The Influence of Recording Technologies on the Early Development of Electroacoustic Music

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ABSTRACT

From the earliest experiments with the manipulation of 78-rpm disks during the 1920s, the technology of recording has played a major role in the evolution of electroacoustic music. This has extended not only to the recording and reproduction of materials but also to key components of the compositional process itself. Although such influences have become less prominent with the advent of digital technology, their impact during the formative years of electroacoustic music was significant and far-reaching. This article examines some key aspects of the pioneering era of creative development through the early 1950s, with particular reference to the Bauhaus sound artists, Pierre Schaeffer and *musique concrète*, and the Cologne studio for *elektronische Musik*.

The development of resources for recording and reproducing sound has had far-reaching consequences for the art and practice of music. Hitherto the processes of synthesis and communication required the physical presence of both performers and audience in a shared experience. Today the social intimacy of an unmediated live performance in the concert hall or opera house is regularly traded for the engineered commercial broadcast or CD, where the intermediate processes of recording and editing have a significant impact on what is delivered to the consumer. This intervention of technology has created an interesting continuum between the quest for authenticity of reproduction and more manipulative applications designed for cultivating genuinely new means of musical expression. This article considers pioneering composers and artists associated with the latter activity who embraced many different aesthetics but also a common goal: the exploitation of recording technology in the pursuit of sonic art.

Key Initiatives: From Groove to Optical Sound Track

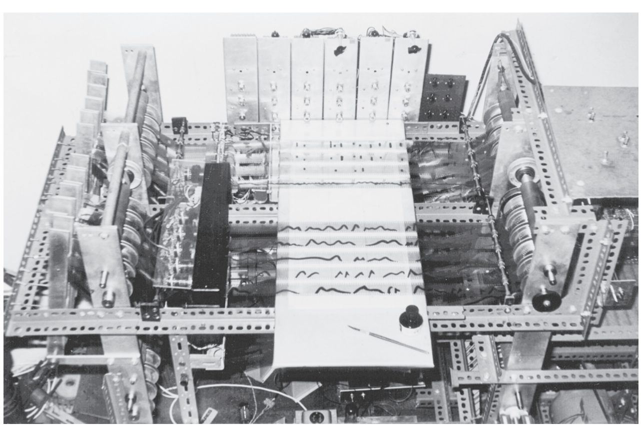
Matching expectation to reality in the search for genuinely new musical horizons presupposes the ability to hypothesize the characteristics of the unknown, and thus many early attempts to explore recording technology as a creative tool were motivated by simple curiosity rather than clarity of purpose. During the 1920s, for example, Paul Hindemith, Darius Milhaud, Ernst Toch and Percy Grainger each individually observed the subjective effects of playing gramophone records at different speeds [1]. Their discoveries, however, were mainly of an exploratory nature, and no detailed records or artifacts have survived for further study [2]. Greater significance can be attached to the work of the Bauhaus artists László Moholy-Nagy, Oskar Fischinger and Paul Arma during the early 1930s, seeking in the first instance to modify the physical contents of the record groove [3]. However, their attempts to modify this acoustical data by scratching new vibratory patterns produced only noisy distortions of the original material, and their attention quickly turned to the medium of optical sound recording, developed in the first instance for the film industry [4].

Two competing systems had emerged, one developed by RCA and the other by Western Electric [5]. In both cases the physical characteristics of audio signals are registered photographically alongside the main sequence of film frames on a continuous track located towards the edge of the film. The Bauhaus artists adopted the RCA system, which produces waveform patterns similar in nature to those encountered in the record groove, registered as an opaque profile within the track [6].

The German filmmaker Walter Ruttman employed optical recording facilities for his pioneering sound-only work *Weekend* (1930), constructed from urban and recreational sounds recorded over a weekend in Berlin [7]. This imaginative collage, however, required only relatively simple editing techniques to juxtapose and overlay the sounds. The Bauhaus artists took an altogether more proactive approach to the manipulation of optical recordings, discovering that the constituent wave patterns could be physically altered using a fine paintbrush and suitable masking solutions and solvents.

