Computer musical instrument shows saxophone note.

The music establishment has tended to react to electronic music the way a scribe might have to the news of the Gutenberg Bible. This new thing means change. The computer-assisted synthesizer has insinuated itself into the inner sanctum. After receiving a major donation from Yamaha, even the prestigious Juilliard School of Music in New York opened an electronic music studio. Juilliard's dean, Bruce MacCombie, admits to owning a Korg synthesizer.

When it comes to teaching music, electronic instruments have several advantages over conventional instruments. Besides the fact that electronic keyboards never need tuning and can be listened to with headphones, synthesizers can be programmed to focus on specific skills. Stanford University's Chowning, for example, has developed a program to help students learn pitch. It keys the pitch of a note to the timbre of specific instruments. A C note might sound like an oboe, for example; an A, like a trumpet. Once the student learns to call the pitch, the timbre can be removed.

"Electronics is opening up music to people who might never have experienced it before," says Iris Gillon, a Juilliard-trained piano teacher in New York City. "That alone is extremely positive." Gillon teaches group lessons using MIDI-capable Casio HT 700s. She also has a $25,000 Steinway concert grand shoved against the wall in her New York apartment.

Proponents of electronic music find the technology liberating. "It's now possible for someone to learn music without physical skills," says electronic musician Herbie Hancock. "People say in a very negative way, 'Well anyone can make music with this,' and that's true. But anything that's going to inspire and bring out a person's creative bent is a good thing."

Some predict that the music of technology may unlock natural musical ability in those who never knew they had it. "My greatest fantasy is of *Homo musicus*", says Gerald Balzano, a "music scientist" at the University of California in San Diego who has degrees in music and cognitive psychology. "That is to say, we really are fundamentally musical, and all we need is a way to get in touch that doesn't depend on our having good voices or coordinated fingers, but really plugs directly into the musicality of our minds."

computer music

Ironically, a problem with computer-generated sound is that it is too perfect. A tremendous amount of technology goes into making computer music sound imperfect. . .as if imperfect humans played it on imperfect instruments. In the world of mathematically generated sounds, for example, the harmonics within the spectrum of a sound are whole number multiples of the frequency of the fundamental pitch. Most acoustic music, however, has slight deviations from perfect whole numbers. A technique of frequency modulation was developed to allow musicians to de-tune the harmonics; they shift the modulating frequencies to produce sounds that are warm, fat, or acoustic.

Performance introduces another opportunity for imperfection. Perfect notes perfectly played are the Holy Grail of music teachers. Musicians, however, aren't as troubled by the hobgoblin of consistency. When researchers at the Institut de Recherche et Coordination Acoustique/Musique (IRCAM) in Paris attempted to isolate the elements of swing by doing a computer analysis of a George Russell number called *All About Rosie,* played by pianist Bill Evans, all their probing computers were able to come up with was that, of the 150 notes performed, no two were of the same duration, intensity, or volume.

To allow for creative irregularity in the way music is performed, John Chowning of Stanford University and Mathews of Bell Labs developed a conductor computer program. It is used with a mechanical baton, also known as a drum baton or simply a "daton." The daton is a joystick and a cloth-covered mallet. With it, a conductor can control the volume, speed, and rhythm of a piece being played by computer. A soloist can rehearse with computer backup, as he might with an orchestra, that is, missing a beat now and then, intentionally or otherwise, speeding up or slowing down to emphasize a mood. The conductor can adjust the pace of the orchestra accordingly.

Carnegie Mellon computer scientist and trumpeter Roger Dannenberg developed software that actually takes the place of the conductor in limited applications. Dannenberg's program not only plays the orchestral part of *Rhapsody in Blue* on a synthesizer while a human plays the piano, it also listens to the piano and adjusts the speed of the orchestra automatically.

I WRITE THE SONGS

Long before there were computers, math provided the structure for much musical composition. *Nuper Rosarum Flores,* for example, a motet written in 1436 by Dufay, uses the same relations of tempo between its sections as the ratios in size between parts of the Florentine cathedral for whose dedication it was composed. Numerology was factored into several compositions by J. S. Bach. Contemporary composer Bela Bartok uses the Fibonacci numerical series in several works. (Named after the thirteenth-century mathematician Leonardo Fibonacci, the Fibonacci series describes each term as the sum of the two preceding terms.)

Music's underlying math-like structure makes its marriage with computers a logical union. The first computer-aided composition programs were written by Lejaren Hiller and Loren Isaacson in the 1950s. However, it has only been since the development of digital synthesis that computer-aided composition has come into its own. Transposed into 1s and 0s, it has become apparent that music is as much an expression of mathematics as computer graphics. Some of the most provocative computer graphics, for example, are the expression of a mathematical phenomena first called "fractals" by mathematician Benoit Mandelbrot, a researcher at IBM's Thomas J. Watson Lab. The deceptively regular irregularities of fractals are also a visual expression of certain characteristics of music. One of the characteristics of a fractal, for example, is self-similarity. That is, an image is made up of miniatures of itself within it. Self-similarity also exists in music. According to music theorist Heinrich Schenker, the canon, fugue, and motivic development are compositional procedures that depend on making new musical material by transforming previous material, i.e., self-similar structures.

Another characteristic of fractals is space-filling curves. These are represented graphically by such well-known fractals as the Koch curve. Space-filling curves are expressed in music too. The composer adds a faster repetition of the motif to each of the notes in the original motif.

