Phantom of the Brain Opera

The Opera Ghost really existed. He was not, as was long believed, a creature of the imagination of the artists, the superstition of the managers, or the absurd and impressionable brains of the young ladies of the ballet, their mothers, the box-keepers, the cloak-room attendants, or the concierge. No, he existed in flesh and blood, though he assumed all the outward characteristics of a real phantom, that is to say, of a shade.

Gaston Leroux
The Phantom of the Opera (1911)

These words speak of a half-crazed musician hiding in the labyrinth beneath the Paris Opera House at the turn of the century, causing strange and mysterious events to further the career of a beautiful young singer. But they could just as easily apply to another unusual but contemporary impresario. This modern phantom certainly stimulates the imagination of artists and everyone else who is fortunate enough to attend a performance of his latest work, *Brain Opera*. And although he doesn't assume the outward appearances of a real phantom, he does work much of his magic using shade of a sort, as we'll see.

The phantom of the *Brain Opera* is Tod Machover, associate professor of Music and Media at the famed MIT Media Lab. Of course, this phantom isn't half-crazed or in hiding. However, he is causing strange and wondrous events to further the musical experience of any and all who care to participate—no matter what their musical background or physical location in the world.

By Scott Wilkinson

Phantom of the Brain Opera

JOHANNES KROEMER

FIG. 1: The Singing Tree produces a vocal timbre based on the purity of the pitch you sing into its microphone. (Courtesy MIT Media Lab)

THE PHANTOM

Machover found his primary inspiration for the *Brain Opera* in the work of Marvin Minsky, a pioneer in artificial intelligence (AI) and one of the guiding lights of the Media Lab. According to Machover, "Minsky is a great thinker about music and the mind and is also a great psychologist. He views the mind as decentralized, without a central consciousness or 'conductor' in front of the 'orchestra.' Rather, the mind is a collection of specialized brain centers or 'agents' that act together to do more and more complex things."

Machover decided to apply these ideas to music. "I wanted to create an opera about how the mind works and, more specifically, about what it feels like to develop coherent ideas from a mass of fragmented sensory inputs. Unity from diversity has been a theme of mine for a long time. In addition, I wanted to create an artistic work that reflects the new culture emerging in places like the MIT Media Lab, which blends art and science, theory and practice."

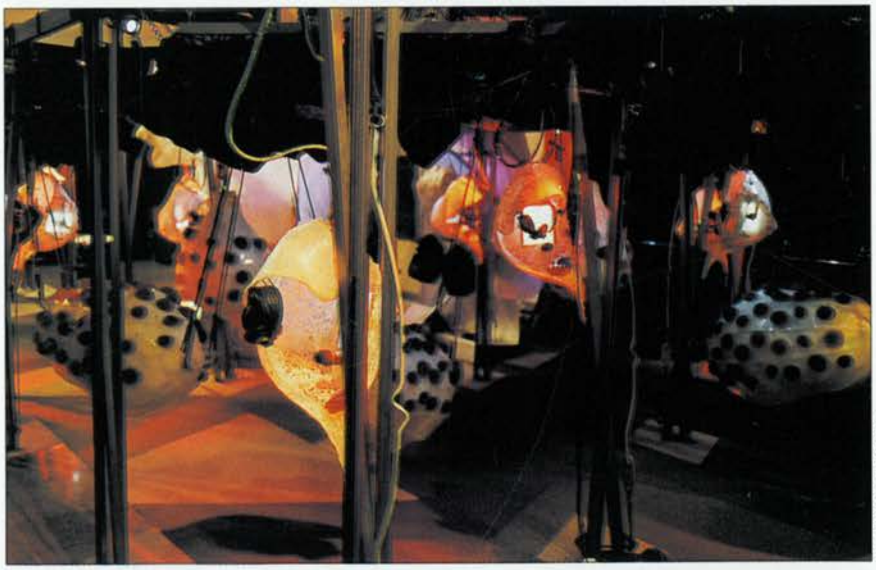
Another important thread in the tapestry Machover wanted to weave is the concept of "active music," in which anyone—regardless of their musical ability—can actively participate in the creation of a satisfying musical experience. Glenn Gould wrote about this in an article on the future of music recording in the April 1966 issue of *High Fidelity* magazine: "In the best of all possible worlds, art would be unnecessary. Its offer of restorative, placative therapy would go begging a patient. The professional specialization involved in its making would be presumption. The audience would be the artist and their life would be art."