By 1932 Fischinger had established the basic principles of composing with "drawn" sound [8], demonstrating how the basic parameters of pitch, time and amplitude interact to create a composite optical waveform [9]. The frequency components of pitched musical sounds exhibit strongly cyclic characteristics, and such features produce distinctive contours when coded in an optical format. Conversely, many percussive

Fig. 1. Daphne Oram's Oramics system, circa 1966. (Photo: Martin Cook, © Daphne Oram Estate. Courtesy of Hugh Davies.)



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sounds are discontinuous, exhibiting noiselike spectra that are much less likely to produce a similar degree of visual coherence. There are, however, no guarantees that attractive patterns will translate into interesting sounds or vice versa, and this lack of continuity led to some highly speculative ventures based largely upon trial and error. Experimentation extended to the use of a variety of sources for optical scanning, ranging from fingerprints and abstract shapes to letters of the alphabet and photographic images [10].

Although this practical linkage of image and sound broke new ground, important precedents for such a closely integrated artistic environment can be found in the work of such artists as Wassily Kandinsky and Franz Marc, representing ideals close to the heart of Expressionism [11]. The use of optical recording technology, however, facilitated a direct correlation between visual representations and their sonic realization. Both Fischinger and Moholy-Nagy experimented with combinations of hand-drawn optical tracks and abstract film images. An extreme example of audiovisual integration is Moholy-Nagy's film *Sound ABC* (1933). In this work, the film component is based entirely upon direct projections of waveform images copied from the accompanying sound track, thus inviting the audience very directly to explore possible relationships between image and sound.

Others were soon to pursue the possibilities of drawn sound tracks, most immediately the Australian filmmaker and sound designer Jack Ellitt, who briefly experimented with the technique in London in 1932 [12]. The work of Norman McLaren is also notable in this context. As a student at the Glasgow School of Art during the early 1930s he became interested in filmmaking, taking a keen interest in Fischinger's work. Having first experimented with overlaid visual images in *Love on a Wing* (1938), produced for the General Post Office film unit in London, McLaren moved to New York in 1939, where the Guggenheim Museum financed his direction of a series of short abstract films using drawn sound [13]. In 1941 he transferred to the National Film Board of Canada, where he was able to continue making experimental films from time to time. The quality of his work is more refined than that of the Bauhaus artists, which was partly a reflection of improved technology. In *Loops* (1948), for example, the movement of loops of red and white against a blue background form an intricate counterpoint with accompanying washes of synthetically drawn sound.

The narrow width of the optical sound track used for standard 35mm film formats proved a major drawback for those seeking to explore the full potential of optical sound synthesis. Having experimented in the USSR with the possibilities of hand-drawn optical sound images in 1929 [14], Yevgeny Sholpo decided to develop a pioneering audio-only synthesis facility known as the Variophone (1932), using the full width of the film as a sound recording area [15]. This desire for more controllable composing tools inspired the Americans John and James Whitney to develop an optical synthesizer in 1947 using a system of pendulums to draw waveform oscillations [16].

In the United Kingdom, Daphne Oram took optical synthesis technology a stage further in the design of her Oramics system (Fig. 1), completed in 1966 [17]. Ten synchronized strips of 35mm film were used to code control information for the operation of an associated synthesizer. Three strips were used to code discrete pitch information using rectangular neumes [18] drawn on lightly traced musical staves, with two further strips available for coding other discrete functions, such as the frequency settings of a tracking filter. The remaining five strips were used for registering continuous functions such as the amplitudes of individual notes.

Today visual representations of sound information are integral features of synthesis and signal-processing software designed for personal computers. Although such sophisticated tools could scarcely have been envisaged during the earlier part of the 20th century, both John Cage and Edgard Varèse recognized the creative potential of optical representations of sound data during the 1930s [19]. At the time their predictions of future resources for electroacoustic composition were predicated upon the continuing prosperity of optical recording. Matters, however, were to take a rather different course with the emergence of a rival technology, that of magnetic tape [20].

Musique Concrète

Of all the pioneering initiatives of the late 1940s and early 1950s in Europe and America, by far the most methodical and reflective was that of Pierre Schaeffer and his associates. Working in the Club d'Essai, Paris, using resources provided by Radiodiffusion Télévision Française (RTF), he developed the art and craft of *musique concrète* [21]. Most significantly, his formative work between 1948 and 1952 involved the manipulation of both gramophone and magnetic recordings.

