find these data in the literature, J. C. Tenney made a small study. The results are shown in Fig. 4. Here the just-detectable difference in the rise times of two tones is shown as a function of the shorter of the two rise times. These data indicate that, for rise times longer than about 5 milliseconds, a ratio of 3 to 2 is just detectable. For times shorter than 5 milliseconds, a difference of 1.5 milliseconds is necessary. Using these data, the composer can select a "scale" of attack functions which are separated by intervals that are equal in terms of the listener's ability to differentiate between the attack functions. Such data are typical of those required by a composer.

Composing with the Computer

So far I have described use of the computer solely as a musical instrument. The composer writes one line of parameters for each note he wishes played and hence has complete control of the note. He is omnipotent, except for lack of control over the noise produced by the random-number unit generators. Here a minor liberty is allowed the computer.

However, composing-programs are a reasonable area of computation, and work in this direction has already been done by Hiller (*5*), Olson (*6*), Brooks (*7*), and others. A number of different approaches can be taken toward composition by computer. At one extreme, the computer can be given a set of rules, plus a random-number generator, and can simply be turned on to generate any amount of music. Hiller's work is perhaps closest to this extreme. In the opposite direction, the human composer can maintain close control of the music, using the computer merely to avoid some of the repetitious and tedious work involved in representing his musical ideas. Once a theme with many notes has been written, a program can be devised for repeating the theme by means of a single instruction. Furthermore, the theme can be modified in simple ways: it can be transposed to another pitch range or played upon a different instrument; its tempo can be changed or its loudness modified. Harmonization of the theme according to simple rules is possible. Other means of modifying or developing a theme in interesting ways may be forthcoming. The composer could, perhaps, form a composition from a set of thematic material, which he supplied, and a set of fixed transformations.

At present, the music-playing program has been modified so as to make transformational development of a theme possible. Certain of the simplest transformations have been programmed. These include all those mentioned above, with the exception of harmonization. As yet not enough music has been generated to assess the significance of this approach.

A slightly different method has been tried by Tenney. His approach is a compromise between a purely random and a completely specified composition. The parameters of the individual notes of the composition are generated as a sequence of independent random numbers by a random-number routine. However, the average value and the variance of these parameters are specified by the composer as functions which change slowly throughout the composition. The "score" of a section of one of Tenney's works is shown in graphic form in Fig. 5. The means and variances of the note-durations, loudness, and other parameters of the various voices are controlled. Indeed, the number of voices playing at a given time is controlled. By this relatively simple algorithm, a long-range structure which can be clearly recognized by the ear is imposed on the composition. Thus, one of the characteristic shortcomings of random compositions —a lack of long-range structure—can be overcome.

The use of computers as an aid in composition is still very new. We hope that by this means the composer can avoid having to write out all the individual notes in a piece of music in order to express his ideas—that he will be able, rather, to write directly in parameters that are much more closely related to his musical objectives, letting the machine generate the individual notes. Whether this objective can be attained remains to be seen.

The Future of Computer Music

I have indicated how almost any sound can be produced by treating the numbers generated by a computer as samples of the sound pressure wave. A very high sampling rate is required, and, if this process is to be useful musically, programs for generating samples from the parameters of notes must be written. A broad set of these programs is now available and has been used for playing, on an experimental basis, a wide range of music. Additionally, studies are being made on possible uses of the computer as an aid in composing. In such studies the computer usually plays its own compositions and constitutes a composer-player team.

Computer music appears to be very promising technically. However, the method will become significant only if it is used by serious composers. At present, our goal is to interest and educate such musicians in its use. We believe that competent work in the field can benefit not only music but the whole field of psychoacoustics.

References and Notes

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