Research in Progress

Digital vs. Analog

DIGITAL RECORDING, which stores the shape of a sound wave in numerical form, is a technology new in the past few years. It has been heralded as superior to the conventional recording technique, which is now, in comparison, called analog, because the shape of the wave is stored as continuous variations in some analogous quantity — intensity of magnetization along a recording tape or the shape of the grooves of a record.

Once sound is put in digital form, the new technique can command all the resources of computer technology. A digital recording should be reproducible an infinite number of times without degradation in quality; there should also be no background noise. Theoretically, with sufficiently frequent sampling and high enough precision of each sample, a digital recording ought to be able to reproduce live sound perfectly.

But you don't buy a theory to listen to music on; you buy a machine. And ultimately the only way to test audio machines is to listen to them. So Jim Boyk, lecturer in music (in both engineering and humanities) and artist in residence, designed an experiment to find out just how good the digital machines sound and whether they are indeed better than the conventional recording technology. Undergraduates Larry Gross and Denes Zsolnay participated in the project from the beginning, and Gary Lorden and F. Brock Fuller, both professors of mathematics, also contributed to the experiment's design.

Perception tests are difficult to design, and Boyk's is the only one he knows of on recording that does not merely compare digital and analog but uses live sound as a simultaneous reference for both. Troops of musicians and listeners ("ideally someone who cares about live music rather than just technology") were drafted for the study, which took place during several days spread over a number of weeks this past summer.

As the musicians — from pianists and other instrumentalists to vocalists — performed in live marathon sessions in Dabney Lounge, the sound was fed across the alley to Thomas Laboratory where it was split in three. One line led directly to the speakers in the listening room, where it could be heard essentially live. The other two were diverted to digital and analog recorders and then to the speakers.

By means of a switch the listener could choose among the direct feed, which was labeled and did not change, and "apples" and "oranges," which represented the two unknowns — one of them digital and the other analog. The test was double-blind. From outside the listening room the apples and oranges were juggled randomly through an arrangement that kept even the operator in the dark as to whether, at any time, apples were analog and oranges digital or vice versa. Or whether both feeds were one or the other, which sometimes happened.

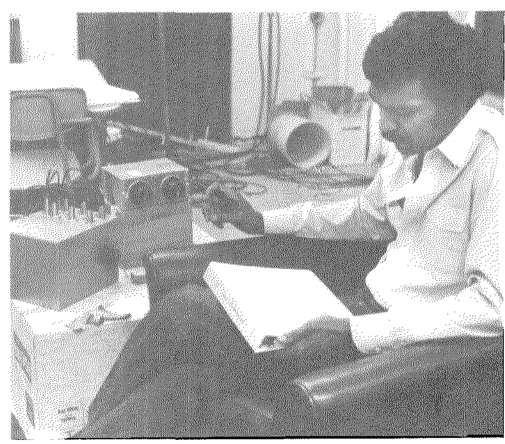
Seventeen subjects sat through 10 or 11 trials each (listening for from one to two and a half hours), switching back and forth among the three as they chose and answering two questions: Are the apples and oranges identical? And, if not identical, which comes musically closer to the direct feed? Listeners were also asked at the end if the apples and oranges were ever equal to the direct feed.

After unscrambling the apples and oranges and analyzing the data listener by listener, Boyk is now in the process of graphing the results. Although neither technique was a unanimous winner, the majority leaned toward analog. All Boyk will say right now is that the experiment clearly does not support the claim that digital recording machines are flawless — or even superior. This does not mean that they can't be improved and may eventually live up to predictions. Of course, proponents of analog recording claim that it too can certainly still be improved substantially.

Although the test was carefully stripped of any opportunity for bias, the results are not entirely surprising to Boyk, who has recently become something of a technological reactionary. His most recent recording (of Prokofiev's sixth piano sonata), which has been praised for its sound, was made with a tape recorder that is not only analog rather than digital but uses tubes instead of transistors. Boyk says this was not for ideological reasons but because the equipment sounded more "musically accurate" than anything else available. □ —*JD*

A microphone picks up the sound of the piano played by Mike Kong in Dabney Lounge.

Jim Boyk (left) and Larry Gross in Thomas Lab thread the tape on the analog machine.



In another room Robert Carr listens, comparing the live feed to "apples" and "oranges."