Despite his professional credentials, Machover agrees with Gould. His own work at the Media Lab has been evolving in precisely this direction. As he recounts, "I believe that music has become too much of a professional specialization over the past century. For most people, it is now a background activity rather than a participatory one. The goal of my work is to try and lift the general level of public participation in music as well as the level of sensitivity and intelligence in listening, performing, and composing."

This brings up two questions: How can nonmusicians generate satisfying music? And if active music becomes widespread, what happens to professional musicians? Machover is committed to developing technology-based answers to the first question. During his first forays into this realm, he developed the concept of the *hyperinstrument,* which is a musical instrument with enhanced sensing mechanisms to measure and expand upon the subtle nuances of a performer's expressive gestures. However, it soon became clear that the same idea could be applied to instruments intended for nonmusicians.

As to the second question, Machover says, "I think those who are already talented will benefit from this direction and will only increase their skills. There will be a place for professionals with open minds and lots of flexibility as well as for amateurs willing to take the responsibility of being collaborators in creating new works and experiences."

And so the *Brain Opera* was born. The



JOHANNES KROEMER

FIG. 2: The Rhythm Tree is the world's largest percussion controller, with 320 separate pads mounted on seven large "pods." (Courtesy MIT Media Lab)


JOHANNES KROEMER

FIG. 3: The Melody Easel lets you "draw" a melody with your finger on a touchscreen. (Courtesy MIT Media Lab)

work is very vocal, although it has no fixed libretto or story line. In addition, it allows anyone to participate in its creation, becoming the "agents" that create individual, disparate elements, which are then combined into a cohesive whole. This mimics the behavior of the brain as described by Minsky and naturally leads to a different performance each time. (For more on the underlying technology of the *Brain Opera,* see the sidebar "Behind the Curtain.")

OF THE BRAIN

Before the actual performance, the audience enters a lobby called the Mind Forest, which is filled with strange and exotic structures that appear positively organic. These are the hyperinstruments that the audience members play with to generate some of the musical material that will be used in the performance. (For more on the technology of these hyperinstruments, see the sidebar "Hypertechnology.")

According to Machover, the organic quality of the instruments is intentional. "The experience and form of the *Brain Opera* is an attempt to make people feel like they're walking into a giant musical brain and becoming an 'agent' collaborating with others to help make each performance of the opera." This "look" was created by architect Ray Kinoshita, visual coordinator Sharon Daniel, and production manager Maggie Orth.

Among the hyperinstruments in the lobby are the Speaking and Singing Trees, which provide an interactive experience for one person each. The Speaking Trees are the only nonmusical hyperinstruments in the *Brain Opera,* but they provide perhaps the most direct expression of the ideas behind the production. The Speaking Trees play recordings of Marvin Minsky talking about his thoughts on music and the mind, and participants are invited to record their own thoughts in response to Minsky's words.

The Singing Trees are also intended as a solitary experience (see **Fig. 1**). Participants are instructed to sing a steady, single pitch into a microphone, which is fed into a computer. The signal is analyzed, and the pitch is determined as soon as the computer sees something that looks stable. This analysis includes a measurement of the "purity" and "calm" of the voice, which influences the resulting music.

"This is my favorite of the hyperinstruments," says Machover. "It's the most sophisticated in the way we tuned it, and it's incredibly responsive when you sing into it. You really get the feeling that it is responding to you. The slightest change in your voice sends the thing rippling. It's responsive without being literal. It doesn't mimic precisely what you're doing; it seems like it's expanding or intensifying whatever you put into it. It feels the most immediate and satisfying to me."