The origin of Schaeffer's interests can be traced back to 1942, when he methodically began to study the subjective characteristics of natural sounds. His training as an electronic engineer encouraged him to establish a quantitative classification of these features, for example, the attack and decay characteristics of individual sounds and the nature of their evolving timbres. In January 1948, Schaeffer started a more rigorous series of experiments in his laboratory, concerned not only with creating a morphology of individual sounds but also with the development of re-synthesis techniques that would allow the sounds' constituent components to be used for the purposes of composition.

The evolution of *musique concrète* was heavily influenced by the functional characteristics of an increasingly outdated recording technology. Notwithstanding the rapid pace of technical advances during the immediate post-war years, Schaeffer had access only to a rudimentary 78-rpm disk-cutting lathe and four turntables for this initial phase of research and development. This situation raises some interesting issues concerning the role of technology in *musique concrète*. The early record experimenters had encountered a number of technology-specific features such as the effect of turntable mass on the resulting speed trajectories when changing from one speed setting to another. Schaeffer's requirements were of an altogether different order, taking on a particular significance by virtue of his deliberate exclusion of any procedures that directly modified the physical content of the recordings.

These self-imposed constraints contrasted sharply with the highly manipulative world of the Bauhaus sound artists. Synthetically generated sounds were incompatible with Schaeffer's concepts, as were the electronic processing of sounds or physical alterations to the contents of the record groove itself other than to isolate individual sounds or segments thereof. Known as *objets sonores*, these components formed the basic materials for composing *musique concrète*. The functional characteristics of the technology thus materially influenced the art and craft of *musique concrète*, in terms of both the creative working environment and the acoustic quality of the results. The recording medium itself suffered from major problems of fidelity. These included a poor audio bandwidth, extending only to about 7 kHz, the high background noise levels and an uneven frequency response that colored the timbre [22]. It was the characteristics of the recording lathe, however, that proved especially significant in terms of the compositional process.

I have already noted above that the cutting of a groove to record acoustic information involves a physical alteration to the record surface. Moreover, the maximum recording time at 78 rpm was very limited, typically little more than 3 minutes with the use of standard 10-inch records, and it soon became clear that two or more playback machines would be required for the construction of longer works [23]. In essence the possibilities were limited to (1) playing recordings backwards as well as forwards, (2) juxtaposing sounds extracted from their original time continuum, (3) playing back recordings at a different speed and (4) creating repeating sound loops by deliberately breaking the groove at selected points [24].

Schaeffer's procedures were further limited by a number of practical constraints. The isolation of sounds or segments within sounds, for example, required the use of a hand-operated volume control during the recording process to attenuate the signal electronically to either side of the chosen extract. Furthermore, several recordings on the same disk required a series of suitably spaced grooves. Even the construction of a simple montage, joining a number of different segments together to create a freshly recorded sequence of sound events, demanded an elaborate set of studio procedures to line up and accurately cue the constituent recordings on different turntables. The playing of recordings in reverse posed particular difficulties. Whereas professional-quality 33⅓-rpm turntables can withstand short-term spinning of the platter by hand in either direction, the same is not true of older 78 systems, given the much larger mass of the pickup arm. The solution here was to reverse-mount an additional arm, allowing the stylus to trail the motion of the groove.

It was inevitable that these operational characteristics materially affected the composition of early *musique concrète* works. Schaeffer's very first complete study, *Étude aux chemins de fer*, for example, constructed from recordings made at the depot of the Gare des Batignolles, Paris, during early 1948, makes extensive use of looped sounds. Here the mechanical and repetitive nature of much of the material, such as the sounds of train wheels passing over joints in the track, usefully reduces the subjective impact of discontinuities every time the stylus jumps across the groove break. In other contexts these abrupt interruptions were to become significant and often undesirable artifacts. Yet another factor limited the flexibility of this technique. The duration of the loop is determined by the rotational speed of the turntable: approximately 0.8 seconds at a standard playback speed of 78 rpm. Further constraints are encountered if attempts are made to increase the loop length significantly by using lower speeds of rotation. At 30 rpm, for example, the loop duration has increased only to 2 seconds, and if the recording speed is reduced any further, the fidelity of reproduction starts to degrade rapidly.

