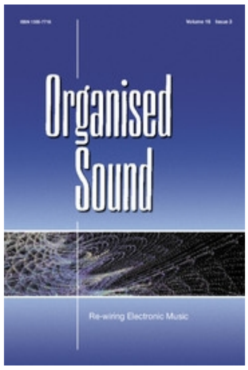

A history of sampling

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Organised Sound / Volume 1 / Issue 01 / April 1996, pp 3 - 11
DOI: null, Published online: 08 September 2000

TUTORIAL ARTICLE

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Since the mid-1980s commercial digital samplers have become widespread. The idea of musical instruments which have no sounds of their own is, however, much older, not just in the form of analogue samplers like the *Mellotron*, but in ancient myths and legends from China and elsewhere. This history of both digital and analogue samplers relates the latter to the early musique concrète of Pierre Schaeffer and others, and also describes a variety of one-off systems devised by composers and performers.

1. INTRODUCTION

Most people are unaware that our current transition from analogue to digital technology is the second stage in a development that began around the middle of the last century, culminating in the mid-1870s. Up to then all communications had been digital,[1] though not necessarily binary, for example the electric telegraph and Morse code as well as much older non-electrical systems like semaphore and Native American smoke signals. It was the virtually simultaneous invention of the telephone (Alexander Graham Bell) and the phonograph (Thomas Alva Edison) that ushered in a century of analogue technology.

The principal technique used in our second digital era was devised by Alec Reeves in 1937–8 under the name *pulse-code modulation* (PCM), in which error correction was also foreseen (Atherton 1988). Reeves, a researcher in telephony for ITT (later STC) in Paris, developed PCM after experimenting with pulse-amplitude, pulse-width and pulse-time (or pulse-position) modulation (figure 1). In the 1990s it is hard for us to imagine the difficulties that were involved in devising such a new digital system in an analogue world, and indeed it was not until the introduction of semiconductors that this approach became practical. The first simple PCM system for radio telephony was operational by 1943; later Reeves' work was developed elsewhere, including a team at Bell Labs headed by Harold Black (1947–8).

[1] Sound is perceived in an analogue way, as continuous events in time, but it is possible to create sounds not only in this way but also digitally, by means of sequences of short impulses that are much too fast to hear individually; this is particularly suited to computers and computer-based equipment, which use a binary system in which all information is coded as 'yes' or 'no', 'on' or 'off'.

At the end of the 1980s other digital methods of solving some of the problems inherent in high quality PCM began to be explored. In figure 1(b) *pulse-amplitude* is shown as a vertical measurement in which information is encoded as the relative height of each successive regular pulse. The remaining possibilities are horizontal, such as a string of coded numerical values for PCM, and the relative widths (lengths) of otherwise identical pulses and their density (the spacing between them). Both of the latter were also explored by Reeves; the former is used today in the similar techniques of *pulse-width modulation* (PWM, used by Yamaha and Technics), *pulse-length modulation* (PLM, used by Sony) and *pulse-edge modulation* (PEM, used by JVC), while the latter is the basis of Philips' *pulse-density modulation* (PDM).

Since the late 1970s the term 'sampling' has been applied in music to the method by which special musical instruments or apparatus digitally 'record' external sounds for subsequent resynthesis. The term was, however, originally used to describe how the waveform of any sound could be analysed and/or synthesised in PCM simply by measuring its amplitude or loudness level at each of a sequence of vertical 'slices' taken many thousand of times per second (figure 2). Because, for musical purposes, these slices are normally made at a frequency of between 40,000 and 50,000 times per second (in other words more than twice the highest audible frequencies), every nuance of even the most complex waveforms can be captured (Watkinson 1991).

Edison's cylinder phonograph was the first system ever devised for both storing and replaying any chosen sound or sequence of sounds. It involved a special storage medium on which the recording could be permanently retained. With the new analogue techniques that Edison and Bell had introduced into a digital world it is hardly surprising that they did not foresee how substantially their inventions would affect the future of the whole planet, and indeed for some time their significance went unrecognised. In 1878, several months after his invention of the phonograph, Edison described several possible applications in a patent which included an early form of *Speak-'n'-Spell* (that does not appear to have been constructed), to teach the relationship between each letter of the alphabet and its sound: a set of typewriter keys, each labelled with a single letter, activated the playback of individual sections of a long cylinder that contained the spoken forms of those particular letters.

In the subsequent century many other recording systems were developed, both analogue and, more recently, digital, all of which have been proposed or utilised as the basis for musical instruments and comparable systems, whereby, cuckoo-like, the instrument has no voice of its own, but can be said to 'speak with the voice of another instrument' (Wiffen n.d. [?1991]). For the lack of any better word, *sampling* is used in this survey to describe all of these methods of storing and replaying sounds, using both analogue and digital techniques. Indeed, recent terminology describing digital systems can not only be usefully applied to analogue ones but also gives us greater insight into the ideas and ingenuity behind them.

