Chapter 1

Music, Electronics and Computers

> *"Although computers have been used in a range of experimental compositions, their most significant application to date is in copying musical parts, a drudgery that traditionally provided employment for hungry composers"*
>
> [Norman Lebrech, 1992, *Companion to 20th Century Music*]

Overview

This chapter is concerned with the ways in which computers and electronic systems have been used in the production of music and examines the effect this has had on musicians and computer users. It is written in the form of a chronological account of the main developments in music technology in the late nineteenth and twentieth centuries and explains the impact on the performance of music. Particular reference is given throughout to the point of contact between the instrument and its performer - the Musician-Machine Interface.

1.1 Setting the Context

In stark contrast to the above comment from the *Companion to 20th Century Music* our modern western world appears to be increasingly interweaving the seemingly independent disciplines of 'Music' and 'Computing'. The technological advances of the latter half of the 20th century have allowed large proportions of the population to have access to music and computing as an integral part of everyday life. The two subject areas are inextricably linked now that digital technology has become the prime method of recording music - and increasingly of producing it.

In this age of rapid technological development it is wise to keep things in perspective by reminding ourselves that music has been a fundamental part of every human society for thousands of years whereas computers have only been widely available to the general public since the 1980s.

It is the purpose of this thesis to step back from the relentless pursuit of technological advancement for its own sake and to examine the ways in which humans interact with computers when involved in musical activities. It is also suggested that by examining some of the ways in which people perform with traditional musical instruments (methods which have been tried and tested throughout history) we can gain valuable insight into the design of interactive computer interfaces in general, the study of which is still, by comparison, in its infancy.

1.2 The Effect of Technological Developments on Music

The generation of sound waves requires physical vibration. As human beings we are equipped with versatile vocal systems which provide us with our most direct way of producing sound; a new-born baby wastes no time in testing this system to the full! However, throughout history, we have used tools to create sounds. The manufacture of such tools or 'instruments' demands technical knowledge and apparatus.

When each new technical innovation is applied to music it influences the range and style of music produced. Sometimes however it is the development of artistic thinking which sets the goals for the designers.

> *"Innovations in musical technology, especially the creation of new instruments and modification of old ones, have been a normal feature of Western music history, moving hand in hand with the expansion of compositional resources. Such parallel development is understandable, since extensions in musical language often require new instruments for adequate realisation, while new instruments open up previously untapped compositional possibilities and thus encourage stylistic transformation".*
>
> [Morgan 1991]

Traditionally, acoustic instruments are played by one or more of the following techniques: plucking, strumming, bowing, hitting, blowing, keying or stopping (placing fingers over holes or on strings).

In all these techniques, the performer's *physical* action causes vibrations in the instrument, thus producing sound. The instrumentalist is therefore continuously in touch with the instrument as it is played. Once electricity is introduced into the range of technological tools available for making music this situation is extended as it is possible to produce electric instruments which can be played without direct physical contact.

It is with the above points in mind that we now examine the history of the development of musical technology from the point where an electronic circuit was first used to make a musical instrument. Special emphasis will be given to the ways in which musicians have been expected to interact with the technology.

1.3 Electronic Sound Generation – early systems

Alexander Graham Bell's experiments with the first telephone systems in the 1870s showed that sound could be converted into electrical signals, transmitted to another place, then reproduced as sound in the new location (Figure 1.1).

Figure 1.1: Alexander Graham Bell speaking into his early telephone

It is therefore no coincidence that some of the first acknowledged electrical musical instruments used noises made by a telephony system.

1.3.1 Accidental Discoveries that produced sound

In 1876 Elisha Gray was working on an alternative to Bell's telephone system. He noticed that some of his circuits oscillated under certain conditions. He converted this into sound via a home-made loudspeaker. By attaching a small keyboard to the device he invented the world's first electronic musical instrument (Figure 1.2). It was known as the 'Musical Telegraph' and Gray even took this device on a musical tour.

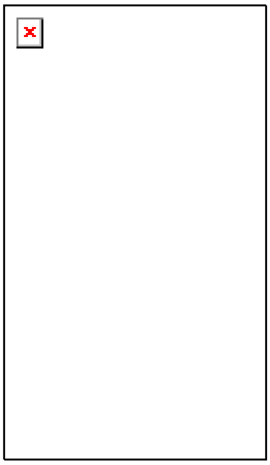
Figure 1.2: The 'Musical Telegraph' (incorporating a small keyboard and oscillator bank)

In 1900 William Duddell was trying to find a way to silence the irritating hum of the electric arc streetlights of the time. He found that he could control the oscillation frequency and he too went on tour with his 'Singing Arc'.

1.3.2 The Telharmonium; an instrument ahead of its time

With the technological emphasis on the development of communication systems, it is interesting to note that the first large-scale electrical musical instrument was concerned with the transmission of music across the telephone network.

The 'Telharmonium' was developed in the last years of the 19th century and was first demonstrated to the public in 1906 in Massachusetts, USA. This remarkable feat of engineering had several visionary design features which did not re-emerge until the latter part of the 20th century. The Telharmonium performance interface consisted of two polyphonic and touch-sensitive piano-type keyboards. The instrument made its sound via electrical generators which were tuned to produce sine waves at various frequencies. This gave rise to the machine's alternative name- the 'Dynamophone'.



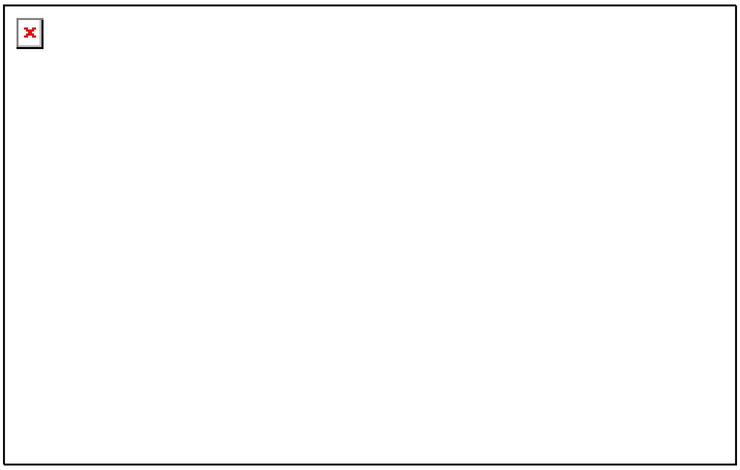


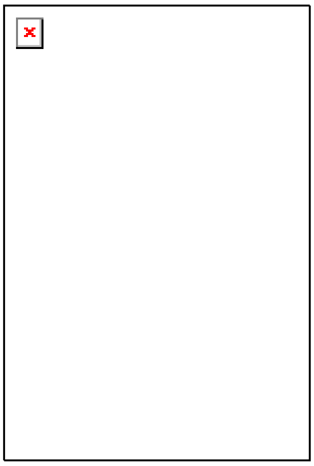
Figure 1.3: One of the Telharmonium's generator wheels (left) and user interface (right)

Limited mixing of sine waves was possible (a crude form of additive synthesis) which gave the player some creative control of the timbre produced. If this instrument had been developed further it might have yielded even more impressive results, but unfortunately several factors conspired to put the inventor, Thaddeus Cahill, out of business. The sheer size of the instrument (it weighed over 200 tons), its monumental power consumption and the fact that it caused major disruptive interference on the telephone network (which was intended to provide the major source of income in the form of paying listeners) meant that the Telharmonium was never used again.

1.3.3 The Theremin; a gestural performance interface

The development of the vacuum tube valve and the current arc oscillator in 1906 had made it possible to create a single sinewave tone and amplify it for playing over a loudspeaker. This prompted the invention of several new electronic instruments.

The Theremin was developed in Russia during the 1920s, and was the world's first non-contact electronic instrument. It consisted of a pair of antennae (one vertical rod, one horizontal loop) which allowed continuous control of the pitch and volume of a single oscillator.



