The Computer Museum

Computer Animation Theater

Hunger	11 minutes
Vol Libre	2 minutes
Carla's Island	3 minutes
Snoot and Muttly	5 minutes
The Adventures of Andre & Wally B.	2 minutes

Hunger 1975

The first film to combine traditional and computer animation. The animator drew the first and last frames of each shot and the computer filled in the "in-betweens" that give the impression of continuous movement.

Vol Libre 1980

The first film with an artificial landscape based on fractals. Sunlight and atmospheric haze are simulated to make the landscape more convincing. Each frame took 15 minutes to compute on a VAX 11/780 computer and was plotted offline using a Dicomed film recorder.

Carla's Island 1980

The first film to model a moving water surface. The ripples are sine waves that travel over a flat surface. The images were rendered by ray-tracing, following rays for a maximum of 2 reflections. As the Sun and Moon move through the sky, the change of lighting is simulated by repeating a single cycle of wave motion with different colors.

Each frame took 15 seconds to compute on a Cray-1 "supercomputer" and was plotted offline on a Dicomed film recorder.

Snoot and Muttly 1984

The characters are 3-dimensional computer models made up of simple shapes such as spheres and cylinders. Convincing personalities are portrayed by sophisticated computer modeling of movement, one of the greatest challenges in animation.

The Adventures of Andre & Wally B. 1984

An animator created the 3-dimensional computer models of Andre and Wally B. as line drawings. The computer then rendered the characters with smooth, realistically illuminated surfaces. The motion is smoothed by adding blur to moving characters. The forest set is completely computer generated, using systems of particles to model 46,254 trees and plants.

Films Acquired by The Computer Museum

ID	Title	Author	Comments	Used?
	Linear Hash User Keys	FRA Hopgood	1972/silent/col	
	Change & chance	FRAH	1969/mag snd/bw	
	Groats	FRAH	1969/sil/bw	
	Syntactic dominos	FRAH	1970/sil/col	
	F E Film	FRAH	1973/col/snd	

All of above are from Atlas Labs, UK, and supplied with documents

	Colliding Galaxies	Alar Toomre (MIT)	nd /bw/sil	
	Galaxy Clustering	AT	1980/6 min/col/sil 207'	
	Display Ads Layout	MIT Museum MIT-ESL	1972/mag snd/color 255'	
	Midas	Paul Bash UC San Fran	nd /col/sil/doc (DNA views)	
	Circal El Des	MIT Museum	1966/sil/bw	
	Kluge	MIT Museum	1966/sil/bw	

All of the MIT films must be returned ASAP

	LEM Movie	Tom Hogan	1967/bw/sil/3 min Adage graphics - "1st realtime cg film of complex 3d objects"	
	Jupiter Magnetosphere	Jim Blinn	nd /col/snd	
	Previews v.7 Coming Attr.	Jim Blinn JPL	Voyager 2 1981/col/sil	
	Voyager 2 Jupiter	Jim Blinn	nd /col/sil doc	
	Voyager 1	Jim Blinn	nd /col/sound	

Saturn	JPL	doc	
"clips"	Geo. Michael	nd	/col/sil
ADAM	Art Olson	nd	/col/sound/4 min
Tomato B.S. Virus	Art Olson	nd	/col/sound/8 min
Appl. Fluid Dynamics	LASL	nd	/850', 24 min/col/snd

THE COMPUTER AND THE IMAGE

POSSIBLE FILMS AND VIDEOS

June 1 1984

Historical

Sketchpad on the TX-2 - film in the collection of the Museum (video)

SAGE the use of graphics in pointing to aircraft tracks and absorbing radar data: clip from film already in Museum collection. (video)

Apollo LEM on the Adage Graphics Terminal 1967 - 1st real time graphics. (16mm)

No ~~GRAIL - Graphical Input Language using the Rand Tablet mid 60's (no copy located yet)~~

General Motors DAC-1 - design augmented by computer - 1960's (16mm)

Kludge - ESL ; Circal

Simulation

Galactic Collision by Alar Toomre, 2-371 MIT, 77 Massachusetts Avenue, Cambridge, MA 02139
2 mins

Two galaxies collide and pull out long trails of matter. Wisps thus produced are reminiscent of photographs of interacting galaxies. Real photograph available to compare with film. (16mm)

~~Galactic Dynamics by Richard Miller, Dept of Astronomy, University of Chicago, 5640 Ellis Ave, Chicago, Ill 60637~~

~~Self-gravitating discs of particles break up into instabilities but if there is a massive halo they form spiral-like patterns. (16mm)~~

Galaxy Clustering in an Expanding Universe by Svere Aarseth, Institute of Astronomy, Madingly Road, Cambridge, UK
5 mins

4000 galaxies are modeled self-consistently in an expanding universe. The film shows how they cluster. (16mm - copy seen from Alar Toomre)

Applied Fluid Dynamics by Los Alamos Scientific Laboratory
22 mins

Corny introductions but interesting computer graphic sequences showing results of simulations of smoke polution, tidal waves, ship hull in waves, artery blockage, internal combustion engine, wind resistance on trucks, nuclear reactor accident. Requires editing down to about 4 minutes.

Voyager Flight Simulation by Charles Kohlase and James Blinn, Jet Propulsion Laboratory 264-443, 4800 Oak Grove Drive, Pasadena, CA 91103

Synthesised Voyager spacecraft travels past Jupiter and Saturn and their moons. A number of versions were made as new data from the actual mission enabled the planets and moons to be modelled more accurately.(16mm)

DNA and Enzyme Reaction by Nelson Max, Lawrence Livermore Laboratory L-73, Livermore, CA 94550

Shaded sphere representation shows interlocking of enzyme with DNA. (video or 16mm requested from George Michael)

Crystal Growth and Nucleation on a Crystal Surface by George Gilmer, Bell Labs, 600 Mountain Ave, Murray Hill, NJ 07974

Simulated crystal growth phenomena.

Visualisation

Zooms on Self-Similar Figures by Nelson Max, obtainable from International Film Bureau Inc, 332 South Michigan Ave, Chicago, Ill 60604

Shows snowflake, Peano and Sierpinski curves.

No

Turning a Shere Inside Out by Nelson Max, source as above

Shows smooth motion which turns a sphere inside out by passing the surface through itself without making any folds or creases. Shows wire mesh, opaque surfaces and exploded views.

No

Powers of Ten by Ray and Charles Eames, Pyramid Films, Box 1048, Santa Monica, CA 90406

Shows structure visible on scales of size from that of subnuclear particles to clusters of galaxies using a mixture of photography and well blended computer animation.

One Dewey Square by Jung Brannen Associates, 177 Milk Street, Boston, MA 02109 contact Bruce Forbes

Video to be prepared for the Museum showing views of the site with and without the new development and going inside building showing details.

Turbine Blade by General Electric, 1000 Western Avenue, Lynn, MA 01910 contact Bill Blundell

Use of CAD in design of critical component in aero engines using vector, 2 and 3d, and shaded raster images

Cinema: Fantasy

Vol Libre by Loren Carpenter, Lucasfilm, PO Box 2009, San Raphael, CA 94902

16mm 8 min

Simulated flight past mountains and lakes with pseudo-rugged mountains. (16mm avaialble from Loren Carpenter - will copy for us)

Carla's Island by Nelson Max, Monaco Film Lab, San Fransisco, CA

16mm 3 min

Realistic waves on the ocean as the sun rises and sets, followed by the Moon.

Hunger by Peter Foldes, permission required from National Film Board of Canada. (try in New York?)

16mm 12 min

Line drawings interpolated by computer of man with insatiable appetite swelling to enormous proportions, haunted by nightmare of starving people consuming him.

Tron by Information International Inc, Corporate Communications Dept, 5933 Slausen Avenue, Culver City, CA 90230

Computer-syntheisised sequence in the motion picure.

The Last Starfighter, Digital Productions

Advertising

Digital Scene Simulation by Information International Inc, Corporate Communications Dept, 5933 Slausen Avenue, Culver City, CA 90230; material will not be available from them but maybe via George Michael at Lawrence Livermore or via Digital Productions, 3416 South La Cienega Boulevard, Los Angeles, CA 90016

Sample reel with logos and advertising clips. Realistic three-d objects, illuminated and spun at very high resolution.

NYIT sequence by NYIT, Computer Graphics Lab, Old Westbury, Long Island, NY 11568 contact Louis Schure

Advertising clips and scenes from The Works and other movies.

Sogitec et al: Space Wagon.

Education

Blinn's Electronic

SEASONS, a 1:20 minute animation of Nature's yearly cycle, was produced for the Children's Television Workshop's SESAME STREET. The original concept and design was adapted for computergraphics by VIDEOGRAF, New York.

Producers: NOYES & LAYBOURNE ENTERPRISES, INC.
Art Director/Director: Eli Noyes
Artist/Animator: Joette Spinelli
Music: Derek Huntington

Produced at VIDEOGRAF, 144 W. 27 St., NY, NY 10001

Hardware: VIA VIDEO SYSTEM ONE
Software: VAE (Via Video's version of the Cromemco Animation Editor-CAE) contains commands to generate video pictures or text, select or change colors, change size or direction of images, combine or move shapes about on a picture, and access pictures using up to seven electronic buffers. ANIMATE allows for real-time cell animation within specified areas of the screen with real-time interactive control of the motion sequence over a background. VAS is an authoring program for real-time color pallette animation of full screen images. The Video Image Sequencer (VIS) program provides the ability to display six full screen images, in a timed sequence, automatically.

Technical Notes: SEASONS' 28 scenes were produced in about 50 hours, mastered to 1" Type "C" videotape (NTSC), with four (4) hours of A/B roll post-production.

NUMERICAL EXPERIMENTS ON THE DYNAMICS OF GALAXIES
R. H. Miller and B. F. Smith

The motion picture films described here are part of a research program into the dynamics of galaxies. They show the dynamical development of various fully self-consistent n-body systems in three dimensions. These computer-generated films show some 2000 points sampled from 100 000 in the full n-body integration, to allow the viewer to appreciate the dynamical development of the system under study. Papers in which the astronomical research is presented are referenced in the entries where each film is briefly described.

The notations at the beginning of each film entry are as follows.

Ames/Chicago designates where the master film copy is located.
Films at Ames may be ordered through
 Photographic Technology Branch, Mail Stop 203-6
 NASA-Ames Research Center
 Moffett Field, Calif. 94035
Films at Chicago may be ordered through R. H. Miller at
 Astronomy and Astrophysics Center
 5640 Ellis Ave.
 Chicago 60637

In either case, your order will be placed with a contracting photographic laboratory. We will make the original available to the laboratory, and we can provide ordering details. Films are available at cost. Be sure to specify the film number (the number following the entry, "Ames") in inquiries directed to Ames.

B&W/Color designation indicates black and white or color film.

The last entry on the line gives the approximate length of the film in feet. Films are all 16 mm, designed to run at 24 frames/second. Running times are 1 minute per 36 feet of film. Current costs run about 25 cents/foot for B&W.

These films show white (or colored) spots on a dark background, and show best in a very dark room. There is no sound track on any of these films.

Additional information may be obtained either from Miller at the address given above (Tel (312) 962 8201) or from
 Dr. Bruce F. Smith 245-3 (Tel (415) 965 5515)
 NASA-Ames Research Center
 Moffett Field, Calif. 94035

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Similar to Toomre's film?

GALAXY COLLISIONS

1. Ames 840 B&W 420 ft.
Collisions I: A Representative Sample. Collisions of two equal-mass spherical galaxies for a variety of initial impact parameters and orbital energies. This film shows four of the collisions to illustrate the features found in the sequence of experiments. It is a good introduction to a spectacular subject.
Reference: Astrophysical Journal 235, 421 (1980).

2. Ames 837 B&W 400 ft.
Collisions II: Nearly Collinear Collisions. This film and the next two show the complete set of collision experiments described in the reference given in the previous entry. These three films are intended for an audience of experts who want to study the dynamics of galaxy collisions in detail. The nearly collinear collisions from the complete set of experiments are shown in this film. There are four experiments at various initial orbital energies.

3. Ames 839 B&W 400 ft.
Collisions III: Hyperbolic Collisions. A set of collisions, all at the same initial orbital energy but with different initial orbital angular momenta. The collision scales so the two galaxies have a velocity of approach of around 500 km/sec at infinite separation. Six collisions are shown in this sequence.

4. Ames 838 B&W 620 ft.
Collisions IV: Parabolic Collisions. The set of collisions of zero initial orbital energy, but with various impact parameters is shown in this film. There are five experiments with different initial orbital angular momenta.

5. Ames 878 Color 90 ft.
Particle Exchange in a Galaxy Collision. A graphical study of particle exchange in one of the parabolic collisions. Particles are colored to show which of the two galaxies they were in initially. The film shows the initial state, rotates it to show the three-dimensional form, then stops rotation and starts the dynamics. At the end of the experiment, the configuration is rotated once more to show the three-dimensional shape. Bounding edges of the computational volume are shown by light lines.
Reference: Same as entry 1 above.

Film from Argonne List

6. Ames 904 Color 415 ft.
Collisions of Disk Galaxies in Massive Halos. Disk galaxies are rendered dynamically stable by embedding them in massive spherical halos. The disks are shown in yellow, the halos in blue. Several collisions are shown with various initial orbital energies, initial orbital angular momenta, disk orientations, and senses of disk rotation. The complete system of disks and halos remains fully self-consistent at all times throughout the collision. This is a spectacular film, shown at the Calgary AAS meeting in July 1981.

7. Ames 907 Color 260 ft. ~ 7min
Collisions of Disk Galaxies in Massive Halos: Short Version. A shorter version of the film of the previous entry. This film is suitable to help describe the complexity of galaxy collisions to non-expert audiences.

8. Ames 930 Color 350 ft.
Galaxy Collisions & Merging. Follows two different collision experiments to merging. Contains alternating views showing first all stars originally in one galaxy, then all stars originally in the other, to follow the dynamics of merging.

GALAXIES IN CLUSTERS

9. Ames 928 Color 400 ft.
Dynamical Friction on Galaxies. A dynamical study in which a spherical galaxy model is placed in a moving uniform-density background of stars. The entire system, galaxy+background, is treated self-consistently. The film shows braking, damage to the galaxy, ablation of galaxy stars, and increased velocity dispersion in the background but no noticeable wake.
Reference: in press.

10. Ames 854 B&W 150 ft.
Tidal Braking. A technical study of a stellar-dynamical bar in an external potential like that in which a galaxy might find itself in a cluster of galaxies. The galaxies retain their barlike forms. Some rotate, when the external tidal force field is weak, others oscillate when the external field is strong. Observable rotation decreases because of the external field.
Reference: Astrophysical Journal 253, 58 (1982).

11. Chicago B&W 300 ft.
Dynamics of Galaxy Clusters. A technical study of the consequences of the "inelasticity" of galaxy collisions, as found in the studies cited in entry 1 above, on the longevity and dynamics of present-day galaxy clusters. A single massive object, that may contain as much as 75% of the mass of the entire cluster, forms within a few cluster crossing-times. This is a 100-body study based on different computer programs from those used for the rest of this list.
Reference: Astrophysical Journal 254, 16 (1982).

12. Chicago B&W 300 ft.
Rotating Galaxy Clusters. A study like that of the previous entry, but the clusters rotate in this film.

SPECIAL DYNAMICAL STUDIES

13. Ames 816 B&W 320 ft.
Streaming Motions in Bar. A technical study of the internal dynamics of a stellar bar, the form found to be dynamically preferred for rotating stellar systems. The bar is shown from both an inertial frame and from a frame that rotates with the bar pattern, to make internal streaming motions within the bar particularly vivid.
Reference: Astrophysical Journal 227, 795 (1979).

14. Ames 929 B&W 325 ft.
Self-Consistent Responses of Galaxies A dynamical study of the self-consistent response of an equilibrium spherical galaxy model to various idealized forms to disturbance. Initial conditions with spherically symmetrical and cylindrically symmetrical inward velocities are tested on self-consistent and non-self-consistent galaxy models for comparison. In another study, the galaxy bounces repeatedly off the walls of a potential well. The galaxy responds nearly spherically to all these disturbances.
Reference: in press.

15. Ames 832 B&W 390 ft.
Polytropic Models I. A series of experiments in which initially spherical galaxies were spun as fast as possible to test their stability to barlike deformations and to see how much they would flatten because of rotation. They flatten very little (E2) in spite of remarkably rapid rotation.
Reference: Astrophysical Journal 235, 793 (1980).

16. Ames 843 B&W 240 ft.
Polytropic Models II. A continuation of the studies of the previous entry. These configurations checked some of the more unusual starting conditions. Film includes experiments R12, R17, G1, and G2 of the paper.
Reference: Astrophysical Journal 235, 793 (1980).

17. Chicago B&W 307 ft.
Old Disk Galaxy Film. The old disk galaxy film of the Miller, Prendergast, and Quirk paper of 1970, which first showed that spiral patterns could be maintained through gravitational forces in a cool self-consistent population. This was a key work which convinced astronomers that other factors, such as magnetic fields, were not necessary to the establishment or maintenance of spiral structure. It also gave the first indications of the stability problem that led to the later suggestion that disk galaxies require massive halos in order to be stable.
Reference: Astrophysical Journal 161, 903 (1970).

STABILITY STUDIES

18. Ames 881 B&W 300 ft.
Schwarzschild Triaxial Model. A study of the dynamical stability of Schwarzschild's triaxial galaxy model by means of numerical experiments. The model shows no detectable disturbances, which implies no dynamical instabilities with growth rates greater than 1/2 per crossing time.
Reference: Astrophysical Journal 257, 103 (1982).

19. Ames 908 B&W 300 ft.
Equilibrium of a Galactic Bar. Dynamical stability study of a triaxial rotating barlike model generated by P. O. Vandervoort and D. Welty. The model is the stellar dynamical analogue of an n=1/2 polytrope, while the configuration is the analogue of a Jacobi ellipsoid.
Reference: Astrophysical Journal 259, 559 (1982).

GALAXY CLUSTERING IN EXPANDING UNIVERSE

20. Ames 918 B&W 300 ft.
The Real Universe. Observational data on galaxy clustering from catalogues by H. J. Rood and J. Huchra, with internal velocity dispersions within the clusters reduced by rules of Jaan Einasto. This observed configuration is rotated to show the three-dimensional form so clumps, filaments, and cellular structure can easily be seen. The film contains several different views, extending to different distance cutoffs, with various absolute magnitude cutoffs, and rotated about various centers. This is the observational standard against which dynamical models are to be compared.

21. Ames 919 B&W 300 ft.
Open Universe. Comparison of three experiments with identical starting conditions but differing in the final value of omega and in the total expansion. The three had final omega=1, 0.1, and 0.03, and ran through total expansions by factors 71, 200, and 500 respectively. Temporal views of each experiment are shown, followed by scenes in which the configurations from each experiment are rotated to allow the three-dimensional form to be seen. The rotating scenes refer to times at which the clumping strengths are the same for each experiment.

22. Chicago B&W 300 ft.
Clustering in Expanding Universe. Gravitational formation of galaxy clusters from initially uniform (white noise) distribution of particles at rest. Clumping is shown as temporal development, then various stages are shown as three-dimensional forms by rotating them. Finally, the combined effects of clumping and expansion are shown together. Film shown at Texas Symposium on Relativistic Astrophysics, December 1980.
Reference: Astrophysical Journal to be published 15 July 1983.

23. Chicago B&W 223 ft.
Neutrino Universe. Gravitational clumping of a set of particles with large initial velocity dispersion, that represent a Universe most of whose mass is in the form of neutrinos of nonzero rest mass. Film shows temporal expansion in comoving coordinates, then shows the configurations rotated to give impression of three-dimensional form. Total expansion a factor 600.
Reference: Astrophysical Journal to be published 15 July 1983.

24. Chicago B&W 300 ft.
Cray Universe. A series of three experiments of clustering of baryonic matter. 100 000 particles on a 64^3 periodic grid (the previous experiments used 25 000 particles on a 32^3 periodic grid). Temporal views only; no rotating scenes.
Reference: Astrophysical Journal to be published 15 July 1983.

COLLAPSING STELLAR CONFIGURATIONS

25. Ames 790 B&W 394 ft.
Three-Dimensional Computer Galaxy Simulation. Initial sphere in balanced rotation. Forms a bar after a spectacular "S" shape. Film contains scenes in which the configuration is rotated to show three-dimensional form.
Reference: Astrophysical Journal 223, 122 (1978).

26. Ames 817 B&W 500 ft.
Collapses of Rotating Spheres of Stars in Three Dimensions. A sequence of 6 collapsing spheres with different amounts of initial rotation and velocity dispersion. All formed bars after various intermediate forms.
Reference: Astrophysical Journal 227, 407 (1979).

27. Ames 845 B&W 425 ft.
Mixup Collapses I. A sequence of collapse experiments started from initial forms deliberately designed to be nonspherical. The object of the study was to determine whether the final bar form required the high symmetry of spherical initial conditions, thus to verify that bars form in a wide range of initial conditions. The sensitivity of intermediate forms (see six collapses entry above) was also tested. All formed bars after various intermediate forms.
Reference: Astrophysical Journal 244, 33 (1981).

28. Ames 846 B&W 230 ft.
Mixup Collapses II. A continuation of the studies of the previous entry. These experiments started from initial conditions with large velocity dispersions, and formed fatter bars (axis ratio closer to unity).
Reference: Astrophysical Journal 244, 33 (1981).

PROTOGALAXIES

29. Ames 855 B&W 400 ft.
Protogalaxies I. A series of experiments in which both gas and stars are present, with a rule for forming stars out of the gas. The experiments start from a rotating uniform-density sphere of gas, and undergo a collapse during which stars form. Stars, once formed, live forever in this set of experiments.
Reference: Astrophysical Journal 244, 467 (1981).

30. Ames 856 B&W 400 ft.
Protogalaxies II. A continuation of the series of experiments in the previous entry, in which stars die after a certain time and return their matter to the interstellar medium as gas.
Reference: Astrophysical Journal 244, 467 (1981).

31. Ames 917 B&W 360 ft.
Protogalaxy Collapse: Stimulated Star Creation. A spectacular example of protogalaxy collapse with stimulated star creation and large return of energy to the interstellar medium as as result of the star formation. A detonation wave of star creation forms, which moves rapidly through the galactic plane and which results in gas being blasted out of the galactic plane.
Reference: "Formation of an Elliptical Galaxy," in Photometry, Kinematics, and Dynamics of Galaxies, ed. D. S. Evans (Austin, Tex., University of Texas at Austin, Department of Astronomy) 1979, pp. 365-368.

COMMENTS

New entries in this version of the movie listing:
8, Galaxy Collisions and Merging,
9, Dynamical Friction on Galaxies, and
14, Self-Consistent Responses of Galaxies

Films most suitable for classes, planetarium lectures, or lectures to amateur astronomer's groups include:
7, Collisions of Disk Galaxies, Short Version
20, The Real Universe
22, Clustering in Expanding Universe
31, Protogalaxy Collapse: Stimulated Star Creation
26, Collapses of Rotating Spheres of Stars
1, Collisions I: A Representative Sample
13, Streaming Motions in Bar
25, Three-Dimensional Computer Galaxy Simulation

NUMERICAL EXPERIMENTS ON THE DYNAMICS OF GALAXIES

R. H. Miller and B. F. Smith

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Particle Exchange in a Galaxy Collision. A graphical study of particle exchange in one of the parabolic collisions. Particles are colored to show which of the two galaxies they were in initially. The film shows the initial state, rotates it to show the three-dimensional form, then stops rotation and starts the dynamics. At the end of the experiment, the configuration is rotated once more to show the three-dimensional shape. Bounding edges of the computational volume are shown by light lines.
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8. Ames 930 Color 350 ft.
Galaxy Collisions & Merging. Follows two different collision experiments to merging. Contains alternating views showing first all stars originally in one galaxy, then all stars originally in the other, to follow the dynamics of merging. Shown at IAU 100 in Besancon, August 1982 and at the AAS meeting in Minneapolis, June 1983.
Reference: Proceedings of IAU Symposium 100, Internal Kinematics and Dynamics of Galaxies, ed. E. Athanassoula (Dordrecht: Reidel), pp. 353-4.

GALAXIES IN CLUSTERS

9. Ames 942 Color 600 ft.
Flyby--A Galaxy in Orbit within a Galaxy Cluster. A study of tidal effects on a galaxy as it orbits through a cluster of galaxies. A disk of particles embedded in the galaxy serves as a tracer to study damage to the galaxy. Shown at AAS meeting in Baltimore, June 1984.

10. Ames 928 Color 400 ft.
Dynamical Friction on Galaxies. A dynamical study in which a spherical galaxy model is placed in a moving uniform-density background of stars. The entire system, galaxy+background, is treated self-consistently. The film shows braking, damage to the galaxy, ablation of galaxy stars, and increased velocity dispersion in the background but no noticeable wake. Shown at AAS meeting in Minneapolis, June 1983.
Reference: in press.

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SPECIAL DYNAMICAL STUDIES

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16. Ames 832 B&W 390 ft.
Polytropic Models I. A series of experiments in which initially spherical galaxies were spun as fast as possible to test their stability to barlike deformations and to see how much they would flatten because of rotation. They flatten very little (E2) in spite of remarkably rapid rotation.
Reference: Astrophysical Journal 235, 793 (1980).

17. Ames 843 B&W 240 ft.
Polytropic Models II. A continuation of the studies of the previous entry. These configurations checked some of the more unusual starting conditions. Film includes experiments R12, R17, G1, and G2 of the paper.
Reference: Astrophysical Journal 235, 793 (1980).

