FH: The use of an artificial neural network seemed to be a way to suggest a piece that would feature a certain change over a long period. It also linked to this particular piece that I found conceptually more stimulating than anything that incorporated randomness as a structuring principle. Also, Cerith, Cageian as he is, had used a random process already for the structure of light emission of a chandelier that was one of his contributions for the Utrecht project. I approached Tommi Keränen if he would like to design such a system for the installation. Tommi mentioned to me that Erkki Kurenniemi had been looking into neural networks for years, and that we should seek advice from him.

RM: Before that, had you come across Kurenniemi's work?

FH: I encountered Kurenniemi through his music in Finland in 2002. The direct and stripped-down structure of "Sähkösoittimen ääniä #4" and "Sähkösoittimen ääniä #1"³ immediately reminded me of pieces by Pan Sonic⁴ or other early publications on the Sähkö label.

RM: And Tudor, was his work a particular interest of yours? Considering that the majority of your practice is in line with what Peter Hoffmann called "explicit computer music," based on abstract synthesis,⁵ any reference to the work of Cage and East Coast experimentalism seems rather a departure.

FH: At first I was amused by the idea of Tudor, who was labeled a virtuoso throughout his career,⁶ at that point partly handing over the control of the work to a machine. I only got more curious about this lineage through ongoing remarks and recommendations by the artist Yasunao Tone that I investigate Tudor's music further. Then, while on an artist's residency at Schindler House in Los Angeles in 2004, I encountered, through a series of visits to the Special Collections at the Getty Center library, some projects to which I've returned on several occasions since then: the catalog of Lyotard's exhibition *Les Immatériaux*,⁷ the archival material to *Experiments in Art and Technology (E.A.T.)*,⁸ and the David Tudor Archives. In 2004 there were relatively few publications of Tudor's electronic pieces available. In the archive, however, I was confronted by a plethora of CDs with a digitized library of tapes made as resources for performances,⁹ and various versions of pieces. In some of these recordings, the sounds of the room in which they

were recorded and how they were recorded stuck out as a significant feature. Shortly after these listening sessions, I was in a studio in San Francisco that was equipped with a vintage Serge synthesizer and a Sony DRE S777, the “first commercial, real-time convolutional reverberator”¹⁰ that modeled existing acoustic spaces based on impulse recordings of the same; with this combination of instruments I made some tracks that, because of the blurring through the reverb, reminded me of abstracted Tudor materials.

RM: All of this was research that would later feed into the 2009 CD *Acid in the Style of David Tudor*.¹¹ And that pseudo-recognition you describe would explain “in the style of,” which otherwise seems a strange claim in relation to a mercurial experimentalist like Tudor. So the composition of the piece itself amounts to a set of (possibly misfiring) recognitions and linkages ... But there were other lines of research that fed into that work too.

FH: Yes, between 2000 and 2004 I worked extensively with a reformulated version of Xenakis’s dynamic stochastic synthesis;¹² wanting to look deeper into forms of nonlinear synthesis, I started to look into the use of chaotic equations in relation to synthesis. While doing this together with Lance Putnam at CREATE,¹³ I came across Dan Slater’s article¹⁴ on chaotic synthesis using a Buchla system in combination with a Comdyna analog computer. Due to a concurrent reading of the writings of Art & Language¹⁵ and their piece *Portrait of Lenin in the Style of Jackson Pollock*,¹⁶ the idea of “... in the Style of David Tudor” germinated.

RM: What was at stake in this piece and Art & Language’s writing around it was the question what a portrait was “of”—that although it may be “of” one thing in the sense of resembling it, in another sense it is always genetically “of” the material circumstances that give rise to it.

FH: That’s right—“in the style of” is exactly this intertwined mutuality of resembling, representing, and causal linking that you describe¹⁷—taking structures consisting purely of (acid) bass lines and analog synthesis and abstracting these, all made with a specific instrumentarium: a Buchla modular synthesizer, a Comdyna analog computer, and here also the artificial neural network.

RM: So, in the end, did you speak with Kurenniemi about the Utrecht piece?

FH: We met in Helsinki some years prior to the collaboration in Utrecht, and then, once the concept to work with an artificial neural network was set, Tommi Keränen met with him again.