The quintessential work to emerge from this formative period of *musique concrète* is *Symphonie pour un homme seul* (1949–1950), produced jointly by Schaeffer and Pierre Henry, who had joined the staff as an associate composer. This essay in 11 movements dissects and reinterprets the internal and external sounds produced by individuals, from shouting, humming and whistling to footsteps, knocking on doors and playing orchestral and percussion instruments. Here the constituent *objets sonores* are for the most part complete sound events in their own right, spoken, sung or performed on instruments. As a result, the processes of re-synthesis are primarily based upon the juxtaposition of these elements to create new perspectives regarding association and contrast.

Our insight into the impact of recording technology on *musique concrète* is greatly enhanced by the detailed day-to-day records kept by Schaeffer during these formative years [25]. From a historical perspective, looking back at a working environment that has no true parallel today, these revelations are most instructive, not least in identifying the precise ways in which technical possibilities and constraints proved to be of such material significance. In 1951 the RTF recognized the true significance of Schaeffer's work, commissioning the studio engineer Jacques Poullin to design a new studio for *musique concrète*. A fundamental consideration was the replacement of the disk cutter with modern recording facilities based upon magnetic tape, consisting in the first instance of a set of mono tape recorders and an experimental three-track machine.

Three further tape-based devices were constructed to assist in the processes of analysis and re-synthesis. The first of these, known as a Morphophone, consisted of a continuous tape-loop system with 10 playback heads, the latter providing successive reiterations of the recorded signal that could be blended to produce a pulsing type of reverberation [26]. The other two systems, known as Phonogènes (Fig. 2), played prerecorded tape loops at different speeds. One machine offered a continuously variable playback speed range. The other created tempered pitch transpositions controlled via a 12-note keyboard, with a two-position octave transposition switch to extend the overall range to two octaves. The transformation in terms of the enhanced range and scope of compositional opportunities thus afforded could not have been more dramatic. In particular it became possible for *objets sonores* of different duration to be looped with ease and considerable precision. Moreover, these sounds could be easily recalled and transformed by reproduction at different pitches.

The initial response from other studio users, however, was far from that expected. Schaeffer's diary for 30 April 1951 notes that "the studio is a battlefield: Everyone is fighting" [27]. His primary associates, notably Henry and Poullin, had come to the view that the use of the tape recorder unwittingly destroyed many of the features intrinsic to the philosophy of *musique concrète*. As a direct consequence, strenuous efforts were made to re-create key features of the older composing environment, with varying degrees of success [28]. The new technology encouraged Schaeffer to modify his notions of *musique concrète* to embrace the more general concept of *experiences musicales*. The influence of newer associates such as Luc Ferrari and François-Bernard Mâche also led to this major reformulation of creative objectives and the technical means for their realization, now including the use of synthesis and processing techniques other than those directly associated with the medium of recording [29].

ELEKTRONISCHE MUSIK

Although a number of the features associated with the formative years of *musique concrète* are unique to its concept, some interesting parallels can be established with the development of *elektronische Musik* in Cologne, established by the radio station Nordwestdeutscher Rundfunk (NWDR) in 1951 [30]. In many respects *elektronische Musik* represented the antithesis of early *musique concrète*, pursuing a philosophy that rejected any use of natural sound sources in favor of an