18. Chicago B&W 307 ft.
Old Disk Galaxy Film. The old disk galaxy film of the Miller, Prendergast, and Quirk paper of 1970, which first showed that spiral patterns could be maintained through gravitational forces in a cool self-consistent population. This was a key work which convinced astronomers that other factors, such as magnetic fields, were not necessary to the establishment or maintenance of spiral structure. It also gave the first indications of the stability problem that led to the later suggestion that disk galaxies require massive halos in order to be stable.
Reference: Astrophysical Journal 161, 903 (1970).

STABILITY STUDIES

19. Ames 881 B&W 300 ft.
Schwarzschild Triaxial Model. A study of the dynamical stability of Schwarzschild's triaxial galaxy model by means of numerical experiments. The model shows no detectable disturbances, which implies no dynamical instabilities with growth rates greater than 1/2 per crossing time.
Reference: Astrophysical Journal 257, 103 (1982).

20. Ames 908 B&W 300 ft.
Equilibrium of a Galactic Bar. Dynamical stability study of a triaxial rotating barlike model generated by P. O. Vandervoort and D. Welty. The model is the stellar dynamical analogue of an n=1/2 polytrope, while the configuration is the analogue of a Jacobi ellipsoid.
Reference: Astrophysical Journal 259, 559 (1982).

GALAXY CLUSTERING IN EXPANDING UNIVERSE

21. Ames 918 B&W 300 ft.
The Real Universe. Observational data on galaxy clustering from catalogues by H. J. Rood and J. Huchra, with internal velocity dispersions within the clusters reduced by rules of Jaan Einasto. This observed configuration is rotated to show the three-dimensional form so clumps, filaments, and cellular structure can easily be seen. The film contains several different views, extending to different distance cutoffs, with various absolute magnitude cutoffs, and rotated about various centers. This is the observational standard against which dynamical models are to be compared. Film shown at IAU 104 in Crete, September 1982.
Reference: Proceedings of IAU Symposium 104, Early Evolution of the Universe and its Present Structure, ed. G. Abell and G. Chincarini (Dordrecht, Reidel), pp. 405-9.

22. Ames 945 B&W 200 ft.
The Real Universe, II. Observational data on galaxy clustering from the CfA catalog of available galaxy redshifts. Velocity dispersions within known Abell clusters have been reduced by Einasto in the same manner as for the previous entry. This version contains some smaller sections, local group to Coma/A1367 and local group to Perseus/Pisces clusters to show filamentary structure more clearly. Like the previous entry, this is an observational standard against which dynamical models are to be compared.

23. Ames 919 B&W 300 ft.
Open Universe. Comparison of three experiments with identical starting conditions but differing in the final value of omega and in the total expansion. The three had final omega=1, 0.1, and 0.03, and ran through total expansions by factors 71, 200, and 500 respectively. Temporal views of each experiment are shown, followed by scenes in which the configurations from each experiment are rotated to allow the three-dimensional form to be seen. The rotating scenes refer to times at which the clumping strengths are the same for each experiment. Film shown at IAU 104 in Crete, September 1982.
Reference: Proceedings of IAU Symposium 104, Early Evolution of the Universe and its Present Structure, ed. G. Abell and G. Chincarini (Dordrecht, Reidel), pp. 411-16.

24. Chicago B&W 300 ft.
Clustering in Expanding Universe. Gravitational formation of galaxy clusters from initially uniform (white noise) distribution of particles at rest. Clumping is shown as temporal development, then various stages are shown as three-dimensional forms by rotating them. Finally, the combined effects of clumping and expansion are shown together. Film shown at Texas Symposium on Relativistic Astrophysics, December 1980.
Reference: Astrophysical Journal 270, 390 (1983).

25. Chicago B&W 223 ft.
Neutrino Universe. Gravitational clumping of a set of particles with large initial velocity dispersion, that represent a Universe most of whose mass is in the form of neutrinos of nonzero rest mass. Film shows temporal expansion in comoving coordinates, then shows the configurations rotated to give impression of three-dimensional form. Total expansion a factor 600.
Reference: Astrophysical Journal 270, 390 (1983).

26. Chicago B&W 300 ft.
Cray Universe. A series of three experiments of clustering of baryonic matter. 100 000 particles on a 64^3 periodic grid (the previous experiments used 25 000 particles on a 32^3 periodic grid). Temporal views only; no rotating scenes.
Reference: Astrophysical Journal 270, 390 (1983).

COLLAPSING STELLAR CONFIGURATIONS

27. Ames 946 Color 360 ft.
Formation of Galaxies with Flat Rotation Curves. Collapse of a two-component system from an initial state that joins smoothly into its surroundings in all directions. A 5% density bump in the center encourages formation of a single blob. Mass densities in the steady-state configurations yield flat rotation curves. A rotating view shows the final shapes. Shown at meeting of Division on Dynamical Astronomy of the AAS, Baltimore, June 1984.

28. Ames 790 B&W 394 ft.
Three-Dimensional Computer Galaxy Simulation. Initial sphere in balanced rotation. Forms a bar after a spectacular "S" shape. Film contains scenes in which the configuration is rotated to show three-dimensional form.
Reference: Astrophysical Journal 223, 122 (1978).

29. Ames 817 B&W 500 ft.
Collapses of Rotating Spheres of Stars in Three Dimensions. A sequence of 6 collapsing spheres with different amounts of initial rotation and velocity dispersion. All formed bars after various intermediate forms.
Reference: Astrophysical Journal 227, 407 (1979).

30. Ames 845 B&W 425 ft.
Mixup Collapses I. A sequence of collapse experiments started from initial forms deliberately designed to be nonspherical. The object of the study was to determine whether the final bar form required the high symmetry of spherical initial conditions, thus to verify that bars form in a wide range of initial conditions. The sensitivity of intermediate forms (see six collapses entry above) was also tested. All formed bars after various intermediate forms.
Reference: Astrophysical Journal 244, 33 (1981).

31. Ames 846 B&W 230 ft.
Mixup Collapses II. A continuation of the studies of the previous entry. These experiments started from initial conditions with large velocity dispersions, and formed fatter bars (axis ratio closer to unity).
Reference: Astrophysical Journal 244, 33 (1981).

PROTOGALAXIES

32. Ames 855 B&W 400 ft.
Protogalaxies I. A series of experiments in which both gas and stars are present, with a rule for forming stars out of the gas. The experiments start from a rotating uniform-density sphere of gas, and undergo a collapse during which stars form. Stars, once formed, live forever in this set of experiments.
Reference: Astrophysical Journal 244, 467 (1981).

33. Ames 856 B&W 400 ft.
Protogalaxies II. A continuation of the series of experiments in the previous entry, in which stars die after a certain time and return their matter to the interstellar medium as gas.
Reference: Astrophysical Journal 244, 467 (1981).

34. Ames 917 B&W 360 ft.
Protogalaxy Collapse: Stimulated Star Creation. A spectacular example of protogalaxy collapse with stimulated star creation and large return of energy to the interstellar medium as as result of the star formation. A detonation wave of star creation forms, which moves rapidly through the galactic plane and which results in gas being blasted out of the galactic plane.
Reference: "Formation of an Elliptical Galaxy," in Photometry, Kinematics, and Dynamics of Galaxies, ed. D. S. Evans (Austin, Tex., University of Texas at Austin, Department of Astronomy) 1979, pp. 365-368.

COMMENTS

New entries in this version of the movie listing:

9, Flyby,
22, The Real Universe, II., and
27, Formation of Galaxies with Flat Rotation Curves.

Films most suitable for classes, planetarium lectures, or lectures to amateur astronomer's groups include:

9, Flyby
22, The Real Universe, II.
7, Collisions of Disk Galaxies, Short Version
24, Clustering in Expanding Universe
34, Protogalaxy Collapse: Stimulated Star Creation
29, Collapses of Rotating Spheres of Stars
1, Collisions I: A Representative Sample
14, Streaming Motions in Bar

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21 May 1984

Oliver Strimpel
Computer Museum,
Congress Street
Boston,
Mass. 02210
U.S.A.

Dear Oliver,

Herewith some information on our activities.

Our main activity is building science centres aroundthe world. As you will see from the list we cover nearly all the sciences.

We have one or two steady lines such as our Auto Projectionist which we have been making for years but always using the work horse projector, the Bell and Howell 2585.

For Britain we make a special 50 cycle unit like the projectors we sold to the Science Museum, South Kensington and the Museum of Cinematography at Bradford, and the "Mary Rose", Portsmouth.

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The loading kit includes a split reeel, conductive foil for the auto stop, mylar splicing tape, a large loading boss and a split reel.

The room lighting dimmer costs a further $295.00. All the necessary plugs and sockets are brought out to effect the interface with the auto stop, film protection device and room lighting control.

Please let me know if I can help in any way. I can do with a trip down to Boston. Its my favourite city.

That's it for now,

Jack Nissen

JACK M.NISSEN

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Crating, Taxes & Duties, (where applicable,) extra.
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0003A	Distance Judging	9,530
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0004	Immersible Liquids	To follow
0008	See Saw Fulcrum	6,370
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0036	Multiples Unit	15,720
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0040	Science Circus	Quote on Request
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Adler Planetarium, Chicago, Ill.
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Museum of Science, Tampa, Florida
Design & Production, Alex, Vir.
Little League Baseball, Williamsport, Penn.
Dayton Power & Light, Dayton, Ohio
St. Louis Museum of Science & Natural History, St. Louis
Michigan State University, East Lansing
Discovery Place, Charlotte, N. Carolina
Museum of our National Heritage, Lexington, Vir.
Parks Canada Smith Falls, Ontario
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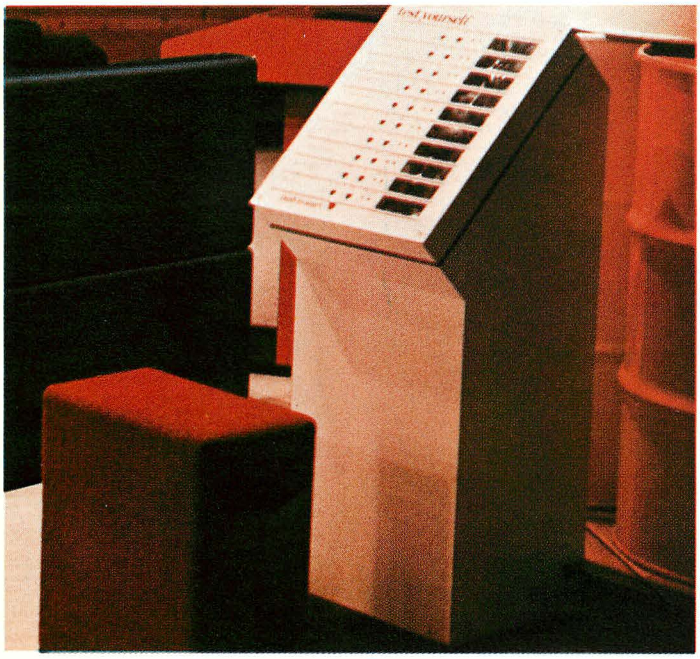

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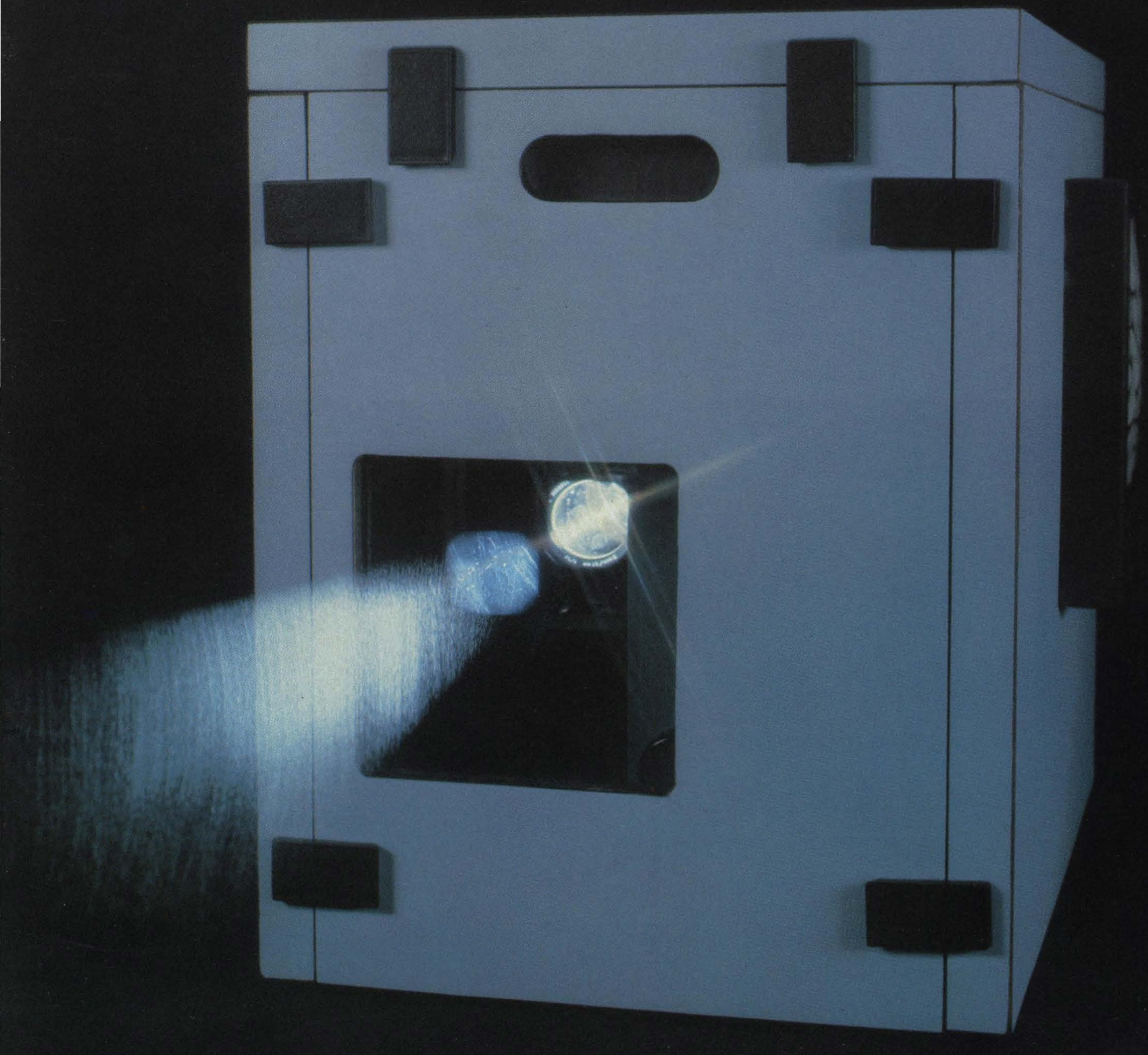

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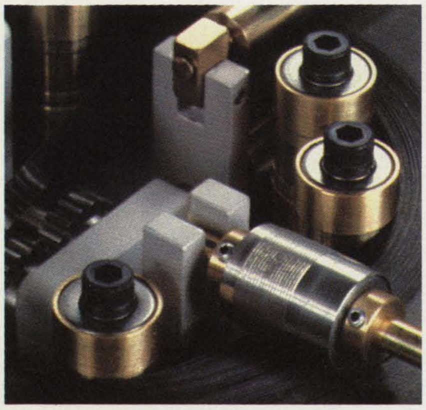

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The ME Auto Projectionist is an automated movie theatre system which owes its reliability and success to four main factors:

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(3) A pancake fan provides forced air cooling at high pressure throughout the unit, enabling the lamp to run very cool, extending its life far beyond that expected of a lamp used in an ordinary projector.

(4) Most of the heat generated by the projector itself is exhausted by a special duct. With forced cooling, film life is also extended.

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PRECISION FILM TRANSPORT MECHANISM
Mounted on a horizontal deck, automatically determines film tension, ensuring smooth reliable trouble free operation.

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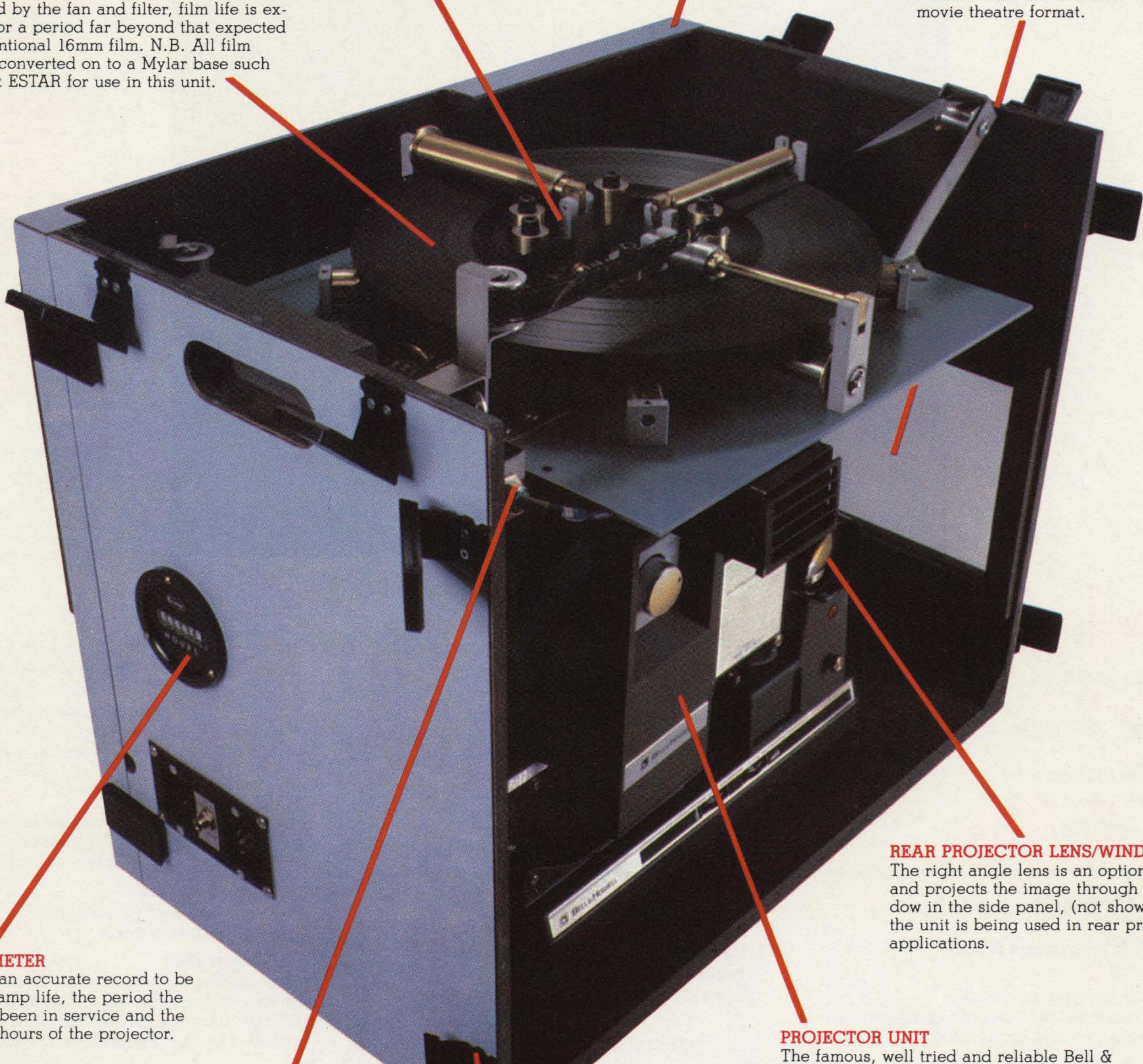

REAR PROJECTOR LENS/WINDOW
The right angle lens is an optional extra and projects the image through the window in the side panel, (not shown) when the unit is being used in rear projection applications.

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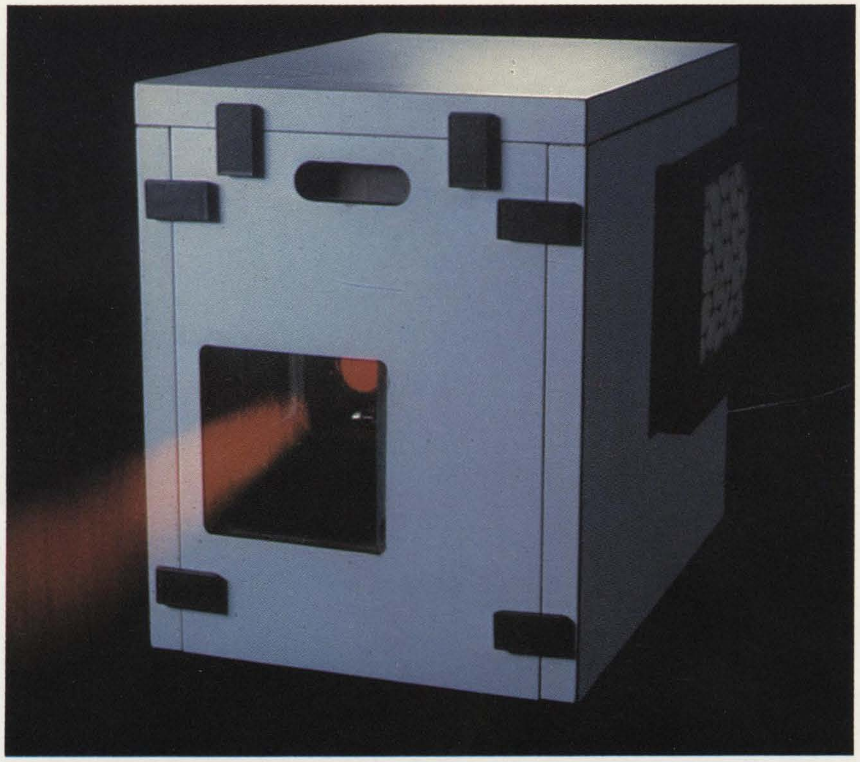
Enable easy removal of both side and top panels, thus facilitating maximum access.

ME
Auto Projectionist

Specifications & Accessories



Specifications:

Width
16 inches (406.4mm)

Depth
22 inches (558.8mm)

Height
20 inches (508mm)

Weight
50 lbs. (22.5 kg)

Voltage
As requested at time of order 50 hz or 60 hz

Power consumption
350 watts

Maximum programme length
30 minutes

Minimum programme length
No minimum as very short programmes can be repeated on one loop of film

Projector
Modified Bell & Howell 16mm movie projector

Lens
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Pancake high pressure fan
110 V 14 watts

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Incorporating: Solid brass machined rollers, Precision ball bearings, Precision machined aluminium posts with stainless steel brackets and fittings, 1/4" solid aluminium base plate.

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Accessories:

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Plugs into the auto "Projectionist" and controls the house lights on cue from the command module. (House light power control 10 or 40 amps to order.)

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The show 'start' low voltage push button can be located at the entrance to the 'mini theatre'; it connects directly into this module, which in turn, by means of a short cable, plugs into the "Projectionist". This completes the 'chain of command' for a show start on demand function.

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For use when the "Projectionist" is employed in the rear screen mode.

Mylar base film
Your standard 16mm film must be transferred on to a tough mylar base such as Kodak ESTAR, thus maximising the long life benefits afforded by the "Projectionist" system.

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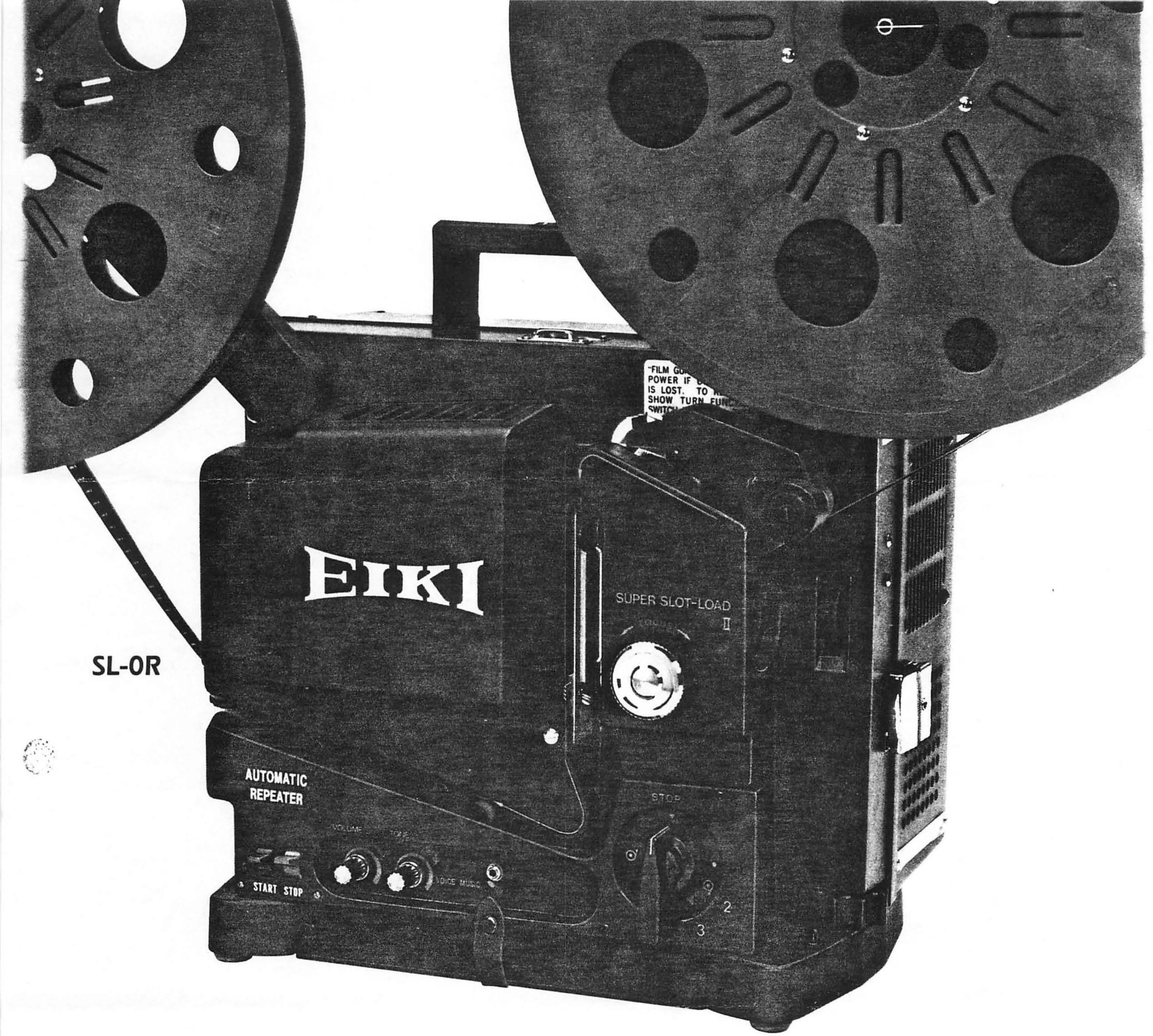

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- Has the basic features of the SL-0 projector.
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- Stops at end of show—rewinds automatically—starts show again automatically or at the push of a switch.
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- Uses easy-to-change optical cueing of projector functions.
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Applications for this repeater projector include:

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- Multi-Media Shows
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- Presentation Rooms

Any film presentation which is repeated on schedule or as required.