RM: What did you make of his work as you became more familiar with it?

FH: I saw Kurenniemi, working as a mathematician, nuclear physicist, and expert in digital technologies¹⁸ as somehow not dissimilar to the “polymath” approach of Iannis Xenakis, Don Buchla, Dan Slater ...

RM: Tudor could also be included in this category, no? His trajectory from performer to composer, and then to the actual development of new electronic instruments, is an interesting one.

FH: Yes—incidentally, one of the most exciting parts of looking through the archival material at the Getty were the odds and ends that, of course, the archivist has organized just as meticulously as the rest: the recipe for a gin and tonic, inquiries about ordering a tandoor oven from India with shipping options both to Stony Point and New York City, handwritten recipes from Tudor’s cookbooks, postcards from Karlheinz and Doris Stockhausen—all of that amongst scores and performance patch diagrams ...

RM: Tudor talks about a search for devices and compositions whose finite situation could lead one to the “open,” i.e., beyond the finite situation of a musical composition and performance. In the case of *Neural Synthesis*, at certain sensitive points thermal “noise” can intervene in the functioning of the neural network. In abstract electronic synthesis, where one is dealing with highly complex instruments that manipulate sound at a low level, and whose behavior can never be entirely foreseen or controlled, is this an inevitability? What is the balance between control and openness in a piece such as “Untitled (F.A.N.N.)”—and is this a problematic that even interests you?

FH: The designers of the original neural network synthesizer talk about the thermal noise affecting the neuron summing lines and its consequence on the “synthesis for adding randomness to the sounds. The neuron gain is set high to maximize amplification of the noise, and then feedback attenuation is adjusted until the network is just at the edge of oscillation. The noise intermittently stimulates oscillation of the network.”¹⁹ “Openness” here is a question of scaling, with the neural network materialized in a hardware synthesizer or the entire software-based conception as used in “Untitled (F.A.N.N.).” Here, the apparent “open” has some clear bounds in “Untitled (F.A.N.N.),” in its updated version shown in *Systemics #2*²⁰ every couple of minutes, the artificial neural network—driven synthesizers and analyzers get interrupted by a short sequence of ascending and descending tones, resembling patterns as described by Albert Bregman in his study *Auditory Scene Analysis*.²¹ This formal and structural intermission corrects the “open,” as only one possible amongst other forms or states.

RM: In general, what’s your perspective on this quest for openness, with its various associations with the random, aleatory, Zen, etc.?

FH: Rather than such a search for an “open,” [I prefer] the rigorous Xenakian dynamic stochastic approach, with its drifting that can be steered where the significant pointers that led to incorporating the artificial neural network at first. It was through this more formalized approach, via the GENDYN code included in *Formalized Music*,²² to what Peter Hoffmann refers to as music out of nothing,²³ on to the chaotic oscillations that

led to Untitled (F.A.N.N.) and “Acid in the Style of...”—in these systems, it was the zones in between cyclical states and noise that I found particularly appealing as sonic material. They have an amazing, inhuman sound quality.

RM: And where does Kurenniemi sit in relation to all of this, in your view?

FH: I don’t see an obvious relation here—the instruments he conceived between 1964 and 1974 don’t deal with the relation of determinacy and indeterminacy so much on the subzero level of instrumental music as Xenakis suggested,²⁴ nor do they resonate with the bricolage of parts that were central to Tudor’s technical setup. Kurenniemi’s instruments are located somewhere else in their playability, appearance, and with their elementary models of sound synthesis.²⁵ Sonically and conceptually they might be closer to another automated music box from that time, the Triadex Muse, designed by Edward Fredkin and Marvin Minsky between 1969 and 1971²⁶—e.g., with the search for an automated composition, thinking of the use of a shift register as a core of the sequencer used in his instrument Sähkökvartetti (Electric Quartet, 1968), to create constantly varying patterns.²⁷

RM: One of the key things about early pioneers in electronic music (we could include both Kurenniemi and Tudor here) is that they often not only composed but also created the instruments upon which their compositions could be played—in fact, in many respects the two activities could not be distinguished from each other. The creation of new machines also harbors a utopian dimension, in that every machine brings with it a vision of the future composition, creation, performance, and appreciation of music. You have worked²⁸ with Xenakis’s UPIC,²⁹ which he conceived explicitly as an educational device, within a utopian vision of what he called “polyagogy”³⁰ that sought to introduce children to new nonmusical or at least nontraditional ways of interacting with sound. Kurenniemi’s DIMI series is particularly fascinating because they embody his investigation and progression over the years. I wonder first of all what are the continuing features across all these devices that are specific to Kurenniemi, to what he was trying to achieve?