2. EARLY IMITATIONS OF SPEECH AND OTHER MUSICAL INSTRUMENTS

The concept of one instrument that sounds like another is not a new one. In Roman times one of the oldest instruments, the *hydraulis*, the early pneumatically powered pipe organ, was expanded by adding separately controllable parallel sets of pipes (ranks) which were later to be identified by the names of other instruments whose timbres they most closely resembled, leading to the large multitimbral instruments that were installed in many mediaeval European cathedrals. By the eighteenth century birdsong imitations and percussive sound effects were occasionally incorporated. From around 1800 a number of large mechanical organs known as *orchestrions* specifically imitated all the instruments of the symphony orchestra or military band with many ranks of pipes and free reeds in addition to built-in percussion instruments. In the second half of the twentieth century imitations of earlier instruments became available on electronic keyboard instruments, and after the supplanting of analogue synthesizers by digital ones during the 1980s, manufacturers even began to cater for musicians' nostalgia by incorporating digital equivalents of the timbres of some of their analogue predecessors; their programmability also made it comparatively simple for users to create their own timbres, and in some cases to set up small third-party mail order businesses to sell them to other owners.

There has also been a long history of speech synthesis, in which the human voice is artificially recreated, for a variety of motives (Davies 1979). This goes back to very early myths and legends, especially from China, such as a bamboo spike fixed below a

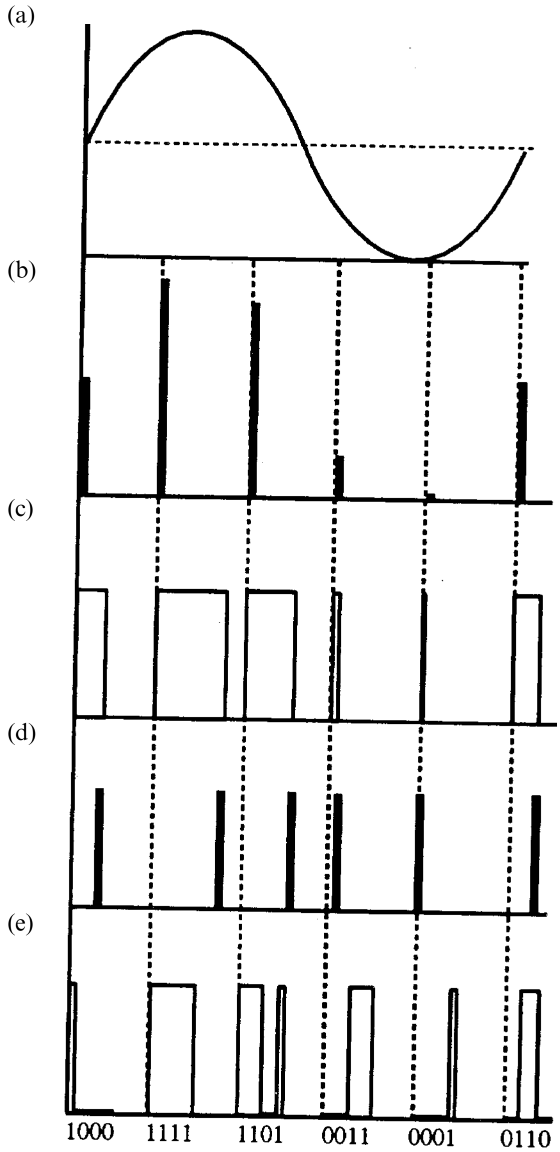


Figure 1. Four different digital versions of the same simple analogue signal (a). For the sake of clarity these diagrams are coded with only 4 bits (normally 14, 16 or more bits are used), and show only a small proportion of the hundreds or thousands of sample 'slices'. A sequence of measurements of an analogue signal requires values both for time (horizontal axis) and for amplitude (vertical axis). All measurements of a digital signal are related to a constant, very short time unit, so that only one value is needed: these diagrams show the signal depicted by pulse amplitude (b), width (c), time displacement (d) and, the simplest, its coded binary numerical value (pulse code) (e). The dotted line in (a) is a representation of the zero amplitude axis normally used to show the positive and negative values of an analogue signal. In all diagrams of figure 1 this zero line has been lowered so that the base line is now zero. This avoids the use of complex coding systems to represent negative numbers.