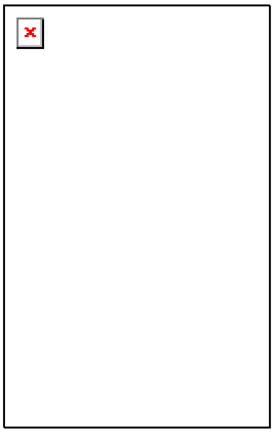


Figure 1.4: The Theremin (left) and its performance (right)

A solo performer would move his hands in proximity to the instrument and thus gestures were directly translated into pitch and volume control. Unlike the Telharmonium, the Theremin attracted a steady stream of interest from composers and was later used in popular music, for example by the Beach Boys (as the solo instrument in *Good Vibrations*). In recent years there has been something of a Theremin revival and a number of performing artists now use them.

1.3.4 The domination of the 'piano' keyboard interface

It is interesting to note that the Theremin offered a totally new player-instrument interface which aesthetically matched the novel and ethereal sound produced. However, subsequent development of electronic instruments focused increasingly on the piano-type keyboard as the standard control interface.

Organs are known to have existed as early as the third century BC. The mechanism for playing them (the keyboard) developed through the ages into a generalised interface for harpsichords, pianos and a variety of percussive stringed instruments. The keyboard is an effective way of triggering, striking or plucking individual notes in a *ballistic* manner (such that notes cannot be altered once hit).

In the early twentieth century electronic instruments offered players freedom from discrete notes and allowed continuous control over the sound whilst it was being played. Therefore it seems somewhat ironic that electronic instruments which were beginning to offer players these freedoms were now restricted to the confines of a keyboard, which has only discrete notes and no continuous control.

There was a prolific surge of development of new keyboard instruments between the two world wars. These included the Electrophon (1921), Staccatone (1923), SuperPiano (1927), Dynaphon (1928), Ondes Martenot (1928), Givelet (1929) and Trautonium (1930).

Most of these keyboards were monophonic (allowing only one note at a time to be played). The exception was the Givelet which permitted several notes to be played at once and even allowed a primitive form of *sequencing* by its ability to play back a series of notes stored in coded form on punched paper tape.

The Givelet was overshadowed by the release of the Hammond Organ in 1935. This gave a much greater polyphony due to its use of spinning tone-wheels (one for each note), rather like a scaled-down form of the Telharmonium. The Hammond Organ enjoyed astounding success in modern churches as a replacement to the Pipe Organ (surprisingly, due to the radically different quality of sound produced) and in the growing area of popular music.

The other keyboard worthy of special mention is the Ondes Martenot. It has survived through to this day, mainly in performances of Messaien's *Turangal✗la Symphony* (1948), because of its alternative method of performance. The player puts a finger through a ring (connected to a cord controlling the oscillator) and slides the hand left and right to produce continuous changes of pitch (glissandi).

Figure 1.5: The Ondes Martenot

As with the Theremin, the sound source was controllable by an interface which allowed its novel sound to be produced in a correspondingly novel way using clearly identified performance gestures.

1.4 Recording technologies – temporal dislocation of sound

The development of the telephone had enabled sound to be converted to electrical signals and to travel from one place to another. The invention of radio meant that music could be heard in a different location to that of the performers. Simon Emmerson [1994(1)] has termed this *spatial dislocation*. The early part of the 20th century also saw a series of innovations in the *storage* of sound. This had a remarkable impact on music since it meant that for the first time it was possible to play music at any time independent of live performers. Emmerson terms this *temporal dislocation.*

The following sections outline the major technologies for recording followed by a comparison of how the technologies can be used in live performance.

1.4.1 Records

The 78rpm gramophone was used increasingly in the early 1900s. An explosion of interest in Jazz between 1918 and 1920 was largely due to the fact that music could now be effectively ‘frozen’ on a record and then sold in large quantities to the general public. Again, the introduction of the 45rpm single was associated with the rise of rock-and-roll. Record players of various types were to dominate the distribution of music to the general public until the 1980s when digital technology began to take over in the form of the Compact Disc (CD). However a medium that was to become very popular for home recording and for copying records was magnetic tape.

1.4.2 Tape

Magnetic recording systems (wire, tape etc.) had been available since the start of the century, but were not generally sold until the early 1930s when broadcasting companies, such as the BBC, used them to record programmes for subsequent radio transmission. By the 1950s the tape recorder was established as the primary recording machine, although the general public still listened to music on record players. The Compact Cassette was (and still is) a very popular format for making recordings from other media (records, radio, CD) especially for use in portable machines such as the Sony Walkman, or in car stereo systems.

1.4.3 Optics

In the 1930s the development of cinematic sound provided a new medium of audio storage. The optical sound tracks on the edge of films could not only be used to record sound, but also allowed a remarkable form of direct synthesis. Composers would use a pen to draw the soundwaves onto the film. Figure 1.6 shows a representation of a section of film with the audio track stored (optically) above the image. The audio track corresponds to images several frames away (not the one immediately below), since the images need to be ‘stepped through’ the projector, whereas the soundtrack is fed through a light detecting amplifier continuously.

It was (in theory) possible to compose any soundwave imaginable, but it was a tedious process and human beings are not naturally equipped with the knowledge of how to draw sound.

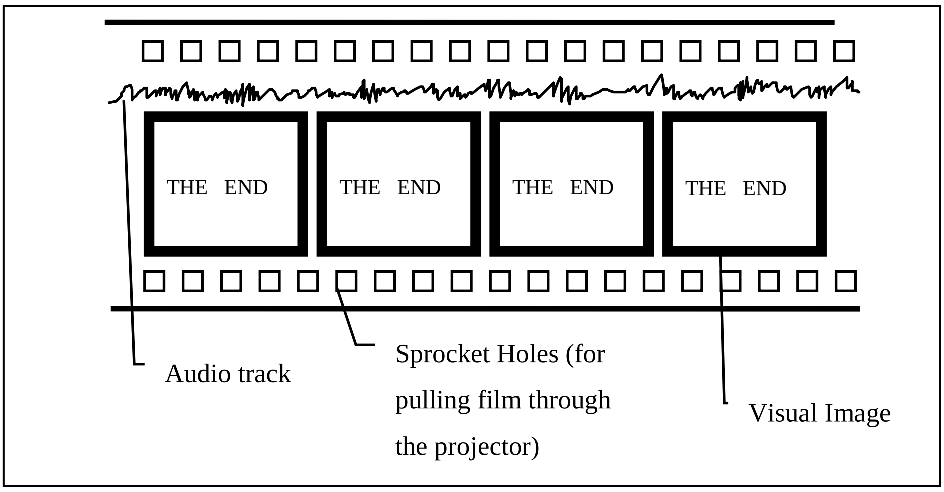


Figure 1.6: Audio track stored optically on film

1.4.4 The use of recording media in live performance

Each of the above ways of recording sound had its own set of advantages and disadvantages.

Record players were used by some composers as a new form of live performance instrument. The disc on which their sound material was recorded could be physically manipulated; spun by hand at continuously variable speeds, played backwards, and moved very quickly to a new part of the sound recording. In this respect, some of Pierre Schaeffer's early performances in the 1940s using several gramophones as live-performance sound sources were very similar (in terms of the technology and the human musical control involved) to the 'scratching' of records by hip-hop DJs from the 1970s onward. In both these musical situations the performer learns how to physically 'play' the sound source and much time is spent in rehearsing and developing the gestural control needed to react in live performance. This is clearly similar to the way that conventional acoustic instrumentalists practise to improve their technique.

It should be noted that the process of recording (or etching) the disc usually meant that the sound must have first existed in the real world prior to being recorded. The physical structure of a disc does not lend itself to being 'edited' in any way. Therefore composers who were primarily interested in creating new sounds and editing existing ones did not find the record player a suitable tool with which to achieve their aims.

The storage of sound on magnetic tape is superficially similar to that of a record player; in both systems an analogue representation of the soundwaves is made on a physical medium. However, the physical forms of the different media determine the methods by which the music is reproduced. Whereas records can be used as a type of performance device (as described above), the situation is very different for tape. Although a reel-to-reel tape player could be 'shuttled' back and forward by hand, its live performance capabilities were regarded as inferior to the record due to the lack of random access to a particular point in the music.