FH: The UPIC appears to me as a kind of universalist instrument allowing seamless navigation between the scales, overcoming classifications between musicians and nonmusicians, as Xenakis pointed out explicitly in part 8 of *The Owl’s Legacy*, Chris Marker’s thirteen-part series on Greek culture and history.³¹ In relation to this, the look and design of Kurenniemi’s DIMIs are of relevance, the filigrane surface of DIMI-A, or the use of mundane objects like coins as an interface element with the Sähkökvartetti (Electric Quartet). They look as if they could have come straight out of Richard Hamilton’s Toaster³² rather than out of a musical studio.

RM: I also wonder whether there is something lost in the era of software instruments and laptop performance. It is difficult to imagine a software archive like the precious archive of Kurenniemi's DIMIs—perhaps this is a kind of fetishism for the physical, but it reminds me of the problem that future literary biographers will have, when all of a writer's correspondence, notes, first drafts, etc. will all have long disappeared into the digital trashcan. More generally, I wonder whether the kind of "extended brain" that is put to work in performances with manually-operated instruments—a brain that is haptic, reflexive, extending into the flesh, as for example in the *Kärlekmaskinen* (DIMIS, otherwise known as *Love Machine*, 1972)—and the concern for the user interface as a mediator between the human and the abstract matter of sound, whether all of this is on its way out of the picture of electronic music. Yourself, do you develop any of the tools you use for a given project with a view to reusing them, or to someone else being able to use them?

FH: Any custom instruments I have used over the years have stemmed from collaborations, dialogues, and "commissions" with other musicians and programmers who authored this software; in most cases they also entered into other distributions or were incorporated into the actual programming environment that they were housed within. Many of these also built upon existing models and research; some of them are actualizations or improvements on certain ideas, e.g., the updated version that Alberto de Campo made of dynamic stochastic synthesis, or Tommi Keränen's interpretation of Trevor Wishart's concept of the waveset, or Jayaganesh Swaminathan's incorporation of an audiologically meaningful third input source in Bertrand Delgutte's auditory chimeras software. The process here is one of a careful reuse every once in a while, which partly of course then ends up maintaining the supporting hardware as well. As you suggest, the physical fetishism is just as prominent in the case of software instruments—that's something that I always found interesting in electronic music specifically: what is the difference between this and that sound, and what are these qualitative differences, how are they linked to the tools as much as to the context they are experienced in?

RM: Kurenniemi expounds at length in Mika Taanila's film³³ on his conviction that the human mind will be able to be "uploaded" into some other kind of machine (rather than a "slime-based" one). This obviously has a connection with what we could call Kurenniemi's "archive fever," his dedication to preserving photographic, video, and other evidence of his everyday life in the expectation that it could be used to reconstruct him one day.

What may have seemed like an individual eccentricity twenty years ago now looks prescient: today, this obsessive media archiving of one's everyday life is the norm. It is not only possible but, I would say, inevitable, that the numerous and increasingly dense personal data archives that a lot of us create voluntarily, as a kind of immaterial labor and an everyday performance, will be drawn upon not only to represent a person

during their life but to reconstruct them after their death. The trend is toward the interconnection of various social media platforms, messaging, and other personalized apps. In effect, this creates precisely the kind of assemblage that Kurenniemi constructs: a network of archive memories dense enough to be “mined” and communicated with, as if it were “the original.”

