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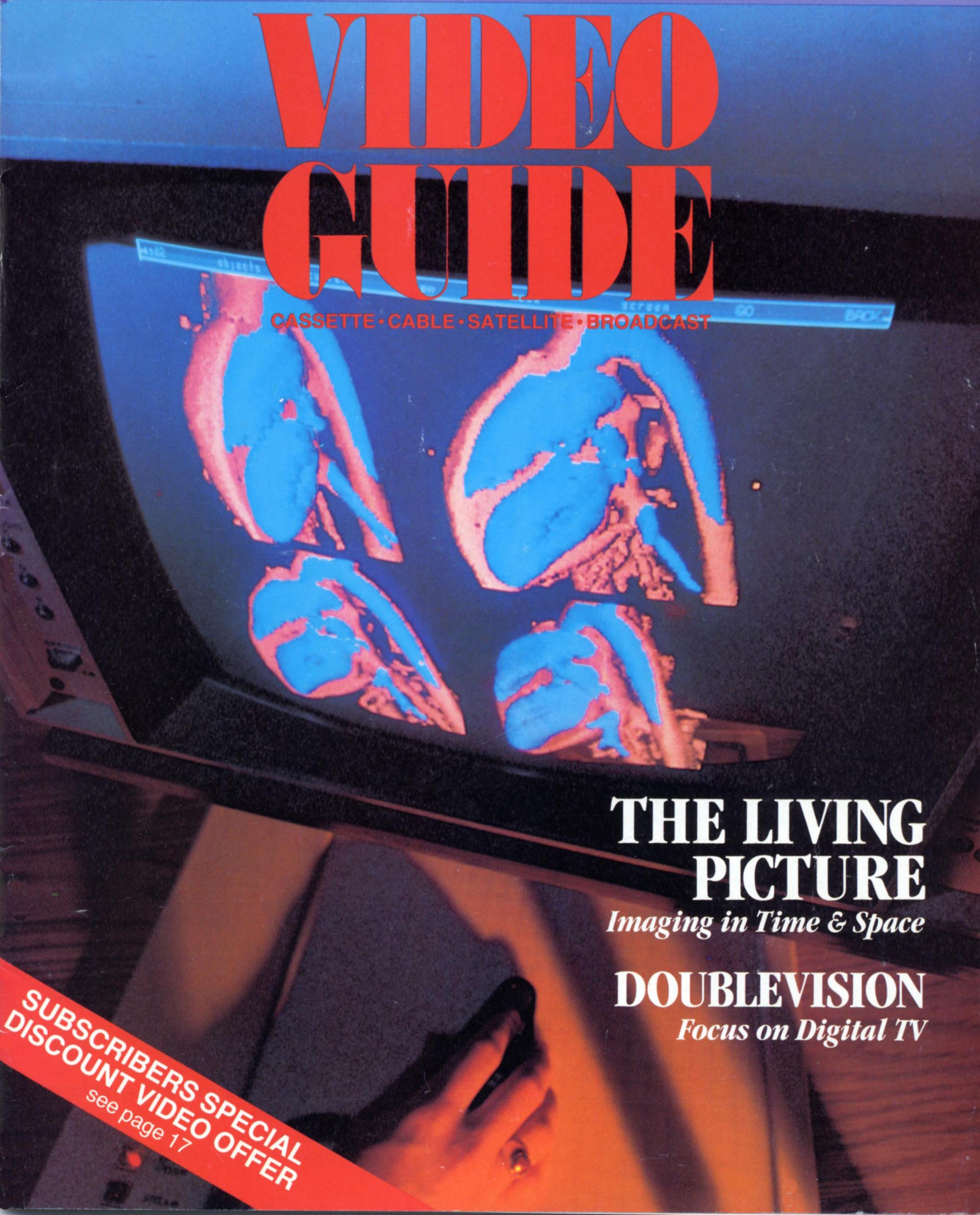

THE LIVING PICTURE

Imaging in Time & Space

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By Joseph L. Streich

THE LIVING PICTURE

The Mayo Clinic's DSR displays the workings of the body in time and space.

Surgeons at the Mayo Clinic are using mathematical scalpels to perform computer surgery and biopsy by numbers. The device that makes this all possible is a new imager called the Dynamic Spatial Reconstructor (DSR). In development since 1976 by Drs. Earl Wood and Erik L. Ritman of the clinic's Biodynamics Research Unit, the DSR records images in time as well as the three dimensions of physical space. The ability to permeate spatial dimensions had led Dr. Richard A. Robb, director of the clinic's research computer facility, to describe the system as a "4D imaging modality." Like Superman with his x-ray vision, doctors at the Mayo Clinic use the DSR to peer *into* a patient's body, selectively rendering skin, organs and bones transparent as they seek and precisely locate the problem at hand—all the while observing the body's myriad functions occurring in real time.