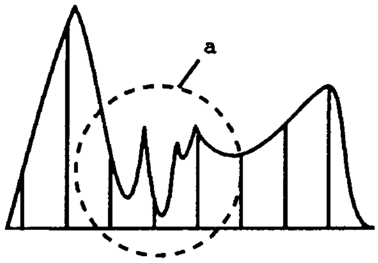


Figure 2. A more complex waveform, showing how its outline can be translated into sampled 'slices'; the closer these are together (in other words, with a higher sampling frequency), the more accurately the signal will be represented. In this example the rapidly changing section (a) would not be sampled correctly.

sliding temple door that ran in a groove in the floor, producing the sounds 'Please close the door' and, in reverse, 'Thank you for closing the door', as well as the speaking heads attributed to several leading European religious figures in the thirteenth century, such as Albertus Magnus and Roger Bacon. Serious exploration with bellows-powered machines began in the second half of the eighteenth century, from simple talking dolls to elaborate keyboard-controlled systems in which mechanical equivalents of the human throat, mouth and larynx were manipulated. One such machine (in which the air was mouth-blown) was constructed in 1863 by Bell at the age of sixteen, only thirteen years before he invented the telephone. A pioneering twentieth century machine was the keyboard-operated *Voder* (Voice Operation DEmonstratoR), devised by Homer Dudley and others at Bell Telephone Laboratories in 1937, a year after their invention of the *Vocoder* (Davies 1984). Simple apparatus for imitating animal sounds from the late eighteenth century onwards featured string-pulled miniature bellows; mouth-blown bird calls and whistles are, of course, much more ancient.

Finally, the very earliest, albeit unwitting, form of sampling. In the late 1960s Dr Richard Woodbridge experimented with retrieving sounds (but did not succeed in his real aim, actual speech) that were 'recorded' from the immediate environment during the decoration of some antique pots, where a pointed stick was used to make fine grooves while the potter's wheel was turning; these sounds obviously included the noises made by the wheel itself (Woodbridge 1969). A report on this inspired Gregory Benford's science fiction story *Time Shards*.[2] A decade later Woodbridge's idea was explored independently by Dr Peter Lewin in Toronto. If any such ancient sounds are to be discovered, today's sophisticated laser beam technology (as used in compact disc players and in a very expensive high-tech LP record player marketed since 1990 by Elp in Japan) with computer enhancement should prove more successful than the experiments carried out by these two men.

Out of all of these ideas, it is only in the case of the decorated pots and the myth of the Chinese temple door, however, that sounds could have been recorded. In the other methods, the recreation of a particular sound quality required a comparable method of generating sound vibrations, often, as with organ pipes and reeds, using a completely different principle of sound production. From the phonograph onwards, this restriction no longer existed. Among Edison's earliest practical applications of the phonograph were, once again, talking dolls.

3. ANALOGUE SAMPLING: ELECTROMAGNETIC

In 1887 Emile Berliner was the first person to extend the idea of Edison's cylinder phonograph successfully, as the disc gramophone. In the following decade Valdemar Poulsen developed the Telegraphone, the first magnetic recorder, using magnetised wire. The earliest proposals for basing a musical instrument on a sound recording system were several keyboard phonographs using multiple prerecorded cylinders or discs (including patent applications made by Michael Weinmeister, Austria, in 1906, Antoine Chatard, France, in 1907, and Demetrio Maggiora with Matthew Sinclair, Britain, in 1908), while an electromagnetic system by Melvin L. Severy (the inventor of the *Choralcelo*[3]), describing the possibility of inscribing recordings of musical notes onto rotating magnetic discs, formed part of his US patent 1218324 (applied for in 1907, but only finally granted in 1917).

After World War I other inventors patented, and in some cases constructed, musical instruments that were based on one or other of the then currently available sound recording techniques (Davies 1984). In parallel with the development of the magnetic recorder as a dictating machine during the 1920s, early patents were granted to K. Fiala (Germany, 1920), R. Michel (Germany, 1925), A. Douilhet (France, 1925) and, especially, Charles-Emile Hugoniot (France, 1921–2) for instruments in which electromagnetic wires, discs or cylinders were the

[2] A researcher's long-awaited discovery of actual 'recorded' speech turns out to consist mainly of everyday chatter; planned for inclusion in a time capsule, perhaps this will not seem any more consequential to the capsule's future discoverers than the rest of its contents.

[3] An exact contemporary of the historically better-known pioneering Telharmonium, the Choralcelo was first demonstrated in 1909. It resembled a two-manual organ; it not only had a normal piano mechanism but also produced sustained organ-like timbres by electromagnetically vibrating the piano strings as well as bars and sheets of glass, wood and metal, using rotating magnetic discs and wheels. For all of this a special machine room was required. Several instruments were installed in private homes in the USA.

recording media. Around 1930 A. Schmalz and Earle L. Kent also explored such approaches, the latter with loops of metal ribbon, and in 1942 a young Cuban composer, Juan Blanco, proposed a *Multi-organ* based on wire loops, but could not afford the fee to patent it. Electrostatic discs containing sampled waveforms photo-etched from oscillograms were proposed in a British patent by Estell Scott (1937). Other similar patents were taken out up to at least 1950 (e.g. Graydon F. Illsey, for magnetic discs), but none of them led to an effective instrument. It was not until 1964 that a successful instrument based on the magnetic tape recording technology of the time was marketed, which is normally considered to have been the first 'sampler': the *Mellotron*.