The Rhythm Tree is the world's largest percussion controller, with 320 pads designed to be played by 10 to 50 people at once (see **Fig. 2**). Seven big sacks that look like bean bags each have many attached pads made of molded polyurethane rubber. Each pad has a different shape; some look like weird plants, noses, or ears.

If there is a lot of pounding in a particular area, the system might turn on some lights or play a big percussive


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FIG. 4: Harmonic Driving lets you "drive" along a computer-generated "road" on a screen while it modifies the music in response to your maneuvers. (Courtesy MIT Media Lab)

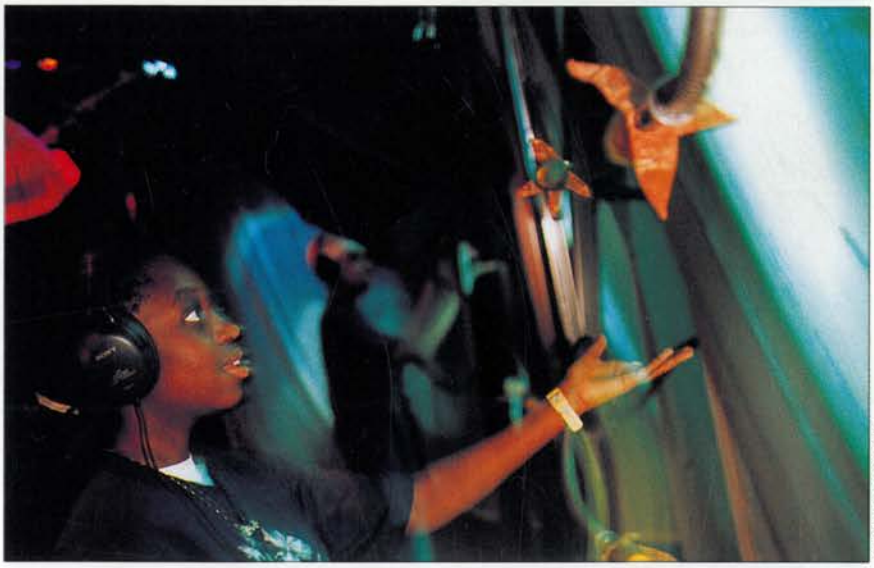
bang. If there's a definite rhythm emerging in an area, the system might quantize it or play a pattern to reinforce the rhythm. The collective behavior is analyzed to produce the final result. In addition, the Rhythm Tree can actually debug itself. If it sees several pads out of commission, it can turn itself off and on again to reset without human intervention.

The Melody Easels can each accommodate one participant and two observers (see **Fig. 3**). This hyperinstrument generates a single-line melody based on what the participant "draws" with a finger on the pressure-sensitive touchscreen. The melodies are core melodic fragments from precomposed *Brain Opera* material, which are manipulated in terms of the complexity of the melody and timbre.

Another hyperinstrument in the Mind Forest is called Harmonic Driving (see **Fig. 4**). From the start, Machover wanted to create a hyperinstrument that feels like a driving-simulation game; anyone walking up to this device would immediately recognize it as such. However, he ended up with a hyperinstrument that goes beyond a straightforward driving game.

You sit behind a "steering bar" and face a projection screen, which displays a computer-generated "road." If you drive skillfully, the road becomes more difficult to navigate. In addition, each fork in the road is marked with red and blue flags; if you take the red fork, the music becomes more intense with sharper attacks and more layers. If you take the blue fork, the music mellows out and becomes more legato.

Finally, there are five Gesture Walls in the Mind Forest (see **Fig. 5**). A large screen displays images from a video projector behind it. Gestures by the person standing in front of the screen are used to manipulate the sound and video image.