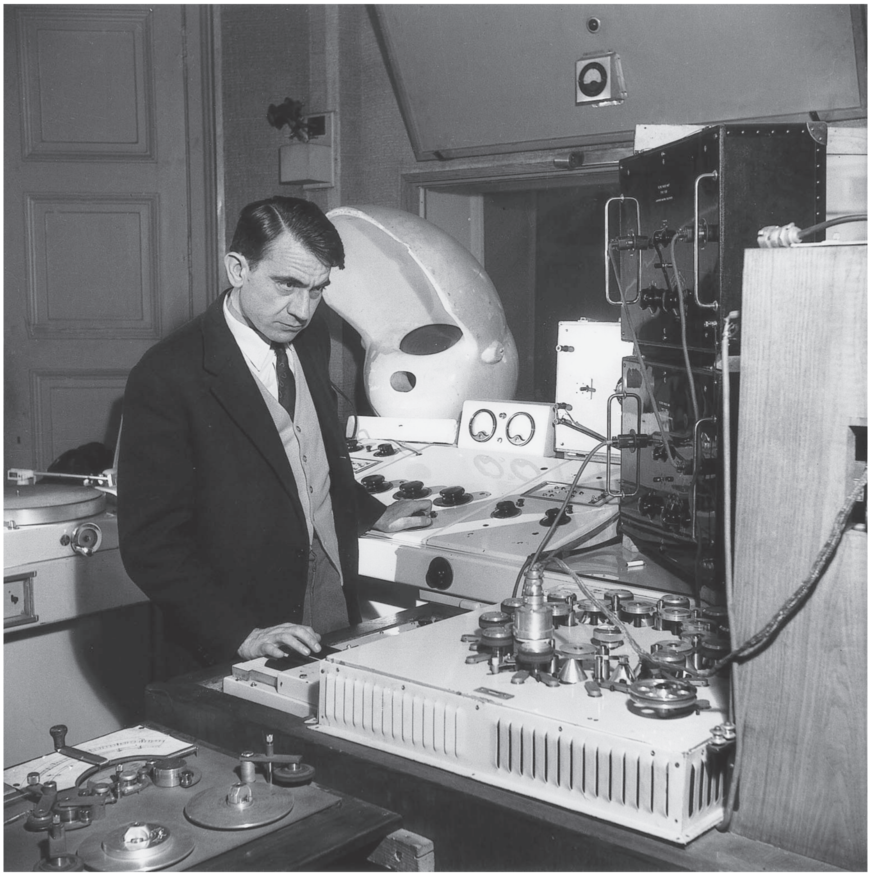

Fig. 2. Pierre Schaeffer in front of a Phonogène, one of the special tape recorders designed for his studio, circa 1963. (Photo: Serge Lido, © Archives Institut National de L'Audiovisuel, Groupe de Recherches Musicales, Paris)

entirely synthetic environment, creating sounds from electronic tone generators. This highly formulaic approach was driven by the desire to further Anton Webern's principles of serialism in order to embrace every aspect of composition, eliminating the use of the traditional music score and its interpretation by performing musicians [31]. The tape recorder became an integral part of this deterministic process, which involved the manipulation of recorded material in ways no less intensive and painstaking than those required for the production of *musique concrète*.

The studio recording facilities consisted of two single-track tape recorders, a variable-speed tape recorder and a four-track recording system [32]. The latter, built by the Albrecht company, consisted of two stereo recorders linked together and synchronized by means of perforations inserted along the edge of each reel of magnetic tape, manufactured to a special width of 17.5 mm. The variable speed facility consisted of a specially modified Allgemeine Elektrizitats Gesellschaft recorder, offering a continuously variable playback speed that allowed recordings to be transposed over a maximum range of about 13 octaves. The quest for total ordering in every aspect of synthesis encouraged the use of a single sound source, a high-precision sine-wave oscillator manufactured by Bruel & Kajer. This device generated a pure electronic tone, entirely free from any harmonic coloration, variable in both pitch and amplitude. Composite timbres, otherwise known as tone mixtures, could be created precisely to order by overlaying sine waves of appropriate frequencies and amplitudes. This working environment demanded a highly methodical approach, using the multitrack recorder to register up to four individually recorded components at a time from the single master oscillator. These components could then be mixed and re-recorded to permit further components to be added as required.

Two of the most significant works to emerge from this early era of *elektronische Musik* were composed by Karlheinz Stockhausen during 1953–1954, at the start of his long and fruitful association with the Cologne studio. Stockhausen had spent the previous year in Paris studying with Olivier Messiaen and just prior to his return he visited Schaeffer's studio and composed a short *concrète* study, *Étude* (1952). In so doing he engaged directly with the art of creating individual sound objects, recording sounds on tape and then isolating selected fragments thereof using a razor blade and splicing tape. Unlike the record groove or the optical sound track, the registration of sound waves on tape produces magnetic patterns that are invisible to the eye, precluding any visual interaction with the data itself. The primary advantage of the medium is the precise and strictly proportional relationship that exists between the duration of a sound fragment and the length of recording tape required for its registration [33]. All that is required is knowledge of the speed of the recorder, expressed in centimeters (or inches) per second, and a ruler to measure out the tape.