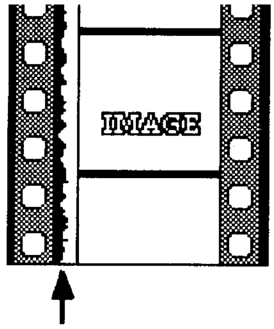
The problems that arose with early electromagnetic systems included the lack of an adequate frequency response, the difficulty of creating a magnetisable surface that was completely constant and the wear and tear produced by its contact with a playback head. Of these, only the latter affected musical instruments based on gramophone discs, but although these were explored in the late 1920s by J. B. Blossom, N. Banks-Cregier and others, they were nevertheless unsuccessful.

4. ANALOGUE SAMPLING: PHOTOELECTRIC

The introduction of the optical film soundtrack for the sound film at the end of the 1920s added a powerful new recording medium in which many of the problems described above were largely solved; the sound is photoelectrically recorded on a narrow track beside the visual images (figure 3(a)), and the fact that it is visible means that it can even be monitored and analysed. Most of the photoelectric organs and organ-like instruments from the late 1920s and 1930s were based on the mechanism of a rotating disc that interrupted the passage of a beam of light between its source and a photocell (already used by Hendrik van der Bijl in 1916 and envisaged in 1921 by Hugoniot), thus avoiding the wear and tear of direct contact with the surface of the recording. Many of these systems used a principle derived from that of the siren, interrupting the light beam by a rotating opaque disc in which holes or slits had been cut (sometimes in combination with a static waveform mask); these do not concern us here, but a few were based on transparent glass or celluloid discs on which photographically derived waveforms were outlined (figure 3(b)).

These discs were created by one of two techniques. In the first, more common method, the waveforms were initially drawn by hand and then photographed, as in the work of Norman McLaren (Davies 1984); some more experimental approaches even involved photographing letters of the alphabet and facial pro-

(a)



(b)

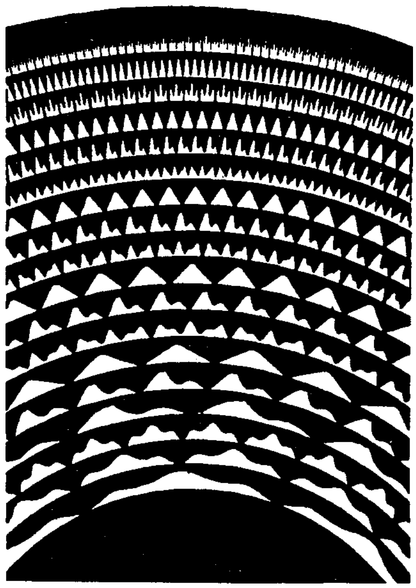


Figure 3. (a) Representation of a short section of film. At the edges are the sprocket holes; the single line of the soundtrack, indicated by the arrow, is a recording of any combination of music, speech and other sounds. In the projector the film is transported in such a way that the soundtrack passes between a light beam and a photocell. (b) Photoelectric tone-wheel (for the *Lichtton-Orgel*); each ring on the glass disc produces one of several different waveforms at a different frequency (the number of times the waveform is repeated in its ring). When the disc is rotated, each ring varies the way in which a light beam affects a photocell.

files. These therefore produced synthesised and not sampled sounds. In the second method, visual representations of sounds from existing musical instruments, such as could be shown on a cathode ray tube, were photographed. (Existing photographic images that do not represent acoustic sources can also be used, as in Guy Sherwin's short abstract films *Speed and Sound* and *Musical Stairs* (both 1977), in which moving images of railway tracks and the steps of a metal staircase are also the source of the optical soundtrack.)

The difference between these two techniques does not necessarily produce any great difference in the resulting sound, especially if an accurate visual representation is copied by hand; it is comparable, in today's terms, to the difference between a realistic digitally synthesised imitation of an existing instrument and a sampled recording of the same instrument. Among the dozen or so photoelectric instruments invented in this period, at least three involved sampled sounds (Rhea 1977, Davies 1984): these were the *Hardy–Goldthwaite organ* (New York, *c.* 1930), Edwin Welte's *Lichtton-Orgel* (1934–6), with discs that were mainly derived from recordings of famous European pipe organs (Davies 1984), and – mainly used for sound effects – the *Singing Keyboard* (Frederick R. Sammis, Hollywood, *c.* 1936). The latter was the closest to the *Mellotron*: a short length of film with optical soundtrack was assigned to each key and played back when that key was depressed. Two further pioneers of photoelectric instruments of the period, Emmerich Spielmann (Austria) in 1931 and Pierre Toulon (France) in the mid-1930s, proposed sampled photoelectric discs, but did not construct such systems, while patents from the period include systems based on film loops by Victor H. Severy and by Clet Bedu, and on discs by the Bechstein piano company.