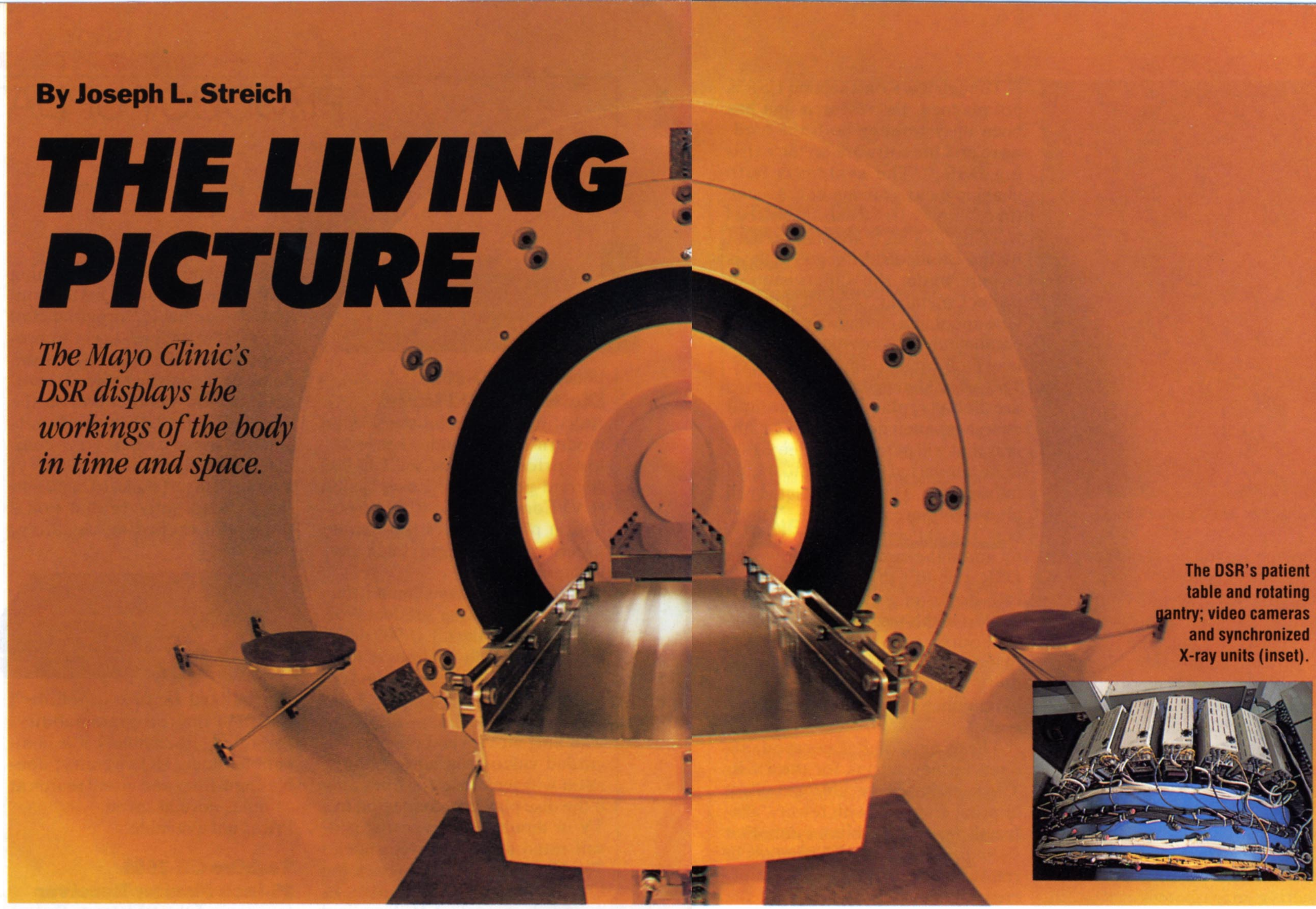
Reconstituted Data

In the last three years, researchers working alone or with data analysts have developed "Image Analysis Work Stations," where they study and manipulate images from the DSR. Four stations are currently on line, with another four in the works. The research unit has provided work stations for other departments within the Mayo Clinic, and for outside institutions that need to analyze data collected on such 3D imaging systems as Magnetic Resonance, CAT-scans or Laser Beam scanning.