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October 25-26, 1982

Film and Video Tapes

The following addresses are sources for the film and video tapes shown during the conference.

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   204 W. John Street
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2. Vol Libre - Loren Carpenter — 16mm
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3. Montana - Jane Veeder — 3/4" video
   1839 S. Halsted Street
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4. Grumman Non-Edge Computer Image - Geoffrey Gardner — 16mm
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7. Voyager II - Jim Blinn — 16mm
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8. Sample Reel — 16mm
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9. Snake, Rattle, and Roll - Frank Dietrich, Zsuzsa Molnar 3/4" video
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11. Euclidean Illusions - Stan VanDerBeek 16mm
Picture Start, Inc.
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12. Carla's Island - Nelson Max 16mm
Monaco Film Lab
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13. A Sphere Turning Inside Out - Nelson Max 16mm
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14. Zoom's on Self Similar Figures
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15. Interactive Roster Graphics Sampler - James Lipscomb 3/4" video
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September 11, 1984

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Curator
THE COMPUTER MUSEUM
300 Congress Street
Boston, MA 02210

Dear Mr. Strimpel:

Please find enclosed a copy of Digital Productions' Demo Reel in 3/4" video cassette format which will give you some examples of commercial advertising as you requested for The Computer Museum opening this fall.

With regard to the 16mm film you had also requested, I have been informed by our Production Coordinator that it will take ten days to transfer the tape. We will forward it to you as soon as it is ready.

Please note the following credit line should accompany any reproduction of the enclosed material.

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Judah Schwartz QM :

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7414

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ask for distribution center ;

Orig 35mm

16mm

No Videotape

Made in

Late 60's

early 70's

3 yrs

all kinds of hardware

SC 4020 to make pictures

QM : 1 free mass particle

1 particle in box

4 scattering

3 " in solid state

1 prob. inter. of qm

4 radiated electric fields from accel particles

each under 4 min

Best Aesthetic : Synchrotron radiation

MKT Edwin Taylor

1. Relativistic Rides: time delays

2. Curves:

Telephone poles on either side of ride,
lean backward way or go faster

Permission OK

Education Research Center in Camb 1960's.

Film & Video.

Strecembeck

Editor

'4-plate'

$400 per mo

1. Cinema 16mm < 30 min Advertising
Hunger / Carla's Island / Vol Libre / SF Video
Interviewing: Cosmos mini (Blinn Tron? Startrek Genesis

2. Sketchpad / Grail / ESL / AGT / Hopgood

3. GE / Jurg Brannen other CAD video / Reactive display & DAC-1

4. Simulation in Astronomy & Fluid Mechanics video or 16mm + Voyager

5. Simulation in Maths 16mm
Zooms in.

Ed Zajac's satellite orbit in cinema. 1963, Communications satellite & Comming Coll
2 paradoxes (George Michael)
602 621 6224 dept of economics
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Paint: Shoup's tape

Artists

7

Simulation (Not in real time)

F 1. Voyager - Blinn

F 2. Toomre

F 3. Aarseth

F 4. Fluid Dynamics

F 5. Molecules

6. Lawrence Cummins: impact comparisons

7. Animation (from NYIT?) See end-points & interpolates.. (Also Pluager)

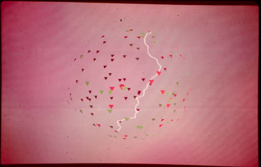
8. Manufacturing process-control (Aydin?)

9. ~~Topology - Turning Sphere inside-out~~

F 10. Zooms on self-similar figures (next to indicating Fractal?)

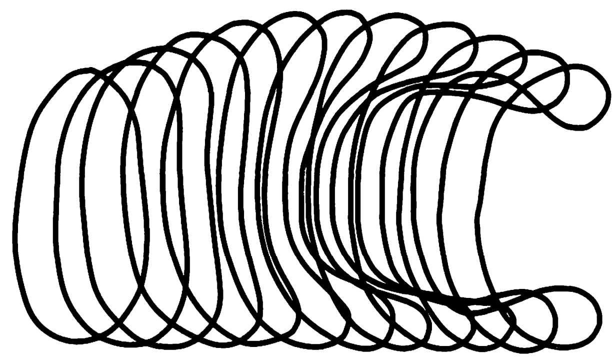
NO 11. ~~The Hypercube: Projections and Slicings~~

F 12. Chuck Csuri: body



a guide to the 16mm film

REGULAR HOMOTOPIES IN THE PLANE: Part I



Mathematician: Nelson L. Max

14minutes color sale $195 rental $10

INTRODUCTION

The subject of regular homotopies is a part of differential topology which is particularly accessible to visual intuition. The two parts of *Regular Homotopies in the Plane* provide a visual translation of the proof of the Whitney-Graustein Theorem[1] which gives the regular homotopy classification of regular curves in the plane. By using a smoothly turning tangent vector, with a spiral image to record its rotation, Part I makes the concepts in Whitney's proof intuitively available to a high school or college audience, without the use of calculus.

CONTENT OF THE FILM

The film opens with the definition of a **regular (closed) curve,** stating five conditions: 1) the curve must be closed; 2) the curve must be continuous; 3) there is a tangent vector at every point; 4) the tangent vector turns continuously as it moves around the curve; and 5) the tangent vector returns, at the end, to its initial direction.

A deformation from one regular curve to another gives an intermediate curve for each instant of time. It is called a **regular homotopy** if 1) each intermediate curve is closed and continuous; 2) each intermediate curve lies in the plane; 3) the curve moves continuously; 4) each intermediate curve is regular; and 5) the tangent vector at a particular point moves continuously during the deformation.

These conditions are illustrated by their violation in five incorrect ways of turning a figure eight into a circle. Then the basic question arises: "Is there any regular homotopy between a circle and a figure eight?" The rest of the film uses the concept of rotation number to prove that there is none.

The rotation number of a regular curve is the number of times the tangent vector rotates going once around the curve. This is recorded graphically by a spiral image which follows the moving tangent vector. The circle and the figure eight are among the examples, and have different rotation numbers. Thus, the following theorem shows that there is no regular homotopy between them.

Theorem: Two regular curves in the plane which are regularly homotopic must have the same rotation number.

The essential point in the proof is that in a regular homotopy we can find a number of intermediate curves so that corresponding tangent vectors stay close from one curve to the next.

The theorem is also used to show that a circle cannot be turned inside out by a regular homotopy. Surprisingly, there is a regular homotopy in three dimensions which turns a sphere inside out; this is the subject of another film in this series.

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The converse, that any two regular curves with the same rotation number are regularly homotopic, is stated, but the proof is deferred to Part II. Part I closes with a specific problem: a pair of curves with the same rotation number between which the viewer is asked to find a regular homotopy.

REFERENCES

The original paper by Whitney[1] is understandable to any student of calculus, and the correspondence between it and the film is readily seen. Chinn and Steenrod[2] contains an elementary and very detailed discussion of winding numbers and homotopies, which can be applied to the derivative vectors considered in the film. Phillips[3] relates the two dimensional case to the problem of turning a sphere inside out.

[1] Whitney, H. "On regular closed curves in the plane." *Composito Mathematica 4* (1937), 276.

[2] Chinn, W., and N. Steenrod. *First Concepts of Topology.* New York: Random House, 1966.

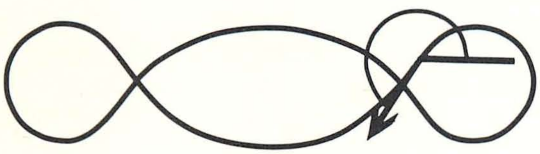
[3] Phillips, A. "Turning a surface inside out." *Scientific American,* Vol. 214, No. 5 (May, 1966), 112.

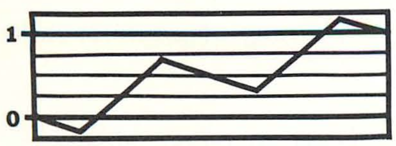
REGULAR HOMOTOPIES IN THE PLANE: PART I was produced by the Education Development Center of the Topology Films Project with support from the National Science Foundation.

Material for this guide was prepared by Nelson L. Max, Carnegie-Mellon University, Pittsburgh, Pennsylvania and Project Director of the Topology Films Project, Education Development Center, Newton, Massachusetts.

a guide to the 16mm film

REGULAR HOMOTOPIES IN THE PLANE: Part II





18½minutes color sale $235 rental $12.50

Mathematician: Nelson L. Max

INTRODUCTION

The Whitney-Graustein Theorem[1] states that "Two regular curves in the plane are regularly homotopic if and only if they have the same rotation number." Part I proved the *only if* half of the theorem, and Part II gives a constructive proof of the *if* half. Although it is conceptually more difficult than Part I, no calculus is required. Instead, the integrals in Whitney's paper are illustrated by the paths traced out by moving tangent vectors.

PROBLEM

Given two curves with the same rotation number, construct a regular homotopy between them.

CONTENT OF THE FILM

The film opens with a review of the concepts of regular homotopy and rotation number, and a statement of the theorem. Two different solutions are shown for the specific problem given at the end of Part I. The film then turns to a construction for the general case. To standardize the two curves one may magnify or shrink them so that they have standard length, and turn them so that their initial tangent vectors point to the right.

The rotation of the tangent vector is recorded on a tangent graph, showing total rotation $f(s)$ as a function of distance s along the curve. In Whitney's paper this is a covering function for the derivative vector, while in the film it is indicated directly by the spiral symbol. Similarly, the integrals in Whitney's paper correspond to constructing a curve by letting a point move in the direction of a changing tangent vector, as specified by a tangent graph.

Given two tangent graphs, $f(s)$ and $g(s)$, one can construct a sequence of intermediate tangent graphs, given by the linear homotopy

$$h_t(s) = (1-t) \times f(s) + t \times g(s).$$

These intermediate curves are used to construct intermediate curves in the regular homotopy.

If the two given curves are centrally symmetric, then tangent vectors at diametrically opposite points will have opposite directions. This will also be true for the curve specified by $h_t(s)$, so the total motion will cancel out, and the moving point will return to its starting point, creating a closed intermediate curve. Thus, for the centrally symmetric case, and in particular, for the example with four-fold symmetry given in the film, this process will give a regular homotopy.

However, in the general case, where there is no symmetry, the intermediate curves constructed this way need not be closed. To fix this, each intermediate curve is squashed by an amount determined by the gap between its endpoints. In the film, the squashing process is indicated by

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a moving segment, whose length is proportional to the distance along the curve, and corresponds to a second term in Whitney's formulas.

This squashing process breaks down in the special case where an intermediate tangent graph is constant (at *0*). In this case, the intermediate curve will be a straight line, and will squash to a point. The film closes with an illustration of this problem, and the graphical equivalent of the extra paragraph at the end of Whitney's proof which fixes it.

REFERENCES

Those who understand integral calculus may enjoy reading Whitney's original paper,[1] and finding the correspondence between his formulas and the constructions in the film. Smale[2] in his thesis solved the corresponding problem in a general surface by a method which led to his solution of the three-dimentional problem[3] which is explained at a popular level by Phillips.[4] Linear homotopies are discussed in Chinn and Steenrod.[5]

[1] Whitney, H. "On regular closed curves in the plane." *Composito Mathematica 4* (1937), 276.

[2] Smale, S. "Regular curves on Riemannian manifolds." *Transactions of the American Mathematical Society 87* (1958), 492.

[3] Smale, S. "A classification of immersions of the two-sphere." *Transactions of the American Mathematical Society 90* (1959), 281.

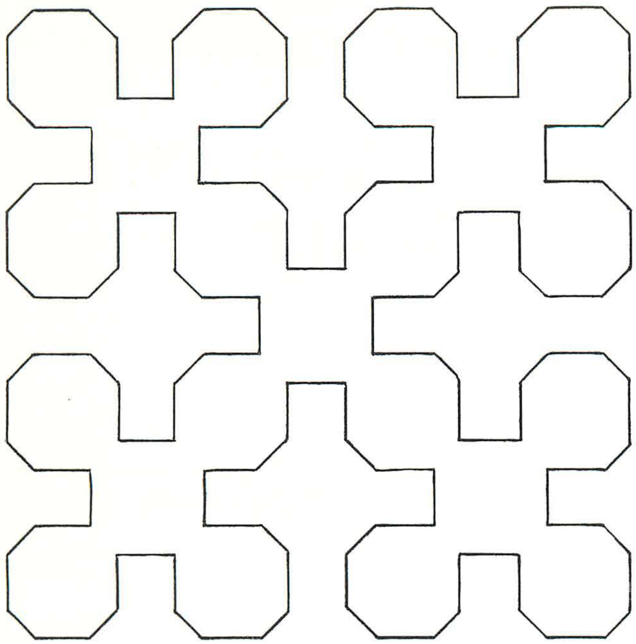
[4] Phillips, A. "Turning of a surface inside out." *Scientific American,* Vol. 214, No. 5 (May, 1966), 112.

[5] Chinn W., and N. Steenrod. *First Concepts of Topology.* New York: Random House, 1966.

REGULAR HOMOTOPIES IN THE PLANE: PART II was produced by the Education Development Center of the Topology Films Project with support from the National Science Foundation.

Awarded the *Golden Eagle,* CINE Film Festival.

Material for this guide was prepared by Nelson L. Max, Carnegie-Mellon University, Pittsburgh, Pennsylvania and Project Director of the Topology Films Project, Education Development Center, Newton, Massachusetts.



SPACE FILLING CURVES

a guide to the 16mm film

25½minutes color sale ~~$295~~ $325.00 *rental* ~~$15~~ $17.50

Mathematician: Nelson L. Max

INTRODUCTION

This film illustrates the concept of a limit curve, as specified by a sequence of approximation curves, and applies it to the construction of space filling curves. Computer animation makes the concept graphically real to those viewers who have studied it, and introduces fascinating ideas about infinity to those viewers who have not. Thus the film can give a glimpse of modern mathematics to high school or college audiences, illustrate limits to calculus classes, or replace lengthy blackboard drawings in mathematics courses exploring the meaning of a curve. Because of the intriguing visual patterns and their motion, the film also makes a connection between mathematics and art.

PROBLEM

Is it possible to construct a space filling curve, that is, a continuous curve which passes through, or covers, every point in a square?

CONTENT OF FILM

After stating that the problem was solved in 1890 by Guiseppi Peano, the narrator shows that a curve of finite length cannot cover up an area, so that a space filling curve must have infinite length. Then the concept of a limit curve is introduced with the familiar example of the circle as the limit of inscribed approximating polygons. Two conditions are stated: 1) every point must approach a limit point, and 2) the limit points must fit together to make a continuous curve. These are further illustrated by the construction of the snowflake curve, which is shown to have infinite length. In all the examples, animation is used to show how the approximation curves move to the limit curve, and the motions of several individual points are followed.

Returning to the original problem, the concept of the limit curve is applied to space filling curves. A simple but naive "back and forth" example is considered, and rejected because a point is found which does not approach a limit. Then two correct examples are given. The first closely resembles Peano's original construction. The second is a closed space filling curve given by Sierpinski. The proof that Sierpinski's curve passes through every point in the square is hinted at visually. The film ends with a two-minute continuous enlargement, magnifying by a factor of over a billion, which shows that none of the approximations cover the square.

DISCUSSION QUESTIONS

Does the snowflake curve cover up any area? How much area does it enclose?

In proving that a limit curve has infinite length, why must one know that the approximating polygons have their vertices on the limit curve? Is this fact true for Peano's and Sierpinski's curves?

How many other space filling curves are there?

Are there more points in a square than on a line?

Can a one-to-one curve pass through every point in a square?

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REFERENCES

Peano's original paper[1] (the first paragraph is seen at the beginning of the film) is in French, and constructs the curve arithmetically, using the base three system. His curve, and a number of others, are shown in Hobson[2]. Sierpinski's original article[3] does contain pictures of his curve, as does Steinhaus[4]. Finally, a complete summary of the film is given, in picture book format, in Max[5], which also expands the ideas and discussion questions with supplementary definitions, illustrations, and proofs.

[1] Peano, G. *"Sur une courbe, qui remplit tout une aire plaine," Mathematiche Annalen 36 (1890)*, 157.

[2] Hobson, E.W. *"The theory and functions of a real variable and the theory of Fourier's series."* New York: Dover Publications, Inc., 1907.

[3] Sierpinski, W. *Bulletin de l'Académie des Sciences de Cracovie, A (1912)*, 462.

[4] Steinhaus, H. *Mathematical Snapshots.* New York: Oxford University Press, 1969.

[5] Max, N. *Space Fillings Curves.* Newton, Massachusetts: Education Development Center, 1971.

SPACE FILLING CURVES was produced by the Education Development Center for the Topology Films Project with support from the National Science Foundation.

AWARDS: *Gold Bucranium* (highest award possible), Padua Film Festival, Italy
Orbit Award (best film), ANZAAS Festival, Australia
Golden Eagle, CINE Film Festival

Material for this guide was prepared by Nelson L. Max, Carnegie-Mellon University, Pittsburgh, Pennsylvania and Project Director of the Topology Films Project, Education Development Center, Newton, Massachusetts

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INTERNATIONAL FILM BUREAU INC.

Topology Short Films Series

A series of short, computer-animated films illustrate the concepts of limit and space filling curves, sphere eversions, and other topological theories. Produced by the Topology Films Project. Supported by the National Science Foundation. Directed by Dr. Nelson L. Max, Lawrence Livermore Laboratory, University of California. Guides for the films are available from International Film Bureau Inc., 332 South Michigan Avenue, Chicago, Illinois 60604 (312/427-4545).

16mm series sale (6 reels) $755.

Videocassette series sale (on one cassette) $335: Limit Curves and Curves of Infinite Length, Sphere Eversions, Limit Surfaces and Space Filling Curves, The Butterfly Catastrophe. Videocassette series sale (on one cassette) $195: Sierpinski's Curve Fills Space, Zooms on Self-Similar Figures.

LIMIT CURVES AND CURVES OF INFINITE LENGTH

14min color silent
16mm sale $215 rental $15.00 vc $175

Seven short computer-animated films describe the construction of limit curves from a sequence of approximation curves and demonstrate that two of these curves have infinite length. The following sequences are included.

Limit Curves I: THE CIRCLE
The circle is constructed as the limit of inscribed polygons, and a point is shown moving to its limiting position. Many points are shown moving simultaneously to their limits.

Limit Curves II: THE SNOWFLAKE CURVE
This nowhere-differentiable curve is constructed from an equilateral triangle by replacing the middle third of each side by a new triangle, and then repeating this process. Points are again shown moving to their limits.

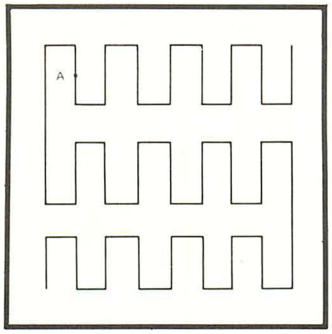
Limit Curves III: AN INVALID CASE
A line is shown moving to produce more and more horizontal zig-zags, until it appears to cover up a square. By watching a chosen point move from one approximation to the next, one observes that it does not approach a limit point.

Limit Curves IV: PEANO'S CURVE
A version of Peano's space filling curve is constructed as a limit of approximations. This time, since the zig-zags are made in alternating horizontal and vertical directions, one observes that the approximating points all approach limit points.

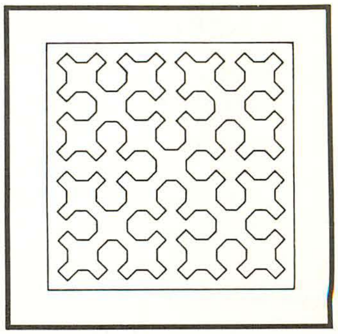
Limit Curves V: SIERPINSKI'S CURVE
Another space filling curve was invented by Sierpinski. Its approximations are illustrated and points are shown moving to their limit positions, leaving colorful traces behind to record their paths.

Curves of Infinite Length I: SNOWFLAKE CURVE
Each approximation is formed from the previous one by swinging out the middle third of each side, and swinging in an extra segment of the same length. This multiplies the length by 4/3 at each stage so that the limit has infinite length.

Curves of Infinite Length II: PEANO'S CURVE
Swinging segments show that the length triples from each approximation of Peano's curve to the next approximation.



Peano's third approximation



Sierpinski's fourth approximation

SPHERE EVERSIONS

7½min color silent
16mm sale $135 rental $10.00 vc $110

Three short films illustrate an eversion of a sphere, a smooth motion which turns the sphere inside out by passing the surface through itself without making any holes or creases. This eversion was invented by Bernard Morin. Several different styles of computer animation illustrate the eversion.

Sphere Eversion I: WIRE MESH
The first sequence shows the early stages of the motion, using hexagonal "chicken wire" and the second sequence, using a rectangular grid, shows the whole eversion. The images are rotated to give a three-dimensional feeling.

Sphere Eversion II: OPAQUE SURFACES
The outside surface of the shaded model of the sphere is colored red and the inside surface is colored blue. The surface starts as a round red sphere and ends up as a blue one to show that the sphere has been turned inside out. The eversion is shown from two perpendicular viewing directions.

Sphere Eversion III: EXPLODED VIEWS
The first sequence shows the sphere sliced in half revealing how the first triple points are created. The next scenes show the surface exploded into triangles and then into rectangles.

LIMIT SURFACES AND SPACE FILLING CURVES

10½min color silent
16mm sale $170 rental $15.00 vc $140

Presents four examples of infinite constructions in two and three dimensions. The first two parts show self-similar surfaces in three dimensions. The next two parts concern Sierpinski's Space Filling Curve first drawn as if it were being traced by a moving point and then modified to make it one-to-one.

VOLUME FILLING SURFACES
Shows a surface which passes through every point in a cube. It is constructed by a limiting process similar to the one used by Sierpinski for his space filling curve. Shows one approximation rotating. In the final scene a continuous zoom, matched to the changing approximations, gives a repeating cycle.

THE ALEXANDER HORNED SPHERE
This surface is homeomorphic to a standard round sphere, but its exterior is not simply connected. Shows the horns growing, swinging around, and interlinking. A continuous zoom on the approximations is included.

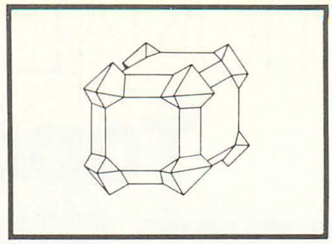
SIERPINSKI'S CURVE DRAWN AS A FUNCTION OF TIME
The curve is drawn as if it were being traced by a moving point that fills in the square triangle by triangle. One can see that the square's center is touched four times. The curve is not one-to-one.

A ONE-TO-ONE CURVE OF POSITIVE AREA
Shows how to modify Sierpinski's curve by opening up infinitely many cracks between the triangles, so that the limit curve is one-to-one and has the same Lebesgue measure (generalized area) as the square.

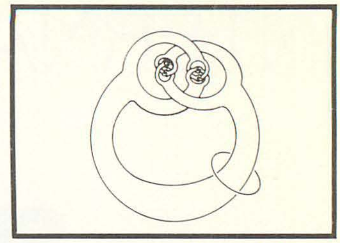
SIERPINSKI'S CURVE FILLS SPACE

4½min color sound
16mm sale $90 rental $10.00 vc $110

Provides proof that Sierpinski's limit curve actually passes through every point in the square. Serves as a complement to the sound film *Space Filling Curves* which mentions such a proof. Computer animation shows that appropriate intervals on the first approximations have limit points inside corresponding triangles. A nested sequence of these triangles is constructed containing a given point in the square, and a pre-image is found in the corresponding sequence of intervals on the first approximation.