JOHANNES KROEMER

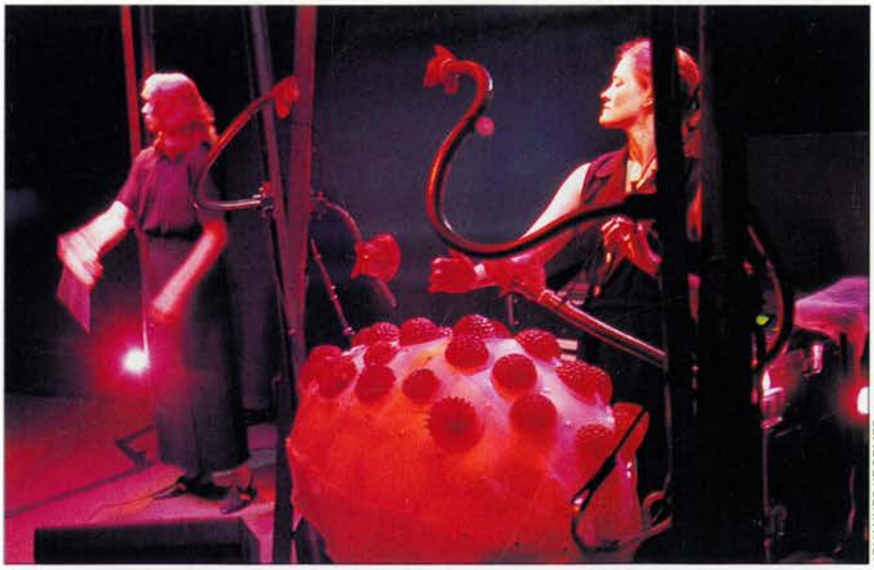
FIG. 5: The Gesture Wall detects your movements with four sensors that resemble flowers mounted on goosenecks at the corners of a large rear-projection screen. (Courtesy MIT Media Lab)

OPERA IS HERE

After the audience has provided its input from the Mind Forest, this material is incorporated into the final 45-minute performance. Information from the lobby computers is downloaded into a master control computer, after which three performers select and manipulate precomposed and audience-generated elements using their own hyperinstruments.

One performer plays a Rhythm Tree pod with some Gesture Wall sensors (see **Fig. 6**), while another performer plays a Sensor Chair. This is the only hyperinstrument that was already mature before the *Brain Opera*. (It was originally developed for magicians Penn and Teller.) When the performer sits in the chair and waves his or her arms and legs around, a lot of control information is generated, which is applied to the music. Anyone touching the seated performer can also affect the receivers, which makes for some interesting collaborations. The third performer uses a Digital Baton, a hand-held device that is sensitive to hand and finger pressure as well as motion in space (see **Fig. 6**).

A large screen behind the performers presents images that are coordinated with the music. These images are used to illustrate Minsky's ideas, highlight



JOHANNES KROEMER

FIG. 6: The nearer of these two performers, Maribeth Back, is playing a Rhythm Tree pod and Gesture Wall sensors, while the other performer, Teresa Marrin, is playing a Digital Baton. (Courtesy MIT Media Lab)

Phantom of the Brain Opera

the actions of the performers, and provide a visual counterpoint to the music. The images come from several laserdisc players and graphics computers.

The performance of the *Brain Opera* includes three movements. The first movement is the most improvisational, beginning with a cascade of sounds collected from the audience. It then develops into a mélange of Minsky's comments and reactions to them from the Speaking Trees, providing one of the threads that tie the movement together.

The musical throughline is Machover's treatment of Johann Sebastian Bach's 6-part "Ricercare" from *The Musical Offering* as well as fragments of music selected by the audience. After the climax, sounds from the Singing Trees are used to bring the music to a point of calm and repose. This movement generally develops from words to sound to music, which represents a transition from everyday life to transformed experience, from free association to more structure.

BEHIND THE CURTAIN

The *Brain Opera* is a natural extension of the MIT Media Lab's hyperinstrument project, which began in 1986. The initial goal was to enhance the virtuosity of professional musicians, such as cellist Yo-Yo Ma, by sensing many nuances of their performance and using that information to enhance and expand their instruments' capabilities electronically. This led to the creation of the hypercello and other hyperstring instruments. Hyperinstruments began evolving into expressive tools for nonmusicians in 1991.

Throughout this project, Machover and his colleagues use radio-frequency (RF) sensing to detect subtle movements of the performer. It's been known for a century that humans have just the right inherent dielectric properties to interfere with electric fields generated by radio transmitters. This is the principle upon which the theremin is based.