A further early application of sampling on optical discs was for storing both sound and speech in some telephone speaking clocks from the mid-1930s. Earlier speaking clocks (probably not used with telephone systems) were based on gramophone discs (as proposed by Edison in his 1878 patent), such as the one devised by B. Hiller in Berlin in 1914 (preceded by his sprocketed celluloid film system of 1911, attributed by another source to Max Markus in 1902), which contained forty-eight parallel disc-like grooves, one for each quarter hour over a twelve-hour period. Telephone speaking clocks were introduced in Rome in 1931 and in Paris in 1932, and may well have employed optical mechanisms, as was definitely the case with a machine built by the Swedish company Ericsson in 1934. In the same period E. A. Speight and O. W. Gill constructed *TIM* (accessed by dialling those three letters) for the British telephone system, which was introduced in London in 1936 and by 1939 was in use in twelve more cities. It contained four separate concentrically banded discs for different segments of the spoken message plus the three electronic timing 'pips' ('At the third stroke it will be . . . precisely: * * *'). One of these machines has been restored and can be seen and heard in the Museum of Science and Industry in Birmingham, UK, while the prototype for the Mk. II version (1954), with three such discs, is on display at the Science Museum in London, UK.

5. MUSIQUE CONCRÈTE

In 1948 at the Paris radio station (RTF) Pierre Schaeffer initiated the activity in *musique concrète* that directly or indirectly influenced nearly all subsequent tape-based compositions. For the first three years, however, this was carried out not with tape recorders but with the older disc apparatus. Just as with the earliest Edison phonographs, machines were available both for recording sounds onto disc and for replaying (as well as mixing) them. A particular technique devised by Schaeffer was the *sillon fermé* (closed or locked groove) in which – similar to the later tape loop – a short sound was recorded in a groove that formed a complete circle rather than spiralling inwards. Schaeffer's diary for 1948 documents the various stages that led him to this new medium, which were initially influenced by the traditional approach of making music with musical instruments in real time. These included the idea of an organ based on gramophone turntables (April 1948), even imagining himself, Hollywood style, surrounded by 'twelve dozen' turntables (Schaeffer 1952). Indeed, he developed a great facility in the studio for 'performing' the playback and level controls of several (often four) playback turntables for creating his early sound collages, thus putting together – especially if the discs contained more than one closed groove – a type of sampling machine.

History, however, led Schaeffer in a different direction. Perhaps the most radical feature of his work was the assembly of the final recording in several successive stages. A further development occurred in 1951, when the French radio obliged Schaeffer's group (initially with great reluctance) to replace all their disc recorders. Several other composers also created pieces by means of disc manipulations around this time (Tristram Cary, London, from 1947; Paul Boisselet, Paris, from 1948; Raymond Chevreuille, Brussels, and Mauricio Kagel, Buenos Aires, from 1950), but none of them matched Schaeffer's sustained and developing compositional activity in the medium. An unusual early example of a work that features treated prerecorded sounds that are to be played back in synchronisation with live performers – possibly the first such work to be written – is Daphne Oram's unperformed *Still Point* (1950) for double orchestra, three prerecorded 78 rpm discs (instrumental sounds) and live electronic treatments of the type that could be carried out at any broadcasting station of the period.

6. THE TAPE RECORDER

At the end of World War II a new tool had emerged, which was to form the basis for the new era in electronic music: the magnetic tape recorder. Earlier problems of the mechanisms, magnetic recording surface and electrical techniques (such as high frequency bias) had been satisfactorily resolved, and the machine was soon marketed with great success. Its earliest creative use, with less than ideal magnetised paper tape as the recording medium, appears to have been in film scores (including *Desde las nubes*, 1948) by the American composer Jack Delano, working in Puerto Rico from 1946. Between around 1948 and 1951 the tape recorder replaced all previous recording systems, such as gramophones and magnetic wire recorders, at radio stations in Europe and North America. Very soon creative experimentation with the new medium began: electronic music studios were set up in several countries, some with specialised forms of tape recorder. In 1953 in Paris, for example, where the group had transferred all their disc techniques to the new medium of tape, Schaeffer patented the *Phonogène*, in which a loop of tape ran past a set of twelve replay heads, any one of which could be engaged by means of a capstan with a different diameter, thus enabling the composer to transpose a sound to any semitone within an octave. Several Canadian electronic music studios received models of Hugh Le Caine's keyboard-controlled *Special Purpose Tape Recorder* or *Multi-Track* (1955), in which up to ten stereo tapes or tape-loops could be individually varied in speed. But even with two or three unmodified tape recorders a variety of imaginative transformational techniques were possible by means of carefully prepared short tape loops; used in different ways a loop could, regularly or irregularly, impose not only a rhythmic pattern but also vibrato, a dynamic outline or an envelope on a single sound source. Such techniques were not restricted to musique concrète studios; they were also, for example, a significant feature of the earliest work in the electronic music studio at the WDR in Cologne. Special-purpose tape recorders from the early 1950s include the *Heiss–Vollmer machine*, which permitted superimposition on a single machine (based on an idea from the WDR studio), and the *Springer machine* (and its later derivative the *Tempophon*), in which a rotating head enabled *either* duration *or* pitch to be modified – rather than both simultaneously.