An approximation to a volume-filling surface



A loop caught on Alexander's horned sphere

ZOOMS ON SELF-SIMILAR FIGURES

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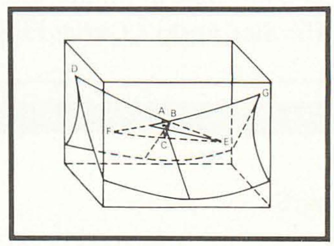
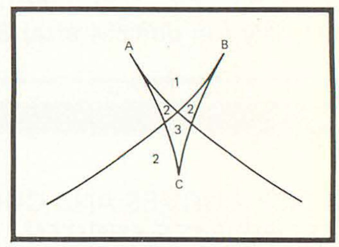
Contains the zoom scenes from five of the other films of the series: The Snowflake Curve, Peano's Curve, Sierpinski's Curve, Volume Filling Surfaces, and the Alexander Horned Sphere. The film can be viewed as computer art and gives insight into many philosophical levels of the infinite in space. Special musical accompaniment.



The butterfly surface in space



Cross section of butterfly surface

THE BUTTERFLY CATASTROPHE

4½min color silent
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Provides an introduction to the mathematics of catastrophe theory, which has enjoyed increasing attention in the physical and social sciences. The three-dimensional butterfly catastrophe surface is represented in four-dimensional space using time as the fourth dimension.

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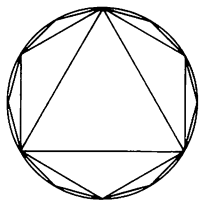
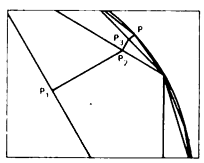
LIMIT CURVES AND CURVES OF INFINITE LENGTH

SPHERE EVERSIONS

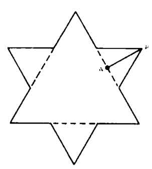
LIMIT SURFACES AND SPACE FILLING CURVES



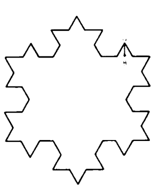
1. Approximation to a circle.



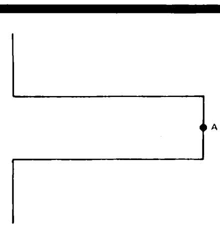
2. Approximating points and their limit point.



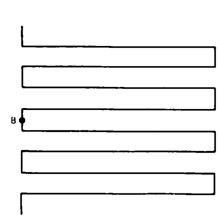
3. Motion from the first to the second approximation.



4. Motion from the second to the third approximation.



6. The second approximation.



7. The third approximation.

The Topology Short Films are a series of short, computer-animated films illustrating the concepts of limit and space-filling curves, sphere eversions, and other topological theories. They are excerpts from the four productions of the Topology Films Project with additional concepts that illustrate two- and three-dimensional topology. The Topology Films Project was supported by the National Science Foundation and directed by Dr. Nelson L. Max, Lawrence Livermore Laboratory, University of California.

LIMIT CURVES AND CURVES OF INFINITE LENGTH

These seven short computer-animated films describe the construction of limit curves from a sequence of approximation curves and demonstrate that two of these curves have infinite length.

LIMIT CURVES I: THE CIRCLE

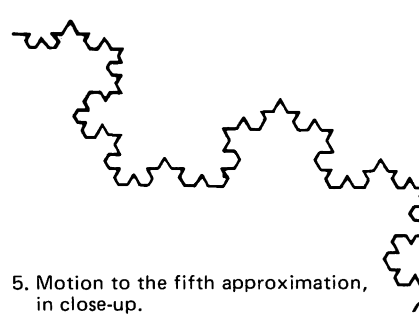
A limit curve is defined by a sequence of approximating polygons. For the circle, the approximations may be chosen as an inscribed triangle, a hexagon, a dodecagon, etc. (see Fig. 1). These polygons move closer and closer to the circle, and their lengths approach the length of a circle. In fact, they were used by Archimedes to compute the length of a circle.

If we watch a specific point on the first approximation, shown in close-up in Fig. 2, we see it move to a corresponding point on the second approximation, the third, etc. It moves less and less at each stage, and thus approaches a limit point P on the circle. Every point on the first approximation approaches a limit point. The limit curve, in this case the circle, is the set of these limit points.

LIMIT CURVES II: THE SNOWFLAKE CURVE

The snowflake curve is defined by a sequence of approximating polygons. The first approximation is an equilateral triangle. The second approximation is formed by pushing out the middle third of each side to form two sides of another equilateral triangle, making a star, as in Fig. 3. The process is repeated again to get the third approximation (see Fig. 4).

The limit curve, invented by Helge von Koch, is called the snowflake curve.[1] Because there are infinitely many new triangles between any two points on the snowflake curve, it has no straight or smooth pieces. Thus, it is termed "nowhere differentiable." A general reference on nowhere differentiable curves is Reference 2.



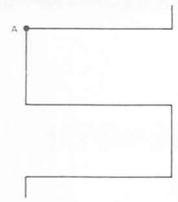
5. Motion to the fifth approximation, in close-up.

The close-up in Fig. 5 shows a point on the first approximation moving to the corresponding points on the successive approximations. The distance each point moves is at most the length of the altitude of one of the little triangles (AP in Fig. 3 and BQ in Fig. 4). These altitudes form a geometric progression of ratio 1/3, so each point approaches a limit point.

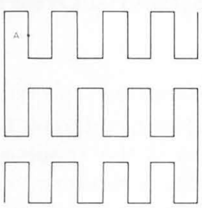
The snowflake curve is the set of these limit points. The order of the points on the first approximation determines the order of the limit points on the limit curve.

LIMIT CURVES III: AN INVALID CASE

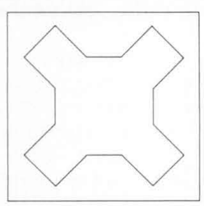
There are two conditions for a sequence of approximation curves to define a limit curve: every point on the first approximation must approach a limit point, and the limit points must fit together to form a continuous curve.



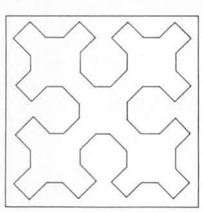
8. Peano's second approximation.



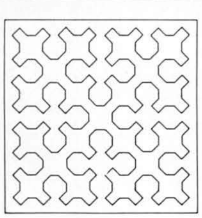
9. Peano's third approximation.



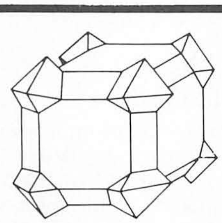
10. Sierpinski's second approximation.



11. Sierpinski's third approximation.



12. Sierpinski's fourth approximation.



14. The surface forming 8 octahedra.

Films IV and V in this series present limit curves that pass through every point of a square. Film III shows a simple way of doing this, which in fact does not define a limit curve. The first approximation is a vertical line, and the second approximation looks like a horizontal zig-zag (see Fig. 6).

To get the next approximation from the one in Fig. 6, the middle third of each vertical segment is stretched across to the opposite side (see Fig. 7). If this process is repeated again and again, the curve seems to cover up a square. Does this sequence of approximations define a limit curve?

To check the first condition, we watch a point move. Point A in Fig. 6 will move to position B in Fig. 7, and then back to A in the next approximation, and so on. It will continually move all the way back and forth and never approach a limit point. Because this point does not approach a limit point, the first condition is violated, and these approximations do not define a limit curve.

LIMIT CURVES IV: PEANO'S CURVE

In 1890 the Italian mathematician Guiseppi Peano constructed a "space-filling curve," that is, a continuous curve that passes through every point in a square.[3] His curve was quite surprising to mathematicians because a line interval is one-dimensional and a square is two-dimensional, yet the curve is a continuous function from the interval onto the square.

Peano gave arithmetic formulas for calculating this function. The approximations shown in this film are a slight variant of his, and are easier to understand visually. Like the invalid example previously discussed, the first approximation is a vertical line, and the second approximation, shown in Fig. 8, has horizontal zig-zags. To make the third approximation in Fig. 9, we use vertical instead of horizontal zig-zags, so they are one-third as large. The next approximation has horizontal zig-zags one-ninth as large as those in Fig. 8, and so forth.

If we watch a point move from one approximation to the next it will approach a limit point. Because the maximum distance a point can move at each stage is one-third the maximum for the previous stage, every point on the first approximation approaches a limit point.

The limit curve is the set of the limit points, and in this case, it is the whole square. So from a picture of the limit curve, we cannot tell in which way it is traced because we cannot see the order of the points.

Here is where we use the approximations. Every point on the first approximation corresponds to a limit point on the square, so the order of the points on the first approximation determines the order of the limit points on the square.

LIMIT CURVES V: SIERPINSKI'S CURVE

The Polish mathematician Waclaw Sierpinski defined a closed space-filling curve that covers up a square and returns to its starting point. Unlike Peano, Sierpinski drew the approximating curves, as shown in this film. One of the approximations is the cross shape shown in Fig. 10. A later approximation (Fig. 11) repeats this shape four times, each at half the size of Fig. 10. A still later approximation (Fig. 12) contains four copies of Fig. 11 and 16 copies of Fig. 10.

As with Peano's curve, this smaller and smaller repetition assures that if we watch a point move, it will approach a limit point. If we watch a collection of points move, they will spread out over the square. The limit curve is the set of these limit points. The *film* **Sierpinski's Curve Fills Space** proves that this set is the whole square. Because the whole square is covered, a picture of the limit curve does not reveal how the curve is traced. The tracing is shown in the film segment **Sierpinski's Curve Drawn as a Function of Time.**

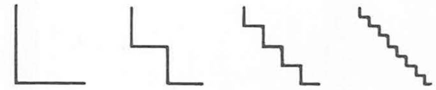
CURVES OF INFINITE LENGTH I: THE SNOWFLAKE CURVE

The snowflake curve is the limit of a sequence of approximating polygons. This film shows that the lengths of the approximating polygons increase without limit, so that the snowflake curve must have infinite length.

To get from one approximation to the next, the middle third of each segment is removed and replaced by two others of the same length. This is visualized by turning the middle third by 60 deg, and then swinging a second segment into the gap.

The result of this process is a new shape that is 4/3 as long as the original segment. Thus, if the triangle that forms the first approximation has length P, then the second approximation has length (4/3) P (see Fig. 3). The third approximation then has length (4/3 x 4/3) P, etc. In general, the n^{th} approximation has length $(4/3)^{n-1}$ P. This number eventually surpasses any constant length, so we say that the lengths of the approximations approach infinity.

However, to conclude that the limit curve has infinite length, we must verify that the approximations are inscribed in the limit curve. To see why this is necessary, consider the sequence of approximations shown in Fig. 13.



13. Approximations of length 2, whose limit has length 2.

If the two segments on the first approximation each have length one, all these approximations have length two. However, the limit curve is a diagonal line of length $\sqrt{2}$, which is shorter than the approximations. This happens because the vertices of the approximation polygons do not lie on the limit curve, so there is no relationship between their lengths.

If the vertices of a polygon lie on a curve and are joined in the same order as on the curve, we say that the polygon is inscribed in the curve. In this case, the length of the polygon cannot be longer than that of the curve because a straight line segment is the shortest distance between two points.

Now each vertex of an approximation to the snowflake curve remains fixed in all later approximations, and thus lies on the limit curve. Hence, every approximation is inscribed in the snowflake curve, and the snowflake curve is at least as long as each approximation. However, we have seen that the approximations get longer than any finite number and therefore the length of the snowflake curve must be infinite.

CURVES OF INFINITE LENGTH II: PEANO'S CURVE

A space-filling curve similar to one constructed by Peano can be defined by a sequence of approximations, as shown in the film segment **Limit Curves IV: Peano's Curve.** Because a curve of finite length covers up a zero area, a space-filling curve that covers up a whole square must have infinite length. We can verify that Peano's curve does have infinite length by looking at the lengths of its approximations.

For example, let us assume that the first approximation is a vertical line of length one. The second approximation (Fig. 8) can be formed from three horizontal lines by bending the ends together, so it is length three. The third approximation (Fig. 9) is nine times as long, and so on. Thus, the lengths of the approximations approach infinity.

To conclude that Peano's curve has infinite length, we must verify that each approximation is inscribed in the limit curve. Note that vertex A on the second approximation remains in the same place in the third approximation, and in fact, forever. From the film segment **Limit Curves IV** we can verify that every vertex on an approximation remains fixed and ends up on the limit curve. Thus, the approximations are inscribed in the limit curve, so we know that the limit curve is at least as long as each of the approximations. Therefore the length of the limit curve is infinite.

SPHERE EVERSIONS

A sphere eversion is a smooth motion of the surface of a sphere, which turns the surface inside out by passing the surface through itself without making any holes or creases. Steven Smale first showed that such an eversion was possible in a theoretical paper in 1959.[4] The eversion presented here was invented by Bernard Morin. It is illustrated in several ways in this series of computer-animated films.

SPHERE EVERSION I: WIRE MESH

The surface is represented as wire mesh that rotates to give a three-dimensional feeling. The first sequence, using hexagonal chicken wire, shows the early stages of the motion; the second, using a more rectangular grid, shows the whole eversion. Because the wire does not obstruct the view, one can see the entire surface at once.

SPHERE EVERSION II: OPAQUE SURFACES

With opaque surfaces only the front layer is visible but the colors add extra information, and the shading reveals the shape of the surface without using rotation. The outside surface is red, and the inside surface is blue. Because the surface starts as a round red sphere and ends as a blue one, it is easy to verify that it has been turned inside out. The film shows the same eversion from two perpendicular viewing directions. In the second sequence we can see the four-fold rotational symmetry of the halfway inside-out position.

SPHERE EVERSION III: EXPLODED VIEWS

Cutting apart the surface reveals the interior layers without sacrificing the color information. The first sequence shows the sphere sliced in half during the early stages of the eversion, and reveals how the first triple points are created. The next sequence shows these same stages with the surface of the sphere exploded into separate colored triangles. In the final sequence, the surface is exploded into squares, picking up where the triangles left off and carrying the eversion past the halfway stage.

A more extensive description of the various stages of the eversion is given in Ref. 5, or the 23-minute sound film **Turning a Sphere Inside Out** available from International Film Bureau Inc.

LIMIT SURFACES AND SPACE FILLING CURVES

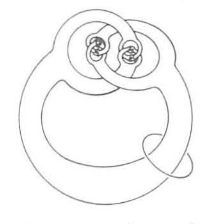
This film presents four examples of infinite constructions in two and three dimensions. The first two segments show self-similar surfaces in three dimension. The next two concern Sierpinski's space-filling curve first drawn as if it were being traced by a moving point and then modified to make it one-to-one.

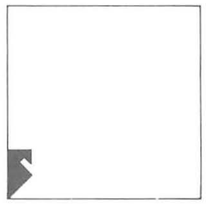
VOLUME-FILLING SURFACES

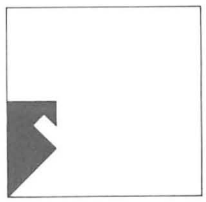
The film **Space Filling Curves** and film segment **Limit Curves V** both show a curve invented by Sierpinski that passes through every point in a square. This film shows a three-dimensional version: a surface that passes through every point in a cube. The images are colorful, and the final three-dimensional infinite zoom is a fascinating visual experience.

The surface begins as a blue regular octahedron. The eight triangles move outward leaving gaps filled by six red squares and twelve yellow rectangles. The eight triangles then turn into eight new octahedra, each one half the size of the original. The octahedra are shown forming in Fig. 14. The process is then repeated, making 64 quarter-sized octahedra, and so forth. The limit surface of these approximations passes through every point in a cube. The film carries the process up to 4096 octahedra, as close to the limit surface as the computer could animate.

The next scene shows the 64 octahedra being created from a viewpoint directly in front of one of the original vertices, giving a profile that resembles Sierpinski's curve. The surface is then rotated and later tilted to give a better understanding of its three-


15. A loop caught on Alexander's horned sphere.


16. The area covered by time t = 0.021.


17. The area covered by time 4t.


18. The area covered by time 16t.


19. The second approximation fills in 8 triangles.


20. The third approximattion fills in 16 triangles.

dimensional structure.

The final scene shows the surface again approaching its limit, viewed with a continuous zoom toward the center point. The zoom rate is matched to the rate of creating new octahedra, giving a repeating cycle.

One may use Sierpinski's curve to cover up a square, stretch and fold the square to cover up an octahedron, and then move the octahedron to cover up a cube, as in this film. The result will be a curve that passes through every point in a cube.

THE ALEXANDER HORNED SPHERE

A simple closed curve in the plane is the image of a one-to-one continuous map of a circle. The Shoenfliess theorem states that such a curve separates the plane into two regions; one is homeomorphic to the interior of a circle, and the other to the exterior.

The Alexander horned sphere is a counter example to this statement in three dimensions. It is the image of a one-to-one continuous map of the surface of a sphere in three-dimensional space. However, its exterior is not homeomorphic to the exterior of a round sphere. This horned sphere is illustrated in the film.

The film opens with two horns growing out from a single point. At the tips of each of these, two new horns grow, and at each of their tips, yet two more. The horns then swing around into various configurations, eventually linking up with each other and spinning around. As long as the horns do not touch each other, the surface remains topologically the same as a sphere.

The actual counter example has infinitely many horns, and the final scene of the film shows these horns growing in an infinite cycle. We zoom in to the surface while new horns are being created in a repeating pattern. One can see that each part of the surface is similar to the whole.

The exterior of the limit surface, with infinitely many horns, is not simply connected: if a loop of string is tied around one of the horns, it cannot be removed (see Fig. 15). The exterior of a round sphere is simply connected, because any loop can be pulled off. Therefore, the two exteriors are not homeomorphic.

SIERPINSKI'S CURVE DRAWN AS A FUNCTION OF TIME

In the film segment **Limit Curves V**, we described Sierpinski's space-filling curve as the limit of a sequence of approximations. In the present film the curve is drawn as it would appear as traced by a moving point. The curve is nowhere differentiable: the moving point darts around in an infinitely wiggly pattern, without ever going in a definite direction.

The square is filled up triangle by triangle, and equal areas are covered in equal times. However, to illustrate both the fine detail of the tracing and the whole square being covered, the speed of tracing has been doubled in several places so that near the end, fairly large triangles are added wth each new frame of the film.

Note that the center of the square is hit four times, and that each side of a triangle is covered twice. The curve is also self-similar so that a small, irregularly shaped region traced near the beginning of the film (Fig. 16) can later be seen two and four times as large (Figs. 17 and 18).

A ONE-TO-ONE CURVE OF POSITIVE AREA

Sierpinski's space-filling curve is not one-to-one because it passes through the center of the square four times and covers each side of a triangle twice. This film shows how to modify the curve to separate all points that the curve hits more than once. The first approximation is Sierpinski's curve filling in a unit square. Because the curve fills in eight triangles in order, they may be spearated as shown in Fig. 19. This leaves smaller triangles still touching, so the next step splits each of the triangles in two, as shown in Fig. 20. The approximating sequence opens up an infinite number of cracks so that all the triangles become separated and the limit curve is one-to-one. Every approximation curve has area 1, and it can be shown that the limit curve does also, in the sense of Lebesque Measure.

The first scene shows this sequence of approximations of constant area. The second scene shows a different set of approximations, each of which is a polygonal line covering zero area. The line starts as the outside of the square, moves to the inside cross of Fig. 19, to the outside boundary of Fig. 20, etc. The limit curve is the same, and this illustrates that every point on the limit curve is a boundary point of both its interior and its exterior.

[1] H. von Koch, "Sur un Courbe Continue sans Tangente, Obtenue par un Construction Geometrique Elementaire", **Archiv for Mat. Astr. och Fysik 1,** 681-702 (1903).

[2] A.N. Singh, "The Theory of Construction of Non-Differnetiable Functions," in **Squaring the Circle and Other Monographs,** Chelsea Publishing Co., New York, N.Y., (1969).

[3] G. Peano, "Sur un Courbe, qui Remplit Toute une Aire Plane," **Math. Ann. 36,** 157 (1890).

[4] S. Smale, "A Classification of Immersions of the Two-sphere," **Transactions of the American Mathematical Society 90,** 281-290 (1959).

[5] N. Max, "Turning a Sphere Inside Out," a guide to the 16mm color film, International Film Bureau Inc., Chicago, (1976).

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TOPOLOGY SHORT FILMS SERIES

SIERPINSKI'S CURVE FILLS SPACE
ZOOMS ON SELF-SIMILAR FIGURES

The Topology Short Films are a series of short, computer-animated films illustrating the concepts of limit and space-filling curves, sphere eversions, and other topological theories. They are excerpts from the four productions of the Topology Films Project with additional concepts that illustrate two- and three-dimensional topology. The Topology Films Project was supported by the National Science Foundation and directed by Dr. Nelson L. Max, Lawrence Livermore Laboratory, University of California.

SIERPINSKI'S CURVE FILLS SPACE

The film **Space Filling Curves** states that Sierpinski's limit curve passes through every point of a square. This film, with narration, provides proof of that fact.

It opens with approximations that move toward the limit curve and appear to cover the square. The first approximation is then divided into eight segments, each of which moves in turn to fill in a triangle. This is also illustrated with 32 segments. Thus, one verifies that small segments of the first approximation end up inside the corresponding triangles. However, one cannot verify visually that the triangle is completely covered because the line in the picture has a nonzero width, and appears to cover more than the ideal line it represents.

To show that every point on the square is covered, we pick an arbitrary point Q on the square. This point belongs to one of the halves of the square, to one of the quarters, etc.

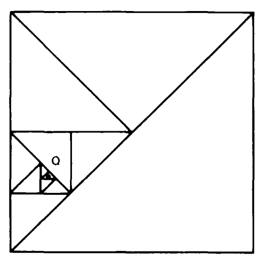
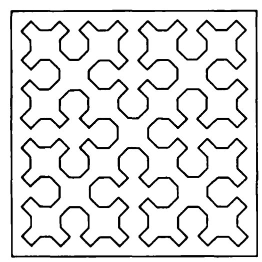
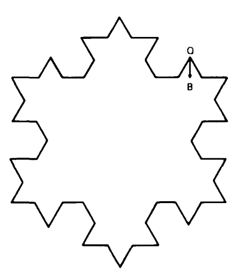


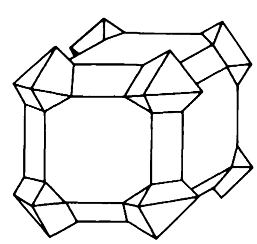
Fig. 1. An infinite sequence of triangles all containing Q.



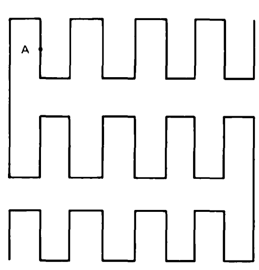
Sierpinski's Curve



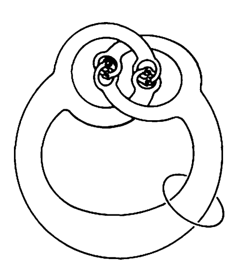
The Snowflake Curve



Volume Filling Surfaces



Peano's Curve



Alexander's Horned Sphere

Thus, there is an infinite sequence of triangles, as shown in Fig. 1, each one half of the preceding one, and all containing Q. These correspond to a sequence of segments on the first approximation, all of which contain a single point P. The film illustrates this construction for a particular point Q, and demonstrates that Q is the limit point corresponding to P using the fact that the segments move to their corresponding triangles. Therefore, the limit curve passes through an arbitrary point Q on the square.

ZOOMS ON SELF-SIMILAR FIGURES

This film contains the zoom sequences from five of the other film segments from the **Topology Short Films Series.** Included are **Limit Curves II: The Snowflake Curve; Limit Curves IV: Peano's Curve; Limit Curves V: Peano's Curve; Volume Filling Surfaces;** and the **Alexander Horned Sphere.** These five scenes all illustrate approximations to the self-similar

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limit curves and surfaces. The approximations repeat themselves at smaller and smaller scales, and the magnification rate is matched to this repetition, giving repeating cycles. Mandelbrot[1] has some good examples of these types of figures.

The Snowflake Curve
The first scene begins with this cycle of deformation and magnification for the snowflake curve. The zoom then stops and the curve moves to its limiting position. Then the magnification begins again, and one can see repeating cycles on the limit curve. The top of the curve, when magnified three times, again fits over the same curve. Thus, the limit curve is self-similar.

Peano's Curve
The second scene shows a point approching a limit on Peano's space-filling curve. The motion of the point leaves a spiral trail that becomes part of the repeating cycle (this is not true for all the limit points).

At first the curve moves five cycles without magnification and appears to cover the square because the width of the line drawn is almost equal to the space between the lines. Then the magnification begins, alternating with motion of the curve.

A piece of the limit curve, when magnified three times and rotated 90 deg, will fit over the same curve. However, because the image of the curve is the whole square, this property must be expressed in terms of the function that defines the curve.

Sierpinski's Curve
The third scene shows Sierpinski's space-filling curve. Several stages of the approximations process are shown before the zoom begins. Graph paper is used to show the magnification. After the smallest grid square fills the screen, the zoom stops, and the curve moves on to the limit that appears to cover the screen. This illusion is a result of the line width. Further magnification would again reveal spaces between the lines.