Records were an inappropriate medium for editing, but tape could be chopped up, rearranged, copied to another tape, looped and sections removed thus providing a completely new way of producing and transforming musical sounds.

> *"When on tape, sound becomes a physical object that can be cut, stretched, rearranged, moulded, and easily re-recorded. A new breed of abstract composers did just that and the result, called "musique concrete", sounded like nothing that had ever been heard before."*
>
> [Chamberlin 1980].

The move from record to tape by Pierre Schaeffer in Paris in the early 1950s (and the use of tape by the rival pioneers of Elektronische Musik in Germany) had a profound influence on sound-based musical composition for the remainder of the century. Live performance with electronic instruments (e.g. record players, Theremins, keyboards etc.) was downplayed in favour of non-real-time preparation of timbrally complex material.

Thus tape recorders generally freed composers from the range of sounds available on acoustic instruments and simultaneously removed the live performance element which had been the central part of music making for thousands of years.

Optical systems of sound composition were never developed to the extent that their pioneers would have hoped for because of the increasing dominance of tape as the primary studio recording medium. It is worthwhile to consider that the composers of optical soundtracks in the 1930s were using techniques of visual sound editing and waveform specification that would later become widely available in the 1980s with the advent of microprocessor-based music systems.

1.5 Amplification of Sound for Live Performance

While all the above developments in the synthesis of new sounds were evolving, there was a gradual revolution taking place in the popular music scene. In order to play to larger audiences several acoustically quiet instruments (such as the guitar) were amplified and played over loudspeaker systems.

1.5.1 Electric guitar

As guitarists explored their newly amplified guitars they discovered that they could play the instruments in new ways; for example they could produce long sustained notes and audible solo lines rather than simply having to strum chords loudly in order to be heard. In addition, it became obvious that the timbral quality of the guitar could be radically altered. In a cycle of development in which the guitar, amplification systems and outboard effects (such as tape-based reverberation systems) underwent continuous alterations, the Electric Guitar evolved into a versatile instrument of fundamental importance to the blossoming of rock and pop music from the 1950s onwards.

Other conventional instruments were also electrically amplified - for example the RadioPiano (1931) and the Violectric (1936).

1.5.2 'Sonic Microscope'

Secondary school music students using the University of York's ‘Sound Experience’ materials are encouraged to . . .

> *“Imagine you are a pioneer explorer in a microscopic world full of undiscovered sounds. Set off with your microphone to collect and highlight sounds that people normally take for granted.”*
>
> [Myatt 1993]

This is exactly what Karlheinz Stockhausen was doing in his *Mikrophonie* pieces in 1964-5. *Mikrophonie I* requires six performers - two to play a large tam-tam in a variety of ways, two to move the microphones (to effectively act as a ‘sonic microscope’) and two to operate the live electronic amplifiers and filters.

Each performer's physical gestures contribute to the final sound, but each of the three groups operates in a different way. The first group actually makes the sound by physical contact with the instrument (a generation process), the second group 'homes in' on various sounds (a selection process) and the final group manipulates the sound via filters and amplifiers (a transformational process).

Thus three completely different styles of live performance technique are present simultaneously in a single musical piece.

1.6 Synthesisers; new forms of Sound Generation and Control

Nowadays the term 'synthesiser' tends to imply a keyboard-based instrument which may include many methods of sound generation or storage. The early keyboard-based devices and the Theremin could be considered to be primitive synthesisers in that sound was produced from oscillating electric currents or rotating wheels. However, the first instrument to form the basis of the modern synthesiser was the 'Monochord'.

1.6.1 The Monochord

The Monochord was one of the sound sources available in the Cologne studio in the early 1950s. It was a live performance instrument which was played by a keyboard which could react to key pressure to control the dynamic response of the sound. Volume could also be controlled by a foot pedal. The Monochord's single oscillator could produce saw-tooth, square and triangle waveforms which could be filtered in order to remove portions of the upper harmonics. It is interesting to note that this instrument, which offered live performance of electronic music (but with limited control of the sound), was relatively under-used by the studio's composers in favour of constructing sounds on tape using a sine-wave generator.

1.6.2 The RCA Synthesiser and the Composer-Programmer

The first large-scale synthesiser offering composers complex control of sound was built in 1956 by the Radio Corporation of America (RCA). This massive machine (which filled an entire room) was programmed by punched paper tape and produced its sound output by directly engraving a gramophone disk (see Figure 1.7).

The designers, Harry Olson and Herbert Belar, were mainly interested in imitating conventional instruments and reproducing synthesised versions of the classical repertoire. The two things they had problems with were the sheer complexity of timbre in acoustic instruments and the fact that an acoustic performer constantly varies the pitch, volume and timbre of an acoustic instrument in a way that it is impossible to imitate by programming pitches in non-real-time on punched tape.

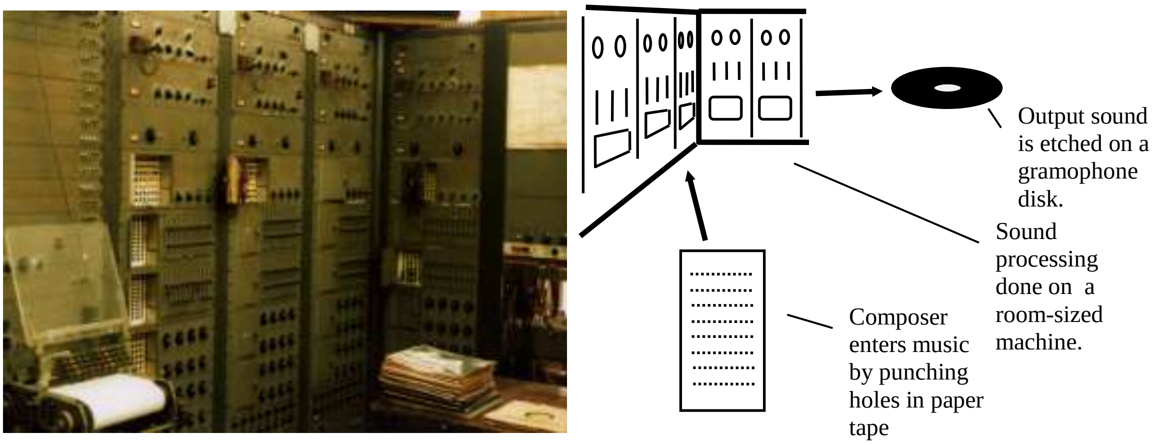


Figure 1.7: Part of the RCA synthesiser showing the paper tape reader and oscillator banks

Composers such as Ussachevsky and Milton Babbit used the RCA synthesiser Mark II to create new complexities of rhythm and novel sounds which were simply not possible with conventional instruments. Thus a new form of composition - sequencing or ‘programming’ was born. The model of ‘composer as programmer’ was thus firmly established.

Many composers have followed this model by producing music which has no further interpretation by a human performer.

1.6.3 Voltage-Controlled Synthesis and Control Dislocation

The goal of using synthesisers as live performance instruments, particularly in the area of popular music, was helped dramatically by the introduction of transistor circuits in the late 1950s. Synthesisers had formerly been either too timbrally weak to be of interest to composers or so large that they occupied a room or at least could only be moved with great difficulty.

Various engineers worked with the new circuits in order to reduce the size of electronic musical instruments, but the most successful and influential design came from Robert Moog. His first transistor-based synthesiser was released in 1966 and was based on voltage-controlled techniques whereby various aspects of the sound generation process could be controlled by a voltage.

Figure 1.8: A modular Moog voltage-controlled synthesiser

The advantage of this method of working was that this 'control voltage' could come from anywhere; a keyboard, a joystick or the output of another part of the synthesiser such as an oscillator.

Peter Manning sees this as a revolutionary step in electronic musical instrument design :

> *"Hitherto the functional characteristics of most studio devices had been controlled by uniquely assigned knobs and sliders. Connections between these units were thus concerned solely with the passing of audio signals from one stage in the synthesis chain to another."*
>
> *"The versatility of transistor-based electronics . . introduced an entirely new dimension: the passing of control information from device to device via a secondary chain of interconnections."*
>
> [Manning 1993]

Perhaps even more importantly the physical characteristics of the musician-machine interface could now be changed without altering the sound synthesis engine.