Commercial performance instruments based on the tape recorder followed soon afterwards. In the 1960s the first successful sampling instrument, the *Mellotron* (later, for legal reasons, manufactured as the *Novatron*), was based, much like the *Singing Keyboard*, on short lengths of magnetic tape (Davies 1984, Vail 1991, Elleridge 1993). Only small quantities of its immediate predecessor, Harry Chamberlin's *Rhythmate* (1952 to *c*. 1980), were built, and neither of its 1970s offspring (using eight-track tape cartridges), Dave Biro and Rick Wakeman's *Birotron* and the *Bandmaster Powerhouse* rhythm machine, was much more successful. Photoelectric sampling systems briefly emerged once again around 1970, with the small *Optigan* (which used flexible 30 cm plastic discs), marketed by the toy manufacturer Mattel as a type of home organ, and its derivative the *Vako Orchestron*. But while a few electromechanical instruments managed to survive during the 1970s, by the early 1980s the advent of digital recording totally superseded all previous sound-generating systems in cost, capability and efficiency. An exception is the work of musician Jacques Dudon, who since the mid-1980s has developed a series of unusual photoelectric instruments, but his hand- and computer-drawn discs use the principle of the optical siren and are not samplers.

7. DIGITAL SAMPLING

The first digital sampling instruments appeared as long ago as 1971. These were electronic church organs manufactured by the Allen Organ Company in Pennsylvania. Like the Welte *Lichtton-Orgel* in the 1930s, the samples were recorded from a wide range of pipe organs, although in this case individual pipes were transported to Pennsylvania or were specially commissioned from organ builders. Rocky Mount Instruments, a subsidiary of Allen, developed this approach further with samples from theatre pipe organs in the portable *RMI Keyboard Computer* (1974), which was virtually a polyphonic synthesizer in which the waveforms were loaded from punched computer cards (Carson 1995). These two instruments were followed in 1979–80 by the first versions of the *Fairlight CMI*, the *Synclavier* and the *Emulator*, all of which were capable of creating new samples.

Digital sampling involves the assessment in terms of amplitude of the waveform of the sound to be recorded, which is sampled in tiny slices at a rate normally between 15 kHz (for telephony) and 50 kHz. Such an analysis is the exact reverse of digital synthesis (and thus closely related), whereby a sound is assembled from a series of similar tiny slices and by a digital-to-analogue converter (figure 2). Since any waveform can be plotted in terms of loudness variations vs time, a digital analysis or synthesis of its contour, however complex, by means of a sequence of sampling slices is sufficient to establish not only its timbre but also its dynamic level. Given this relationship between sampling and digital synthesis, it is not too surprising to learn that the designers who founded the Ensoniq company in the mid-1980s found that the digital synthesis chip they had developed for their first product was also ideal for sampling. Thus they decided to launch the company with the highly successful *Mirage* keyboard sampler.

In the same period the manufacturers of the two top-end computer-controlled digital synthesizers which were largely based on sampling, the *Fairlight CMI* and the *Synclavier*, began to extend the digital storage capacities of the instruments substantially; in the case of the *Fairlight* this necessitated a new model. They targeted their systems not so much at musicians but at the commercial recording industry, as 'tapeless studios' – thus the relationship between recording systems and musical instruments based on the same principles came full circle. Speaking clocks also became digital in the 1980s, such as British Telecom's *Chronocal* (1984), a sampler in which PCM-encoded speech and electronic 'pips' are stored in ROM (Read Only Memory) and accessed under microprocessor control.