Reconstituted data is viewed and manipulated in a number of ways. Using a joystick, the on-screen image can be rotated for examination from any perspective. Images can be color-coded according to blood or oxygen levels present, presented in three-dimensional "wire-mesh" fashion or in segmented or contoured form. "Dissolution programs" simply erase view-blocking surfaces, allowing the user to see what is taking place behind them. The research unit is continually developing new software for displaying and analyzing—"interrogating," in their parlance—the stored data. These new techniques make it possible to extract entirely new findings at any time from previously existing data.

The DSR is primarily used in research applications at the clinic, but its findings often help patients in the clinical aspects of their cases. Research conducted on the DSR has helped resolve controversies over the functional and structural relationships between the heart and lungs, revealing that the pressure environment of blood in the lungs plays an important role in maintaining "constant heart volume." Other technologies would not be able to capture the entire cycle of the heart in action, or provide the three-dimensional perspective necessary for accurate measurements. Fluoroscopic techniques using tracer dyes might be 20 to 30 percent off, according to Dr. Robb.

As Robb describes it, "Congenital heart defects in children are marked by very complex plumbing, with valves and vessels in the wrong places. It's a 3D problem, and the Dynamic Spacial Reconstructor is outstanding in helping to unravel this complex anatomy and plan out surgery."



The DSR's patient table and rotating gantry; video cameras and synchronized X-ray units (inset).

Hearts and Minds

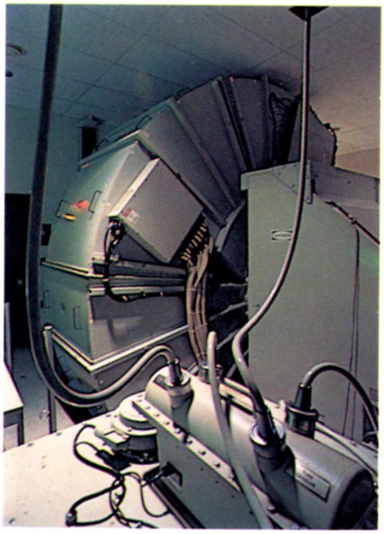
Dr. Fred Bove, a cardiologist specializing in coronary artery research at the clinic, notes that "the DSR is the only thing available in the world right now" to get the information needed for his research. "It's an entirely new way of practicing medicine," he enthuses. Dr. Bove compares the current method of inserting a catheter from the patient's leg—to inject dye into the coronary arteries and take a series of exposures—with the ease and effectiveness of using the DSR: "There's a small amount of risk to the patient when using a catheter," he notes. "[The catheter process is] a labor-intensive process as well, and quite expensive—over $2000 to perform."

No catheterization is needed when using the DSR. A smaller amount of dye is injected into the aorta, and a single 15-second exposure supplies sufficient data for extensive 3D analysis on one of the work stations. Noting that between four- and five-hundred-thousand catheterizations are performed annually, Dr. Bove estimates that a new DSR system built strictly for coronary artery tests would pay for itself within five years if $550 were charged per test. "People often complain that high technology is inflating medical bills. In this case, high-tech saves money. By the year 2000 we're going to see a much different way of practicing cardiology . . ."

In another ongoing extramural project, a Texas researcher is focusing on the rate of heart growth in Greyhounds. Once every six months, the canines are examined for a week so that the researcher can chart changes in their heart volumes, functions and growth rates. Renal profusion and intestine motility are also studied via the DSR. The movement of products through the stomach and intestines—the emptying and filling of these organs—are a "dynamic event" and uniquely appropriate to the DSR's capabilities.

A Dr. Chesebro is using the DSR to study heart failure and the effect on patients of drugs like Milrinone. Newer drugs stimulate contractions of the heart, but over time they may be weakening the pumping function itself in certain patients. Dr. Chesebro uses the DSR to measure the volume of the chambers of the heart—how much, how fast it changes—and the effect of the filling pressure on the heart's ability to pump. "The DSR permits measurement within 5 percent of true volume, and lets us monitor volume changes from moment to moment," remarks Dr. Chesebro. "It's probably the most accurate measuring system we know today. Biplane angiography and echo cardiography are much less accurate." He also points out that the DSR's greater accuracy makes it possible to get reliable data from smaller groups of patients—20 or 30, instead of 150 to 200.