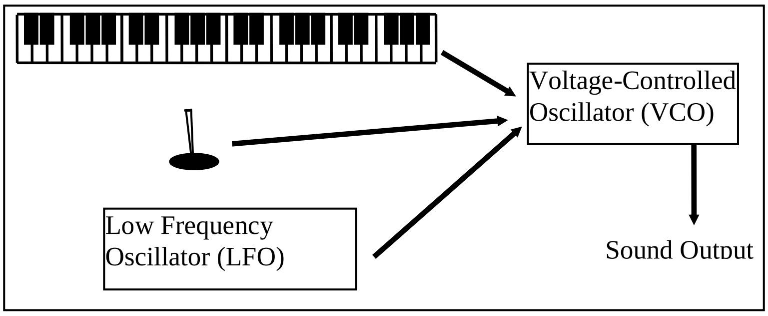


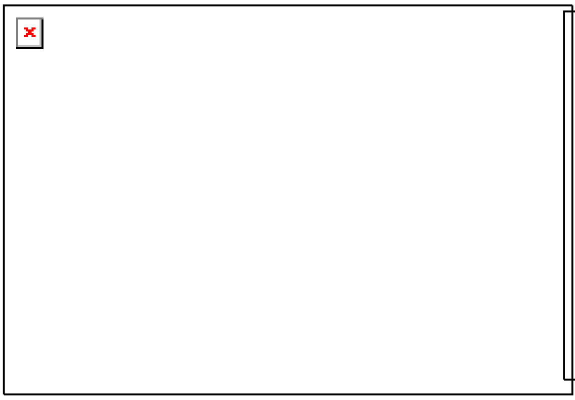
Figure 1.9: Voltage control allows sound source to be independent of controller

This dissociation of control device from synthesis engine was to come to fruition with the specification of the MIDI protocol, which is described later in more detail.

The Moog synthesiser and its competitors were generally played via a monophonic keyboard. As the prices reduced, they became so popular that various rock bands began to use the synthesiser increasingly in preference to the electric guitar.

1.6.4 Drawing Sound

One musical system from this period which took advantage of these new voltage control possibilities was developed at the BBC Radiophonic Workshop in the early 1960s by composer Daphne Oram. She devised a system of ‘Drawn Sound’ synthesis known as ‘Oramics’. The composer specified various sonic parameters by drawing them onto a transparent plastic sheet which was moved across a strip of photocells. These cells reacted to the pen strokes on the film and subsequently controlled a monophonic voltage-controlled synthesiser.



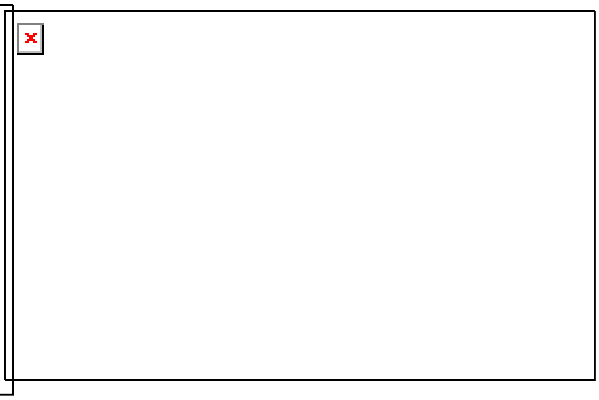


Figure 1.10: Daphne Oram (left) and the ‘Oramics’ optical synthesiser

It should be noted that despite the superficial resemblance of Oramics to the `Optical Film Track' compositions of the 1930s the paradigms in which the composers worked are very different. On film the soundwaves themselves were drawn, whereas with Oramics the composer was effectively drawing a series of control codes. In this respect an Oramics user worked in a similar manner to the way a composer might write a traditional score.

1.7 Computer Instruments Without Performance Interfaces

The development of the digital computer and its subsequent application to music synthesis, storage and playback is one of the most important and influential developments in the technology of music in the twentieth century.

In 1957 Max Mathews produced *MUSIC I* the world's first computer program that could synthesise sound. Mathews was working at the Bell Telephone Labs on the digitisation of sound. The goal was to store sound as a stream of numbers, send it as a stream of pulses down a telephone cable, then reconstruct it at the far end. It was a natural step to try transmitting music and then to experiment with the generation of sound from algorithms running on the computer.

> *"This was called direct computer synthesis of sound because there is essentially no intermediate device necessary to synthesise the sound"*
>
> [Chamberlin 1980]

MUSIC I was very limited in its scope as it could only produce a single triangular waveform, but it prompted the rapid development of a series of increasingly more complex programs. By 1962, not only had Mathews developed a much more open-ended synthesis program (MUSIC IV) which inspired several American composers, but the current computing technology had become much smaller and more accessible thanks to the newly invented transistor circuitry. Over the next few years many universities developed their own versions of the MUSIC series of programs, using different programming languages on different hardware platforms. The reader is referred to Dodge and Jerse [1997] for a detailed description of the historical development of these synthesis languages.

In 1986 at the Massachusetts Institute of Technology (MIT) the latest version of the MUSIC program was translated into the C Programming language by Barry Vercoe. The advantage of 'C' was that it was widely available on many different hardware platforms and programs written in C tended to run faster than those written in other languages. This new program was known as *Csound* and is today one of the most widespread and popular direct synthesis programs - mainly because it was not commercialised, but was instead made available to anyone who wanted to use it.

1.7.1 Parametrical Control for Non-Real-Time Computer Music

The majority of the variations on MUSIC IV (including Csound) had followed its fundamental design very closely and differed only in syntactic detail and in the range of commands available. Mathews established the concept of a computer-controlled *score* and *orchestra* by which all communication took place with the computer.

The orchestra was a text-based file which specified how sounds should be synthesised in terms of a number of simple algorithms (known as *Unit Generators*) defined within the program. The composer would describe how these units should be connected together and where their inputs should come from. The score, also a text file typed in by the composer, was a time-based list of numbers which formed the inputs to the network of unit generators (see Figure 1.11).

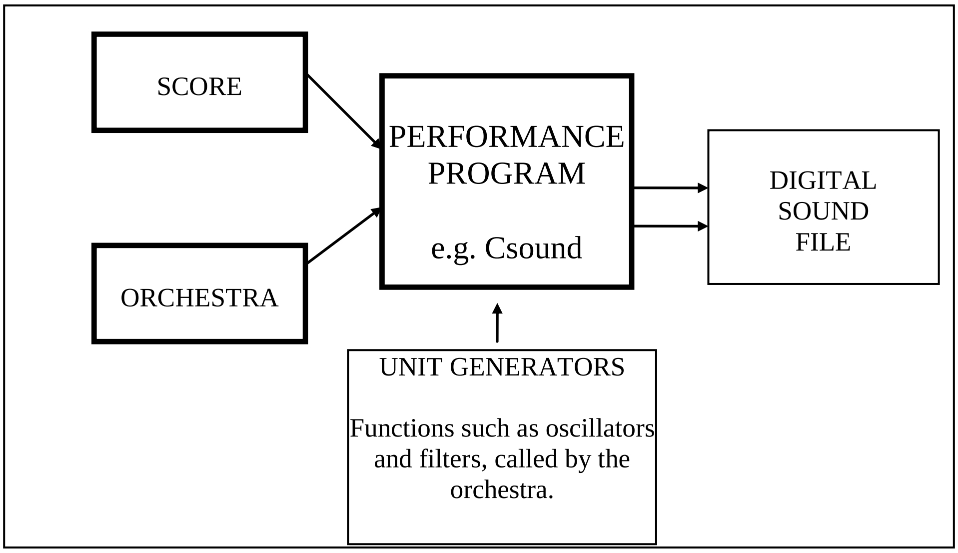


Figure 1.11: The concept of the non-real-time computer instrument

Thus the composer was given the role of 'algorithmic instrument designer' and of 'parameter specifier'. The program took both the score and the orchestra and did the 'performance' itself by writing each generated sound sample to a file, usually taking many minutes to produce each second of sound. The technology did not allow interaction, but only non-real-time specification of numbers.