Volume Filling Surface
The fourth scene is an analogous volume-filling surface. Sierpinski's curve produces four half-sized copies of itself in each quarter of a square, while the surface produces eight half-sized copies of itself inside the cube that it fills. Thus, the original blue octahedron creates 8 copies of itself, then 64, and so on.

The Alexander Horned Sphere
The final zoom focuses on Alexander's horned sphere, which grows a pair of horns, each of which grow to more interlocking horns on their tips. The horns never touch, but in the limit they become so tangled that a loop of string around one of them could not be removed. So, the exterior of the surface is not simply connected, and is thus not topologically equivalent to the exterior of a sphere.
The magnification shows that each small pair of horns is similar to the first pair. The film ends with a plane moving back from the movie screen, obliterating all parts of the surface that lie in front of it.

[1] B. Mandelbrot, *Fractals, Form, Chance, and Dimension* (Freeman, San Francisco, California, 1977).

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BUTTERFLY CATASTROPHE—one of the Short Topology Films
4½min color silent 16mm sale $90 rental $10.00 vc $110

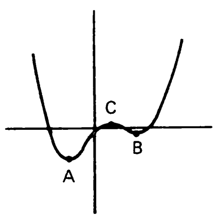

Fig. 2. Graph of $y = x^4 - 3/2\,x^2 + 1/2\,x$.

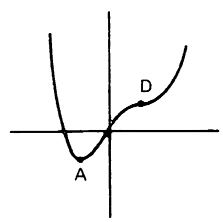

Fig. 3. Graph of $y = x^4 - 3/2\,x^2 + x$.

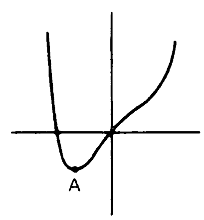

Fig 4. Graph of $y = x^4 - 3/2\,x^2 + 3/2\,x$

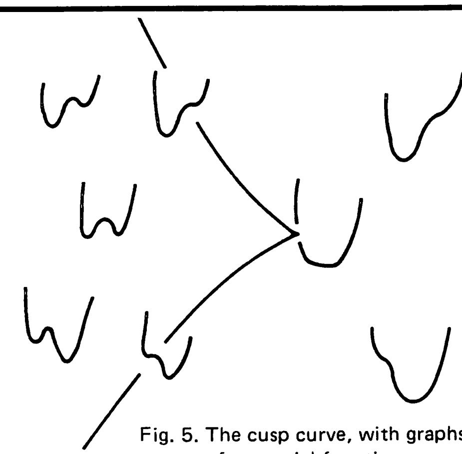

Fig. 5. The cusp curve, with graphs of potential functions

The Topology Short Films are a series of short, computer-animated films illustrating the concepts of limit and space-filling curves, sphere eversions, and other topological theories. They are excerpts from the four productions of the Topology Films Project with additional concepts that illustrate two-and three-dimensional topology. The Topology Films Project was supported by the National Science Foundation and directed by Dr. Nelson L. Max, Lawrence Livermore Laboratory, University of California.

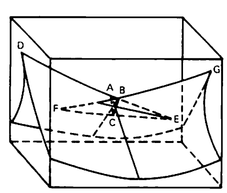

Fig. 1. The Butterfly surface in (f,g,h) space, for e = −1.

This film provides an introduction to the mathematics of catastrophe theory which has gained increasing attention in the physical and social sciences. The three-dimensional butterfly catastrophe surface is shown in four-dimensional space using time as the fourth dimension. Each frame of the film gives a time slice as a two-dimensional surface in space. In the first half, this surface is shown opaque, as if it had been folded and shaped from material blue on one side and yellow on the other. In the second half, the surface is further sliced by a series of parallel planes, and the resulting cross-section curves are shown glowing against a black background.

The surface changes shape as the time parameter, labeled "e" in the titles, varies from +1 to -1. At several points in the film, e is kept fixed at -1, and the resulting surface shown in Fig. 1, is rotated to give a better understanding of its three-dimensional structure. This surface is also sliced away by a moving cross-sectional plane to show how the cross-section curves vary. The central section, ACB in Fig. 1, is a butterfly-shaped curve that gives the catastrophe its name. Below is a short introduction to the equations and geometry of two catastrophes, the cusp and the butterfly. Many examples and applications of these catastrophes are given by E.C. Zeeman[1, 2]; the theory was first proposed by Rene Thom.[3]

Basically, catastrophe theory tries to understand discontinuities that arise in mathematical models in the physical and social sciences. In a physical system, the dynamics are often modeled by a potential function $y = V(x)$, of a position variable x. The equilibrium positions of x will be critical points where

$$\frac{dy}{dx} = 0 .$$

In Fig. 2, which shows the graph of

$$y = x^4 - \frac{3}{2}x^2 + \frac{1}{2}x ,$$

points A and B are stable equilibria at minima, where

$$\frac{dy}{dx} = 0 \text{ , and } \frac{d^2y}{dx^2} > 0 .$$

Point C is an unstable equilibrium at a maximum, where

$$\frac{dy}{dx} = 0 \text{ and } \frac{d^2y}{dx^2} < 0 .$$

If a ball were placed in the potential well near B, it would roll back and forth, and, in the presence of friction, come to rest at B.

Let us suppose that the potential of a system is varied continuously, as a function of control parameters. Often, near a special point in the parameter space, the potential can be approximated by a polynomial. For example, the potential for the catastrophe machine described in Refs 1 and 2 is adequately approximated, near a cusp point, by the function

$$y = x^4 + ax^2 + bx \qquad (1)$$

of one position variable x, and of two control parameters a and b. A special case, with a = − 3/2 and b = 1/2, is the potential of Fig. 2.

Continuing with the rolling ball analogy, let us suppose the ball is in the minimum at B, and the control parameter b is gradually increased from 1/2 to 3/2. When b reaches 1 as shown in Fig. 3, the minimum at B and the maximum at C coalesce at the point D, where

$$\frac{dy}{dx} = 0 \text{ and } \frac{d^2y}{dx^2} = 0.$$

D is an inflection point with horizontal tangent, and a neutral equilibrium. If b is increased past 1, the ball will fall into a new stable equilibrium at A. Fig. 4, for b = 3/2, has only this one equilibrium.

As we watch the x position of the ball as b increases, we see it change gradually as the minimum at B varies, and then fall suddenly to A as b passes 1. This sudden fall appears discontinuous if the ball's approach to equilibrium is fast compared to the rate of change of the parameter b. Thus, the point (a,b) = (− 3/2, 1) is called a catastrophe point, and the set of such points in parameter space (where $\frac{dy}{dx}$ and $\frac{d^2y}{dx^2}$ are both zero) is called the catastrophe set. This particular point (− 3/2, 1) is called a fold point, after the fold that occurs when the set of equilibrium points in (a,b,x) space is projected down onto (a,b) space.

Catastrophe theory seeks to understand the geometric structure of these catastrophe sets in terms of standard examples called elementary catastrophes, of which the fold is the most simple. Two others are the butterfly, shown in the film, and the cusp.

The cusp catastrophe is the catastrophe set for the potential of Eq. (1). A parameter pair (a,b) is in the set whenever there exists a position x where the graph of the corresponding potential has a critical point that is an inflection point.

The critical points are the solutions of the equation

$$\frac{dy}{dx} = 4x^3 + 2ax + b = 0 \,, \qquad (2)$$

and the inflection points are solutions of the equation

$$\frac{d^2y}{dx^2} = 12x^2 + 2a = 0 \,. \qquad (3)$$

Thus, the catastrophe set contains those pairs (a,b) for which the two equations have a simultaneous solution. To get an equation for this set, one must "eliminate" x from these two equations. If we solve (3) for x and insert the answer in (2), we get the equation

$$b^2 = -\frac{8}{27}a^3 \,. \qquad (4)$$

The solution is the cusp-shaped curve shown in Fig. 5, which also shows graphs of several potential functions drawn near their parameter pairs. Inside the curve, the graphs have two minima and one maximum, and along the curve one of the minima cancels with a maximum, leaving only one minimum for graphs outside the curve. Thus, the curve consists of fold points. At the cusp point K = (0,0), all three critical points coalesce into one, in the polynomial $y = x^4$.

The butterfly surface is the analogous catastrophe set for polynomials of degree six. We consider the potential function

$$y = x^6 + ex^4 + fx^3 + gx^2 + hx \,, \qquad (5)$$

depending on the four control parameters e,f,g, and h, and the position variable x. An arbitrary polynomial of degree 6 in x can be put in this form by translations along the x and y axes, and a change of scale (possibly including a reflection). Thus, this four-parameter family contains examples of every shape of graph for a polynomial of degree 6. We can find the catastrophe set as we did above for the cusp. The critical points for the potential of (5) are solutions to

$$\frac{dy}{dx} = 6x^5 + 4ex^3 + 3fx^2 + 2gx + h = 0. \qquad (6)$$

The inflection points are solutions to the equation

$$\frac{d^2y}{dx^2} = 30x^4 + 12ex^2 + efx + 2g = 0. (7)$$

Thus, the catastrophe set contains those points (e,f,g,h) in the four-dimensional parameter space for which Egs. (6) and (7) have simultaneous solutions in x. It is possible to eliminate x from these two equations and get a single equation in e,f,g, and h for the three-dimensional catastrophe surface. However, it is quite tedious, and the resulting equation is not very revealing.

The pictures in the film give a feeling of the shape of the surface by using e as the "time" parameter, and showing a two-dimensional surface in (f,g,h) space on each frame of the film. Such a surface for e = −1 is shown in Fig. 1.

Sections in the (g,h) plane are also sliced for fixed values of e and f. At certain points in the film, e is kept fixed at −1 and f is varied, or f is kept fixed at 0 and e is varied. This shows how the cross-section curves in the (g,h) plane change with e and f.

One of these curves, for e = −1 and f = 0, is shown in Fig. 6. (It is also the center section in Fig. 1.) It represents the catastrophe set of the two-parameter family of potentials

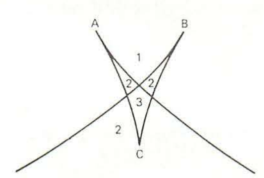

Fig. 6. Cross section the butterfly surface, at e = −1 and f = 0.

$$y = x^6 - x^4 + gx^2 + hx \,. \qquad (8)$$

A polynomial of this form may have as many as three minima and two maxima. The (g,h) regions in Fig. 6 are labeled by the number of minima of the corresponding potential. The arcs of the catastrophe set represent fold points where a maximum and minimum coalesce and cancel, and where a discontinuity in the x position could occur At the two points A and B, two minima and a maximum coalesce, while at C, two maxima and a minimum come together. Thus, these are examples of the cusp catastrophe, and the piece of the catastrophe set near them is matched by the curve in Fig. 5, appropriately moved and slightly distorted.

The surface of Fig. 1 consists of fold points and appears creased at a curve DBECFAG of cusp points. The corners E and F of this curve represent swallowtail points where two maxima and two minima coalesce, as in the polynomial $y = x^5$.

The full catastrophe set in the four-dimensional parameter space contains three-dimensional regions of fold points, two-dimensional regions of cusp points, and one-dimensional curves of swallowtail points. There is also one butterfly point at (e,f,g,h) = (0,0,0,0), corresponding to the polynomial $y = x^6$.

The main theorem of the catastrophe theory states that for almost all potentials of one position coordinate and four control parameters, the catastrophe set will contain only these four types of points. Thus, the general catastrophe set in four dimensions can be understood in terms of its butterfly points, swallowtail points, etc., in the same way that one can understand Fig. 6 as containing three examples of Fig. 5.

[1] E.C. Zeeman, "Castatrophe Theory", **Scientific American, 234**(4), (1976).

[2] E.C. Zeeman, **Catastrophe Theory** (Addison Wesley Publishing Company, Reading, Mass., 1977).

[3] Rene Thom, **Structural Stability and Morphogenesis,** (W.A. Benjamin, Inc., London, 1975).

180/2M

VOL LIBRE

one of the 1st computer animated film with integrated soundtrack

1st Fractal movie

1980 first shown accompanying paper at SIGGRAPH

Evenings & Weekends. Vax 11/780 ; 512×512 Dicomed film recorder

15 minutes comp time per frame

Entire film computed & shot before saw any motion

≤ 2 mins = 1420 frames

inc titles

frames double ~~8~~ computed 12 frames doubled to 24

Shading model

Atmospheric Haze

1st A

Algorithm: mid-point displacement method using triangular database

Limit on splitting decided by run-time; couple of pixels across.

300 triangles in data base

No antialiasing; spare time project

180 digitized points w tablet

Computer triangulated then did compute displacement

Geometry consistent from any point of view

Things were stable

If random, would have been

Split in different order depending on which way looking

More efficient for movies ; mountains in front of camera.

Guarantees reproducibility when only part of data base was amplified.
Made film to prove this.

~~Contribution only~~
Construction only when camera is looking.

Key development : the ability to have a stochastic model w random shapes & random properties & have structure generated in arbitrary order & be connected from view to view.

Used all the time now at Lucasfilm.

Stochastic modelling in scan-line order ; (primarily to reduce memory req's)

Movie frames have 10's of millions of polygons.
So unmanageable have ~~a~~ working set of polygons.
Minimize complexity at once.

Road to Pt Reyes & Hills & rock + Graphics to some architect

Needs slides back by ~~early~~ & July 1.

Natural Terrain

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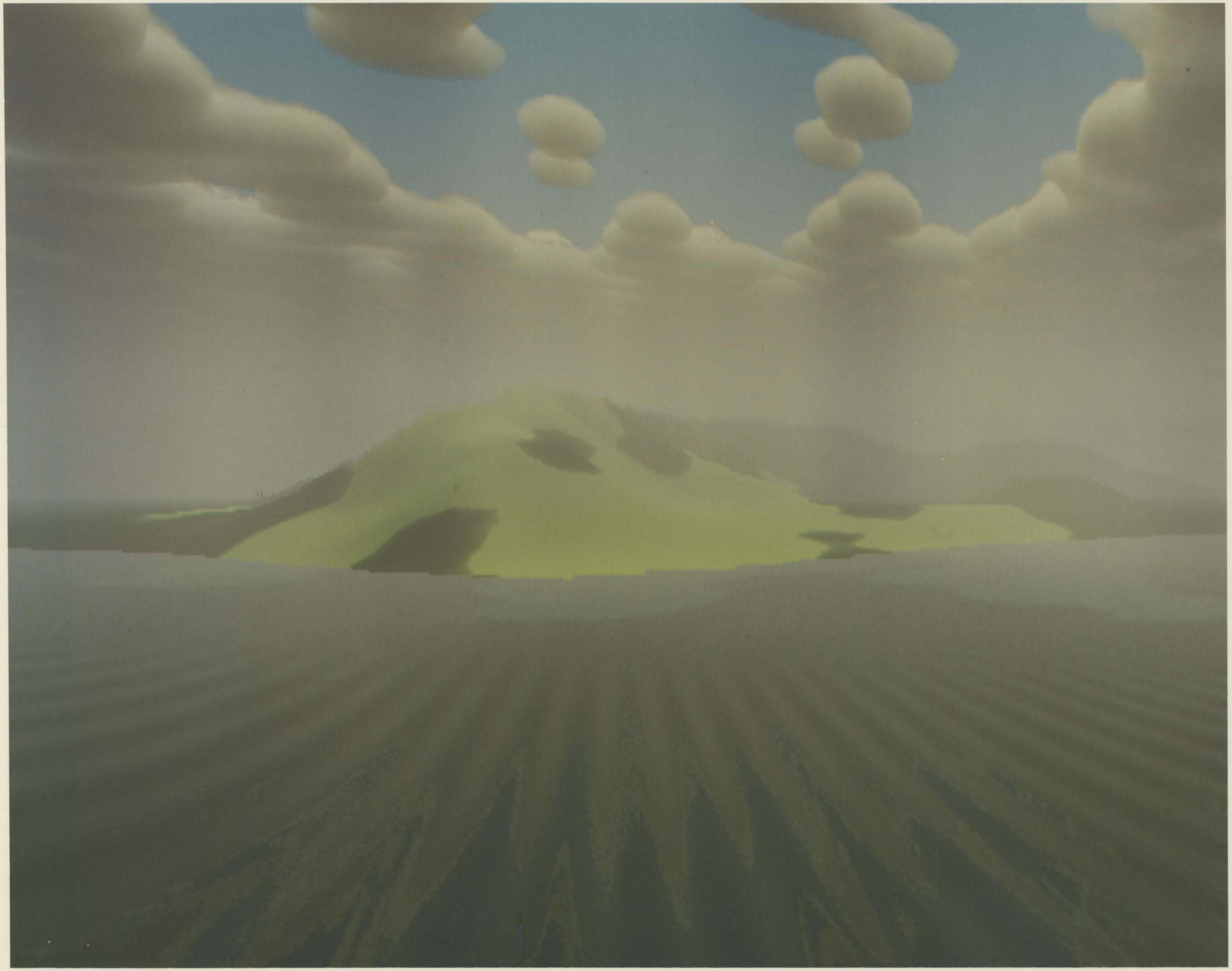

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Vectorized Procedural Models for Natural Terrain: Waves and Islands in the Sunset

Nelson L. Max
Lawrence Livermore National Laboratory

Abstract

A ray-tracing procedural model is described, in which ocean waves and islands are rendered by different but related algorithms. The algorithms are based on analytic formulas involving arithmetic operations, trigonometric functions, and square roots, and are organized for a vectorizing compiler on a Cray 1, a "supercomputer" with a vector pipeline architecture. Height field methods are used, one vertical scan line at a time, to trace the direct rays to the ocean, where they are reflected. Approximate methods are then applied to find whether the reflected rays meet any other object on their way to the sky. The output, at eight bits per pixel, gives information for shading, e.g. the angle of the surface normal for rays meeting the islands, or the angle of elevation from the horizon for rays continuing unobstructed to the sky.

The output is recorded on a magnetic tape for each frame in one cycle of the wave motion, and plotted offline on a Dicomed D-48 color film recorder. The eight bits per pixel are interpreted by a color translation table, which is gradually changed as the wave cycle is repeated to simulate the changing illumination during sunset.

Key Words

Ray tracing, vectorized, pipeline, height field, natural terrain, color table animation, piercing, line buffer, reflection, procedural model, water waves.

C.R. Catagories 8.2, 3.14

Introduction

A ray tracing algorithm for raster computer graphics follows the ray from the observer through each pixel, as it meets and possibly reflects from surfaces in a scene. Newell [1],and Rubin and Whitted [2] have proposed procedural models for ray tracing. Each object comes with its own algorithm to detect whether and where a ray meets it, and to determine the reflection and/or shading. If algorithms requiring a search in a data base are excluded, and combinations of standard analytic functions are used instead, such algorithms can run efficiently on a vector pipeline machine. The algorithms reported here were implemented on a Cray 1, but the CDC Cyber 205 and the TI ASC have similar pipeline architectures. Such machines can perform arithmetic operations much more efficiently when the same operation is applied to large vectors of operands, in which case one says that the computation is vectorized.

This paper presents vectorized procedural algorithms for natural scenes, including reflections from water surfaces rippled by superimposed traveling sine waves. Minnaert [6] has excellent explanations for the optical phenomena during sunsets, and produced by reflections in water waves. Schlachter [3] has proposed a model for random wave fields, which involves table look-up of precomputed narrow band waveforms, and is thus not easily vectorized. Information International used an illumination model to produce a leader for Pyramid films [4], showing beautiful cycloidal waves in the sunset. More complex effects, such as the reflection of objects in the water, require the tracing of reflected rays. Whitted [5]describes an algorithm which exhaustively traces all reflected and refracted rays, but which operates very slowly. In the current work, each ray is reflected a maximum of two times from the water, and then continues toward the other objects in the scene, which are diffusely reflecting. This allows the tracing to be treated in a uniform vectorized manner, resulting in much higher efficiency.

Color Table Animation

Color table animation has been used by Shoup [7] on a single picture in a frame buffer. In the movie described here, this technique is used instead with a periodic cycle of frames to expand it to a longer film.

The pictures are plotted offline from magnetic tape, by a Varian V-75 minicomputer controlling a Dicomed D-48 color film recorder. The Dicomed operates at 8 bits per pixel, and can pass the 8 input bits through a color translation table before recording onto film. For the pictures presented here, the same data was input three times, and recorded once through each of the red, green, and blue filters, with a different color translation table in each pass. The 256 available colors in this "paint by numbers" scheme were divided up into groups; one group was used for green island colors, one group for brown island colors, and one group for sky or sun colors. Within each group, the numbers coded for illumination information which, together with the current position of the sun, was used to specify the color. The ray from the eye through the center of each pixel was traced until it ended up at its final destination, either piercing an island or continuing on to the sky, perhaps after reflecting once or twice on the water. A number in one of the groups was then assigned to the pixel, as described below. Note that this procedure makes anti-aliasing between islands and sky impossible.

To make the longest sequence in the film, one cycle of periodic motion was recorded on tape, and repeatedly rendered onto film. The sun was gradually moved around a great circle C in the sky, and the color tables were changed appropriately, so that the repeated frames were differently illuminated each time through the cycle.

Color Specification for Diffuse Reflection

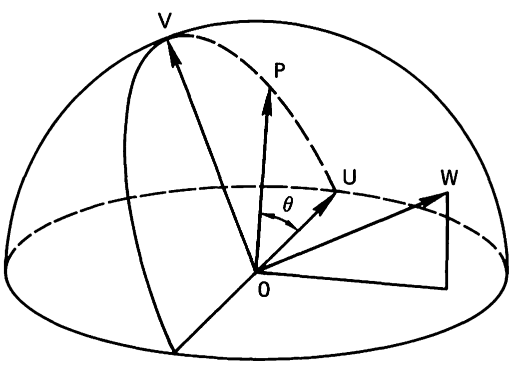


Figure 1

Figure 1 shows a unit sphere centered at the observer O, on which the circle C is projected. The vector U points to the setting sun, the vector V points toward the sun at its maximum elevation, and the vector $W = U \times V$ is normal to the plane of C. The angle θ between P and U is $2\pi/24$ times the number of hours before sunset. The sun's position as a function of θ, is

$$P(\theta) = U \cos\theta + V \sin\theta$$

Suppose a ray traced from the observer through a given pixel ends up, perhaps after reflection, at a point on diffusely reflecting object where the unit surface normal is N. If $N \cdot P < 0$, the surface faces away from the sun, and will be in shadow. If $N \cdot P > 0$ the point may or may not be illuminated, depending on the presence of other surfaces between it and the sun. The pictures here were computed assuming no other surfaces cast shadows.

Since $N \cdot P = N \cdot U \cos\theta + N \cdot V \sin\theta$

$$= N \cdot U \sqrt{1-\sin^2} + N \cdot V \sin\theta,$$

$N \cdot P$ becomes zero when $\rho(N) = \sin\theta$, where

$$\rho(N) = -\frac{N \cdot U}{\sqrt{(N \cdot U)^2 + (N \cdot V)^2}} = -\frac{N \cdot U}{\sqrt{(1 - N \cdot W)^2}}$$

For a given position P(θ) of the sun, the arc on the surface where $\rho(N) = \sin\theta$ divides the surface into a region in light and a region in shadow. A sequence of these arcs divide the surface into regions which successively darken as the sun sets. Thus, a function of the form $A + B\rho(N)$ can be used to specify the color number. When the sun is at position P(θ), those numbers which are greater than $A + B \sin\theta$ correspond to shadows, while numbers decreasing from this value become brighter, with the number $A + B \sin(\theta - \pi/2)$ the brightest. The two parameter family of normal vectors has been reduced to one parameter, which is not sufficient to simulate Lambert's law of diffuse reflection. Nevertheless, this shading scheme does indicate the shape of the surface.

In order to break up the boundaries between the "paint by numbers" regions, a random number between 0 and 1 is added to $A + B\,\rho(N)$ before the result is truncated to an integer. The seed of the random number generator is set to the same value at the beginning of each frame, so the texture generated by this process will not jitter from frame to frame.

Color Specification for the Sky

The sky is normally a darker and more saturated blue near the zenith than near the horizon. During sunset, the brilliant sky colors also occur in approximately horizontal bands. Thus the z component of a ray reaching the sky can be used in computing a code for the color.

All the ray tracing and hidden surface computations are done by the Cray 1, and the Varian V-75 controlling the film recorder has no knowledge of the scene which produced a given raster image. However, the V-75 can compute a simple function of the color code in the input data and the raster position of the pixel to determine the output color on the film. The color translation is such a function, depending only on the input data. Another such calculation adds the sun's disk to the appropriate pixels by the rule: "If the pixel is above the horizon and entirely inside the sun's disk, and the input data specifies a sky color, then render the pixel sun color." An additional rule for anti-aliasing might read: "If the pixel is above the horizon and near the boundary of the sun's disk, and the input data specifies a sky color, render the pixel an appropriately weighted average of sun color and the sky color."

