Overview

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Synthesis techniques are central to the idea of digitally generated sound. The computer or other digital synthesis hardware must be instructed in some fashion to produce the sound. A synthesis technique is a set of rules for ordering and controlling those instructions.

It is a popular assumption that the computer can create any sound. While this may be theoretically possible, the difficulty lies in specifying the sound with sufficient accuracy without getting bogged down in minute details. Part of the training of the computer musician consists of learning the "handles" provided by synthesis techniques and learning how to manipulate them to achieve the desired musical ends, whether at the level of part of a note or at the level of an entire concert.

The last few years have brought the development of a wide variety of digital synthesis techniques, many of them discussed in this part. The emphasis on *digital* is important here. Many of these techniques have been known in one form or another for decades or even centuries, but, for the most part, their application in the realm of audio synthesis became feasible only with the development of digital technology.

Some of these techniques are motivated by the desire to replicate the sounds of traditional instruments; the precision attainable with the digital computer makes such a possibility attractive indeed. Other synthesis techniques offer ease of implementation, or the capability of producing more sounds (or more complex sounds) with a given amount of hardware. Some techniques have been derived from particularly elegant mathematical gymnastics. Inevitably, compositional issues enter into the formulation of a synthesis technique; the possibility of composing the microstructure of sound along with the rest of the musical work provided part of the motivation for the founding of electronic music studios in Europe after World War II (Stockhausen 1953). This same concern can be found in some of the work presented here.

In this brief overview, it will be impossible to do justice to the history or the scope of synthesis techniques. A more technical discussion can be found in Moorer 1977. However, I will at least mention each of the synthesis techniques represented in this part, and in many cases I will provide pointers to related work in the field (see also Chamberlin 1980).

The most straightforward way of instructing a computer to synthesize a sound is to record the sound into the computer and then play the sound back. Once the sound is recorded, it can be manipulated by the computer in a manner analogous to musique concrète. Many composers have explored these possibilities in the digital domain. A similar approach, which might be called wavetable lookup synthesis, has been used successfully at the Institut de Recherche et Coordination Acoustique/Musique (Barlow 1980).

Historically, additive synthesis is the most important and influential synthesis technique. A technical overview is given in Moorer 1977. This technique often serves as a standard against which other synthesis techniques are measured. Briefly, additive synthesis can be explained by analogy to light. Light can be broken down into its constituent spectral components by passing it through a prism; every shade of light has its own characteristic mixture of spectral components. In the same way, sound can be passed through the equivalent of a prism in order to break it down into its spectrum. Usually these spectral components look like the sine or cosine curves (sinusoids) of trigonometry. Of course, the individual spectral components of light are not ordinarily visible, except in rainbows. Likewise, we do not ordinarily hear the separate spectral components of a sound. However, it is possible to replicate a given sound to a high degree of accuracy by adding together the proper audio spectral components; hence the name additive synthesis. A next step, then, is to add together some arbitrary set of spectral components in order to make previously unheard sounds. The theory for this synthesis technique is closely tied to models of sound and auditory perception that date back to the ancient Greeks. Thus, this technique has dominated thinking about synthesis for a considerable amount of time. Risset's early *Catalogue* (1968), for example, included several additive-synthesis instruments. Many of the synthesizers currently available on the commercial keyboard market and many of the other synthesizers discussed in part II are built around this technique.

In spite of its prominent position, additive synthesis has some drawbacks. One of these is the immense amount of data needed to accurately specify the spectral components. As Rolnick shows in article 25, handling this much data can bring a synthesis system to its knees.

Frequency modulation (FM) is well known to lovers of high-quality radio. It turns out that the same formulas that form the basis for FM radio transmission can also be used to generate musical sound. Like additive synthesis, FM permits control of the audio spectrum with enough precision so that the composer has adequate control of the resulting sounds.

In many cases FM turns out to be more economical in terms of the hardware required to produce a given sound and the amount of data needed to specify a sound. FM is introduced here with the classic paper (article 1) of Chowning, who developed the technique and provided early compositional examples, such as his work *Turenas* (1972). Morrill (article 2) and Schottstaedt (article 4) offer applications of FM to the replication of sounds of traditional instruments, such as the trumpet tones used in Morrill's *Six Dark Questions* (1978–79). Chowning (1980) has also extended FM to the realistic simulation of vocal tones, as in his work *Phōnē* (1981). LeBrun (article 5) and Schottstaedt present an extension of FM theory beyond that given by Chowning in article 1. The variant of triangle FM developed by Saunders (included here, in a corrected and expanded version, as article 3) offers implementational advantages, especially for small computers. Finally, Truax (article 6) presents an approach to compositional structure based on some inherent properties of FM. Since this article first appeared, Truax has continued to explore this area, as shown by his composition *Arras* (Truax 1982). Some other compositional applications derived from this technique are discussed in Holtzman 1981.

A corresponding synthesis technique, amplitude modulation (AM), although widely exploited in analog studios, has not yet found widespread use in digital studios. Dashow (1980) has explored some compositional applications.

Pioneering studies of waveshaping were conducted by LeBrun (1979) and Arfib (1979). Roads offers a less technical, less mathematically demanding introduction in article 7. In article 8, Beauchamp presents the results of his work attempting to emulate the sounds of traditional instruments, in this case the cornet. Beauchamp's approach is practically indistinguishable from waveshaping as a synthesis technique, although his work was done independent of LeBrun and Arfib.

A related set of techniques known as summation formulas are discussed in Moorer 1976 and Moorer 1977.

A considerable amount of work has been devoted to modeling the behavior of the physical parts of a musical instrument with mathematical formulas (see, for example, Hiller and Ruiz 1971 and Smith 1983). However, this approach has not yet found widespread use in synthesis for composition.

Another large class of synthesis techniques is subsumed under the term *subtractive synthesis*. Rather than adding together a selected number of spectral components, as in additive synthesis, the subtractive approach starts with an easily generated signal rich in spectral components (such as noise or a pulse train) and attempts to produce the desired result through a series of filtering operations. In article 9, Cann offers an introduction to linear prediction, which can be used as a kind of time-varying subtractive synthesis. Linear prediction has been used in a variety of compositions, such as those by Charles Dodge and Paul Lansky. A variant of linear prediction called cross synthesis (Petersen 1975, 1976) allows the composer to cross one instrument or sound with another, producing talking orchestras and other unusual effects.

Synthesis by instruction is a technique that has not yet been widely adopted at the majority of studios, perhaps because it is difficult to relate this technique to the sounds produced by traditional instruments. However, as Berg discusses in article 11, this is a technique that is truly wedded to the computer. Berg's article includes part of a composition realized with this technique.

The theory of granular synthesis, on the other hand, was developed before digital audio synthesis became popular. Roads discusses its history and theory and provides a useful introduction in article 10.

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