So influential were Mathews' programs that even today, when it is technologically possible to perform with complex synthesis algorithms in real-time, much software is designed in terms of the composer specifying number streams.

1.7.2 Hybrid Digital and Analogue music systems

MUSYS was an alternative hybrid digital-analogue system developed in 1970 by Peter Zinovieff (from the company EMS). Its two digital computers were used to control an extensive set of analogue synthesisers, filters and modulation units.

Unfortunately for the composer every single instruction had to be pre-programmed either by typing in each register value or by making use of an elaborate array of spinning wheels and binary light patterns to program the registers. The score could be altered by stopping the program, updating a register, and restarting the program to immediately hear the result. However, no performance interaction was possible while the sound was being generated.

1.8 'Conducting' Interfaces for Computer Music

While many composers around the world were busy following the MUSIC IV philosophy and were effectively turning into computer programmers, Max Mathews became concerned with the performance interface. Musicians using the MUSIC series of programs had no interactive feedback and so could not perform.

It is a common assumption that this was simply due to the lack of processing speed available in the computers of the time. Although the excessively long wait between writing the score and hearing the output does indeed hamper the composer's operation it is not the fundamental problem; indeed, most orchestral composers have traditionally had to wait a long time between writing the score and hearing the result. Computers often gave a faster turnaround time than conventional orchestral composers were used to, which was one of the reasons that computer-based music systems became popular. However, the main reason for MUSIC-type programs being unsuitable for live performance is their need to have pre-prepared files of textual and numerical information. This information cannot be effectively generated or altered by the composer/performer in real time - even if the computer instantly processes the results and produces the sound. This important point will be returned to later in this thesis.

Various designers and composers therefore deemed it necessary to explore alternative methods of giving the computer synthesis unit the information it needed in real time.

1.8.1 Real-time manipulation of a Computer Score

In 1970 Mathews worked on a system which used a computer to help the composer to specify control instructions by displaying a visual representation of the instructions on a monitor. The sound was generated in real-time by a complex analogue synthesiser. It was called *GROOVE* - Generated Real-Time Output Operations on Voltage-controlled Equipment, and was also a ‘hybrid’ system because of the way it used both analogue and digital technology. The score was specified by typing a series of codes into the computer. The computer then controlled the analogue synthesis units by translating the score into a series of instructions to a set of relays and DACs (Digital to Analogue Converters). In addition to the score being played back, the performer could modify various parameters in real-time by using a joystick or a small piano-type keyboard.

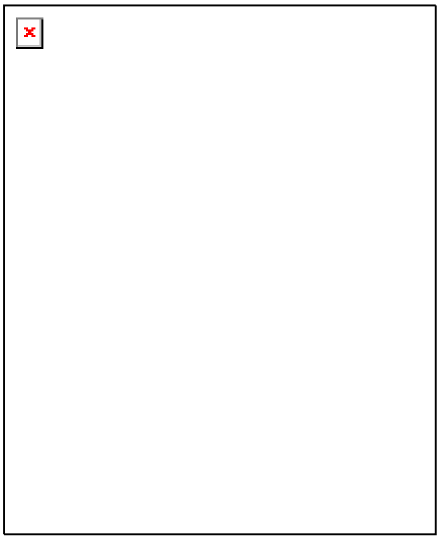


Figure 1.12: Max Mathews’ *GROOVE* system

It was at this time that the direction of Mathews' work became strongly focused on the idea of conducting a computer-stored score; a philosophy which has continued in most of his subsequent work to date.

> *“The composer does not personally play every note in a score, instead he influences (hopefully controls) the way in which instrumentalists play the notes. The computer performer should not attempt to define the entire sound in real time. Instead the computer should contain a score and the performer should influence the way in which the score is played”*
>
> [Mathews - cited Manning 1993].

Mathews effectively defines the equations ‘Performer = Conductor' and 'Computer = Instruments + Players + Score'. It could be held that this is not the most helpful of directions to take as it elevates the computer to the position of being in charge of what is played, leaving the performer to simply adjust how it is played.

1.9 Digital Computers with Performance Interfaces

The advent of the affordable microprocessor immediately launched a growth spurt in the production of portable computers and associated musical devices, some of which are described below.

1.9.1 Synclavier; a portable digital synthesiser

In 1976 a new musical performance instrument was designed around a special 16-bit microprocessor. The performer played a piano-type keyboard and had a bank of buttons which controlled the synthesis - hence the name ‘Synclavier’.

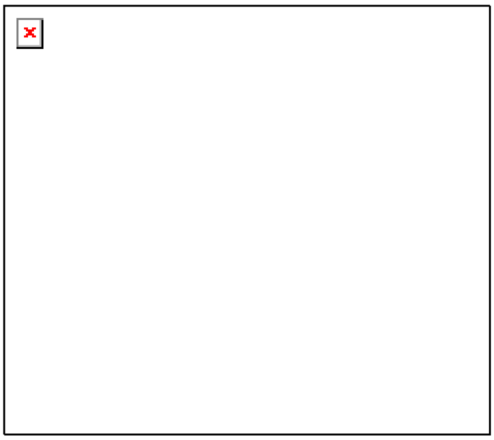


Figure 1.13: The Synclavier

The buttons operated sine-wave generators to allow interactive additive (and frequency modulation, or FM) synthesis and also facilitated the control of amplitude envelopes. The keyboard was polyphonic, but in addition there was a strip-sensor for continuous variations in pitch (like the Ondes Martenot). There were also two foot pedals which allowed continuous changes of volume and any other parameter during performance.

Soon after its release as a performance keyboard, additional hardware became available which extended the editing facilities. A visual display unit (VDU) allowed the user to see the parameter settings more clearly and the user's synthesis configurations could be stored on a floppy disk.

1.9.2 The Fairlight Computer Music Instrument

Towards the end of the 1970s another system emerged which also addressed the needs of an ever increasing market for reasonably flexible but instant synthesis. The 'Fairlight Computer Music Instrument' (CMI) was a pioneering device that became very popular with commercial bands and recording studios. Its novelty was the digital storage and playback of sound (sampling) combined with an interactive computer display.

Figure 1.14: The Fairlight Computer Music Instrument

Like the Synclavier, the Fairlight also used foot-pedals and a keyboard for the performance interface, but the editing functions were dramatically improved. Users could draw their own waveforms on the screen by using a light pen (similar to the Optical Film soundtrack composers in the 1930s), or specify sound parameters via a QWERTY keyboard using a series of control codes.

Peter Manning notes the advantage of a user being able to change 'mode' of operation when using such devices. Of a similar system, the *Con Brio ADS 200*, he stated:

> *"The ability to migrate freely between gestural and strictly notated control over device functions is a particularly distinctive feature".*

[Manning 1993].

1.9.3 SSSP; experiments in gestural control

Further advances in the performer interface were made by Bill Buxton and his team in their Structured Sound Synthesis Project (SSSP). The hardware consisted of a suite of digital oscillators which could be configured for additive synthesis, FM or 'VOSIM' - a vowel-sound algorithm. The novel performer interface required players to hold onto a set of plastic bands and move their hands freely in space, with the option of watching the display on an interactive graphics unit. The screen could also be accessed directly using a tracker-ball. The layout of the display would take on the characteristics of the current editing option; for example dragging notes onto a stave when in 'score' mode, or drawing amplitude envelopes on a grid, or moving graphical objects (such as sliders) when in 'synthesis editing' mode.

Such forms of graphical interaction were to become much more widespread with the advent of microcomputers.

1.10 The Consumer Digital Music Revolution – interfaces for everyone

The Fairlight and Synclavier systems were widely used in studio and live performance work, particularly in the popular music industry where a fast turnover of musical material was of utmost importance. Many of the original systems are still in use and their design philosophies have had an enormous influence on many subsequent systems.

By the early 1980s a revolution had occurred in the world of music technology. With microprocessors widely available and increasingly cheap, there was an explosion in the number of computer-based musical instruments and processing systems.