FH: How to deal with Kurenniemi’s personal “archive fever” and the recent compulsion to archive “anything from academic research into preexisting archives or those still to be constructed, through exhibitions fully or in part based on them, to frantic competition among private collectors and museums in the acquisition of these new objects of desire,”³⁴ as Suely Rolnik suggests? Kurenniemi showed a progression from one register to the next, the period of his musical instruments was followed by a study of tuning systems³⁵ and theoretical conceptions on neural networks; it’s essential to do something else with all that material, rather than a mere scholarly reactivation or reorganization. Where does the “new” fit in?

In 1963, Xenakis wrote in the Subscription Bulletin promoting *Musiques Formelles*: “Having been obliged to make a clean sweep of so many subconscious or acquired traditions, new points of reference had to be put on record, in the same manner as my ‘works’ that result from or are provoked by the same, in order to not forget. For using man’s ability to ‘engrave’ is necessary in this tunnel, this darkness. ... This book is the temporary fruit of reflections, of trials and errors, of certain ways of thinking and doing, for example, music. Therefore, it is the tails of the coin whose heads is my musical work. Thus perhaps it may be of some pragmatic use.”³⁶

RM: This question of identity and identity traces leads me to ask what figure of the “network” means to us now: at a certain point it was a figure of hope for spontaneous emergence, for a kind of automated creativity “inspired” by biology. The ceding of authorial control to the contingencies of a semiautonomous machine seemed naturally part of the same liberatory agenda as Cage’s experiments in contingency. Today the network is more likely to appear to us as an insidious mechanism of social control. Tweaking the parameters of a network, exploring its quasi-autonomous space of possibility, searching for configurations that produce a pleasing result—isn’t this the job of a specialist in a control room directing police in order to quell a demonstration, fully informed by theories of chaos dynamics and network-inspired theories of crowd control? What do you think were the features that Tudor found appealing at the time of *Neural Synthesis*, and how does your point of view on the technology differ?

FH: Was it a pragmatic issue, one of introducing further destabilization into his performance process? Tudor was curious about autonomy since working on “Pepsillator,” a piece composed for the Pepsi Pavilion³⁷ at the Expo 1970 in Osaka, in which electronic processors were arranged in a feedback circuit to create an autonomous electronic

system with “no input.”³⁸ Evolutionary models of growths and dynamic systems have been a recurring interest for composers, even in more institutionalized settings such as IRCAM.³⁹ In her anthropological study of the institute, Georgina Born comments:

More generally, the impression of how the aesthetic was raised within IRCAM’s daily culture was through intellectuals’ sudden infatuations with new scientific, especially biological, analogies for music: a kind of constant, arbitrary, conceptual foraging. Thus, walking along the top corridor of offices one afternoon, I passed an American composer, a squatter who was keen to find a place within IRCAM. He talked with excitement of a new branch of genetic biology that promised to provide beautiful conceptual models for composition. Another day, noticed in a tutor’s room a large glossy book on Mandelbrot’s fractal geometry, a fashionable area of mathematics concerned with formulating the “logic” behind the apparently random shapes found in nature (for example, the shape of coast-lines). The tutor was learning about this with a view to importing it into his compositional schema. I learned later that it was being referred to more widely by artists trying to bring science into their work.⁴⁰

In the liner notes to *Neural Synthesis*, Forrest Warthman mentions the less theoretical and more pragmatic role of the neural network as an extended audio-signal router and synthesizer and also notes that the “the role of learner, pattern-recognizer and responder is played by David, himself.”⁴¹ With “Untitled (F.A.N.N.)” I was more interested in using the learning, structuring, and pattern-recognizing functions of the artificial neural network to produce a highly abstracted music in the style of ...

RM: Going back to this blurring of the lines between brain, network, this extended cognition, Tudor also seems to be prescient: before he even came into his own as a composer, as a performer he had become a kind of “neural instrument” himself, in the sense that composers would write specifically for him. We could see the use of a neural network as instrument—or, as he seems to suggest, as collaborator—as deliberately extending the erasure of distinctions between instrument and performer, interpreter and composer.

FH: The artificial neural network in “Untitled (F.A.N.N.)” is constantly changing the parameter settings of all synthesis processes. The composer Robert Ashley, a contemporary to Tudor, spoke of composition as “the process of constantly making a decision about when you’re going to update what you’ve just done.”⁴²

RM: There are only complex “transformers” (in philosopher Jean-François Lyotard’s phrase) for ultimately inhuman flows of information, never to be mastered by a sovereign will.