Similarities between music and math that are only intuitive become obvious when the two are translated into the same language. Mathematician A. Davidson, who works with nonlinear dynamics—the basis of chaos theory—at IBM's Thomas J. Watson Research Center, has developed a mathematical way to put chaos to music. Davidson is an amateur musician. His interest in math and music produced an unexpected synthesis one day when he was working with M. J. Feigenbaum's quadratic map, the first mathematical proof of the existence of some universal properties inherent in the transition to chaos in nonlinear systems. Feigenbaum's equation produced slightly altered, but definitely recurring, patterns in a system that appeared to be chaotic.

"It was exactly how I came to regard music," Davidson recalls. "To maintain your interest, music must present some sort of pattern that you can recognize. It must prove that it is a pattern by repetition. But you will be quickly bored if the pattern is always strictly repeated. Instead composers use many tricks to shift the pattern and still keep it recognizable." Davidson's trick was to transform the numbers in Feigenbaum's quadratic maps into notes on a scale and let chaos sing. The resulting composition made its debut at a lecture at the Technical University of Denmark before a class studying computer modeling techniques. Davidson admits the chaos-generated music garnered less than rave reviews. However, 80 out of 100 in attendance were willing to call the recurring patterns, generated by chaotic maps, music.

More conventional compositions have been generated by CHORAL, an expert system written by IBM researcher Kemal Ebcioglu. Ebcioglu has a master's degree in music composition and a doctorate in computer science. His CHORAL program adds bass, tenor, and alto parts to melodies entered in the soprano. Ebcioglu incorporated Bach's harmonizations in the program's knowledge base, which applies 350 rules to the creation of computer-generated harmonies.

"It is a well-known fact that rules are not by themselves sufficient for producing beautiful music," Ebcioglu admits. "Composers use additional knowledge—what we call talent—for choosing among the many possible correct extensions of the partial composition at each stage of the process." What it lacks in natural talent Ebcioglu's program makes up for in dexterity. A typical choral composition requires 30 minutes of IBM mainframe time and involves 23 billion simple instructions.

PLAY IT AGAIN, SAM

Having written a piece of music, the next step is to hear it performed. Duke Ellington is said to have kept his band playing all year just to be able to hear the music he wrote the night before. The computer makes it possible to link composition, performance, and even publication. Mel Powell, a jazz pianist who played with Benny Goodman and a founder of Yale's Electronic Music Studio, uses a computer program called "Professional Composer" by Mark of the Unicorn to write music. He plays it back immediately using another program called "Performer." If he likes what he hears, he can print out the score on a laser printer.

By joining composition and performance, the computer makes it possible to integrate performance into the composition process. It's a kind of interactive editing. The computer turns a synthesizer into a multitrack recording studio that boasts some capabilities even the best studios can't match. For instance, there is no need for cutting and splicing. Many programs that run on PCs can delete misplayed notes the same way a word processor zaps out unwanted paragraphs. Some music programs can also tighten rhythm, change the key, and alter playback speed without changing the pitch. Improvements realized in performance can then be instantly incorporated in the score.

Musicians have to develop new skills to make music with the new technology. They also have to learn to express the skills they already have in a way that their new instruments can understand. Observes composer/programmer George Boulez of IRCAM: "Perhaps for the first time in history a composer has to explain and formalize the way he or she develops and manipulates concepts, themes, and relations in a musical context in order for technicians (who may have little musical training) to bring them into existence."

The technology required for a computer to sit in on a live performance is especially daunting. To perform live, a computer has to be capable of generating or manipulating between 16,000 and 40,000 samples (a sequence of binary numbers that describes a waveform) per second. Only recently have computers become fast enough to do it in real time so live music can be performed in concert with computer music. One of the first compositions to integrate computers into a live performance is *Repons*, by IRCAM's Boulez. It was first performed in 1981 by a French avant-garde chamber music group. *Repons* not only changes the music's relation to itself, but also the music's relation to the audience. During a performance, the instrumentalists are in the middle of the concert hall. The audience sits around them. And the soloists are placed around the periphery. One computer rebuilds the samples in a fraction of a second, while another acts as a kind of audio signal traffic controller. It routes notes around the concert hall, adding the dimension of "spatialization" to the performance. The sound of the soloists moves around speakers at speeds depending on the sound's loudness, which is proportional to the amplitude of the sound's waveform.

You don't have to be a musician to appreciate that something different is going on when the composer speaks of his performance in these terms: "The electronic manipulations involved in the two short passages from *Repons* were implemented by means of a single 4X patch that programs six modules for spatialization, five for multiple delays, 30 for frequency shifting and assorted noise-reduction modules for each soloist."

THE SOUND OF THE FUTURE

The new technology makes it possible to introduce new dimensions to the design of musical instruments. Notebender by Key Concepts, for example, has two axes of touch sensitivity on its keyboard. A musician can control the degree of force with which a note is played and, by moving the key forward and back, can modulate the pitch at the same time.

The keyboard is the most popular way to communicate with a computer. However, there is an assortment of foot pedals and even a breath controller that can be used. Guitar synthesizers have been developed with rubberized patch buttons that the player can press with his feet while his fingers are busy picking.

The flexibility of electronic instruments has cut into the appeal of their more conventional ancestors. Sales of electronic keyboards passed $1 billion in 1987, up 52 percent from 1985. By contrast, piano sales peaked in 1978 at 282,171 units, and fell to around 175,000 in 1987. "As the piano was the instrument of the nineteenth century, the computer is the instrument of the late twentieth century," observes Rand Steiger, composer and assistant music professor of the University of California at San Diego.