An example of the developments taking place at this time was a range of hardware known as the 'IRCAM-4' series. Composers and engineers in Paris at the Institut de Recherche et Coordination Acoustique/Musique (IRCAM) worked together with the aim of producing a powerful and flexible synthesis engine. The '4C' contained a bank of configurable oscillators and envelope shapers of which various parameters could be adjusted in real-time using a set of sliders. Unfortunately, the goal of achieving the composer's aims of being able to play complex synthesis algorithms in real-time was only attainable by requiring the composer to set everything up in specific low-level assembler code.

The 4X (which is still in use at the time of writing) uses a Digital Signal Processor (DSP), running alongside the microprocessor, to handle the large amounts of addition and multiplication operations required by the synthesis engine in real-time. A similar contemporary device, known as the ‘DMX-1000’, was also a fast calculation engine that was equally difficult to control because of the necessity of programming inventively in low-level code.

1.10.1 Real-time Digital Synthesis on VLSI chips

While the academic research institutes were developing such flexible (but costly and unfriendly) devices, the commercial music manufacturers were producing an unprecedented number of keyboards to supply the ever increasing demand for synthesisers. With more pop music bands using synthesisers, the requirement for cheaper ‘home’ and ‘school’ keyboards drove down market prices and brought in a whole new range of large companies (such as Yamaha, Roland, Oberheim and Casio) producing competing products.

The production of these cheaper instruments was only made possible by the recent advances in VLSI (Very Large Scale Integration) technology which allowed companies to customise their own fast circuit designs onto a single silicon chip.

The Casio *VL-tone* of 1981, though regarded as a toy by many (and resembling an overgrown calculator), was the first synthesis and sequencer unit which could be purchased for under thirty pounds.

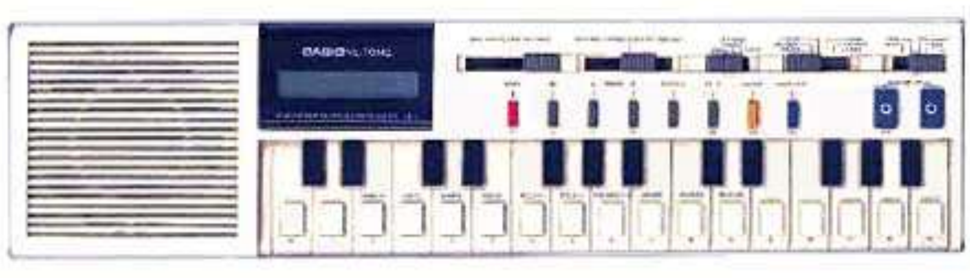


Fig 1.15: The Casio VL-tone

It launched a torrent of new keyboard synthesiser devices from a growing number of manufacturers. These products were electronically incompatible with each other as every device's internal digital operation was custom designed, and there was no protocol for inter-device communication.

1.10.2 MIDI - the Musical Instrument Digital Interface

Players of voltage-controlled analogue synthesisers had been able to make rudimentary connections between different devices by taking the control voltage of one keyboard and making it drive the synthesis unit of another. This allowed a form of 'keyboard coupling' similar to the function with which church organists are familiar, allowing one keyboard manual to slave to another. However, the connections and voltage levels were not standardised and, more importantly, this form of analogue voltage linking could not apply to the new digital synthesisers.

Between 1981 and 1983 an international group of electronic musical instrument manufacturers met together to discuss ways of implementing a standard protocol for the interconnection of digital music devices. The resulting *v1.0 MIDI Protocol* was adopted by practically all major electronic musical instrument manufacturers and has thus had a profound influence on the world's electronic music-making ever since.

The MIDI Specification is a description of the manner in which electronic instruments are to be physically connected (i.e. the electrical description of the interface) and perhaps more importantly a list of the messages which can be transmitted between devices. MIDI allows devices to communicate at the real-time *control* level only; audio data cannot be transmitted in this manner (only in a non-real-time 'sample dump' form). Its assumed model for devices is the keyboard synthesiser. Thus communication consists primarily of key-press data, supplemented by optional 'continuous' controls (actually 128 discrete levels by default) which transmit attributes such as the position of the pitch-bend wheel.

MIDI has its critics and its champions, but no-one doubts the enormous effect it has had on the way in which electronic musical instruments have developed in the 1980s and 90s. The critics tend to look at the limitations of the MIDI specification from both the 'electronic connection' and 'message format' points of view.

> *"MIDI instrument control is limited to selecting a patch, triggering it with one of 128 key numbers, and optionally wiggling one or more controllers to which the patch may or may not respond in a useful way. The advantage of MIDI is easy control of pre-set synthesis techniques. The disadvantage is greatly reduced generality of control, and greatly limited synthesis specification".*
>
> [Smith 1991].

Many of the developments outlined in the remainder of this chapter were possible primarily because MIDI had been accepted as an international standard of control-rate musical data. Many people were given access to music making for the first time because of the widespread acceptance of MIDI.

1.11 Performance Instruments in the MIDI Age

Inevitably the majority of new instruments were keyboard based because that was the medium which originally prompted the MIDI specification and subsequently influenced its message format.

1.11.1 The Yamaha DX7

One of the earliest Digital MIDI synthesisers was the Yamaha DX7 which was to become perhaps the best-selling electronic keyboard of all time (even though more keyboards are sold nowadays, sales are distributed between a vast number of different models). The DX7 introduced the general public to FM synthesis and it became known for 'not sounding like other synthesisers'.

Figure 1.16: The Yamaha DX-7 synthesiser

As well as its polyphonic velocity-sensitive keyboard with an 'aftertouch' pressure bar and pitch and modulation wheels, the DX7 allowed various parameters to be controlled by a breath-controller. Although not used by many owners, this offered another option for shaping note timbre or envelope during live performance whilst the player's hands were in use on the keyboard.

1.11.2 Sequencing, Sampling and Synthesis

By the mid-1980s several very important developments had taken place. Digital sound samplers (such as the Ensoniq 'Mirage' and the Akai 'S' series) were now available at a fraction of the cost of the Fairlight. Sound sources were now *multi-timbral*; allowing several different voices to be played on one physical device; each voice assigned to its own MIDI channel. Such sound sources were often small boxes with no performance interface as they could be played via MIDI from an existing interface - or even directly from a computer.

1.11.3 MIDI Modules; sound generators without interfaces

Smaller boxes with no moving parts meant that these MIDI modules could be sold at much lower prices than their keyboard counterparts and thus more 'costly' synthesis and sampling techniques were made affordable to the home user. This downward spiral of price caused a revolution in the studio recording industry with increasing numbers of people doing most of their compositional preparation work, if not the whole recording, at home.

With modules now widely available as comparatively cheap MIDI sound sources, it was possible to break away from the domination of the piano-type keyboard. One could use completely novel performance interfaces as long as the MIDI messages being sent to the sound module were in the form of semitone key-presses and associated continuous controllers.

Most of the major manufacturers produced drum machines of one sort or another. Some were simply dedicated sound modules with a range of pads for programming a drum sequence (such as the *Linn Drum* series, see Figure 1.17), while others offered a well-crafted set of percussion pads which would be easy to use for a drummer.

Figure 1.17: The Linn Drum computer

1.11.4 Guitar Interfaces

Guitarists were very keen to enter the world of synthesised sound and so various manufacturers produced guitar-to-MIDI converters. Some guitar interfaces were simply modified ‘pick-ups’, fitted to an electric guitar, which sent MIDI messages in response to the pitch of each string. Whilst they allowed guitarists to use the traditional playing interface, they became the subject of much criticism regarding their speed of response and the lack of performance subtlety which was possible over MIDI. Some manufacturers responded by building custom guitar-type interfaces which reacted faster (some of which can only make sound with the aid of a MIDI sound module). However, many guitarists have found that an acoustic instrument, put through an assortment of effects units, is their favoured way of accessing new sounds whilst retaining full performance intimacy.

1.11.5 Wind Instrument Interfaces

Wind instruments have also been the subject of re-invention in the age of MIDI. These have varied from the simple Yamaha ‘Breath Controller’, already mentioned, via easy-to-use instruments with limited flexibility such as the Casio ‘MIDI Horn’, to quite complex instruments such as the Yamaha WX7 (see Figure 1.18).