In Dr. Chesebro's work, contrast material is injected into the heart's right side so that its rate of appearance on the left side may be studied. Weakened hearts can pump out only 10 to 20 percent of the blood present with each beat, compared to an "ejection fraction" of 50 percent of a normal heart. Currently, in planar photography, selective injections reveal each artery individually and the patient must be turned and rephotographed from numerous angles. Dr. Chesebro's goal with the DSR is to have a single dye injection reveal the entire coronary artery tree: "Diseased arteries do not narrow in an orderly, hour-glass fashion; trying to analyze separate 2D x-rays, you might assume too much or too little narrowing based on misleading angles. In addition, the arteries curve around the heart in three-dimensional space. The DSR can separate the arteries from the heart, or turn the heart around for you, so you can understand it in all three dimensions. The DSR offers a new, exciting way of accurately imaging heart arteries."



DSR imaging: 'biopsy by numbers.'

A Work in Progress

Despite its amazing capabilities, the DSR is still a work in progress. Its first funding came as a $4.5 million grant from the National Heart, Lung and Blood Institute and the National Institutes of Health in 1976. Only $2 million of that money went into the scanner itself; the majority was spent on manpower and engineering to build the system. Maintenance and staffing for the DSR currently costs a half-million dollars annually. And though the clinic has no immediate interest in building a second DSR, Dr. Robb estimates that building one today would cost $1.5 million.

In its current configuration, the DSR consists of a ring of 14 x-ray tubes, each capable of creating 60 images per second while the entire array rotates around the patient. These images are displayed on fluorescent screens, which are in turn scanned by RCA image isocon video cameras. The video signals are fed into Oktel analog videodisc recorders, which are not unlike the machines that first provided slow-motion replays for TV sports programs. The 20-second capacity of these units does limit the maximum recording time currently possible on the DSR, however.

The analog video signal, now stored on a videodisc, is digitized and fed into the "reconstruction computer" at the heart of the DSR: a Charles River Data Systems (CRDS) Universe 68, combined with a Mercury Zip 32 array processor. This hybrid machine performs the intricate calculations that turn the multiplicity of separate two-dimensional x-ray images—recorded fractions of seconds and inches apart—into amazing 3D views of activity within the human body. The DSR *can* work with as many as 28 x-ray tubes and cameras, which would effectively halve the amount of time needed for an exposure. The current 14-tube setup was deemed effective in gathering sufficient data to compile images, however, and the amount of x-ray exposure (1 rad/second)—while more than a CAT-scan (10-12 rads)—is far below the dosage received in an angiogram (50-150 rads), a process replaced by the DSR.

A CDC Cyber mainframe computer originally helped develop and test the software used in the DSR, and is still used in image analysis: 4 work stations connected to the Cyber can time-share image data stored there. Each station features a CRDS Universe 68 computer, AED Graphics Display, Houston Instrument tracing pads and a variety of Conrac and Jupiter color or black and white video monitors.

Though work on a second DSR is not planned, the research unit has been busy refining both the hardware and the software on the existing DSR. "The system is both changing and growing at the same time," notes Dr. Robb. New software is constantly in development by the Biomedical Image Analysis Group, under the supervision of project manager Dennis Hanson. One upcoming change in the DSR's equipment will provide a quantum leap forward in its imaging powers. The original image isocon cameras are being replaced by Fairchild charge coupled device (CCD) cameras that will permit the video signal to be converted directly into digital information. The CCD cameras will also eliminate the slight "image lag" the old cameras were subject to, and at the same time improve the DSR's ability to distinguish separate shades of grey by 500 percent. As part of this upgrading, the analog videodisc recorders will be replaced by Gould-DeAnza digital units that will expand the DSR's maximum recording time to 30 seconds.

These new digital components open up new vistas for the DSR. The system will be able to collect improved images with fewer "artifacts" (erroneous bits of data that show up as noise or false details in reconstructed images), and increased sensitivity will permit the viewing of thicker organs—allowing data to be collected from the brain or stomach, or from heavier patients. (Dr. Chesebro's work is generally restricted to patients weighing under 70 kg.) Dr. Robb sees the DSR moving into brain scanning, plus renal and hepatic disorders: "We didn't originally anticipate how to use and display the data from the DSR. We had to develop techniques as we went along. It's as if we had the eye, and then had to build the brain to analyze the information. It's a never-ending process, and the system is in a state of constant evolution. The possibilities are as numerous as you can imagine." □