During the development of hyperinstruments and the *Brain Opera*, Joe Paradiso and Neil Gershenfeld designed the basic RF sensing circuitry. Called the Fish after the fact that certain fish can sense weak electric fields, this device includes one low-frequency, low-power RF transmitter and four receivers that are like little AM radios tuned to the frequency of the transmitter. The receivers sense the change in signal strength as the intervening electric field is altered by someone's movement within it. The transmitter and receivers are connected to metal plates via conductive wires and positioned to create any desired sensing geometry.

The Fish operates in one of two modes: Transmit and Shunt. In Transmit mode, someone stands or sits on a metal plate and becomes an antenna for the transmitter. Their movement relative to the receiver plates changes the signal strength, which is proportional to the user's distance from each plate. If no one is sitting or standing on the transmitter plate, no signal is present.

In Shunt mode, the transmitter and receivers are placed near each other, so there is always some signal present. When a person moves between the transmitter and receiver plates, a "shadow" is cast on the receiver plate, reducing the signal strength accordingly. (I told you this phantom worked much of his magic using shade!)

An HC11 microprocessor digitizes the receiver signals and then translates them into MIDI note and controller messages. A Fish and metal plates are installed in various fanciful structures that are actually theremin-like hyperinstruments to be played by the audience and performers.

In most cases, the Fish sends MIDI messages to a Windows computer installed in the hyperinstrument. The computer runs a program called *ROGUS*, the central MIDI processing software written by Ben Denkla and Patrick Pelletier. In fact, Denkla was in charge of the entire software infrastructure for the *Brain Opera*, and Pete Rice was responsible for the performance-system software.

Written in C++ for portability and speed, *ROGUS* replaced HyperLisp on a Macintosh, which they had been using in the Lab to process MIDI data before the *Brain Opera* was born. For a project of this scope, they needed to go beyond the 1-port, 16-channel limitation of HyperLisp, which is also less reliable than C++ for real-time applications.

They also wanted to move to the Windows platform to develop the *Brain Opera* software because they thought sponsorship would be easier to come by. (It was. IBM came through with a generous grant.) In addition, Windows NT is a very stable development environment; according to Denkla, "Bugs in your code don't bring the entire system down like they can on the Macintosh." However, they use Windows 95 to run the *Brain Opera* software in performance because it has better hardware support for the 8Port/SE MIDI interfaces they use.

The centerpiece of *ROGUS* is the Score Player, which is very tricky code written by Pelletier. The Score Player offers low-level dynamic control over how a MIDI file is played. According to Denkla, "The music in the *Brain Opera* is oriented toward playing precomposed MIDI files and modifying them as they play rather than generating algorithmic music on the fly. For example, the system might change the channel of a track to change the instrumentation. It can also transpose, change tempo, and perform many other manipulations."

As mentioned earlier, each hyperinstrument includes its own PC running *ROGUS*, which looks for MIDI messages from the Fish and uses them to manipulate the MIDI file playback. The altered MIDI file is then sent to one or more local synths. The data generated by *ROGUS* is also collected for use in the final performance of the *Brain Opera*. All told, the production utilizes 45 networked computers (using 10BaseT or 100BaseT Ethernet) and 40 synths and samplers.

The second movement is a continuous piece of music that highlights the performers and their hyperinstruments. Much of the music is precomposed with different degrees of possible alteration in each section, and the tempo tends to accelerate.

Each section of this movement is related to one of the Mind Forest experiences. It begins with melodic fragments from the Melody Easel, which are woven into longer phrases, becoming themes that are used in the rest of the piece. This is followed by "Minsky Melodies," which uses Minsky's comments as a "libretto" for the music and graphic images on the screen. The next section is the "Brain Opera Theme Song," a wordless melody that combines the disparate motifs from the Mind Forest in a lively, upbeat piece. Music from Harmonic Driving provides a galloping climax to this movement.