Figure 1.18: Casio Horn (left) and Yamaha WX-7 wind controllers

This latter instrument can be customised to the requirements of an individual user. For example, the mapping of the fingering to the notes produced can be altered, the sensitivity to air movement can be adjusted to suit the player's breath and the lip pressure sensor can be changed to suit the performer's preferences.

It is interesting to note how few MIDI wind controller players there are compared with the corresponding number of keyboard players. It would be too easy to presume that this is because MIDI was designed for keyboards and therefore any other type of device cannot really be expected to work as well. On the contrary, there are players who produce performances of much greater subtlety using MIDI wind controllers than most keyboard players could hope to achieve.

The primary reason for the small numbers of players of such instruments is that they are difficult to play. This is by no means a criticism of the manufacturers; in fact it is perhaps a commendation. MIDI lends itself to the easy switching on and off of pre-determined synthesised and sampled sounds. Keyboards are an accessible interface for this switching operation, and people approaching a keyboard instrument for the first time (for example in a music shop) get an immediate and impressive response. In contrast, a person encountering a typical wind controller takes a long time to get any form of control over the sound produced, but once the learning process is fairly advanced there is a range of performance subtlety available which would simply not be possible on a keyboard.

The important area of ‘practising to gain performance intimacy’ and ‘experimenting with complex instruments’ will be returned to later as one of the key issues in this thesis.

1.12 Home Music Production on Microcomputers

During the mid-1980s the concept of the ‘desktop microcomputer’ became a reality. It was now possible for powerful computing facilities to be available in every home, office and school. There was consequently a great need for an improvement in user interfaces. The Apple Macintosh was the first widely available microcomputer to be supplied with a standard graphical interface, driven by the user with the `pointing, clicking and dragging' actions of a mouse (see Chapter 2). Atari followed suit with the ST range which were not only cheaper, but came with a built-in MIDI interface.

1.12.1 Types of music software

Over the last ten years there has been a dramatic increase in the types of software available for music on microcomputers. It would be totally impractical to list the full range of programs available, but the main focus has been on the following functional categories:

- Sequencing (Recording, Editing and playback of MIDI information)
- Notation (Producing conventional musical scores)

- Sampling / Hard-disk recording (Recording, Editing and Playback of Digital Audio)
- Instrument Editors (Graphical control or storage of synthesis parameters)
- Composition (Either aiding the composer, or Algorithmic Composition)
- Education/Instruction (Music tutors, Reference information)
- Studio Automation (Routing of signals and control of complex MIDI set-ups)
- Performance Instruments

It is this last category which is of particular relevance to this thesis. The phrase "This software turns your computer into a musical instrument" has too often been used inappropriately as an advertising slogan. It usually refers to the use of the word 'instrument' to mean:

> *"instrument : tool, implement, means; person, thing made use of; contrivance for producing music"*
>
> [Collins - GEM dictionary]

This implies any use of a computer where the output is sound thus including practically all of the above categories. This thesis uses the term 'Performance Instruments' to refer to those devices which produce sound in real time under the direct control of a human player. We shall return to this topic in Chapter 3 by taking a closer look at one such MIDI-based performance system.

1.12.2 Manipulation of sound using computers

In the late 1980s there was a sharp increase in the speed/price ratio of DSP chips. As microcomputers began to incorporate these devices as part of the standard hardware, it was possible to perform fast, if not real-time, digital audio operations in a graphically-controlled environment. Up until this point, composers using microcomputers relied on external custom hardware to handle the audio-rate data. One such system was the Composers' Desktop Project (CDP), developed in conjunction with the University of York, UK, which provided audio-handling hardware (in the form of the *SoundSTreamer* buffering device) which enabled composers to use an Atari ST computer to run suites of sound-editing software.

The release of the *NeXT* computer in 1988 offered a real leap forward in terms of what composers could achieve in a desktop environment. It contained two microprocessors (one specialised for floating-point calculations) and a 56001 DSP chip which could handle compact-disc quality audio in real-time and a high-resolution graphics screen.

By 1991 the ‘IRCAM Musical Workstation’ had been designed around the NeXT computer and a series of custom-built processing cards. It is important to note that there was enough processing power in the NeXT to run high-quality graphics simultaneously with high-powered audio generation and processing algorithms.

For the first time it was possible for composers to use software with an interface which had been designed specifically for ease of use. Up to this point, composers had been required to be low-level computer programmers, working at a machine level in order to maximise the machine's speed of operation.

User-centred software design had taken great strides forward with the introduction of microcomputers such as the Apple Macintosh. The real-time nature of MIDI had enabled the development of a range of interactive music-oriented software. With the advent of the next generation of RISC and DSP-based microcomputers (such as the NeXT and the Silicon Graphics ‘Indigo’) composers could work with custom digital audio algorithms in an environment which allowed data to be manipulated graphically. Much of the software developed for MIDI applications was now adapted to handle digital audio.

1.13 Systems for Capturing Performance Gesture

Now that computers are fast enough to be able to run real-time audio and allow humans to interact with the algorithms we must ask ourselves the question “how can a computer be used most effectively for real-time performance?” The point of interaction between the human player and the technology being operated needs to be studied in more detail.

1.13.1 Drawing

The 'UPIC' system, developed during the early 1980s with much input from composer Iannis Xenakis, was a drawing interface not unlike the 'Oramics' system (see section 1.6.4) of two decades earlier. In its later versions a light-pen was used to draw wave shapes and envelopes on a special screen. These would then be formed into a score where note events could be freely drawn and listened to immediately.

Because of its direct approach to score and sound specification it was very popular as a teaching aid.

1.13.2 Conducting

One school of thought, pioneered by Max Mathews, views the orchestral 'conductor' as the paradigm on which interfaces should be modelled.

The *GROOVE* system (discussed earlier - see 1.8.1) was modified to produce the *Conductor* program which could interpret the movements of a hand-held wand and control various parameters of a score held in the computer [Mathews, 1988]. Mathews [1989] developed a variety of systems which gradually became more physical, culminating in the popular *Radio Drum* (see Figure 1.19).

Figure 1.19: Max Mathews demonstrating the Radio Drum

This drum-like sensor can be struck by the performer in various places and with a range of force in different strokes. It is also capable of detecting the position of the beater in a 3D space above the drum using an array of small radio antennae contained in the drum's surface. The Conductor program interprets these signals as perturbations to the score, and the music is played via MIDI. It was later developed into the *Radio Baton* which has been used in a variety of interactive works.

1.13.3 Hand Gestures: Gloves and wires

Designers have investigated the possibility of using the subtlety of movement that a human hand can produce to control a variety of musical parameters. The hand movements can be sensed by a computer mouse, an ultrasonic beam, a data-glove or by custom-built hardware devices.

The STEIM team in Amsterdam, led by Michael Waisvisz, produced a two-gloved device called *The Hands* [Waisvisz, 1985]. The performer wears gloves which sense finger position and hand separation and convert these to a stream of control signals. Waisvisz was re-establishing the tradition of electronic gestural instruments begun by Leon Theremin. Figure 1.20 shows a meeting of the two inventors, playing a duet on their gestural instruments from opposite ends of the twentieth century.

Figure 1.20: Leon Theremin and Michael Waisvisz

A further development consisted of a lattice of wires which were under tension [Krefeld, 1990]. *The Web* allowed players to subtly pull the wires about and disturb the tension distribution and thus influence the musical signals. Both of these developments show much promise for *explorative* control over a complex set of parameters.

1.13.4 Body Movement: Sensors and Beams

Various non-contact devices have been invented in recent years. Generally these are ‘beams’ (of light or ultrasound) which are used to detect the player’s movement in space. The device senses the point at which the beam is broken, and this is converted into a MIDI message, so that sound can be made using a MIDI sound module (see Figure 1.21).

The EMS *Soundbeam* [Swingler, 1994] uses a series of ultrasonic sensors to convert the movements of dancers (for example) into MIDI messages.