In order to show the glimmer of the sun reflecting in the water, some of the 256 possible numbers are assigned to identify the highlights produced by different possible sun positions. A ray reflected in the direction of the unit vector R can meet the sun's disk only if $|W \cdot R| < \cos\delta$, where δ is the angular radius of the sun, about .75 , and W is the unit vector normal to the plane of the sun's motion, as in figure 1. If this is the case, then for afternoon positions of the sun, between U and V in figure 1, the z component R_z of R can be used to identify the time of day when these reflections produce the highlights. For other times of day, the same z component can be used to determine the sky color as before. Thus, a second range of z component codes is used to identify reflected rays along the track of the sun. As the unit vector P in the direction of the sun approaches a position with a specific z value, the corresponding table entry is changed smoothly from its sky value to the sun color, and then back again as the vector P passes and a new table entry brightens. At least one entry is sun color at any time, and adjacent entires are intermediate between sky and sun color. In addition, a third range of z component codes is used for values of $|W \cdot R|$ between cos δ and cos $(3\,\delta)$, to give further intermediate colors for rays deviating horizontally from the sun's position. These intermediate colors allow the reflections to change continuously with the time of day, and serve to increase the area in highlight and to anti-alias the edge of the bright highlight areas. An appropriately scaled random number is added to $|W \cdot R|$ and to R_z before they are thresholded to determine the color. This again breaks up the boundaries between colored regions in the sky, and in its reflection. Figure 4 shows the result when the water is perfectly still. The sun's reflection is oblong because δ was chosen larger to brighten the glimmer, and is trapezoidal because the sun is following a diagonal course as in figure 1, so that W is not horizontal.

Water Waves

Waves on the surface of water are affected by two forces: gravity and surface tension. However, when the wavelength is longer than a few inches, gravity is the dominant force. The motion of the water is described by non-linear partial differential equations. In an approximate solution to these equations, valid for waves of small amplitude, the velocity c is proportional to the square root of the wavelength λ:

$$c = \sqrt{\frac{g\lambda}{2\pi}} = \sqrt{\frac{g}{k}}$$

Here $k = 2\pi/\lambda$ is called the wave number, and g is the acceleration of gravity. The height of the free surface can be approximated to first order by the wave train

$$z(x,t) = a \cos k(x - ct) = a \cos (kx - \omega t)$$

Here a is the amplitude, and $\omega = kc$ is the angular frequency in radians per second. On a two dimensional surface, the wave train is further specified by a wave vector (ℓ, m) such that $\ell^2 + m^2 = k^2$. The equation for the surface of a long crested wave train then becomes

$$z(x,y,t) = -h + a \cos (\ell x + my - \omega t)$$

where h is the distance of the mean sea level below the eye at z = o.

In the linear first approximation, these wave trains pass through each other without modification, and a wavey surface can be represented as a sum of several wave trains:

$$f(x,y,t) = -h + \sum_{j=1}^{n} a_j \cos (\ell_j x + m_j y - \omega_j t) \quad \ldots 1)$$

If a cycle of waves is to be repeated in a film, this function must be periodic in time, and the frequencies ω_j must all be multiples of some fundamental frequency. Since $\omega = kc$ and $c = \sqrt{\frac{g}{k}}$, this means that the wave numbers must be proportional to the square of the frequencies.

If the largest wave has a period equal to the repeating cycle, and wavelength λ, the available wavelengths are thus λ, $\lambda/4$, $\lambda/9$, $\lambda/16$, ... This puts some restrictions on the superimposed wave trains, but it is still possible to produce a reasonable looking surface. More random surfaces have been studied by Schachter [3] and Longuet-Higgins [8] .

Water waves with large amplitude have wide shallow troughs, and narrow more highly curved crests, as shown in figure 2. Thus the cosine wave approximation is inadequate for large amplitudes, and a more precise solution is required. There is an exact solution to the equations of motion in which a vertical section of the free surface takes the form of a cycloid.

If the water is excited from rest by wind on its surface, or a group of waves entering from a distance, one can prove that the curl of the velocity vector field remains zero, i.e., the flow remains irrotational. The exact solution just mentioned is not irrotational, and is therefore unreasonable.

Stokes [9] gave a method for calculating periodic irrotational waves of finite amplitude by successive approximation of their fourier series. If the waves are symmetrical about their peaks at x = 0, the fourier series takes the form

$$z(x,t) = \sum_{n=1}^{\infty} a_n \cos n k (x - ct) \quad \ldots 2)$$

Let $a = ka_1$ be the maximum slope of the first term of this series. Stokes solved for the other amplitudes as expansions in powers of a, and found, to fourth order,

$$a_1 = a/k$$
$$a_2 = (a^2/2 + 17a^4/24)/k$$
$$a_3 = (3a^3/8)/k$$
$$a_4 = (a^4/3)/k$$

Figure 2 shows the contribution of these first four terms to the shape of the wave. Schwartz [10]

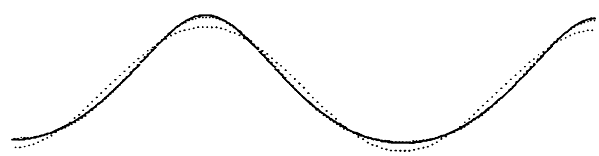


Figure 2. Stokes' approximations to water wave forms.

has recently found many more terms of this series by computer. The resulting waves are called Stokes waves, and form a one parameter family of shapes, depending on the value a. Their velocity also depends on a, but only in the quadratic and higher terms. This effect has been neglected here.

A few terms of the series 2) can easily be added into the sum 1) to give the waves of large slope a more realistic appearance. In the pictures here, only the second order term was added to the largest wave. For more speed, it would be possible to expand the first few terms of 2) as a polynomial in cos k (x - ct), so that the cosine need only be computed once.

Hidden Surfaces for Height Fields

Fishman and Schachter [11] have described an algorithm for rendering raster images of height fields, i.e., single valued functions of two variables. Assume f(x,y) is such a function, and an observer at (0,0,0) looks along the y axis at the surface z = f(x,y), projected onto a picture plane at y=1. A vertical scan line in this plane at x=s contains the projections of points lying in the plane x=sy.

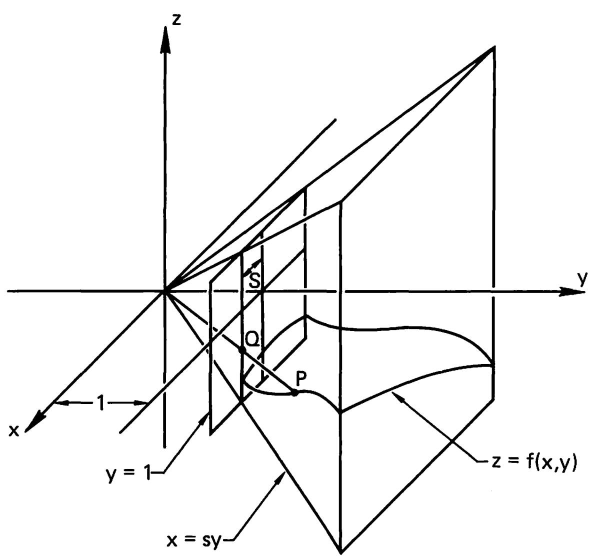


Figure 3. Perspective projection along a vertical scan line.

In figure 3 the point P = (sy, y, f (sy,y)) on the surface projects to the point Q on the picture plane at height z = g(y) = f(sy,y)/y. Although f is single valued, the function g(y) in general is not. The height field algorithm in [11] computes $g(y_i)$ for evenly spaced values of y_i, and assigns to a pixel the color of the surface at the first (sy_i, y_i) where $g(y_i)$ exceeds the z value for the center of the pixel. Such evenly spaced y_i are clearly inefficient for showing an unbounded surface in perspective, since the projected points become increasingly dense near the horizon. Instead, the expected density σ of projected values $g(y_i)$ per pixel should be constant. This will be the case if $y_i = h/(i\sigma)$, where the surface is assumed to lie near the plane z = -h.

This choice of y_i reproduces the detail of the small ripples near the eye, but does not waste time near the horizon. For the pictures here, $\sigma = 4$.

The values $g(y_i)$ are computed from equation 1) in a vectorized loop. In FORTRAN array notation, let $y(i) = y_i$ and $g(i) = g(y_i)$, and let h(k) be the z value in the picture plane of the center of pixel k. The following loop computes the array yp, where yp(k) is the approximate y value for the point projecting into pixel k.

```
    k = 1
    DO  30  i = 2,n
 40 IF (g(i).GT. h(k)) THEN
       yp(k) = y(i-1) + (y(i) - y (i-1))*
  1           (h(k) - g(i-1)) / (g(i) - g(i-1))
       k = k + 1
       GO TO 40
       ENDIF
 30 CONTINUE
```

This loop cannot be vectorized because the indices k change in an unpredictable manner, but it constitutes only a small part of the computation.

Once the values $y_k = yp(k)$ have been found, the partial derivatives $\partial f/\partial x$ and $\partial f/\partial y$ of the surface at each point $(x,y) = (sy_k, y_k)$ can be computed from equation 1):

$$\partial f\,(sy_k,\ y_k,\ t)\ /\partial x = -\sum_{j=1}^{n} \ell_j\, a_j \sin\,(b_j y_k + c_j)$$

$$\partial f\,(sy_k,\ y_k,\ t)\ /\partial y = -\sum_{j=1}^{n} m_j a_j \sin\,(b_j y_k + c_j)$$

where $b_j = \ell_j s + m_j$, and $c_j = -\omega_j t$

The range of k is much larger than the range of j, so the loop on k is made the inner one. It can be easily vectorized, taking advantage of the common subexpression $a_j \sin\,(b_j y_k + c_j)$. The surface normal $(\bar{x}, \bar{y}, \bar{z})$ is then computed by

$$\bar{z} = 1/\sqrt{(\partial f/\partial x)^2 + (\partial f/\partial y)^2 + 1}$$

$$\bar{x} = -\bar{z} \cdot (\partial f/\partial x)$$

$$\bar{y} = -\bar{z} \cdot (\partial f/\partial y)$$

If a ray is traced from the eye to the point (sy, y, f (sy, y)), its reflection can be found using the normal vector $(\bar{x}, \bar{y}, \bar{z})$ and the formulas in Blinn [12]. The shading will be computed by tracing this reflected ray to its final destination.

The Islands

The same height field hidden surface algorithm is used for the islands, which are represented as elliptical paraboloids with superimposed cosine terms to give rolling hills. However, the shading is determined from the direction of the normal vector, rather than from the reflected ray.

The elliptical paraboloid for island k is given by

$$P_k(x,y) = h_k - e_k(x-X_k)^2 - f_k(x-X_k)(y-Y_k) - g_k(y-Y_k)^2 \quad \ldots 3)$$

where (X_k, Y_k, h_k) is the highest point on the paraboloid. After the cosine terms are added, the surface becomes

$$Q_k(x,y) = P_k(x,y) + \sum_{j=1}^{n_k} a_{jk} \cos(\ell_{jk}x + m_{jk}y) \quad \ldots 4)$$

The maximum perturbation that the cosine terms can make is

$$d_k = \sum_{j=1}^{n_k} a_{jk}$$

Similarly, the maximum perturbation a water wave from equation 1) can make on the sea level -h is

$$d = \sum_{j=1}^{n} a_j$$

Therefore, any visible points (x,y) where the island protrudes above the level of the ocean lie inside the ellipse

$$P_k(x,y) + d_k + h + d = 0$$

The sample values (sy_i, y_i) need only be taken inside this ellipse.

The height field computation is performed for the ocean surface and also for all the islands, and the surface closest to the viewer is chosen to shade each pixel. This gives a brute force depth buffer hidden surface algorithm on each vertical scan line, which gains its efficiency through the vector pipeline processing.

Each island is actually formed from three paraboloids of different colors. The beach is a shallow brown paraboloid, which is rendered tan because of its nearly horizontal surface. The cliffs are rendered by a steeper brown paraboloid, and the rolling hills above them are made of a third green paraboloid. The simple depth buffer algorithm could take the union of these three paraboloids and compute the nearest point. However, when comparing the hills above the cliffs, it is actually the farther of these two surfaces which is visible, so special logic is required. This is simplified by defining the hills by the same equation as the cliffs, and taking the top of the cliffs to lie in a single plane. Whenever the equation generates a point above this plane, the height above the cliff level is decreased by a constant factor, and the point is colored green. A more realistic cliff line would result if a separate equation were used for the hills.

Tracing Reflected Rays

A ray reflected from the ocean must be traced to find out if it pierces any other objects before meeting the sky. Since these rays do not originate at the eye, an involved computation would be required to reproduce for reflected rays the accuracy provided by the height field algorithm for the direct rays. Instead, the scene is approximated by simpler quadratic surfaces, which permit direct ray piercing algorithms.

For the purposes of ray piercing, the islands are represented by equation 3), without the cosine terms. A position S at a distance t along the ray in direction (R_x, R_y, R_z) from the point (Q_x, Q_y, Q_z) is given by the vector function

$$(S_x, S_y, S_z) = (Q_x+tR_x, Q_y+tR_y, Q_z+tR_z) \quad \ldots 5)$$

To find the distances t_1 and t_2 at which this ray pierces the paraboloid, S_x and S_y are substituted into equation 3) and the resulting surface height is set equal to S_z; giving

$$P_k(Q_x+tR_x,\ Q_y+tR_y) - Q_z - tR_z = 0$$

Since $P_k(x,y)$ is quadratic in x and y, this yields an equation in t of the form

$$at^2 + bt + c = 0 \quad \ldots 6)$$

whose coefficients are expressed in terms of the constants in equations 3) and 5).

The well-known quadratic formula gives

$$t = \frac{-b \pm \sqrt{d}}{2a}$$

where the discriminant $d=b^2-4ac$. The quadratic formula is vectorized by using the absolute value of d in the square root, and the smallest root t_1 is found. If d is negative the ray actually misses the paraboloid, and if t_1 is negative, the ray meets it in the negative of the reflected direction. These cases are eliminated in a second vectorized loop, which also checks whether t_1 is less than the distance to the closest island found so far for the ray. If all the conditions are met, the name and distance to the closest island are updated.

Since the islands represent the intersections of cliff and hill paraboloids, the ray must pierce both paraboloids to hit the island. If the hill surface has the same equation as the cliff, except for an abrupt change in slope at the cliff edge, the formulas for the coefficients a, b, and c of equations 6) for the two paraboloids contain many common subexpressions, which leads to greater efficiency.

When the nearest island (if any) has been found for each ray, the surface normal at the piercing point is evaluated from equation 4) with all the cosine terms, and used to find the shading as before. This is similar to the approximation used by Blinn [13] to render wrinkled surfaces; the wrinkles show up in the interior shading, but not on the profile. The discrepancy in the reflection of the profile would never be noticed if there were ripples in the water. Figure 4 shows a reflection in completely still water. The bright highlight on the cliff results from normal vectors which face towards the sun, computed by the wrinkle algorithm at piercing points which would

Figure 4. Islands near sunset in still water.

Figure 6. Islands near sunset allowing two reflections from waves.

Figure 5. Islands near sunset with one reflection from waves.

Figure 7. The same data as in figure 6, with early afternoon lighting.

not actually be visible to the observer if the wrinkles were taken into account.

It is also possible for a ray from the observer to be multiply reflected from the water surface. Rays glancing off the downslope of a wave which faces away from the observer reflect in a direction with negative z component, or with insufficient positive component to clear the next wave. Also, since the height function algorithm is only approximate, the interpolated value of y may correspond to a point Q on the surface which is actually hidden from the observer, and the ray from the observer may even approach Q from below the water surface. In figure 5 the z component of each reflected ray has been replaced by its absolute value, and no secondary reflections have been processed. The colorful bands on the waves' downslopes are produced by rays which in reality would never reach their simulated final destination. For a more realistic (but less colorful) image, secondary reflections on the water must be taken into account.

For this purpose, the first crest of the wave of largest amplitude in front of the reflected ray is approximated by a parabolic cylinder which is tangent to the crest and has the same curvature as the Stokes wave at the crest. A parabolic cylinder is a degenerate form of an elliptical paraboloid, and a simplified version of the piercing algorithm discussed above is used to find the piercing point. The normal to the actual wave at the x, y coordinates of the piercing point is then used to find the second reflected ray. It is still possible that a third reflection could occur, but this is unlikely, and is not considered. Instead the z component of the second reflected ray is replaced by its absolute value.

About 10% to 15% of the rays undergo secondary reflection. When these cases are detected from the discriminant of the quadratic equation 6), their data is copied ("compressed" or "gathered") into consecutive positions in auxilary data vectors. This allows subsequent calculations for these cases to be efficiently vectorized. The resulting second reflected ray is then copied back ("decompressed" or "scattered") into the arrays containing the first reflected rays, so that all the rays can be continued together to meet the islands or the sky.

Figures 6 and 7 show the results of this algorithm. They are made at 1020 x 1023 pixel resolution, using the same 8 bit data, with different color translation tables. The computation time was 34 seconds on the Cray 1, and the plotting time 5 minutes on the Dicomed, including 45 seconds to backspace the tape twice between color passes.

Directions for the Future

There are several possible improvements for these pictures. First, no account has been taken of refraction. According to Fresnel's law, (see Cook and Torrence [14]) a glancing ray is almost completely reflected by a water surface, but for rays closer to the surface normal, a substantial fraction of the energy is refracted into the water. Conversely a ray approaching the surface of the water from below will have this same fraction refracted into the air. Sunlight scattered back up by small particles in the water may refract toward the observer. Thus the front surfaces of waves take on the color of the water rather than the color of the sky, and appear dark green. To handle this refraction correctly, one would need many interpolated colors between sky color and water color, and initial tests indicated that an 8 bit color table is inadequate for this purpose. A larger (software) color table could be used, or the ray tracing program could output the actual red, green, and blue values for each pixel instead of one color table index.

When sunlight reflects from rippled water and then strikes another object, one can see ripples of light on the object. It should be possible to trace a family of sun rays meeting a small patch of water, and then trace the reflected and refracted rays until they pierce a small object extending above and below the water line. The rays could be averaged into an array representing the surface of the object, to create the ripples of illumination. The illuminated object could also be seen by reflection in the water, and by refraction through it, modified and attenuated by the scattering.

Finally, it should be possible to render clouds by the height function techniques. The deviations of the clouds from a mean cloud level could be computed using formulas involving polynomials, cosines square roots, ...etc. The shading would not depend on the normal vector, but rather on the depth below mean cloud level. The height field algorithm could be modified to handle double valued functions whose domain is only a subset of the plane. As before, an approximation would replace the height field algorithm for reflected rays. These would be traced till they pierced the mean cloud level. If the piercing point lay in the domain of the cloud function, the shade would be assigned according to the color of the cloud below the x, y coordinates of the piercing point. Clouds between the sun and the water would intercept the rays generating the highlights, and cause shadows in the sun's glimmer on the water. The clouds could also glow in the sunset.

Acknowledgments

This work was inspired by the films of Turner Whitted and Loren Carpenter. I would like to thank Turner Whitted for encouraging conversations, John Engle, Al Shannon, and Frank McMahon for helping me vectorize the FORTRAN code for the Cray 1, John Guckenheimer for pointing out references [9], the reviewers for pointing out references [3] and[11], Don Faul and Steven Williams for carefully reading the manuscript, Dick Rau and Rick Simms for making last minute color corrected prints, and many friends and colleagues for suggesting ways to make the pictures more realistic. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

Disclaimer

References

[1] Newell, M. The Utilization of Procedure Models in Digital Image Synthesis. PhD Thesis, University of Utah (1975)

[2] Rubin, S., and Whitted, T., A 3-Dimensional Representation for Fast Rendering of Complex Scenes. Computer Graphics Vol. 14, No. 3 (1980) pp. 110-116

[3] Schachter, B., Long Crested Wave Models. Computer Graphics and Image Processing Vol. 12 (1980) pp. 187-201

[4] Pyramid Catalogue, (1981) Pyramid, Box 1048 Santa Monica, or poster available from Jannes Art Publishing, Chicago

[5] Whitted, T., An Improved Illumination Model for Shaded Display. Comm. ACM Vol. 23, No. 6, (1980) pp. 343-349

[6] Minnaert, M., Light and Color in the Open Air. Dover Publications, Inc. (1954) New York

[7] Shoup, R., Color Table Animation. Computer Graphics Vol. 13, No. 2 (1979) pp. 286-292

[8] Longuet-Higgins, M., The Statistical Analysis of a Random, Moving Surface. Proc. Roy. Soc. of London Vol. 249 (1957) pp. 321-387

[9] Stokes, G.G., Mathematical and Physical Papers. Vol. 1 (1880) p. 341, Cambridge University Press

[10] Schwartz, L., Computer Extension and Analytic Continuation of Stokes' Expansion of Gravity Waves. J. Fluid Mech. Vol. 62, part 3 (1974) pp. 553-578

[11] Fishman, B., and Schachter, B., Computer Display of Height Fields. Computers and Graphics Vol. 5 (1980) pp. 53-60

[12] Blinn, J., Models of Light Reflection for Computer Synthesized Pictures. Computer Graphics Vol. 11, No. 2 (1977) pp. 192-198

[13] Blinn, J., Simulation of Wrinkled Surfaces. Computer Graphics Vol. 12, No. 3 (1978) pp. 286-292

[14] Cook, R., and Torrance, K., Reflectance Models for Computer Graphics. Vol. 15, No. 13 (1981)

AUTHOR INDEX

Carla's Island

Max

Film res: 512 x 384 : 7 secs per frame on Cray

: :

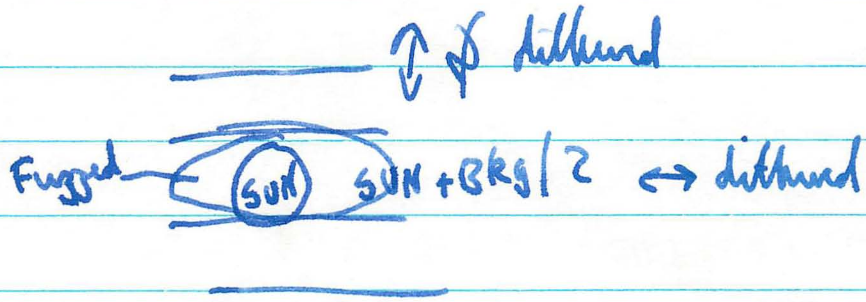
256 colors in color table

Negligable

144 frame cycle put on mag tape
Done offline from using Vaxen.

Moves sun,

Bands of color



14 colors from orange - blue in sky

Would look stripy if no dither

1. Still scene 3 cycles } identical repeats
2. Storm Waves build up 3 cycles "
3.

Last 2 min w slow sunset + moon
20 cycles + 6 sec per cycle 144 frames

Refraction

Mix ; % light reflected / refracted
Mix according to Fresnel proportion

Sloan has refraction
3 passes, one for R, G, B. Still only 256.

In CLUT same data for RGB.

Specify each R, G, B component separately.
Sloan seems a new alg for clouds.

Fusion film : 'Inertial Confinement Fusion'
Longer film : Nelson did a [illegible] part in it.

Richard Service (multimedia group) 422-[illegible]02 37
at CCC

Mark Summers (project engineer) 422-0681

PRINT #E1

ISLANDS IN MOONLIGHT

Nelson L. Max

1981

These three views were made from the same set of 8 bit color numbers in a 1020 x 1024 raster, by changing the color table which assigns the red, blue, and green intensities to each of the 256 different colors. The scene was computed in 35 seconds by a vectorized ray tracing and reflection algorithm on the CRAY-1. It was copied to tape and rendered in 5 minutes on the Dicomed D48 color film recorder, including 45 seconds to backspace the tape twice between the separate color passes.

The scene is completely described by superimposed sine waves for the ocean, and polynomials with superimposed sine waves for the clouds and islands. Thus the input data consists of a small number of coefficients; there is no coordinate data base as in a polygonal model.

PRINT #E2

ISLANDS IN EARLY AFTERNOON

Nelson L. Max

1981

These three views were made from the same set of 8 bit color numbers in a 1020 x 1024 raster, by changing the color table which assigns the red, blue, and green intensities to each of the 256 different colors. The scene was computed in 35 seconds by a vectorized ray tracing and reflection algorithm on the CRAY-1. It was copied to tape and rendered in 5 minutes on the Dicomed D48 color film recorder, including 45 seconds to backspace the tape twice between the separate color passes.

The scene is completely described by superimposed sine waves for the ocean, and polynomials with superimposed sine waves for the clouds and islands. Thus the input data consists of a small number of coefficients; there is no coordinate data base as in a polygonal model.

PRINT #E3

ISLANDS AT SUNSET

Nelson L. Max

1981

These three views were made from the same set of 8 bit color numbers in a 1020 x 1024 raster, by changing the color table which assigns the red, blue, and green intensities to each of the 256 different colors. The scene was computed in 35 seconds by a vectorized ray tracing and reflection algorithm on the CRAY-1. It was copied to tape and rendered in 5 minutes on the Dicomed D48 color film recorder, including 45 seconds to backspace the tape twice between the separate color passes.

The scene is completely described by superimposed sine waves for the ocean, and polynomials with superimposed sine waves for the clouds and islands. Thus the input data consists of a small number of coefficients; there is no coordinate data base as in a polygonal model.

Print #E5

CLOUD SIMULATION

Nelson Max

1984

Clouds were modeled mathematically and combined with other scene elements to produce a synthesized, completely computer-generated, picture.

Print #E6

SCENE SIMULATION

Nelson Max

1984

Clouds were modeled mathematically and combined with other scene elements to produce a synthesized completely computer-generated, picture. Interesting elements in this picture are the shadows cast by the clouds and the wavelets forming on the water.


6 months
Computer Animation
1500 sq.

Conference Information

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RECEIVED
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15 July 1985

Mr. Oliver Strimpel
THE COMPUTER MUSEUM
300 Congress Street
Boston, MA 02210

Dear Oliver:

I seem to be going through my notes a lot lately and I just ran into the enclosed letter I received from Bill Ninke of Bell Labs in 1971. It contains a list of computer graphics based films that were shown at the 1969 Spring Joint Computer Conference. I don't know that they're all animation, but certainly they all played an important part in the history of computer graphics.