During the second half of the 1980s sampling became a common part of every manufacturer's electronic keyboard range (surveys have included Gilby 1987, Samplers 1989, Samplers '94 1994), not only in dedicated instruments but also as an additional method of generating more complex sounds. Since 1988, synthesizers, electronic organs and pianos have increasingly featured both synthesised and sampled sounds (or 'resynthesis', in which synthesised sounds are based on modified samples). These are sometimes kept as separate groups of waveforms and sometimes more intimately fused. Thus, for example, Roland's *Linear Arithmetic* synthesis (as in the D-series of synthesizers) provides several choices that include mixing synthesised sounds with PCM ones derived from samples and the two types ring-modulated together, while the sounds of some other recent instruments are created by placing a sampled attack in front of a synthesised body. By 1991 80 per cent of synthesizers were based on sampling/synthesis combinations, and with computing power greatly increasing and at the same time becoming much cheaper, the distinction between the two will soon become even more blurred. It is likely that samplers, which have to date stored their samples on floppy disks, hard disks or CDs to be loaded into RAM (Random Access Memory) when required, will soon access sounds in real time directly from permanently running high-speed hard disks, CDs, or some future storage medium.

A new area of the popular music industry in the 1990s has been the growth of selections of sampled sounds on third-party commercially available CDs and CD-ROMs, supplying a vast range of recordings of many instruments and sounds (as well as rhythmic patterns), including sample libraries created by well-known musicians in rock and jazz, such as Keith Emerson, Giorgio Moroder, Miroslav Vitous and Hans Zimmer; a close parallel to this is the rapid expansion of clip-art for computer graphics. Some of the sample compilations that are devoted to analogue electronic instruments include a few *Mellotron* samples, while in 1994 the Mellotron Archives produced the first CD-ROM devoted entirely to this early type of sampler (Kean 1994).

8. EXPLORATIONS OF SAMPLING BY MUSICIANS

Apart from commercial productions, a number of one-off instruments and systems based on treatments of prerecorded sounds have been built or adapted by musicians for their own performances. Earlier ones involved storage on disc or film soundtrack, while more recent ones have been based on magnetic tape or actual sampling machines. Once again only those that use sampled sounds are described here. Gramophone records were experimented with (especially by means of reversal of playing direction and speed changes) in the 1920s and 1930s by composers such as Darius Milhaud, Edgard Varèse and Stefan Wolpe (at a Dada performance in 1920 where eight record players ran at different speeds playing back different pieces of music, combining serious and popular music and including recordings of a Beethoven symphony played very fast and very slow), but did not result in any compositions, except for three recorded studies (now unfortunately lost[4]) produced by Paul Hindemith and Ernst Toch in 1929–30.

John Cage composed several works that involve gramophone records: an early tape composition *Imaginary Landscape No. 5* (1951–2), which consists of eight layers of precisely timed extracts from any combination of forty-two gramophone records, and live performance in *33⅓* for twelve gramophones (1969) and part of the accompaniment for the singers in *Europeras 3, 4* and *5* (1990–1), while in his *Imaginary Landscape No. 1* (1939) test recordings containing constant and variable frequency oscillator sounds are manipulated by hand. Various hand-held pointed objects replace the gramophone stylus in part of Mauricio Kagel's *Acustica* (1968–70). Other manipulations of records occur in the rhythmic 'scratching' adopted by disc jockeys in the 1970s, which is only one of the wide range of transformation techniques developed since 1979 by Christian Marclay for his performances with multiple turntables (Cutler 1994). Marclay often features composite discs assembled from different fragments, an approach that was pioneered in an experimental manner in 1965 by Milan Knížák under the title *Broken Music* (his *Bossa Nova Suite* of 1990 is an excellent example of this). Such work was featured in a European touring exhibition *Broken Music* on the theme of the record as art object (Block and Glasmeier 1989). More recent explorers of scratching include David Shea, Martin Tétreault and Philip Jeck (Dery 1992), whose *Vinyl Requiem* (1993) is performed by three people with more than 200 vintage record players.

[4] At a conference in Berlin in 1993 it was reported that in the mid-1980s the discs by Hindemith had been offered to the director of a German musicological institute, who refused them, after which their owner almost certainly threw them away!

Such an approach already characterised the very first sound collage recordings, created in the late 1920s in Germany in particular. Hindemith and Toch's *Grammophonmusik* studies, based on instrumental and vocal recordings, were mentioned earlier. After the introduction of the film soundtrack for the 'talkies' in the late 1920s, a number of film makers used the soundtrack on its own, without visuals, because it was the only existing longer duration recording medium (compared with the 3–4 minutes of one side of a 78 rpm disc), and one that could easily be cut and spliced. Only two of these survive: Fritz Walter Bischoff's *Hallo! Hier Welle Erdball* and Walter Ruttmann's better-known *Weekend*,[5] which evokes life in Berlin through intercutting words, music, sounds and noises. Film music during the 1930s, especially in France, featured various treatments of sound recordings – similar to those mentioned with gramophone records, and probably created with discs before being transferred to celluloid – by composers such as Yves Baudrier, Arthur Honegger and Maurice Jaubert (Davies 1968). Often an eerie quality was added to the sound by writing out and recording the music in reverse, then playing the recording backwards, as Jaubert did for the cortege-like slow motion pillow fight in *Zéro de conduite* (1933).