The third movement begins with music generated by participants on the Internet. The *Brain Opera* system is

HYPERTECHNOLOGY

When someone sings a note into a Singing Tree, its computer analyzes the vocal quality with software written by Eric Metois. Then it sends MIDI messages to the local Kurzweil K2500, which produces a sound based on a large vocal-sample library stored in its 128 MB of sample RAM. These samples are mixed with various processed ROM sounds, and the result is a vocal timbre that changes its harmonic characteristics and behavior depending on what you sing.

Unlike most of the other hyperinstruments, the Singing Tree does not use *ROGUS*. The MIDI data is generated by a compositional algorithm written by John Yu and refined by Will Oliver that determines timbre, harmony, and rhythm of the music based on the vocal input. This algorithm is also used in conjunction with the input from the Internet.

In the Rhythm Tree, each pad includes an embedded polyvinyledine flouride (PVDF) wire, which is a piezoelectric material used to make microphone diaphragms, in addition to a microprocessor. The microprocessor is an 8-bit RISC integer processor with a 4-input A/D converter that measures how the PVDF wire bends. This determines the position and velocity of strikes on the pad as well as the type of strike (sharp or dull) and the amount of continuous pressure on a pad, if any.

Up to 32 microprocessors are connected in series to a controller, which converts the data into MIDI and sends it to the local *ROGUS* computer. The computer then sends MIDI messages to an Akai S2000 sampler, which includes samples of percussion and spoken phrases. Ara Knaian designed the Rhythm Tree pads and algorithms, and Maggie Orth contributed to the shape and molding of the instrument.

The Melody Easel consists of a pressure-sensitive touchscreen, which encodes the pressure information with 8-bit resolution and delivers precise *x-y* coordinates of the touch location. This data is sent to a *ROGUS* computer as well as another computer that generates graphics on the screen in response to the user's movements with software written by Chris Dodge. The *ROGUS* algorithm, written by Kaiyuh Hsiao, combines sampled vocal notes from a K2500 and more complex and changing timbres from a Yamaha VL1 and Korg Prophecy.

The Harmonic Driving "steering wheel" is actually a bar attached to a stiff spring with Fish transmitter and receiver plates mounted on it. As you manipulate the bar (twist right and left; bend forward, backward, right, and left), the Fish signals are sent to a *ROGUS* computer. Using an algorithm written by Pete Rice, *ROGUS* plays and manipulates precomposed musical fragments on an E-mu Morpheus and communicates with an IBM RS6000 RISC computer, which generates and manipulates the graphics with underlying software written by Rolf Rando and algorithms by Matt Gorbet.

In the Gesture Wall, Fish receiver plates are mounted on goosenecks at the four corners of the screen. A participant stands on the transmitter's metal plate in front of the screen and moves. The receiver data is sent to a *ROGUS* computer, which analyzes the signal for gestural characteristics. A separate computer stores the video images, which were created by Sharon Daniel, and transforms them in response to the user's gestures with software written by Chris Dodge.

The Sensor Chair consists of a chair with a transmitter plate on the seat, four receiver plates mounted on a frame in front of the seat, and two additional receiver plates on the floor in front of the chair. The performer becomes a transmitter antenna by sitting on the plate; waving arms and legs around causes the signal strength at each receiver to change. The Sensor Chair was already mature before the *Brain Opera*, so the Macintosh-based HyperLisp software was retained in this case rather than being rewritten it in *ROGUS*.

The Digital Baton, which was designed by Teresa Marrin with help from Joe Paradiso and Maggie Orth, is a hand-held wand with five pressure-sensitive resistors embedded in the surface to measure hand and finger pressure, three orthogonal accelerometers to measure the motion of the baton through space, and an IR LED mounted in the tip. A camera with a position-sensitive photodiode tracks the baton's LED as it moves through space. Both the baton and the camera are connected to a *ROGUS* computer.