I believe Ninke is still with Bell Labs and, in fact, is probably still at Holmdel should you want to get in touch with him.

Warmest regards,

MACHOVER ASSOCIATES CORP.

C. Machover
President

CM:pb
"C"

Bell Laboratories

Holmdel, New Jersey 07733
Phone (201) 949-3000

July 26, 1971

Mr. Carl Machover
Information Displays Inc.
333 North Bedford Road
Mount Kisco, New York 10549

Dear Carl:

Enclosed is a list of movies I presented at the 1969 Spring Joint Computer Conference. Also enclosed are several lists I obtained in conjunction with assembling the movie program. I hope these are of some value to you.

Sincerely,

Bill

W. H. Ninke
Head, Digital Systems
Research Department

HO-1385-WHN-ess

Sources of Movies

1. "The Window", Control Data Corporation, 16 mm sound, color, 14 1/2 min.

    Mr. David R. Carson
    Digigraphics Division
    Control Data Corporation
    10 Third Avenue
    Northwest Industrial Park
    Burlington, Massachusetts 01804

2. "Computer Graphics Progress Report", Lockheed-California Co., 16 mm sound, color, 10 min.

    Mr. D. L. Bickel
    Dept. 80-32, 67, Plt. A-I
    Lockheed California Co.
    P. O. Box 551
    Burbank, California 91513

3. "Computer Graphics in Exploration and Production", Mobil Research and Development Corporation, 16 mm, sound, color, 12 1/2 min.

    Mr. Franz Selig
    Mobil Research and Development Corp.
    Field Research Laboratory
    P. O. Box 900
    Dallas, Texas 75221

4. "One Picture Is Worth A Thousand Printouts", Pratt and Whitney Aircraft, 16 mm, sound, color, 13 1/4 min.

    Mr. W. J. McCarthy
    Pratt and Whitney Aircraft
    Florida Research and Development Center
    Box 2691
    West Palm Beach, Florida 33402

5. "SARF - Signature Analysis Research Facility", A-C Electronics Research Laboratories, 16 mm, sound, color, 13 min.

    Mr. Gordon Stanley
    AC Electronics Defense Research Laboratories
    General Motors Corporation
    6767 Hollister Avenue
    Goleta, California 93017

6. "General Circulation Movie", National Center for Atmospheric Research, 16 mm, color, magnetic sound track, 3 min.

    Mr. David Robertson
    Computing Facility
    National Center for Atmospheric Research
    Boulder, Colorado 80302

7. "Carrier Approach Visibility Study", The Boeing Company, 16 mm, sound, color, 7 min.

    Cameron Film Productions
    222 Minor Avenue North
    Seattle, Washington 98109

8. "Computer Image Gen. II," General Electric Company, 16 mm, color, silent, 3 min.

    Mr. R. A. Schumacker
    Bldg. 3, Room 264
    General Electric Company
    Electronics Park
    Syracuse, New York 13201

9. "Numerical Control Parts Programming", Lockheed-Georgia Company, 16 mm, sound, color, 12 3/4 min.

    Motion Picture Film Library
    Zone 30, B-2 Building
    Lockheed-Georgia Company
    Marietta, Georgia 30061

10. "Computer Designed Windshield Wiper Systems", Chevrolet Motor Division, General Motors Corp., 16 mm, sound, color, 17 min.

    Mr. E. E. King
    Chevrolet Motor Division
    General Motors Corp.
    30003 Van Dyke
    Warren, Michigan 48090

11. "Terminal Operating Services for Graphic Job Processing", IBM Corporation, 16 mm, color, sound, 9 1/4 min.

    Mr. Neil F. Michelsen
    IBM Corporation
    112 East Post Road
    White Plains, New York 10601

12. "The Reaction Handler", Department of Computer Science, University of Utah, 16 mm, b & w, sound, 9 min.

    Dr. William Newman
    Department of Computer Science
    University of Utah
    Salt Lake City, Utah 84112

13. "On-Line Parsing of Mathematical Expressions", System Development Corporation, 16 mm, color, sound, 8 min.

    Mr. M. I. Bernstein   no longer available
    System Development Corporation
    2500 Colorado Avenue
    Santa Monica, California 90406

14. "Computerized Architectural Drafting System", William W. Bond, Jr. and Associates, Architects and Engineers, 16 mm, sound, color, 10 min.

    Mr. Edward B. Ebbing, Jr.
    William W. Bond, Jr. and Associates
    3742 Lamar Avenue
    Memphis, Tennessee 38118

15. "Fallout Shelter Analysis by Computer Graphics", Department of Architecture, University of Utah, 16 mm, sound, color, 8 3/4 min.

    Prof. Stanley W. Crawley
    Dept. of Architecture
    University of Utah
    Salt Lake City, Utah 84112

16. "Transition to Tomorrow", IBM Corp., 16 mm, sound, color, 14 min.

    Mr. Neil F. Michelsen
    IBM Corporation
    112 East Post Road
    White Plains, New York 10601

COMPUTER GRAPHICS THEATER

PRESENTED AS PART OF THE

1969 SPRING JOINT COMPUTER CONFERENCE

Technical Session 30
Friday, May 16, 1969
(Main Auditorium)

The Computer Graphics Film Theatre consists of sixteen films representing a wide variety of computer graphics applications. The films are grouped into six categories with announced category starting times. This has been done to provide continuity to the theatre and also to allow those with specialized interests an opportunity to view only the films in the corresponding interest areas, if they so desire. The categories, included films, and approximate category starting times are listed below.

Schedule of Films

Applications Surveys (1:15 p.m.)

"The Window", Control Data Corporation

"Computer Graphics Progress Report", Lockheed-California Co.

Data Analysis, Curve Fitting, Modeling (1:45 p.m.)

"Computer Graphics in Exploration and Production", Mobile Research and Development Corporation

"One Picture Is Worth A Thousand Printouts", Pratt & Whitney Aircraft

"SARF — Signature Analysis Research Facility", A-C Electronics Research Laboratories, General Motors Corporation

Simulation (2:15 p.m.)

"Untitled" — (Global Weather Circulation Simulation), National Center for Atmospheric Research

"Carrier Approach Visibility Study", The Boeing Company

"Untitled" — (Real-time Color Electronic Scene Generation), General Electric Company

Mechanical Design (2:30 p.m.)

"Numerical Control Parts Programming", Lockheed-Georgia Company

"Computer Designed Windshield Wiper Systems", Chevrolet Motor Division, General Motors Corporation

Programming (3:00 p.m.)

"Terminal Operating Services For Graphic Job Processing", IBM Corporation

"The Reaction Handler", Department of Computer Science, University of Utah

"On-Line Parsing of Mathematical Expressions", System Development Corporation

Architectural and Other Design (3:30 p.m.)

"Computerized Architectural Drafting System", William W. Bond, Jr. and Associates, Architects and Engineers

"Fallout Shelter Analysis by Computer Graphics", Department of Architecture, University of Utah

"Transition to Tomorrow", IBM Corporation

SHARE XXXII GRAPHICS FILM FESTIVAL

Chairman: Marvin J. Kaitz (VCC)
Visual Computing Corporation
10810 Washington Boulevard
Culver City, California 90230

Date: Wednesday, 5 March 1969, 5:15 p.m.

The SHARE Graphics Film Festival provides exposure to various techniques involved in computer graphics, e. g. graphical input, output, and processing of information. The films shown are intended to be interesting, informative, stimulating, and occasionally suggestive. Most of the films presented can be obtained directly from the film originator. The title and source of each film is listed in the order of presentation.

1. "Heart Motion by Computer Graphics"
   Alan H. Gott
   Aerospace Corporation, B-2
   P. O. Box 1308
   San Bernadino, California 92402

2. "CAMP - Computer Aided Motion Pictures"
   Dr. Donald D. Weiner
   Syracuse University
   Dept. of Electrical Engineering
   Syracuse, New York 13210

3. "One Picture Is Worth A Thousand Printouts"
   Walt J. McCarthy
   Pratt & Whitney Aircraft, FRDC
   P. O. Box 2691
   West Palm Beach, Florida 33402

12 min
305/844-7311

4. "Miscellaneous Film Clips"
   Frances Honey
   Computer Image Corporation
   2162 South Jason Street
   Denver, Colorado 80223

5. "SARF - Signature Analysis Research Facility"
   Gordon Stanley
   A-C Electronics Research Laboratories
   Santa Barbara, California 93100

805/968-1011
George Lendaris

6. "On-Line Parsing of Mathematical Expressions"
   M. I. Bernstein
   System Development Corporation
   2500 Colorado Avenue
   Santa Monica, California 90406

7. "Incredible Machine"
   Bell Telephone Research Laboratories
   c/o Pacific Telephone Film Library
   1145 North McCadden Place
   Los Angeles, California 90038

(Inquiries may be referred to local film service libraries in other areas of the United States)

MUSICAL SELECTIONS

1) Peter Zinovieff and Alan Sutcliffe, Wokingham, England
ZAST. — Composed on an ICL 1905 computer and executed on a PDP-8/S computer.
2nd Place, IFIP Contest, Edinburgh, Scotland, 1968

2) A. Roberts
SONATINA FOR CDC-3600 — Composed and played on a CDC 3600
1. Scherzando
2. Adagio in eigth tones
3. Rondo in free pitch

3) Hubert Kupper, Duesseldorf, Germany
EXPERIMENT IN COUNTERPOINT
OPUS 21 — Composed on an IBM 360 Model 65. Played on piano and organ.

4) Pietro Grossi and collegues, S2FM (Studio di Fonologia Musicale di Firenze), Firenze, Italy

From the classical composition of Johann Sebastian Bach: THE MUSICAL OFFERING
Super thema regium
Quaerendo invenielis
Super thema regium
— Executed on a GE-115 computer.

From the classical composition of Nicolo Paganini: CAPRICCIO n. 5 — Executed on a GE-115 computer.

Three original works: — Composed and executed on a GE-115 computer.
1. MIXED PAGANINI
2. PERMUTATIONS OF FIVE SOUNDS
3. CONTINUOUS

5) R. P. Nederpelt, The Hague, Netherlands
PARTITA FOR ORGAN — Composed on a computer, executed on an organ.

FILMS-GROUP ONE

"COMPUTER GENERATED BALLET" BY A.M. NOLL, BELL LABS. – stick figures · OK 4 year olds –
"TWINKLE" BY OLIVER G. SELFRIDGE, LINCOLN LABS. –
"HUMMING BIRD" BY PROF. C.S. CSURI, OHIO STATE UNIVERSITY – stunned - dimension
"ASPEN TALK" BY JOHN WHITNEY, SR. – excellent –

FILMS-GROUP TWO

"A COMPUTER TECHNIQUE FOR PRODUCTION OF ANIMATED MOVIES" BY KENNETH C. KNOWLTON, BELL LABS. – bug
"BINARY BITS" - INFORMATION INTERNATIONAL
"PERMUTATIONS" BY JOHN WHITNEY, SR. – good
"STUDIES WITH RANDOM TEXTURES" BY B. JULESZ AND C. BOSCHE, BELL LABS.
"COMPUTER ART" CALIFORNIA COMPUTER PRODUCTS, INC.

– [illegible] Res. Center – [illegible] Schwartz –

Mr. William Ninke

Attachment to
6-2520-20-03

Boeing Films on Computer Graphics

Commercial Airplane Division, Renton, J. J. Gilmour, (206) 237-9634.

THE LEADING EDGE, describes many division computing activities including graphics. An excellent film by Charles Eames.

Commercial Airplane Division, Seattle, William Fetter, (206) 655-2291.

A4B-F4B CARRIER LANDING, simulates cockpit visibility by Computér Graphics.

ENGINE REMOVAL SIMULATION, describes a ground systems application.

THE SECOND MAN, shows articulation of a human figure model.

Aerospace Division, Seattle, ~~Richard Yanak~~ George Johnson, (206) 773-~~3592~~ 4946.

THE SCOPE SYSTEM, describes an interactive management system.

Aerospace Division, Huntsville, Vince Commissio, (205) 842-4942.

You may contact directly. ND

TRW SYSTEMS - "ON-LINE COMPUTER" 16MM - Color - Sound - 17 Minutes

The film shows a 4-console system of time-sharing on a BR-340 computer. The system consists of two keyboards and a graphic display of the oscilloscope. It essentially commits an engineer or a scientist to program his own program by a series of key probes on a keyboard, and while he is doing this, he is in direct communication with a computer. The oscilloscope provides back displays to help him dialog. The film shows about five applications of engineering structural design.

IBM - "FRONTIERS IN COMPUTER GRAPHICS" 16MM - Color - Sound - 21 Minutes

This film demonstrates large graphic IBM consoles in use in a variety of applications. These consoles are equipped with light pens, function keyboards and standard keyboards. The system demonstrated is multi-programmed, e.g., it supports two graphic consoles while a batch stream is operating in the background. Several companies prepared the nine applications shown.

ARTHUR D. LITTLE, INC. - "HISTORY OF COMPUTER GRAPHICS"
16MM - Silent - Color - 40 Minutes

Several demonstrations tracing the hardware and software aspects of CAD from alphanumeric input/output consoles through light-pen function-button large CRT displays. The work centers largely on that done at the Cambridge Research Laboratory of MIT.

CONTROL DATA CORPORATION - "THE WINDOW" 16MM - Color - Sound - 12 Minutes

A well done marketing movie featuring Control Data's 270 graphic console. Aside from the interesting sequence concerning the background of large graphic terminals, the movie contains excerpts from several application areas developed principally at the Lockheed Georgia Company. Amongst them is numerical control part programming and airfoil design.

LOCKHEED CALIFORNIA COMPANY - "LOCKHEED ALPINE"
16MM - Silent - Color - 5 Minutes

Done by Lockheed California Company on IBM's Alpine System. The first minute is devoted to quick shots of several applications including aircraft control simulation, two dimensional structural properties, and wire-frame rotation. The remainder of the film, about four minutes, depicts an aircraft structural designer producing an engineering layout involving the design of an access door in a bulkhead of the fuselage of a helicopter. The demonstration involves retrieving loft information and standard part information as well as producing hard copy on a microfilm recorder.

ADAGE INCORPORATED - "ADAGE GRAPHICS TERMINAL IN ACTION"
16MM - 1 Minute

This film will bring you face-to-face with a significant step forward in the technology of computer graphics. The film titles and the moving 3-D images of the Lunar Excursion Module "in flight" were created by the Adage Graphics Terminal and filmed in real-time. The action you see was filmed continuously--no special techniques like single frame filming or stop-action shots were used.

NOTE: Tho' no sound track, the film should be seen at regular sound speed (24 frames per second).

FORD SURFACE DEFINITION
16MM - 4 Minutes - Black & White - Silent

IBM 2250 APPLICATION - DEMOS 1966 SJCC
16MM - 20 Minutes - Color - Silent

LOCKHEED CALIFORNIA COMPANY - "COMPUTER GRAPHICS ON ALPINE"
16MM - 30 Minutes - Color - Silent

Demonstrates several applications.

MIT - "SKETCH PAD"
16MM - 25 Minutes - Black & White - Silent

TOMORROW'S WORLD - COMPUTER DRAWING

16MM - 5 Minutes - Black & White - Sound

This film is a copy of a videotape made by the British Broadcasting Company and shown to the British public on the BBC's program "Tomorrow's World" in August, 1968. Although no mention of TRW is included, it features Alan H. Halpin and Norman J. Schweitzer of the CAD Staff working at the 2250 console in Building 80. They demonstrate the use of the MACDRAFT program to design a house, complete with swimming pool and palm tree, and never a disclaimer explaining that this is not the normal TRW usage.

This film is a good introductory film and is aimed at the general public, but should never be shown to professionals in computer-aided design. Some of the spoken comments are diverting.

COMPUTER GENERATED MOVIES - A ROBOT SIMULATION -- Belongs to: Leonard Friedman
STN/8072
X65977, CCC: 3115
"Medical Information Systems Dept."

A software system, intended for controlling a robot, presented a challenge in debugging and checkout. The solution is to have the computer paint each frame of action on a CRT according to the program's "decisions". This is done in real time, resulting in an animated cartoon effect. The system also uses a grafacon (RAND TABLET) to permit setting up "problems" for the robot.

A 15 minute movie demonstrating powerful debugging tool (and the robot's behavior) will be shown.

SESSIO. REPORT GUIDE 27 SHARE XXXI | 10/3. DATE | 3:30 TIME | Garden ROOM | Page 1 of 2

Graphics DIVISION | Software PROJECT | Special Effects COMMITTEE

Graphics Film Festival
SESSION TITLE

Marvin J. Kaitz CHAIRMAN | VIS INST. CODE | Visual Computing Corporation AFFILIATION

10810 Washington Blvd., Culver City, Calif. 90230 (213) 836-0111
ADDRESS AND PHONE

~~Purpose of~~ The Film Festival ~~was~~ will to provide exposure to various techniques involved in computer graphics, e.g. graphical input, output, and processing of information. The films shown ~~were~~ intended to be interesting, informative, stimulating, and occasionally suggestive. Room capacity was exceeded with over 200 attendees.

Most of the films presented can be obtained directly from the film originator. The title and source of each film is listed in the order in which they were shown:

N 1. "Daisy Loop" ∞
Leigh Hendricks
Sandia Corporation, Division 9424
P.O. Box 5800
Albuquerque, New Mexico 87115

*SC 2. "Reactive Displays" 7
Mr. James Craig
Public Relations Staff
General Motors Corporation
3044 West Grand Blvd.
Detroit, Mich. 48202

This film was provided by Neil Michelson of IBM.

C 3. "Scattering of Quantum Mechanical Wave Packets from Potential Well and Barrier" 4
Mr. Wayne Hudson L-71
Lawrence Radiation Laboratory
Livermore, Calif. 94550

*SC 4. "Terminal Operating Services for Graphic Job Processing" 12
IBM Corporation (see your local IBM rep)*

SC 5. "Standard Station Commercial" 1
Mr. Lee Harrison III
Computer Image Corporation
2162 South Jason Street
Denver, Colorado 80223

(over)

* SC 6. "Numerical Control Parts Programming" 13
Motion Picture Film Library
Lockheed-Georgia Company
Zone 30, B-2 Bldg.
Marietta, Georgia 30060

* C 7. "General Purpose Systems Simulator" 15
Patrick Haverty
The RAND Corporation
1700 Main Street
Santa Monica, Calif. 90406

SC 8. "Engine Removal" 10
Mr. William A. Fetter
The Boeing Company
P.O. Box 707, M.S. 7C-01
Renton, Washington 98055

SC 9. "Concepts in Introductory Quantum Mechanics" 12
Edwin Goldin
c/o Dr. Ludwig Braun
Polytechnic Institute of Brooklyn
333 Jay Street
Brooklyn, New York 11200

C 10. "Computer Art" 12
same source as No. 3

SC 11. "Lee's Carpets Commercial" 1
same source as No. 5

* SC 12. "Frontiers in Computer Graphics" 19
IBM Corporation (see your local IBM rep)*

* IBM Films are also available at no cost from:

Modern Talking Picture Service, Inc.
1145 No. McCadden Place
Los Angeles, Calif. 90038

They may refer inquiries to their local film service offices in other areas of the United States.

ONLINE COMPUTER GRAPHICS CONFERENCE CG82

COMPUTER AIDED ANIMATION
A Short Review

John Lansdown
System Simulation Ltd
50-51 Russell Square
London WC1B 4JX

Two types of animation are defined: character or cartoon animation and modelled animation. The first of these is said to be 'surface structured' and the second; 'deep structured'.
The role the computer can play in both these forms is discussed and it is argued that the motivation behind the use of the machine is different in the two cases.
Some of the problems involved in using the computer are outlined from the author's experience in creating computer-animated films over a number of years. The problems arise both from the limitations of computing and from the difficulties in communication and understanding between designers and computer personnel.

INTRODUCTION

For our purposes, we can assume that there are two basic types of animation:

- character animation, and
- modelled animation

By 'character animation', we mean the conventional cartoon animation of the Walt Disney, Hanna-Barbera variety in which drawn characters representing people, animals and so on, in varying degrees of realism, move about in painted scenes.

By 'modelled animation', we mean the drawing and manipulation of more general representations which move about in 3-D space.

Animation artists are excellent at character animation. They can embue their characters with life-like features and considerable charm. They employ, to great effect, a whole battery of well-established techniques to make the movements correct and (within the conventions) to give the illusion of realism. They do not, in general, have the same facility at modelled animation and this has led to the creation of a new set of computer-based techniques to assist in the task. This is not to imply that character animation cannot be assisted by computers - far from it as, we shall see below - but, in that case, the motivation is different. In character animation, computer techniques are used primarily to reduce costs and minimise tedium. In modelled animation, they are used because, very often, they are the only feasible way of performing the tasks involved.

CONVENTIONAL ROSTRUM ANIMATION

In creating an animated film by conventional means, there are a number of processes to be gone through:

1. The initial design:
   This is often worked up in a pictorial form using a 'storyboard' - a set of drawings resembling a comic strip which indicates the key scenes of the film.

2. The key frames:
   The significant peaks of movement of the characters are drawn corresponding to the timing required.

3. Inbetweening:
   The frames between the peaks of movement are drawn in order to produce a sense of animation. For the

smoothest movement 24 or 25 frames must be drawn for every second of animation.

4. Line testing:
   The drawings, now photocopied onto transparent acetate (cel), are filmed under a rostrum camera in order to test the quality of the movements produced.

5. Painting:
   After any modifications arising from the line tests, the cels are painted not only to introduce colour but also to give the animated characters a sense of solidity as they pass in front of the background drawings.

6. Filming:
   The final filming under the rostrum camera is carried out and the soundtracks added.

Apart from assisting in the control of the rostrum camera movements (a feature more and more in evidence), the conventional animation process can also be helped by computer graphics techniques in a number of areas, notably:

- producing the key frames and inbetweens
- painting

PRODUCING THE KEY FRAMES AND INBETWEENS

The process of making all the drawings of the characters and the backgrounds necessary for even a small cartoon film has always been a very labour-intensive business involving hundreds, perhaps thousands, of man-hours. Often, of course, drawings are made in parts so as to allow sections to be used in different scenes without apparent repetition. Thus, for example, Yogi Bear's head would be drawn separately from his body to enable the same drawing to be used in a variety of appropriate places with the body in different attitudes, as well as to allow different head positions (when, talking for instance) to be used with the same body. The various cels comprising a particular frame - say one each for head, body, arms, legs and background - would be assembled under the rostrum camera from instructions listed in a 'dope' sheet.

The cost of producing the large numbers of drawings needed has led in recent years to a process of considerable simplification not only in drawing style but also in animation - often each drawing is shot twice, or even three times, in order to stretch the movements and reduce the number of inbetweens to be created. In addition, only limited parts (arms, legs or mouth perhaps) are animated at all. Such shortcuts are acceptable for some applications but give rise to a somewhat jerky and wooden appearance.

Two computer-based techniques have been devised in order to allow a return to smooth movement. They are:

1. Interpolated inbetweening

2. Skeletal framing.

Interpolated Inbetweening
Given two key frames which have been manually or automatically digitised, it is possible to get the computer to create the necessary inbetweens. It usually does this by mathematically interpolating either the endpoints of the lines comprising the frames (in the case of line drawings) or the pixel positions (in the case of raster drawings). When this happens, we start at the first keyframe showing all its information and gradually substitute more and more of the second until none of the first is left. However, as the computer holds no 'model' of the object being drawn, the inbetweening can only be done in 2-D by this technique and, if the key frames are very different or unless great care is taken in matching elements, the scene will break up from frame to frame. This can be an interesting effect if not overdone, but it is very different from conventional inbetweening. Peter Foldes prize-winning animated film, 'Hunger', exploited the technique to the full.

When animators do manual inbetweening, they use the key frames simply as guides. The drawings they create are visualised from a mental model of the object being drawn, so that they can infer information which might be missing from one key frame to the next (as when, say, an arm passes behind the body). Computers on the othe hand, can only use the information they have in the key frames themselves.

A number of ideas have been suggested to get over this limitation (CATMULL78), ranging from artificial intelligence techniques to the much more practical, manual intervention. Perhaps the most interesting of these ideas is skeletal framing.

Skeletal Framing
BURTNYK76 outlines a method of using 'skeletons' of figures rather than the figures themselves as a basis for inbetweening. A skeleton is essentially a stick figure which the animator sketches in order to convey to the computer the form of the movement required. This simplified form is easy for artists to draw, so that they can create the whole sequence including inbetweens in a short time by concentrating on the movement alone rather than the minutiae of drawing and characterisation. The role of the computer is to take the skeleton and clothe it with the details of the figure with which it has been previously supplied.

This method is especially good for human and animal body movements and, because of its simplified form, often allows animators to see these movements displayed by the machine in real-time (something that is not normally possible for complex pictures). It is not, however, suitable for dealing with changes in such things as facial expression. To properly cope with these, manual inbetweening is usually needed.

Alan Kitching's ANTICS animation program (KITCHING80) has excellent facilities for skeletal animation and allows artists considerable scope for dynamic and realistic movements as a result.

PAINTING
When, as now frequently happens, the pictures have been converted to raster graphics form, the process of colouring them in and creating backgrounds has been enormously improved by the introduction of paint systems. (WALLACE81, for example, suggests a ten-fold reduction in time taken for this task).

Sitting at a paint system console, an artist can call up individual pictures and, simply by touching a point within an area to be filled, can have the whole area automatically coloured to a chosen hue. The colours themselves are normally picked from a pallete displayed on part of the screen and, of course, can be standardised throughout a film.