This simple physical relationship allowed Stockhausen to explore the musical potential of complex rhythmic structures, using tape fragments of predetermined length and duration to create precisely ordered patterns [34]. Aspects of this direct engagement with the operational characteristics of the recording medium were to feature in his first two Cologne works, *Studie I* (1953) and *Studie II* (1954). In the case of *Studie I* Stockhausen determined the duration of each tone mixture by taking the value of the strongest frequency within the mixture and dividing this number by 10. He then applied this new number as the physical length, in centimeters, of the tone mixture recording. In *Studie II* the composer generated the tone mixtures themselves from short extracts of each tone, precisely measured and spliced together in order of ascending frequency to create a tape loop. He then processed the resulting sequences of arpeggios via a reverberation unit to create a quasi-continuous, dynamically pulsing sound.

As in the case of *musique concrète*, the evolution of *elektronische Musik* was to embrace increasingly more flexible approaches to the art and practice of composition, embracing both the synthetic and the natural sound worlds. Although the electronic facilities became increasingly sophisticated, the tape recorder, editing block, razor blade and splicing tape still provided the primary means of shaping and manipulating such materials for many years.

Such a close bonding of recording technology to the compositional process had yet another parallel in terms of concomitant developments in the United States, starting with the Music for Magnetic Tape project. This was pioneered in New York by the filmmakers Louis and Bebe Barron in 1948 and subsequently developed by a group of experimental composers during 1951 and 1952 that included Earle Brown, John Cage, Morton Feldman, David Tudor and Christian Wolff [35]. Notwithstanding their allegiance to a very different set of aesthetics than those of Paris or Cologne, these composers wielded the razor blade with equivalent precision and purpose, using short extracts selected from all manner of recordings to create abstract works of significant complexity and diversity. Works such as *Imaginary Landscape No. 5* and *Williams Mix* by John Cage formed part of this venture, the editing flexibility of magnetic tape proving invaluable in the prosecution of Cage's interests in the use of chance as a tool for composing. These random-selection tape techniques were revisited for the construction of *Fontana Mix*, completed in the Studio di Fonologia Musicale, Milan, in 1958 [36]. In 1955 the Canadian scientist and composer Hugh Le Caine completed the prototype for a multi-track tape recorder that allowed six different reels of tape to be played simultaneously, with independent control of their playback speeds. This extension of the tape loop principles used in the design of Schaeffer's Phonogènes led to five different production versions over the following 12 years, the first being installed at the University of Toronto in 1959.

New Horizons: The End of a Pioneering Era

The late 1950s proved a watershed in the evolution of electroacoustic music. Traditional concepts of studio design reached their zenith with a second wave of studios that, like their predecessors, relied upon the tape recorder as both a general-purpose recording medium and a primary tool for shaping and manipulating sound material. This period of expansion embraces both the Studio di Fonologia Musicale, established in 1955 by Luciano Berio and Radio Audizioni Italiani (RAI) in Milan, and the San Francisco Tape Music Center (SFTMC), established by Ramon Sender and Morton Subotnick in 1959 [37]. Both centers of creativity drew freely upon the role models of *musique concrète* and *elektronische Musik*, breaking down further the ideological boundaries associated with these pioneering developments.

This expansion increased the pressure for improvements to the technology, not least in terms of reducing the high dependency upon manual cutting and editing procedures to manipulate sound material. The seeds of a design revolution, however, were already bearing fruit, starting with the launch of the RCA synthesizer in 1956, subsequently installed at the Columbia-Princeton Electronic Music Center in 1959 [38]. Its use of a punched paper tape control system to regulate a comprehensive range of synthesis and processing facilities transformed the technology that had originally inspired the Pianola into a powerful, programmable means of creating electroacoustic music without the intermediate assistance of a tape recorder [39].

By the mid-1960s, the concept of integrated design had led to the commercial voltage-controlled synthesizer, launching a technology that offered increasingly powerful and versatile facilities for both composition and performance [40]. Tape-based composition, however, was to remain a popular medium for a number of years, its eventual demise being heralded by the development of digital recording and an increasing emphasis on computer technology.