Notes

1. "Neural Synthesis" here refers to the composer David Tudor's neural network-based sound synthesizer as well as to compositions and recordings made with it originally conceived as part of Merce Cunningham's *Enter*, which premiered at the Opéra de Paris Garnier in 1992. Paris. See David Tudor, *Neural Synthesis No. 2*, Ear-Rational ECD 1039 (1993), and *Neural Synthesis Nos. 6–9* (2 CDs), CD 1602, Lovely Music (1995).
2. Mark Thorson, Forrest Warthman, and Mark Holler, "A Neural-Network Audio Synthesizer," *Dr. Dobb's Journal-Software Tools for the Professional Programmer* 18, no. 2 (1993): 50–65.
3. Erkki Kurenniemi, *Äänityksiä/Recordings 1963–1973*, Love Records (4)—LXCD 637, CD, Finland (2002).
4. Pan Sonic (originally called Panasonic) is a Finnish experimental electronic music duo consisting of Mika Vainio and Ilpo Väisänen.
5. See Peter Hoffmann, "Sleeve Notes to Russell Haswell's and Florian Hecker's Kanal GENDYN Recording," Editions Mego, Vienna (2011).
6. Austin Clarkson, "David Tudor's Apprenticeship: The Years with Irma and Stefan Wolpe," *Leonardo* 14 (2004): 5–10.
7. Les Immatériaux, March 28–July 15 1985, Grande galerie—Centre Georges Pompidou, Paris.
8. E.A.T.—Experiments in Art and Technology—is a nonprofit organization devoted to promoting the interaction between art and technology, which was launched in 1966 by Billy Klüver and Fred Waldhauer together with Robert Rauschenberg and Robert Whitman. For further information, see "Collection of Documents Published by E.A.T." at the Daniel Langlois Foundation for Art, Science, and Technology, Montreal, and "Records of the Organization Experiments in Art and Technology" at the Getty Research Institute, Special Collections, Los Angeles.
9. John Driscoll and Matt Rogalsky, "David Tudor's Rainforest: An Evolving Exploration of Resonance," *Leonardo* 14 (2004): 25–30.
10. "Sony DRE S777," Dec. 1999, <http://www.soundonsound.com/sos/dec99/articles/sonydres777.htm>.
11. Florian Hecker, *Acid in the Style of David Tudor*, Editions Mego, Vienna (2009).
12. Peter Hoffmann, "The New GENDYN Program," *Computer Music Journal* 24, no. 2 (2000): 31–38.
13. CREATE is the Center for Research in Electronic Art Technology at the University of California, Santa Barbara.
14. Dan Slater, "Chaotic Sound Synthesis," *Computer Music Journal* (1998): 12–19.
15. Charles Harrison, *Essays on Art & Language* (Cambridge, MA: MIT Press, 2003).

16. From Harrison, *Essays on Art & Language*:

“A Portrait of V. I. Lenin in the Style of Jackson Pollock” is the title of a painting, or, more precisely, it is a title given to some individual paintings within a series produced by Art & Language. ... An exhibition of “Portraits of V. I. Lenin in the Style of Jackson Pollock” was held at the Stedelijk van Abbe Museum, Eindhoven, in 1980. The title is also the title of an essay published by Art & Language, and it is the title of a song with words by Art & Language and music by Mayo Thompson, which was recorded by The Red Crayola in 1980. Before it was any of these things, however, it was a linguistic description, an ironic proposal for an impossible picture, a kind of exasperated joke (129)

17. See Robin Mackay, “Climate of Bass Hunter,” CD sleeve notes to Hecker, *Acid in the Style of David Tudor*.

18. See Erkki Kurenniemi, *100 Notes—100 Thoughts*, introduction by Lars Bang Larsen, Documenta 13 (e-book, Hatje Cantz, 2011).

19. Thorson, Warthman, and Holler, “A Neural-Network Audio Synthesizer.”

20. *Systemics #2: As We May Think (or, The Next World Library)*, Kunsthal Aarhus, September 21–December 31, 2013.