One area within taped electronic music has been that of quotation from pre-existing music, usually by other composers, just as in instrumental and vocal works from every type of music in the second half of the twentieth century. More acute problems of copyright and plagiarism can be caused, however, because of its employment of actual recordings (thus involving performers and their record companies in addition to composers), especially where the quoted extracts are of more than a couple of seconds in length, and thus potentially recognisable. Among the best known early work in this vein is James Tenney's *Collage No. 1* ('*Blue Suede*') (1961), which is based entirely on Elvis Presley's recording of *Blue Suede Shoes*. Around 1970 a Californian composer lost a court case brought against him by two of the leading electronic music composers in New York for the unauthorised use in one of his tape works of extracts from their own music. With the advent of digital samplers in the 1980s this became common among record producers in popular music, where it was considered worth 'stealing' even a single sound, such as a bass drum, from another record (legend has it that one record producer sampled someone else's bass drum sound only to find that it had in turn been previously sampled from an earlier recording of his own). The most interesting example in recent experimental music has been the work of the Canadian John Oswald, the undistributed CDs and master copies of whose 1989 'not for sale' *Plunderphonic* were handed over to be destroyed in order to avoid litigation, especially because it not only based one track on a song recorded by Michael Jackson, but also featured on the cover the singer's face collaged onto a naked female body (Oswald 1990, Cutler 1994). With support from various musicians and publishers Oswald has continued his sophisticated work in this vein (begun around 1975), including a CD to celebrate the fortieth anniversary of the record company Elektra based on recordings by its own artists (1990) and *Grayfolded* (1994), based on fifty-one live performances of a song by the Grateful Dead, who had given him free access to their personal archive.

Live manipulations of prerecorded magnetic tape in the manner of playing a musical instrument have been explored by a number of musicians since 1960, making particular use of the fact that the tape can be played forwards or backwards. Short lengths of tape provide the sound sources in Laurie Anderson's *Tape Bow Violin* (1977), replacing the hairs on her violin bow, on which they are drawn past a replay head mounted on the violin. A similar system was used in an early instrument by Michel Waisvisz, where lengths of tape are pulled backwards and forwards by hand past a replay head mounted on a stand. Even shorter prerecorded tape fragments were glued to flat surfaces and played back by a hand-held replay head in Nam June Paik's *Fluxusobjekt* (1962), Jon Hassell's *Map* (1967–8) and his quartet *Superball* (1969), and Akio Suzuki's more recent *Lateral Thinking Instrument*; in the two later examples, strips of tape are lined up parallel to each other to form a two-dimensional rectangular block that can be played back from any direction. Dick Raaijmakers' *Der Leiermann* (1991) features a complete recording of Schubert's song of that name, about an organ grinder, played back on a converted reel-to-reel tape recorder on which the tape is spooled through the heads rather unsteadily by turning a crank-handle.

Commercial digital samplers are now used in the performance of a variety of contemporary compositions, in particular in the work of François-Bernard Mâche since 1986, including *Tempora* (1988) for three samplers, and in recent works by Michel Waisvisz, beginning with *The Archaic Symphony* (1987); the sophistication of his control system 'The Hands', developed since the early 1980s, has also permitted him in *The Voice Catcher from Steim* (1994) to process in real time sounds recorded from members of an audience in less formal situations. Samplers have also not been immune to unusual explorations by composers. Sophisticated performance controls of cheap samplers with limited capabilities, such as those built into effects pedals for live performance

[5] A CD 'single' of *Weekend* was issued in 1994 on Metamkine MKCD010 (France).

treatments, have been developed by Nicolas Collins in *Devil's Music* (1985) and in much of his subsequent work, especially when used with his highly effective modified trombone controller. More recently the New York group 'Impossible Music' (Collins, David Weinstein, Tim Spelios and Ikue Mori) 'interferes' with the programming of portable CD players to make them function as simple samplers for musical purposes, with all the expected methods of editing and looping, just as was done earlier with analogue record decks and tape recorders; indeed a CD player designed for such 'scratching' was recently marketed.

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CD-ROMs OF SAMPLERS

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This article was first printed in *Experimental Musical Instruments* (August 1989), substantially expanded in *ReR/ Recommended Sourcebook* 0401 ('Music under new technology', 1994) and further slightly expanded in *Feedback Papers* 40 (July 1994) and, in Slovakian translation, as 'Dejiny samplovania', in the anthology *Avalanches 1990-5* (M. Murin (ed.)) (Spoločnost' pre nekonvenčnú hudbu, Bratislava, 1995). The present version contains several short additions, including two complete paragraphs, and more recent bibliographic references. Computer graphics by the author and Tony Myatt.