COMPUTER GRAPHICS WORLD

GRAPHICS TECHNOLOGY

Chaotic Compression

A new twist on fractal theory speeds complex image transmission to video rates

By Michael F. Barnsley & Alan D. Sloan

The massive volumes of data associated with computer graphics severely check the use of low-bandwidth communications devices for image transfer. Multiple users can easily overload even the markedly higher bandwidth of local area networks. Potential applications go unrealized as the cost of transmitting graphics increases directly with improved performance and greater complexity.

But algorithms based on fractal geometry can encode image data at high compression ratios—in excess of 10,000 to one. It is possible to transmit such compressed image files at video rates (30 frames per second) over normal telephone lines. A new graphics device, the Iterated Function System Image Synthesizer, makes it possible to decode these compressed files at several frames per second. The technology holds promise over other solutions to the problem of transmitting today's sophisticated computer graphics.

A Perspective on Transmission

A 1000-by-1000-resolution computer graphics image with eight bits of color information per pixel needs one megabyte of data for specification. The transmission of this image over a 2400-bit-per-second line takes over 55 minutes. Compounding the problems of cost and delay, extended transmission times expose data to degradation.

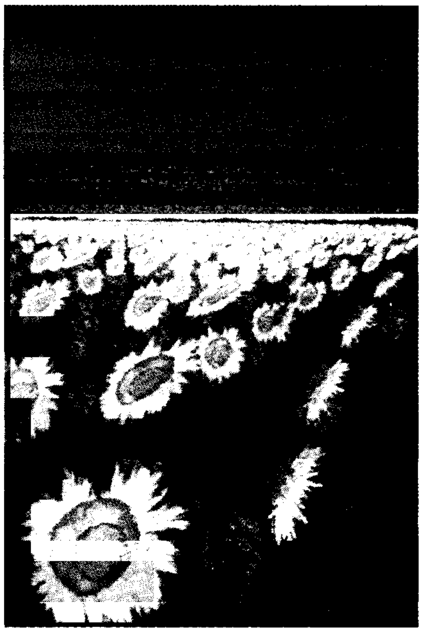
A one-megabyte-per-second Ethernet line transmits the same image in one second, but two users who are each exchanging one minute of animation of such images consume an hour of time. Given these burdens, it's easy to see why there is no multiple-user network for animating high-resolution images at video rates.

Transmission times are proportional to transmission bandwidths. At current rates, for example, it takes three hours at a total transmission cost of $42 (25 cents per minute) to send our sample image 1000 miles on a 2400-bps toll line. The same image can be sent to the same address in 16 seconds at a cost of 51 cents on a 56,000-bps T1 line.

Confounding Performance

Paradoxically, continuing improvements in computer graphics hardware and software only compound the problem. Faster hardware increases the rate of graphics production and thus increases demand on transmission. The quest for realism

Ten thousand-to-one compression ratios can be realized with a new method based on chaos theory, fractal geometry, and affine transformations. While transmission can approach or exceed video rates, the challenge now is to reconstruct images as rapidly.
Below: "Sunflower Field" and "Arctic Wolf," images compressed at 10,000:1 at Georgia Tech.



Laurie Reuter & Arnaud Jacquin, Georgia Tech Research Corp.

Michael F. Barnsley and Alan D. Sloan are professors of mathematics at the Georgia Institute of Technology (Atlanta). Barnsley and Sloan are also officers of Iterated Systems Inc. (Atlanta).

drives graphics software to produce images of increasing complexity. Greater image complexity means more information that must be transmitted for each image.

Sophisticated printers also increase transmission requirements. A new color printer from Tektronix is a case in point. Producing an A-size, 24-bit-deep color printout at 300 dpi can chew up over 9M of data. Even at the Integrated Services Digital Network bandwidth of 64,000 bps, it will take over 15 minutes to supply the necessary data to the printer. Data compression and reconstruction clearly offer the greatest potential for relief from the costs associated with even the fastest communications technologies.

Digital data compression consists of encoding and decoding phases. In the encoding phase, an input string of integer-based (I) bits is transformed into a coded string of complex number-based (C) bits. The ratio of I to C bits is the compression ratio. In the decoding phase, the compressed string regenerates the original data. If the compression ratio is two to one, then in the time it would take to transmit one uncompressed image, two compressed images can be transmitted.