Each of the performers has a K2500, Morpheus, VL1, and Prophecy to play with. The audio from these synthesizers is routed to Yamaha ProMix 01 mixers, which are also controlled by the performers' computers. The outputs from each ProMix 01 are sent to a big Mackie 8•Bus mixer, which feeds the house sound system and monitors. The sound system was set up by Ed Hammond, who also helped Eric Metois and Noah Schottenfeld with the sound design and live-performance mixing.

connected to the Internet with a T3 line. Netnauts with Streamworks' *Xing* client software, a real-time streaming audio and video application for PC, Mac, and UNIX platforms, can see and hear the performance live in real time by visiting the *Brain Opera* Web site (brainop .media.mit.edu). This site also has a link to the Streamworks Web site (www.xingtech.com), from which *Xing* is available for free.

Those with Java-equipped browsers can also participate in real time by manipulating an onscreen hyperinstrument called the Palette, which drives the same compositional algorithm used in the Singing Trees. Internet participants can also upload sound and graphic files to the *Brain Opera* system, which are played and displayed during the performance.

This movement ends with the Finale, which brings everything together. The onstage performers play along with Internet participants, and many of the previously heard elements return. The intensity builds, leading to a recapitulation of the "pseudo-Bach" heard in the first movement, but at a much faster tempo. This is accompanied by a "cantus firmus" that is modified by the online players.

The *Brain Opera* ends with a resonating C-major harmony in which all sounds combine to form a unified whole, followed by a quiet coda that almost resolves but leaves the chromatic ambiguity of Bach's "Ricercare" hanging in the air (and the audience's minds).

INSIDE YOUR MIND

The *Brain Opera* premiered at New York's Lincoln Center in July 1996. It then went on tour to various cities around the world, finishing its initial run in Tokyo in December. It is now back at the Lab, undergoing a tune-up and refinement in preparation for future productions. Machover is eager to improve the system for its next appearance. "We will install the system at the Media Lab from January through April 1997 so we can fix the remaining bugs and improve various aspects of the lobby, performance, and Internet experiences.

"We'll then go out on tour in the U.S., Asia, and Europe. I expect the Internet activities will be made more responsive and intuitive, and the back-and-forth between the lobby and performance will become more fluid and dramatic. We will most likely tour through 1998 and look for a permanent home for the *Brain Opera* between now and then. There are discussions of producing a CD-ROM connected to the Internet during the coming year."

According to Machover, "The goal of the *Brain Opera* is not just to have the audience members contribute musical sounds or spoken text, thoughts, memories, or favorite songs, but to prompt a reflection on the significance and deeper meaning of each. In this integration of diverse sonic sources, the attempt is to explore how our minds turn fragmented experience into coherent views of the world.

"If the interactive lobby experience is fragmented, marked by an individual journey through a dense barrage of seemingly unrelated impressions and experiences, then each performance of the *Brain Opera* in the adjacent theater