Communication Gap

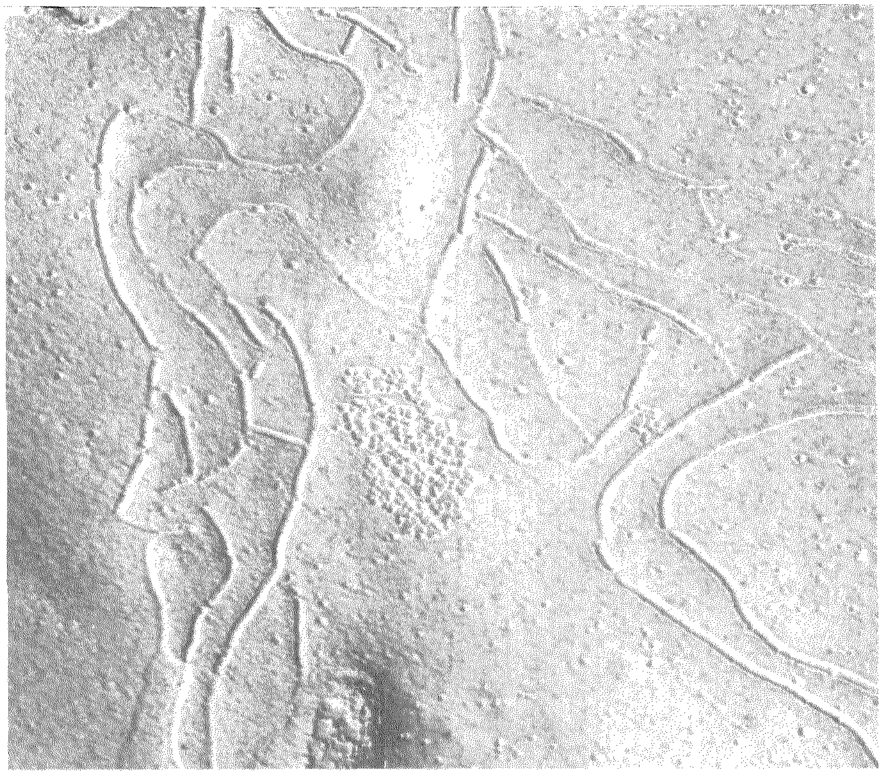
NEIGHBORING CELLS "talk" to each other over a communication system very much like a telephone. The cell's "Ma Bell" is what Jean-Paul Revel, the Albert Billings Ruddock Professor of Biology, calls the system, and for several years he, along with his collaborators, particularly senior research associate Barbara Yancey and graduate student Bruce Nicholson, has studied the intricacies of how this mechanism works.

Interaction between specialized cells — for instance, neurons communicating with each other — has been recognized for a long time. But research, including that in Revel's lab, has shown that all cells exchange information with their neighboring cells through "gap junctions" in their membranes.

The membrane surrounding a cell is a bimolecular film of phospholipids. These have a dual personality consisting of fatty acid residues (facing inward in the membrane) and a polar, hydrophilic end that faces the exterior of the membrane.

Because charged hydrophilic substances such as potassium ions (the most abundant charged ionic species in the cytoplasm of cells) don't dissolve well in the hydrophobic portion of the membrane phospholipid, the membrane has a high resistance to electric current. The cytoplasm inside the cell can be equated for present purposes to a salt solution rich in potassium ions, and it has a low resistance. When cells are touching, current passes easily from the inside of one to the inside of another, even though it has to cross two high-resistance membranes, one for each of the cells of the pair. There must be special devices where the cells touch to allow the current to cross the two opposed membranes.

Revel studies these membranes by freezing them in liquid nitrogen. They are then cracked open and a metal replica of the surface observed in the electron microscope. The micrographs reveal the presence of intra-membrane particles, or "imps," made up of protein molecules. Where cells touch, there are close-packed patches of very special imps. Six protein molecules, along with the phospholipid, form a flower-like structure with a hole in the middle; two of these arranged end to end, one in each cell membrane, form an aqueous path that allows ions to pass from one cell to another.



This electron micrograph shows a gap junction as a close-packed patch of IMPs. The sinuous strands are another membrane specialization not involved in communication. Each IMP is about 60 Å wide.

Not just ions go through this gap junction, but also molecules — not huge ones, of course, such as proteins, but a lot of interesting compounds that control the cell's behavior and metabolism. Researchers are very interested in figuring out what kind of molecules can pass through the junctions, since this exchange could play a role in a number of important functions. Communication through gap junctions is essential in getting organs to function harmoniously; for example, to keep the heart beating as a pump, cells must contract in the proper order after a proper delay. Potassium ions channeled through the gap junctions provide the signal at the right time. It has also recently been discovered that through gap junctions the differentiation of the female ovum is arrested until ovulation. And exchanges between cells can make up for cell deficiencies in certain genetic diseases.

Revel is also interested in figuring out how the gap junctions are put together. To isolate the junctions, the cells are put in a dilute medium; the osmotic shock causes them to blow up like balloons. When the insides leak out, you are left with the membrane, most of which will dissolve in detergents, leaving only the junctions. A gap junction is about half lipid, and the rest consists largely of a single protein species. With the protein sequenator recently developed at Caltech for research in molecular biology, part of the amino acid sequence of the protein molecule from the liver cell junction has already been determined. Knowing exactly how the protein is structured may lead to an understanding of how it is regulated, how its synthesis is determined, why and how it gets into the membranes, and how the gap junctions form.