What has nonetheless been lost in these changes is the intimate and very productive relationship that developed between many composers and the physical representation of their sound materials as tangible objects to be handled and manipulated as entities in their own right. For all the additional sophistication offered by modern graphically based sound-editing facilities, not least the ability to manipulate the physical characteristics of sound waves in a visual environment, the clicking of the editing mouse offers a very different type of creative experience.

References and Notes

1. See Herbert Russcol, *The Liberation of Sound* (Englewood Cliffs, NJ: Prentice-Hall, 1972) p. 68.

2. The Hochschule für Musik in Berlin took an early institutional lead in 1928, facilitating a research program in the manipulation of phonograph records involving both Hindemith and Toch.

3. During the recording process, acoustical waveforms are converted into equivalent oscillations via a cutting stylus, used in turn to register a corresponding pattern of vibrations in the record groove. These patterns are clearly visible under a microscope.

4. See Glossary.

5. The RCA system uses a Variable Area format whereby fluctuations in the audio signal are registered as variations in the width of sound track exposed to light during recording and thus rendered opaque when the film is developed. The rival system developed by Western Electric uses a Variable Density format whereby these fluctuations are represented by corresponding variations in the overall opaqueness of the entire sound track.

6. The variations in the solid profile are analogous to the outline of a dark mountain range observed at a distance against a bright skyline.

7. This work proved an important reference point for several works associated with *musique concrète* and the subsequent Groupe de Recherches Musicales, for example *Presque Rien No. 1* (1961), by Luc Ferrari, which starts out as a similar collage of country and seaside sounds before proceeding to more elaborate transformations.

8. See Glossary.

9. Credit for similar discoveries is also due to another German artist with Bauhaus connections, Rudolf Pfenninger. Pfenninger's work on drawn sound led to a pioneering demonstration film, *Tönende Handschrift* (1932). See also Robert Lewis and Norman McLaren, "Synthetic Sound on Film," *Journal of the Society of Motion Picture Engineers* **1** (1948) pp. 233–247.

10. Fischinger and Moholy-Nagy experimented extensively with these possibilities.

11. Kandinsky's interests in linking visual images with theories of musical timbre were strongly stimulated by his association with Schoenberg. Futurists such as Luigi Russolo and Bruno Corra were also interested in the association of sound with color.

12. Unfortunately, none of his experimental materials have survived. See Roger Horrocks, "Jack Ellitt: The Early Years," *Cantrills Film Notes* (1999–2000) pp. 93–100.

13. Sadly, only *Allegro* (1939) was to survive and even this film eventually disintegrated as a result of too many performances.

14. Other artists, such as Arseny Avraamov, carried out similar experiments in the USSR.

15. Aspects of this technology were subsequently adapted for the ANS synthesizer, developed at the Moscow Experimental Studio in 1958 and named after Alexander Nikolayevich Scriabin.

16. See John Whitney, "To Paint on Water: The Audiovisual Duet of Complementarity," *Computer Music Journal* **18**, No. 3, 45–52 (1994).

17. Further details of Oramics can be found in Daphne Oram, *An Individual Note: of Music, Sound, and Electronics* (London: Galliard; New York: Galaxy Music, 1972). (Oram's piece, *Four Aspects,* appears on *Not Necessarily English Music,* Vol. 11 of the Leonardo Music Journal CD Series. A note about her work, written by Hugh Davies, is included in LMJ11's CD Companion section.)

18. See Glossary.

19. See, for example, John Cage's essay "The Future of Music: Credo" (1937), reproduced in John Cage, *Silence* (London: Caldar and Boyars, 1968) pp. 3–6, and Edgard Varèse's 1937 address to a meeting of the Seattle Arts Society, reproduced in Fernand Ouellette, *Edgard Varèse*, Derek Coltman, trans. (London: Caldar and Boyars, 1973) pp. 146–147.

20. Since the film industry subsequently migrated towards magnetic sound tracks, it is somewhat ironic that the digital revolution has re-established the fortunes of optical sound recording within the film industry.