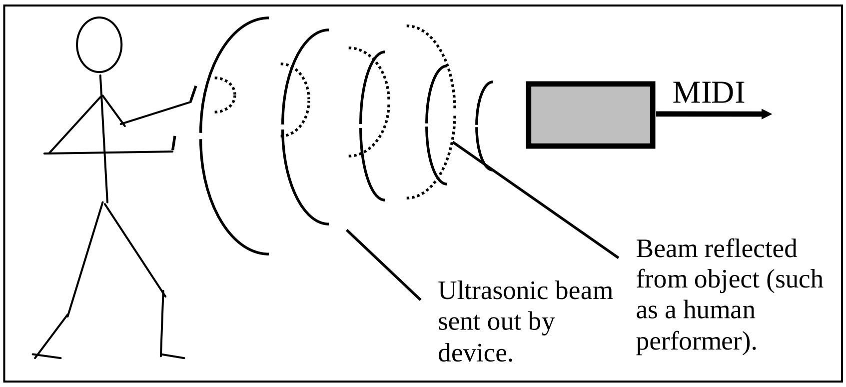


Figure 1.21: An ultrasonic device for capturing linear human gesture

The University of York's *MidiCreator* system [Abbotson, 1994] will turn any electrical switch or resistance control into MIDI (see Figure 1.22). Thus dials, levers, switches, even bits of wire immersed in water can be used as a musical instrument. The *MidiGesture* is an ultrasonic beam which plugs into the creator.

Figure 1.22: The MidiCreator and MidiGesture systems

All these devices are used widely in helping people with disabilities to gain access to music. Switches, sensors and beams can be configured to suit particular physical problems and can be played without the combination of fine control and considerable physical effort required by many acoustic musical instruments. People are even investigating how to use variations in skin resistance and brain-waves to drive MIDI and computer systems [Tanaka, 1993].

1.13.5 Hand Gestures: Computer Mouse

MidiGrid [Hunt, Kirk, 1988] is a software environment (developed by the author at the University of York UK) which turns the computer into a musical performance instrument based upon the computer 'mouse' controller. A 'grid' of boxes appears on the computer screen and the user moves a cursor (by using the computer mouse) and instantly plays the notes in each box.

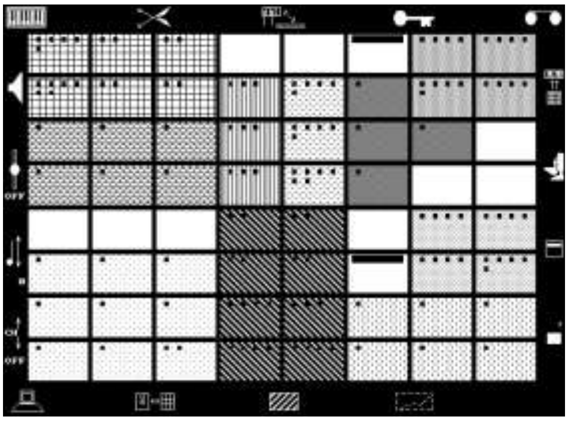


Figure 1.23: An example MidiGrid screen showing notes, chords and sequences

Users quickly discover that different gestures produce different musical results. The ‘grids’ can be stored on disk and can consist of hundreds of boxes full of user-definable layouts of MIDI notes, chords and sequences.

A categorisation of further, more recent, developments in the area of computer instruments can be found in section 3.2. MidiGrid is covered in more detail in section 3.3.

1.14 Networks for Interactive music

Many systems exist nowadays which allow the user to construct ‘networks’ of musical processing objects. Often these objects are represented by graphical icons on a computer screen and are connected together using a computer mouse. This type of software package allows the user to devise interactive musical environments, where certain gestures produce specific musical results. Two specific examples of this are ‘Max’ and ‘MIDAS’.

1.14.1 Max; visual programming for interactive music

Max [Puckette, 1988] is a program, written in the 1980s by Miller Puckette, that allows composers to define interactive musical environments. It offers a fast way of prototyping performance environments and sound-processing techniques. The composer uses the computer’s graphical screen to connect together a set of boxes that each represent a simple process.

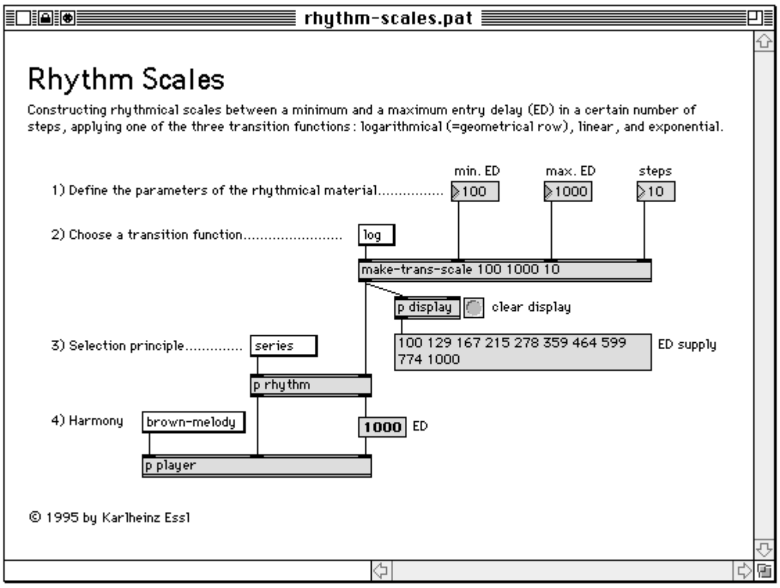


Figure 1.24: An example screenshot from Max

For example it is possible to connect a 'get a note from a MIDI keyboard' object to a 'transpose a note up one octave' object. The output of such an example network would then collect notes from a MIDI keyboard and transpose the pitch up an octave. More complex networks can be built up to achieve a variety of interactive musical situations.

1.14.2 MIDAS; an audio-visual toolkit

The University of York UK's 'MIDAS' [Kirk, Hunt, 1996] system is designed to run on a variety of computing platforms. Composers can use it to design interactive multimedia compositions and installations in the confidence that these works will be performable even if the current computing technology goes out of date. MIDAS can also operate on many computers at the same time (in the form of a computing *network*). This networking ability means that extra processing power (which is vital for real-time performance) can be added into the system without changing the composer's interface. Composers can work with MIDAS in a variety of ways - from graphically connecting together icons that represent audio-visual functions (similar to *Max),* to programming the system in computer code. It is used as the technology to build the interface tests associated with this thesis, and is covered in more detail in Chapter 6.

1.14.3 The Internet; communication across the world

The exponential growth in recent years of the world-wide interconnection of computers - known as the Internet - is transforming the way that people communicate. Two visible signs of this are the growth of personal *email* addresses and the perceived necessity for a company to have its own ‘home-page’ on the World Wide Web (WWW).

Bill Gates [Gates, 1998] claims that it will not be long before the entire commercial music industry is overturned or transformed by the Internet. The present sluggish (if not tedious) response of the Internet when downloading sound files may make us suspicious about the feasibility of some of these ideas. However, many people believe that in a few years’ time we will no longer buy tapes or Compact Discs (CDs), but will download the tracks of our choice from on-line catalogues or even download them in *real-time* and pay for them for each time we listen. At the time of writing there are various experimental programs such as *LiveJam* [LiveJam, www] which are allowing people in different countries to take part in live improvisation using MIDI instruments across the Internet.

1.15 Summary

Electronics and computer technology have had an ever increasing transformational effect on the storage, distribution and production of music in the twentieth century. Each new invention brings its own new method of operation which must be learnt by its users. Tape and computers have created an entirely new mode of operation in the musical world; the complete preparation in advance of a piece of music which is 'performed' simply by playing back the recording. However the essence of music for thousands of years has been its interactive human quality and given the recent technological advantages (which have made real-time audio computing possible) it is no wonder that the search continues for ways to produce new performance instruments.

The real-time control of digital audio is a very new subject area and one that requires much thought and innovative input. In particular it is important to concentrate on the requirements of composers and performers and not of software and hardware designers. It is the purpose of the rest of this thesis to examine the subject of computer control of real-time operations in greater detail. To set this discussion in context, Chapter 2 looks at the subject of Human Computer Interaction.