A simpler and quicker (although not so precise) method of identification of proteins has yielded multidimensional "fingerprints" indicating that each organ may have its own unique gap junction protein; in other words, each organ has a different telephone system. It is not yet known but is under investigation why this is and to what extent these different systems can communicate with each other. Or, as Revel puts it: Can a princess phone talk to a Mickey Mouse phone? He will probably find out. □ *–JD*

Halley Heralded

HALLEY'S COMET, although still about a billion miles away, has been sighted on its return trip to the center of the solar system. Last seen in 1910-11 as it sped off on the outward leg of its elliptical orbit, this time the comet will reach its closest approach to the sun in 1986. Right now it's about 20 million times too faint to be seen by the unaided eye.

So it took extremely far-sighted instruments to spot it at its current distance. A Caltech team led by graduate student David C. Jewitt and staff member G. Edward Danielson was the first to do so — on October 16 — with the 200-inch Hale Telescope at Palomar Observatory and a sensitive electronic camera. The camera, known as PFUEI for Prime Focus Universal Extragalactic Instrument, consists of a charge-coupled device (CCD) developed by NASA for the Wide-Field/Planetary Camera of the Space Telescope. James A. Westphal, professor of planetary science, and James E. Gunn, formerly at Caltech and now at Princeton, designed and built the camera system for work at the Palomar telescope. The CCD, a tiny chip of silicon, is far more sensitive than usual photographic plates used in astronomy.

To see Halley's comet, the nucleus of which is only a few miles in diameter, at a billion miles, not only would the detector have to be very sensitive, but the searchers would have to know where to look. The Caltech team did, since the comet's position had been predicted by Donald Yeomans of the Jet Propulsion Laboratory. They took seven 480-second exposures about 10 to 15 minutes apart. After considerable computer processing, the very faint object was found near the predicted location and moving at the predicted rate.

Comet Halley has been moving back toward us since 1948, when it reached the outer limit of its orbit, 3.2 billion miles out — beyond the orbit of Neptune. When the comet nucleus, which has a mass of about a billion tons, gets closer to the sun and warms up from solar radiation, some of the volatile materials in the nucleus will vaporize to create the familiar glowing head, or coma. The brilliant tail, which always streams away from the sun and can reach a length of millions of miles, is composed of dust propelled by solar radiation pressure and ionized gas molecules accelerated by the solar wind. Comets are believed to be frozen bodies of gas and dust, leftovers from the formation of the solar system, that inhabit a vast cloud far beyond the outer planets (about one light year from the sun). Once in a while the gravity of a nearby star will perturb one into a sunward trajectory. There are hundreds of known comets with orbital periods ranging from 3.3 years to 2 million years, as well as hundreds of nonperiodic comets.

Halley's comet takes an average of 76 years to complete its orbit. That comets do return was discovered in 1695 by the English astronomer Edmund Halley, who used Isaac Newton's theories of gravitation to calculate the orbits of several comets. He observed that the orbit of a comet he had seen in 1682 was similar to ones seen in 1531 and 1607 and predicted correctly that it would return in 1758. It did and has roughly every 76 years since. Halley's comet has also been traced back to 240 B.C.

The Caltech team's confirmed sighting of Halley's comet on its latest approach is the first of a series of planned worldwide observations, which will be coordinated by the International Halley Watch from JPL and the University of Erlangen-Nürnberg in West Germany. The Caltech effort to spot the comet also included research fellow Donald P. Schneider; Alan Dressler of the Mount Wilson and Las Campanas Observatories of the Carnegie Institution of Washington; Caltech Professor of Astronomy Maarten Schmidt; and staff member Barbara A. Zimmerman.

Comets are interesting to planetary scientists and astronomers because they are thought to be samples of the primitive solar system. Data will be collected concerning Halley's orbit and velocity, its interaction with the solar wind, its physical and chemical composition, its possible magnetic properties, and every other aspect scientists can think of. It will be studied from ground-based observatories as well as from airplanes, balloons, the Space Shuttle, the Space Telescope, and several satellites. Five spacecraft (two Soviet/French, two Japanese, and one from the European Space Agency) will fly by the comet in March 1986. The European spacecraft, named *Giotto*, may come as close as 600 miles to the comet. Several American scientists are co-investigators on some of the experiments that *Giotto* will carry, since NASA's spacecraft plans were scrapped because of a tight budget.

Halley's comet will be most visible to the average viewer at its closest approach to the earth in November-December 1985 and after it has rounded the sun and its tail is longest in April 1986. □ — *JD*

Giotto probably used the 1301 appearance of Halley's comet as a model for the Christmas star in his 1303 fresco in the Arena Chapel of Padua.