21. See Pierre Schaeffer, *À la recherche d'une musique concrète* (Paris: Éditions du Seuil, 1952).

22. The associated resonant peaks are especially prominent if the playback stylus directly drives an acoustic horn.

23. These technical requirements provided an interesting bonus, since they facilitated early experimentation with spatial projection using independent loudspeakers for each turntable. This was first explored in *Symphonie pour un homme seul,* composed jointly by Schaeffer and Pierre Henry and performed live at the first public concert of *musique concrète,* staged in the hall of the École Normale de Musique, Paris, on 8 March 1950.

24. Such techniques have a number of features in common with the hip-hop art of turntabilism, pioneered by artists such as Kool Herc, Afrika Bambaataa and Grandmaster Flash during the 1970s. Although the pioneering work of Schaeffer provides an important precedent for such activities, it is important nonetheless to recognize that the musical objectives of *musique concrète* and hip-hop are driven by different aesthetics, and caution must be exercised in making direct comparisons.

25. See Schaeffer [21].

26. A more compact version of such an arrangement was subsequently marketed as a commercial product in the early 1960s, known as the Watkins Copycat.

27. Schaeffer [21] p. 96.

28. A fuller perspective is provided in Peter Manning, *Electronic and Computer Music* (New York: Oxford Univ. Press, 2003).

29. This expansion of activities led to the birth of the Groupe de Recherches de Musique Concrète in 1953, renamed Groupe de Recherches Musicales (GRM) in 1958.

30. Although NWDR is now known primarily for the work of Karlheinz Stockhausen, the responsibility for its conception and technical design fell to others, notably Werner Meyer-Eppler, Herbert Eimert, Robert Beyer and NWDR technical director Fritz Enkel.

31. See Glossary.

32. The technical specification of the early Cologne studio has been variously misrepresented, largely as a result of faulty recollection and post hoc documentation. In this context the description recorded in the archives of NWDR may be taken as definitive. See Fritz Enkel, "Die technischen Einrichtungen des Studios für elektronische Musik," *Technische Hausmitteilungen des Nordwestdeutschen Rundfunks* **6** (1954) pp. 8–15; translated as "The Technical Facilities of the Electronic Music Studio of the Cologne Broadcasting Station," by David Sinclair, *National Research Council of Canada*, Technical Translation No. 603 (1956).

33. The same is also true in the case of optical sound tracks, except that the tape is shuttled frame by frame rather than at a steady speed.

34. Stockhausen was not the only visiting composer to conduct such experiments in Schaeffer's studio. His teacher Olivier Messiaen also completed a short rhythmic study, *Timbres-durées*, in 1952.

35. The project terminated in 1952 when members of the group left to pursue their interests elsewhere.

36. Cage first encountered the ancient Chinese text on random selection, the *I Ching*, in 1950 and used chance operations in the selection and ordering of recorded sounds for these pieces. See Michael Nyman, *Experimental Music: Cage and Beyond* (Cambridge, U.K.: Cambridge Univ. Press, 1999).

37. The SFTMC became a public access studio in 1961.

38. See Harry F. Olson and Herbert Belar, "Electronic Music Synthesizer," *Journal of the Acoustical Society of America* **27,** No. 3, 595–612 (1955).

39. The RCA synthesizer was originally supplied with a directly coupled disk-cutting lathe to record its sound output, a feature soon discarded in favor of the tape recorder.

40. The key development in this context was the sequencer, a device that allowed the functions of the synthesizer to be programmed electronically rather than mechanically, as was the case with the RCA synthesizer.

Discography

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Glossary

drawn sound—any method of synthesis that seeks to create sounds from the shapes of hand-drawn images, using an optical playback system to convert these characteristics into acoustic waves.

neume—a generic term for the various scored representations of music prior to the evolution of modern music notation during the 17th century. Rectangular neumes were widely used in the 13th and 14th centuries, their sounding duration being indicated in the first instance by the length of the rectangle.

optical sound recording—a recording technique whereby the characteristics of sound waves are coded photographically onto film. In conventional use the associated variations in air pressure are coded as equivalent variations in film exposure, registered via a modulated light beam.

serialism—a technique that developed from Arnold Schoenberg's principles of composing with 12 tones, first formulated in the early 1920s and developed further by his pupils, notably Alban Berg and Anton Webern. This ordering of the notes of the chromatic scale in fixed permutations was extended in due course to other attributes of instrumental writing such as their duration and dynamic articulation.

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