> "I wanted to create an opera about how the mind works."
> —Tod Machover

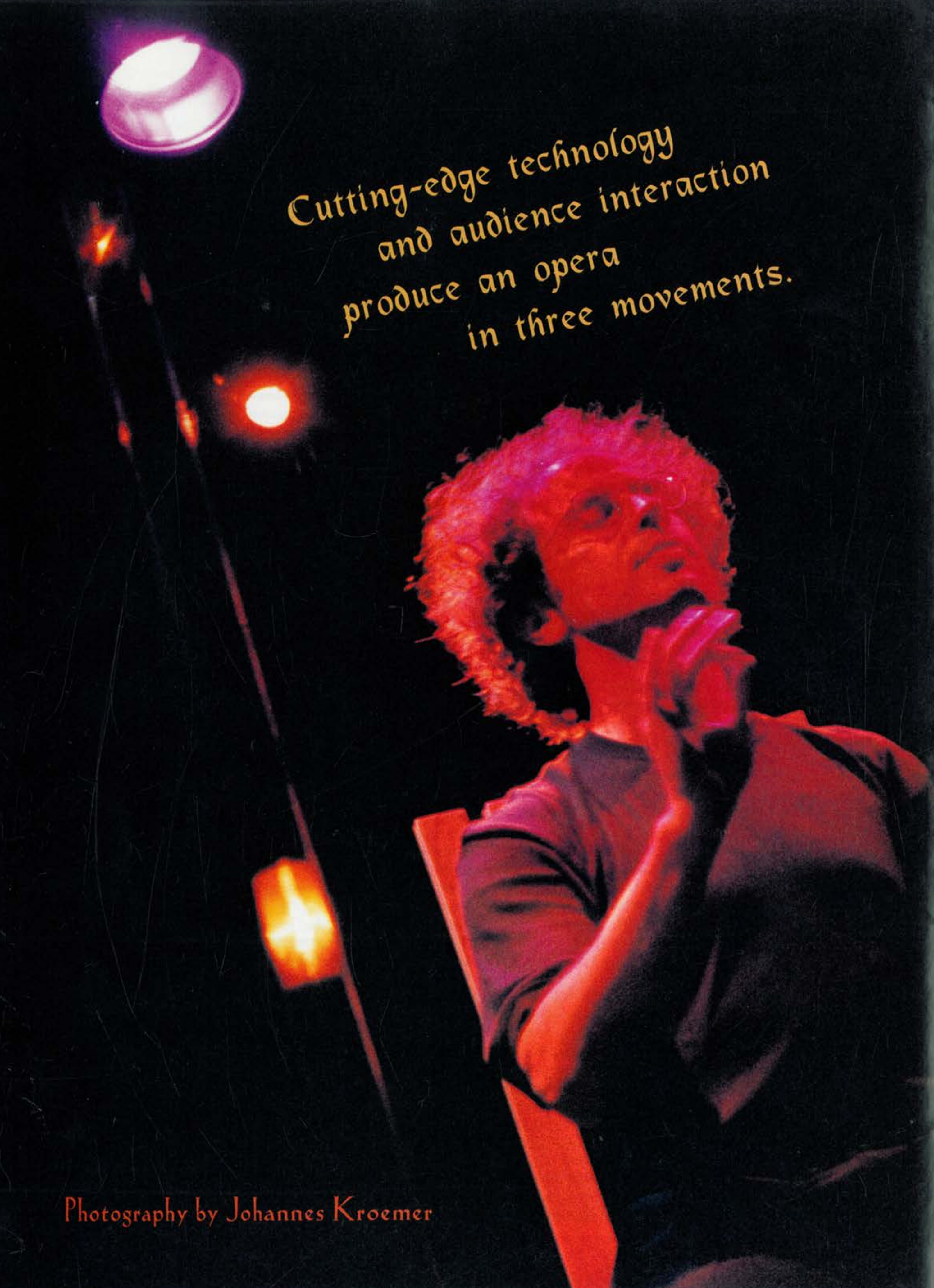
is an attempt to create a new kind of balance between the ordered complexity of Bach and the exuberant chaos of Cage, with a touch of the early Beatles' youthful energy thrown into the mix. The audience is right in the middle of this search, which makes the artistic experience more palpable and visceral to each active person as it underlines the collaborative nature of the project as a whole.

"It is this kind of audience involvement—not the mere manipulation of our hyperinstruments—that makes the *Brain Opera* truly an 'opera.' Although the work does not have a linear narrative, which I have avoided at every step of the design process, it certainly has *lots* of voices—professional and amateur, singing and speaking, individual and communal—and the texture is very vocal, even operatic.

"More significantly, the *Brain Opera* does have a significant dramatic progression, which is the voyage of each audience member through the maze of fragments, thoughts, and memories to collective and coherent experience. Just the process of understanding the scenario of each instrument—how it is played and what it means—and seeing how these turn into full musical structures in the performance, is a very rich and involving story in itself. One of our deepest hopes is that the *Brain Opera* will encourage people to be excited by the desire to, as Minsky puts it, 'look inside and hear what is going on.'"

Or, to paraphrase Andrew Lloyd Webber's lyricist Charles Hart, the phantom of the *Brain Opera* is there inside your mind.

EM *Technical Editor* **Scott Wilkinson** *looks forward to attending a performance of the* Brain Opera.



Photography by Johannes Kroemer