High-ratio image compression slashes transmission time and costs. For example, an uncompressed minute of 30 frames-per-second animation for a 24-bit-deep, 1000-by-1000 color image takes seven months to transmit over a 24-bps line at a cost of $75,000. Compressed at a 10,000-to-one ratio, the same minute of animation takes 30 minutes to transmit at a cost of about $7.50. On a 1.544 million-bps line, uncompressed transmission takes eight hours at a cost of $339; compressed at 10,000 to one, it takes just three seconds at a cost of four cents.

There are several major classes of image-compression techniques, including transform and predictive types. Transform techniques are destructive in the sense that the original image cannot be reconstructed exactly from the image code. Zoran Corp. (Santa Clara, CA) offers a chip-level image compression processor that employs transform techniques. And the International Standards Organization and International Telegraph & Telephone consultative committee

have been working on image compression standards. But the compression ratios being discussed are basically pretty low.

For example, one exact compression method—a type of method calling for exact reconstruction of an image—calls for a ratio of just two to one. There are several exact methods, but they aren't particularly useful. In one experiment, a photo montage was run-length encoded, producing a 60-percent increase in data length. Unix provides a Huffman encoder which yields a compression ratio of 10 to nine. A Ziv-Lempel compression algorithm in public domain yields a compression ratio of five to four.

on a line between P(n) and Vk where $V_1 = A$, $V_2 = B$, and $V_3 = C$. Throw away the first 25 points and plot the rest. The result is independent of the initial point P(0) as well as the sequence of random numbers which were chosen in its generation.

When suitably generalized, this process leads to full-color images like the sunflowers and Arctic wolf on the preceding page. Inspired by *National Geographic* photographs, Georgia Institute of Technology graduate students Laurie Reuter and Arnaud Jacquin encoded each of these images at a ratio exceeding 10,000 to one. Both images are decoded by a random iteration algorithm like the one described.

The chaotic-compression technique is computation-intensive in both the encoding and decoding phases.

An experimental device reconstructs compressed video images at the rate of about four frames per second.

Such ratios are common to exact compression methods.

General Electric has announced the Digital Video Interactive compression system developed at the David Sarnoff Research Center ("DVI Video/Graphics," July, p.125). As the DVI compression ratio increases above 10 to one, the loss of high-frequency information becomes more apparent. But fine detail isn't as critical for motion video as for still images, so the DVI can produce a credible video at a 100-to-one ratio.

The new method described here has been used to encode complex graphics at exact compression ratios of 10,000 to one. It can be used with classical compression techniques to increase yields even further—up to one million to one in the case of "A Cloud Study," shown at SIGGRAPH '87. The method is based on chaotic dynamic systems theory. A simple example illustrates the procedure.

Given a triangle with vertices A, B, and C, choose an initial point P(0) at random in the triangle. An iterative procedure (affine transformation) transforms a point P(n) to P(n + 1) at the n^{th} step as follows.

Choose a number k at random from among the numbers 1, 2, or 3. The point P(n + 1) is the midpoint

An experimental prototype device introduced at the Meeting of the Applied and Computational Mathematics Program of the Defense Advanced Research Projects Agency (DARPA) in October, the Iterated Function System Image Synthesizer (IFSIS) decoded video images at the rate of about four frames per second. Because of the extreme compression ratios, this device can be coupled loosely to any host, which will treat it as if it were a printer—only it produces complex color images instead of text.

Networking and high-resolution, real-time animated graphics can be realized simultaneously by means of IFSIS-type devices. The demonstration at the DARPA meeting served as proof-of-concept for faster transmission devices with higher resolution. Once the higher-performance IFSIS devices are combined with 64,000-bps telecommunications, full-color animation transmission and reconstruction at video rates over phone lines will become a commercial reality.

Research into rapid image decoding and reconstruction methods continues with the objective of the development of a marketable system within a year. **CGW** drives graphics software to produce images of increasing complexity. Greater image complexity means more information that must be transmitted for each image.

Sophisticated printers also increase transmission requirements. A new color printer from Tektronix is a case in point. Producing an A-size, 24-bit-deep color printout at 300 dpi can chew up over 9M of data. Even at the Integrated Services Digital Network bandwidth of 64,000 bps, it will take over 15 minutes to supply the necessary data to the printer. Data compression and reconstruction clearly offer the greatest potential for relief from the costs associated with even the fastest communications technologies.