21. Albert S. Bregman, *Auditory Scene Analysis: The Perceptual Organization of Sound* (Cambridge, MA: MIT Press, 1994).

22. Iannis Xenakis, *Formalized Music: Thought and Mathematics in Composition* (Hillsdale, NY: Pendragon Press, 1992).

23. Peter Hoffmann, “Music Out of Nothing? The Dynamic Stochastic Synthesis: A Rigorous Approach to Algorithmic Composition by Iannis Xenakis.” PhD dissertation, Technische Universität Berlin.

24. Iannis Xenakis, “Determinacy and Indeterminacy,” *Organized Sound* 1 (1996): 143–155:

Therefore our problem is linked with the question of determinacy and indeterminacy in the widest sense and with so-called causality in physics, which is an aspect of determinacy. Below the zero-level of instrumental music that I have discussed, there are deeper levels which are dealt with by experimental and theoretical acoustics. The first of these lower levels is described in the language of sound synthesis, which is based on Fourier analysis of sound structure. This is the level of the analysis or synthesis of harmonics. Below this level is—due to computers—the level of the individual sound samples, up to 50,000 samples per second, representing a very high fidelity in the analysis of a sound. Probably one can discover even lower levels; I am personally convinced that sampling rates should go higher than 50,000 per second, because even at that level there is already quite a distortion.

25. See Jari Suominen, “Erkki Kurenniemi’s Electronic Music Instruments of the 1960s and 1970s,” <http://www.lahteilla.fi/kurenniemi/julkaisu/Suominen.pdf>.

26. On the Triadex Muse, see Laurie Spiegel, “Regarding the Historical Public Availability of Intelligent Instruments,” *Computer Music Journal* 11 (1987): 7–9.

27. Suominen, *Erkki Kurenniemi’s Electronic Music Instruments of the 1960s and 1970s*.

28. Russell Haswell and Florian Hecker, *Blackest Ever Black* (Electroacoustic UPIC Recordings), Warner Classics and Jazz, London (2007).

29. "UPIC" stands for "Unité polyagogique informatique du CEMAMu." See Henning Lohner and Iannis Xenakis, "Interview with Iannis Xenakis," *Computer Music Journal* 10 (1986): 50–55.
30. See Robin Mackay, "Blackest Ever Black; Haswell & Hecker; Rediscovering the Polyagogy of Abstract Matter," in *Collapse 3* (Urbanomic: Falmouth, 2009).
31. See http://monoskop.org/Chris_Marker#The_Owl.27s_Legacy_.28L.27H.C3.A9ritage_de_la_chouette.29.
32. See Richard Hamilton, *Collected Words 1955–82* (Stuttgart: Thames & Hudson, 1982), 72, 90 (90 in color).
33. Mika Taanila, *The Future Is Not What It Used to Be* (Tulevaisuus ei ole entisensä), 2002.
34. Suely Rolnik, *Archive Mania*, Documenta 13 (Hatje Cantz, 2011).
35. Erkki Kurenniemi, "Chords, Scales, and Divisor Lattices," this vol.
36. Xenakis, quoted in Sharon Kanach, "Xenakis's Hand, or The Visualization of the Creative Process," *Perspectives of New Music* (2002): 190–197.
37. Billy Klüver, Julie Martin, and Barbara Rose, *Pavilion: By Experiments in Art and Technology* (EP Dutton, 1972).
38. Ron Kuivila, "Open Sources: Words, Circuits, and the Notation-Realization Relation in the Music of David Tudor," *Leonardo Music Journal* 14 (2004): 17–23.
39. IRCAM is the Institut de Recherche et Coordination Acoustique/Musique, Paris.
40. Georgina Born, *Rationalizing Culture: IRCAM, Boulez, and the Institutionalization of the Musical Avant-Garde* (University of California Press, 1995).
41. Forrest Warthman, liner notes for David Tudor, *Neural Synthesis Nos. 6–9* (2 CDs), CD 1602, Lovely Music (1995).
42. Robert Ashley, *Perfect Lives* (Dalkey Archive Press, 2011).

Writing and Unwriting (Media) Art History

Erkki Kurenniemi in 2048

edited by Joasia Krysa and Jussi Parikka

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