Digital data compression consists of encoding and decoding phases. In the encoding phase, an input string of integer-based (I) bits is transformed into a coded string of complex number-based (C) bits. The ratio of I to C bits is the compression ratio. In the decoding phase, the compressed string regenerates the original data. If the compression ratio is two to one, then in the time it would take to transmit one uncompressed image, two compressed images can be transmitted.

High-ratio image compression slashes transmission time and costs. For example, an uncompressed minute of 30 frames-per-second animation for a 24-bit-deep, 1000-by-1000 color image takes seven months to transmit over a 24-bps line at a cost of $75,000. Compressed at a 10,000-to-one ratio, the same minute of animation takes 30 minutes to transmit at a cost of about $7.50. On a 1.544 million-bps line, uncompressed transmission takes eight hours at a cost of $339; compressed at 10,000 to one, it takes just three seconds at a cost of four cents.

There are several major classes of image-compression techniques, including transform and predictive types. Transform techniques are destructive in the sense that the original image cannot be reconstructed exactly from the image code. Zoran Corp. (Santa Clara, CA) offers a chip-level image compression processor that employs transform techniques. And the International Standards Organization and International Telegraph & Telephone consultative committee

have been working on image compression standards. But the compression ratios being discussed are basically pretty low.

For example, one exact compression method—a type of method calling for exact reconstruction of an image—calls for a ratio of just two to one. There are several exact methods, but they aren't particularly useful. In one experiment, a photo montage was run-length encoded, producing a 60-percent increase in data length. Unix provides a Huffman encoder which yields a compression ratio of 10 to nine. A Ziv-Lempel compression algorithm in public domain yields a compression ratio of five to four.

An experimental device reconstructs compressed video images at the rate of about four frames per second.

Such ratios are common to exact compression methods.

General Electric has announced the Digital Video Interactive compression system developed at the David Sarnoff Research Center ("DVI Video/Graphics," July, p.125). As the DVI compression ratio increases above 10 to one, the loss of high-frequency information becomes more apparent. But fine detail isn't as critical for motion video as for still images, so the DVI can produce a credible video at a 100-to-one ratio.

The new method described here has been used to encode complex graphics at exact compression ratios of 10,000 to one. It can be used with classical compression techniques to increase yields even further—up to one million to one in the case of "A Cloud Study," shown at SIGGRAPH '87. The method is based on chaotic dynamic systems theory. A simple example illustrates the procedure.

Given a triangle with vertices A, B, and C, choose an initial point P(0) at random in the triangle. An iterative procedure (affine transformation) transforms a point $P(n)$ to $P(n + 1)$ at the n^{th} step as follows.

Choose a number k at random from among the numbers 1, 2, or 3. The point $P(n + 1)$ is the midpoint on a line between $P(n)$ and Vk where $V_1 = A$, $V_2 = B$, and $V_3 = C$. Throw away the first 25 points and plot the rest. The result is independent of the initial point P(0) as well as the sequence of random numbers which were chosen in its generation.

When suitably generalized, this process leads to full-color images like the sunflowers and Arctic wolf on the preceding page. Inspired by *National Geographic* photographs, Georgia Institute of Technology graduate students Laurie Reuter and Arnaud Jacquin encoded each of these images at a ratio exceeding 10,000 to one. Both images are decoded by a random iteration algorithm like the one described.

The chaotic-compression technique is computation-intensive in both the encoding and decoding phases. An experimental prototype device introduced at the Meeting of the Applied and Computational Mathematics Program of the Defense Advanced Research Projects Agency (DARPA) in October, the Iterated Function System Image Synthesizer (IFSIS) decoded video images at the rate of about four frames per second. Because of the extreme compression ratios, this device can be coupled loosely to any host, which will treat it as if it were a printer—only it produces complex color images instead of text.

Networking and high-resolution, real-time animated graphics can be realized simultaneously by means of IFSIS-type devices. The demonstration at the DARPA meeting served as proof-of-concept for faster transmission devices with higher resolution. Once the higher-performance IFSIS devices are combined with 64,000-bps telecommunications, full-color animation transmission and reconstruction at video rates over phone lines will become a commercial reality.

Research into rapid image decoding and reconstruction methods continues with the objective of the development of a marketable system within a year. **CGW**