Difficulties arise when the original image has been scanned in, rather than drawn. When this happens, the image might be incomplete or otherwise defective with the result that the filling algorithm is fooled into missing out areas or spilling into unauthorised places. If this occurs, manual clean-up is necessary.

Raster graphics pictures can normally be used for animation only if they have been suitably anti-aliased.

ANOTHER AID TO CONVENTIONAL ANIMATION

WALLACE81 describes the system installed at Hanna-Barbera Studios to assist in assembling the necessary layers of artwork into one single composite frame. Ingenious techniques are used to minimise the number of merges by holding images which do not change over successive frames. The whole process tries to simulate a hypothetical, ideal multiplane animation rostrum camera.

MODELLED ANIMATION

The techniques to assist in conventional animation touched upon above - useful and cost-reducing though they are - do not fully exploit the facilities that computer graphics can offer and, mostly, only automate processes that were previously carried out manually. Modelled animation, on the other hand, opens up the possibility of creating images and movements which are difficult to achieve by conventional means. In particular, smooth and complex three-dimensional movements, as well as accurate representations of objects, are facilitated.

We can think of the conventional animation method as 'surface structured' in the sense that, when the computer assists, it deals with the images themselves and not with some underlying model of the objects represented. Modelled animation, in contrast, is 'deep structured' in that it creates and manipulates a model of the objects and produces its images from this.

Usually, modelled animation needs to be a cooperative effort between the designer (who prepares the storyboard and animation ideas) and the computer programmer (who has to implement these in an efficient and suitable manner).

For this deep structured and rather more difficult type of work, we have the following steps which arise after the storyboard is prepared:

1. Object description

In order to allow the complete and general three-dimensional animation of drawn objects, it is necessary that they be fully described in the mathematics of the computer (such as sets of coordinates and formulae). Depending on the amount of realism needed, these descriptions must embrace not only the geometry of the objects but also such things as their colour, texture, reflectance, translucency and so on. Much work is being done on convenient and compact methods of creating these descriptions which, at their best, now make it possible to depict virtually any object in considerable realism - albeit often at very great cost.

It must be noted that, in many cases - particularly in advertisements - designers require the depicted objects to change their forms substantially during a sequence. The need for physical transformation has to be reflected in the object description and this fact often prevents the programmer from using some of the shortcut graphic methods such as priority hidden line techniques (FUCHS80) in order to speed up computation and display.

The object description stage is the one which requires the most thought on the part of the programmer.

2. Animation

Drawn objects depicted in cartoon animation are frequently distorted by stretching, bending and twisting - usually for humorous effect but also to display dynamic movement more effectively. However, unless they need to change their physical forms in the manner described above, modelled objects are usually simply rotated, zoomed and transformed about the screen in controlled and realistic (though often very dynamic) perspective. This is fairly easily done by mathematical techniques which are now well-understood. As with conventional animation, all movements must be 'faired', that is carefully accelerated from rest and to rest. Fairing is easily incorporated into the mathematics which the computer uses for display and this helps to give computer animation its special characteristics.

The animation stage is the one which requires the most thought on the part of the designer.

3. Line testing

Because of the complexity of the images to be drawn, it is unlikely that these can be computed at real-time speeds. In this case it is normal for simplified images to be created which can be used to test the movements in real-time.

4. Recording

When all is satisfactory, the images are recorded frame-by-frame onto video, film, or COM devices. Alternatively - and this is the technique we use most frequently in System Simulation Ltd (LANSDOWN82) - line drawings are produced on paper or cel for filming under a conventional rostrum camera. Sometimes full-size negatives are made of these images to enable optical tricks or even hand colouring to be carried out.

SOME PROBLEMS AND DIFFICULTIES

In the remainder of this paper, we will deal with some of the problems that arise in attempting to do modelled animation. Although the remarks apply to the experience of System Simulation Ltd, we believe they are of general application and interest.

Problems of Description

From the account of the stages involved in modelled animation given above, we see that the object description and the animation itself are often inextricably bound together. It is rarely possible for the programmer to define objects independently of their movements because it so frequently happens that, as the objects move through 3-D space performing some complex gyrations, they assemble or disassemble, acquire or lose parts, or merge with other objects.

For this reason it helps if designers think of themselves as choreographers dealing with a group of dancers consisting of the parts of the objects. From the outset it is essential for the programmer to know the broad details of the choreography envisaged but, more importantly, how many dancers are involved. An extra gyration or two, a rotation or even a mirror imaging of the picture can be taken in the programmer's stride. An extra dancer introduced at the last minute is often a problem. If the object is finally to divide or merge in a way which was not originally catered for in the object description, fundamental and costly changes might need to be made.

This is a problem. And one which we do not relish posing because it inhibits creative thinking on the part of the designer. We appreciate too, how difficult it is to envisage a complex set of motions and arrangements in space so that the choreography has to be largely carried out in a trial and error manner. But it cannot be stressed too highly that the major part of the computer animator's work is in object description (if the object is at all complicated). That task is the most time-consuming and costly, not to say, tedious, in the whole process. If it has to be done more than once, all the joy - never mind the profit - goes out of a job.

A question immediately arises: 'What about all the effort that is going on into object description for CAD, such as the work of BRAID75, VOELCKER77, and others as described in BADLER78 and REQUICHA80; can't this help?'

Because so much of our animation is for advertising real products which cannot be built up of well-behaved primitives such as cylinders, cubes or spheres, we are unable to describe them in the simplified forms some of this research covers. Clients wish to have thir products depicted as realistically and accurately as possible - even in line drawing form. Indeed, this need for realism is made even more important when it is necessary to match the drawings against live action. Thus it is rarely possible to use short cuts in the description of these objects.

The Information Needed

To enable the programmer to put the descriptive information into the computer, nothing is better than the drawings the manufacturer uses to make the product itself. Obviously these are not always available, because they represent industrial or even military secrets - but they are certainly the primary source of information. The next best thing is the product - or an accurate model of it. The last resort, the thing the programmer likes least and which causes the most difficulty, is an artist's drawing of the object. If such a thing is the only option, it should be drawn as large as convenient on millimetre graph paper with centre lines and so on set on the major lines of the grid. Centres of circles and arcs (and their extents) should be marked and dimensioned. Remember that the drawing might have to be digitised either by hand or by one of the techniques outlined in LANSDOWN81 so that accuracy is far more important than aesthetics.

Checking on the Movements

Most animation of interest will deal with objects and movements which are too complex to be computed in real time (at least, if computers of reasonable size and, hence, cost are to be used). Sequences have therefore to be computed and displayed frame-by-frame. The quality of the object depiction can be judged from individual frames but movement usually requires the preparation of a line test. This can be produced either by photographing directly off the screen in 16mm, or by filming paper output under the rostrum camera. Very often simplified images can be used at this stage and double framing is sufficient for most purposes.

Remember, there is little difficulty in the programmer producing drawings in parts (providing these reflect the object description) so that any objects that do not move in a sequence can be omitted or put on a separate drawing to those which do move. This might simplify line testing and final filming.

Communication
Unless the designer and programmer are familiar with each other's work, communication of ideas between the two can sometimes be a problem. In general, computers will not be used unless the animation is a complex one difficult to do by hand. Thus description of it can often be awkward.

A storyboard is of considerable assistance to the programmer as it can show how the designer expects the images to appear on the screen. Note that the storyboard need not be of presentation quality; rough sketches are perfectly adequate. Indeed these are to be preferred if they allow the designer to show the appearance of more frames than otherwise. Accompanying the storyboard should be a set of timings which should be as close as possible to the finished requirements. It is useful for the designer and programmer to meet and discuss ideas before the storyboard is prepared.

It is possible for the designer to sit with the programmer in front of the screen and fine-tune predefined images or movements but this is not a quick process. Frames can sometimes take several minutes to build up and apparently trivial changes to a movement or an object shape might involve much program alteration. Programmers would normally prefer to be properly briefed and then allowed to work on the changes in peace although this is not an invariable rule.

There are, however, two invariable rules:

1. Always ask for what you need

2. Never ask for more than you need.

It is surprising how frequently designers do not get precisely what they want because they assume some difficulty that might not exist. Computer animation is very different from hand animation. It uses different techniques and methods so that things which might be difficult to do by hand might be simple by computer, and vice versa. The only way to find out is to ask. The programmer will certainly protest if required to do something too difficult or costly.

Conversly, asking for more than is needed can be counter-productive. For example, asking for full hidden line drawings when they are to be traced or painted is often a waste of time and money. Hidden line computation (especially when it cannot be assisted by priority techniques) can take ten times longer than wire frame computation. Furthermore, it requires a different form of object description. A compromise between the two is partial hidden line work where all the faces of an object which are hidden by itself are omitted. This too, requires a different object description form but adds little to the computation load.

SUMMARY

In summary we can say that computers can assist the animator in a number of ways. To get the fullest advantage of the possibilities, it is essential that the designer and the programmer come together as early as possible in the process to agree on the approach. Animation is a creative art so that it is unlikely that everything a designer wants is already programmed. This means that animation programmers must be thought of as members of the creative team who have their own special contribution to make.

REFERENCES

BADLER78
Three-Dimensional Representations for Computer Graphics and Computer Vision
N Badler and R Bajcsy
Proceedings ACM-SIGGRAPH 1978

BRAID75
The Synthesis of Solids Bounded by Many Faces
IC Braid
CACM April 1975 (18) 4

BURTNYK76
Interactive Skeleton Techniques for Enhancing Motion Dynamics in Key Frame Animation
N Burtnyk and M Wein
CACM Oct 1976 (19) 10

CATMULL76
The Problems of Computer-Assisted Animation
E Catmull
Proceedings ACM-SIGGRAPH 1976

FUCHS80
On Visible Surface Generation by a Priori Tree Structures
H Fuchs, Z M Kedem and B F Naylor
Proceedings ACM-SIGGRAPH 1980

KITCHING80
ANTICS from Stone Age to Steam Age
A Kitching
British Kinematography Sound and Television Aug 1980

LANSDOWN81
Graphical Input and Digitising Techniques - A Review
J Lansdown
Proceedings Online CG82 1982

LANSDOWN82
Computer Assisted Animation
J Lansdown
Computer Graphics World April 1982

REQUICHA80
Representations for Rigid Solids: Theory, Methods and Systems
AAG Requicha
ACM Computing Surveys Dec 1980 (12) 4

VOELCKER77
Geometric Modelling of Mechanical Parts and Processes
HB Voelcker and AAG Requicha
Computer Dec 1977 (10) 12

WALLACE81
Merging and Transformation of Raster Images for Cartoon Animation
B A Wallace
Proceedings ACM-SIGGRAPH 1981

Three Dimensional Graphics

Cranston/Csuri Productions

Cranston Center
1501 Neil Avenue
Columbus, Ohio 43201
614/421/2000

Patricia A. Moore
Director of
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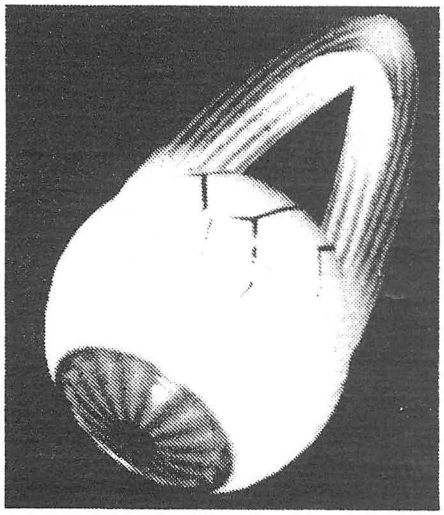
Custom and Syndicated Computer Generated Animation and Design

BACK STAGE

SEPTEMBER 2, 1983

Computer Animation & Live Action Detail The Human Body

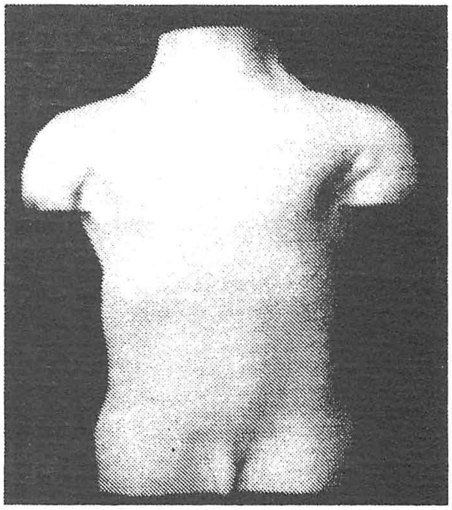
A new approach to explaining the human body and its functions is being developed by Goldcrest Multimedia Television, Ltd., London, England, and Cranston/Csuri Productions, Columbus, Ohio. Based on the book, "The Body Machine," edited by Dr. Christian Barnard, the project, with the same title, involves a series of 25-minute computer animated and live action films each detailing special areas of the body, its senses, organs, and processes.



Human eye created for "The Body Machine" series via three dimensional solid shaded raster graphics.

Each 25-minute program mixes live action footage of human activity with computer animated body systems to depict functions of the body as they occur. The computer animation simulates these complex functions with extraordinary accuracy without the organic reality considered unsavory to the viewer. The live action sequences have been filmed in the United Kingdom, U.S.A., France, Greece, and Italy while all of the computer animation is being produced in Columbus, Ohio. The series will be released early in 1984.

Goldcrest Film and Television, a British producer of feature films, was involved in the production of "Chariots of Fire" and "Gandhi."



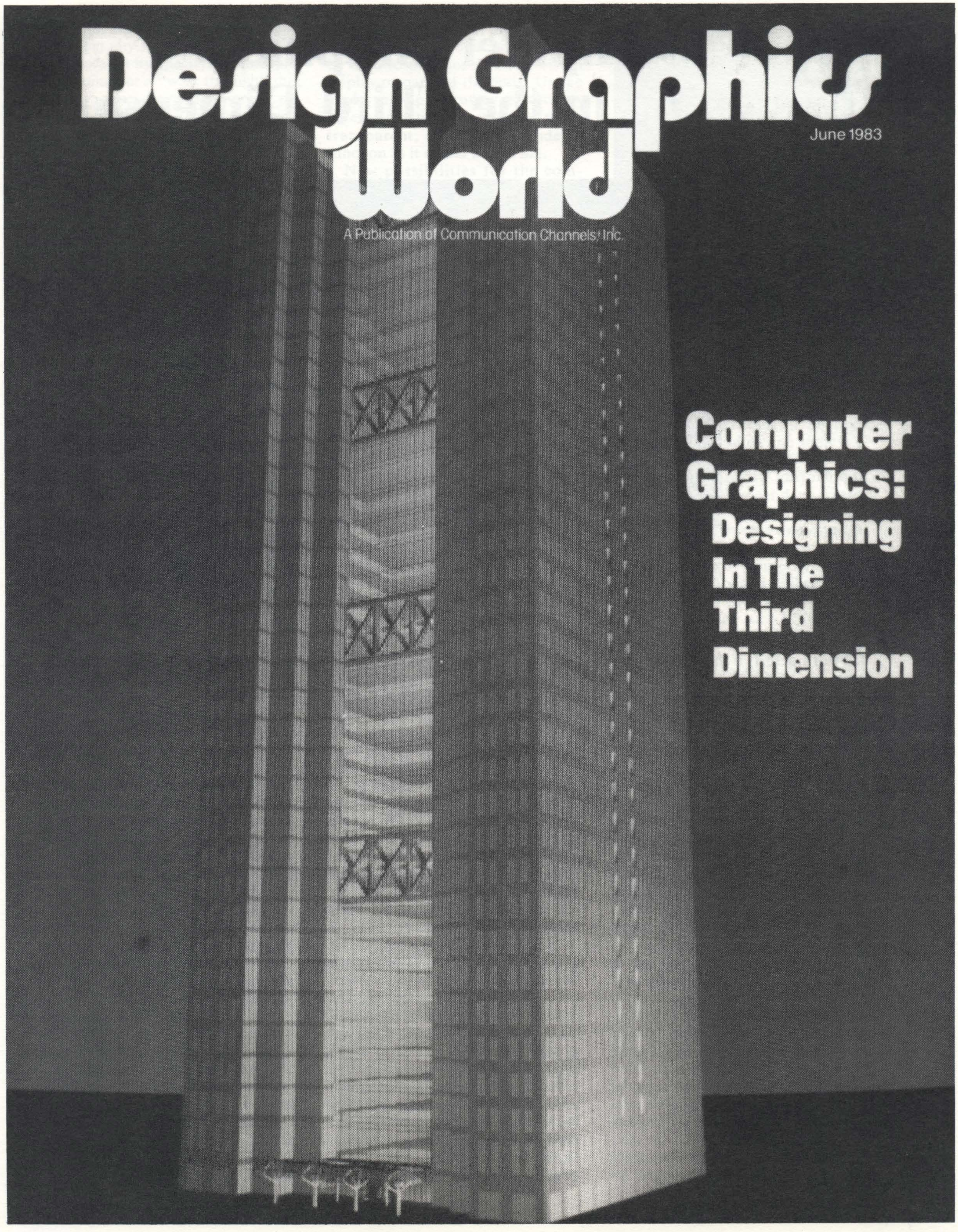
Male torso created for "The Body Machine" series via three dimensional solid shaded raster graphics. Animator was Don Stredney of Cranston/Csuri Productions.

Cranston/Csuri Productions, 1501 Neil Avenue, Columbus, Ohio 43201 (614) 421-2000 develops and produces computer-generated three-dimensional solid-shaded raster graphics based on its own state-of-the-art software and hardware technology. Projects include major network program intros and promotion spots, television commercials, and special effects for the film industry.

Design Graphics World

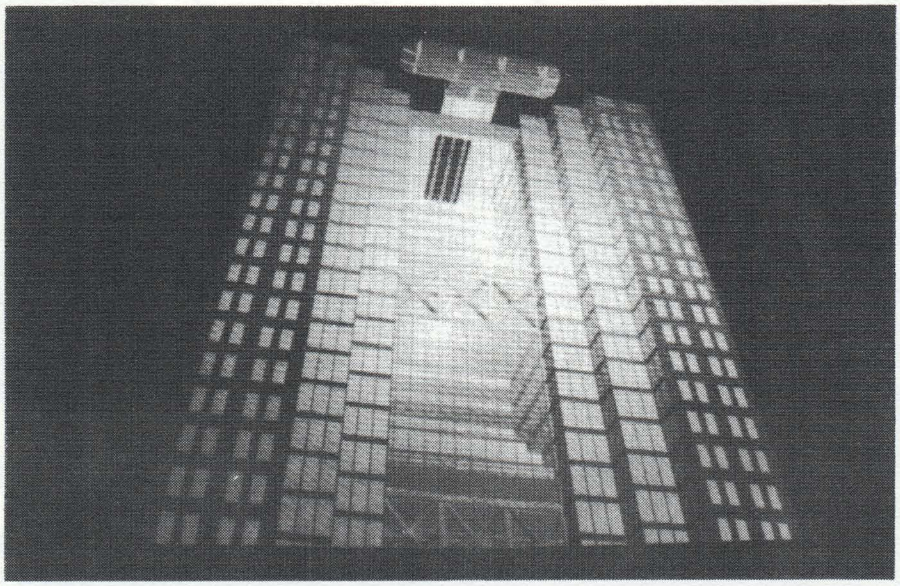
June 1983

A Publication of Communication Channels, Inc.



Computer Graphics: Designing In The Third Dimension

Computer Graphics: Designing in the Third Dimension



Cranston/Csuri animators translate architectural drawings into coordinates for computer input as a three dimensional data base. Graphics display software provides full color (not shown here) representations of a building from any viewpoint.

Skeletons bound across a patchwork desert; a forest of pencils grow, on an empty plain; three-dimensional colored cubes swirl and glisten in a dark and distant space.

Far from being an artist's surreal fantasy, these images are the product of a computer's precise mathematical calculations and they hint at the coming technology in buildings' design. Instead of paper and pen, architects soon may rely on computers and videotape for the design and display of the office buildings and cities of the future. Computers allow architects to view their creations both inside and out, from all conceivable angles, in any light.

"Computers enable us to take a 50-story building and position it against a realistic skyline," said Professor Charles Csuri, an acknowledged pioneer in the field of computers and animation. "Before the ground is even broken, we are able to see the building through the eyes of a passing pedestrian, a neighboring tenant or a bird passing overhead."

Computer synthesis of buildings not only is faster but also is less expensive than the construction of physical models. In addition, a videotape of the finished product can be produced for effective presentation to potential investors.

> *". . . with computers we are able to go places and see things that have never been seen before. We can do the impossible . . . move a fifty story building."*

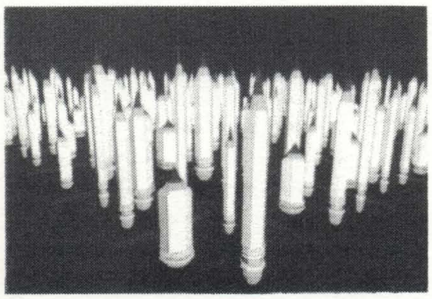
"In one case," said Csuri, executive vice president of Cranston-Csuri Productions, Inc., (CCPI), Columbus, Ohio, "we designed a videotape that allowed the urban developers to walk down a city street and to step inside the renovated buildings and take a look around." He added that the city officials were impressed; the development group relieved. "It's not easy to put a 10-foot model on a plane, but you can always pop a videotape in your briefcase."

The images demonstrating the leading edge of computer-generated graphics baffle and delight the senses. But, their applications extend far beyond entertainment, impacting such diverse fields as architecture and urban planning; advertising; industrial design and product development; medicine and the military. Computer graphics is a science that is expanding as rapidly as the computer's capabilities. It provides a service whose myriad uses and benefits are only beginning to be understood.

"The images produced by computers can be as clear and concise as any photograph," said Professor Csuri. "Yet with computers, we are able to go places and see things that have never been seen before. We can do the impossible — travel through the human body or move a 50-story building."

Computer graphics animators translate architectural drawings into coordinates for computer input as a three dimensional data base. Graphics display software having many parameters — including lighting models and perspective — provides full color representations of a building from any viewpoint. Animation is generated by specifying multiple viewpoints for a "walk through" the building before construction of physical models. Computer programs enable designers to synthesize buildings and provide animation within weeks while traditional model makers generally take months to construct scale models.

The graphics can be effective in helping a design team deal with problems encountered during a product design project. An image of the product can be displayed on the screen and controlled in real-time using wire frame animation. As the project moves further into development stages, more and more sophisticated pictures become useful when dealing with color, surface texture,



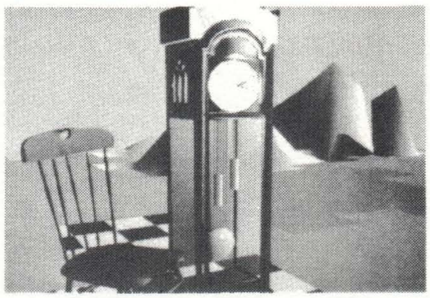
A forest of pencils grow on an empty plain: it is imagery brought to life.

shape, etc. Any constraints the designer must deal with during the course of the project, such as the number of ounces in a container or the exact dimensions of an object, can be "remembered" by the computer so that any new designs will be accurate. With computer graphics, a designer has the capability of being more accurate and more innovative.

CCPI, one of a few computer graphics and animation companies in the United States, has developed an opening sequence for ABC-T.V.. ABC-T.V. art director Stu Stolz, said CCPI was very special in its field, that he had not seen anything like their work elsewhere. "The first commercial users to embrace the new graphics technology came from the entertainment field," Csuri explains. "In recent years, advertisers have turned to computers to create eye-catching television spots; movie producers have employed them for dramatic special effects, like those used in 'Star Wars' and 'Tron'."

These applications barely tap the computer's capabilities. For instance, computer graphics already can benefit the field of medicine. Information fed into a computer can be used to produce an exact visual display of parts of the body. Unlike a photograph, however, a computer-generated object can be made transparent, or it can be made to function as it would in real life.

New possibilities for the computers' use continue to come to light, sometimes to the surprise of their users. As the expertise and ability of



Certain effects can be achieved without constructing expensive models or sets.

operators expand, so do possible uses for the technology. Computers already simulate events, such as test flights, which are too dangerous to attempt in reality. Product durability can also be tested for response under various conditions.

Projected use

CCPI's pioneering efforts with the technology have been noticed in some far-flung quarters. A group of scientists approached CCPI after discovering the ruins of what they believed to be an American version of England's Stonehenge. The scientists' research had indicated that the historic site once marked the positions of the sun, although they were unable to prove their hypothesis with the remaining ruins.

CCPI proposed to employ pictures and a data base — developed by the scientists, along with the computer — to display the shadows and reflections caused by the sun during various times of the day and year. With the computer's aid, the team will be able to recreate a scene that took place thousands of years ago.

The results of this experiment will be far reaching in suggesting further uses for computer graphics. As Csuri pointed out, "Conventional animators are able to create realistic images, but it's tedious. Traditional methods require that frame-after-

The animation system enables the generation of images real or unreal.

frame be produced with only minimal changes made to each one. With thirty frames-per-second of video, there simply is not the time to add the highlights, shadows, reflections and transparencies that make a picture three-dimensional. As a result, conventional animation usually appears flat."

But, computers can be programmed to produce the same picture over and over again with only minor variations in pattern and color. Given the proper data, a computer is able to calculate and develop the movements necessary to get from point A on the screen to point B. It is the computer's efficiency, reliability and ability to follow directions that allow the machine to produce such life-like images.

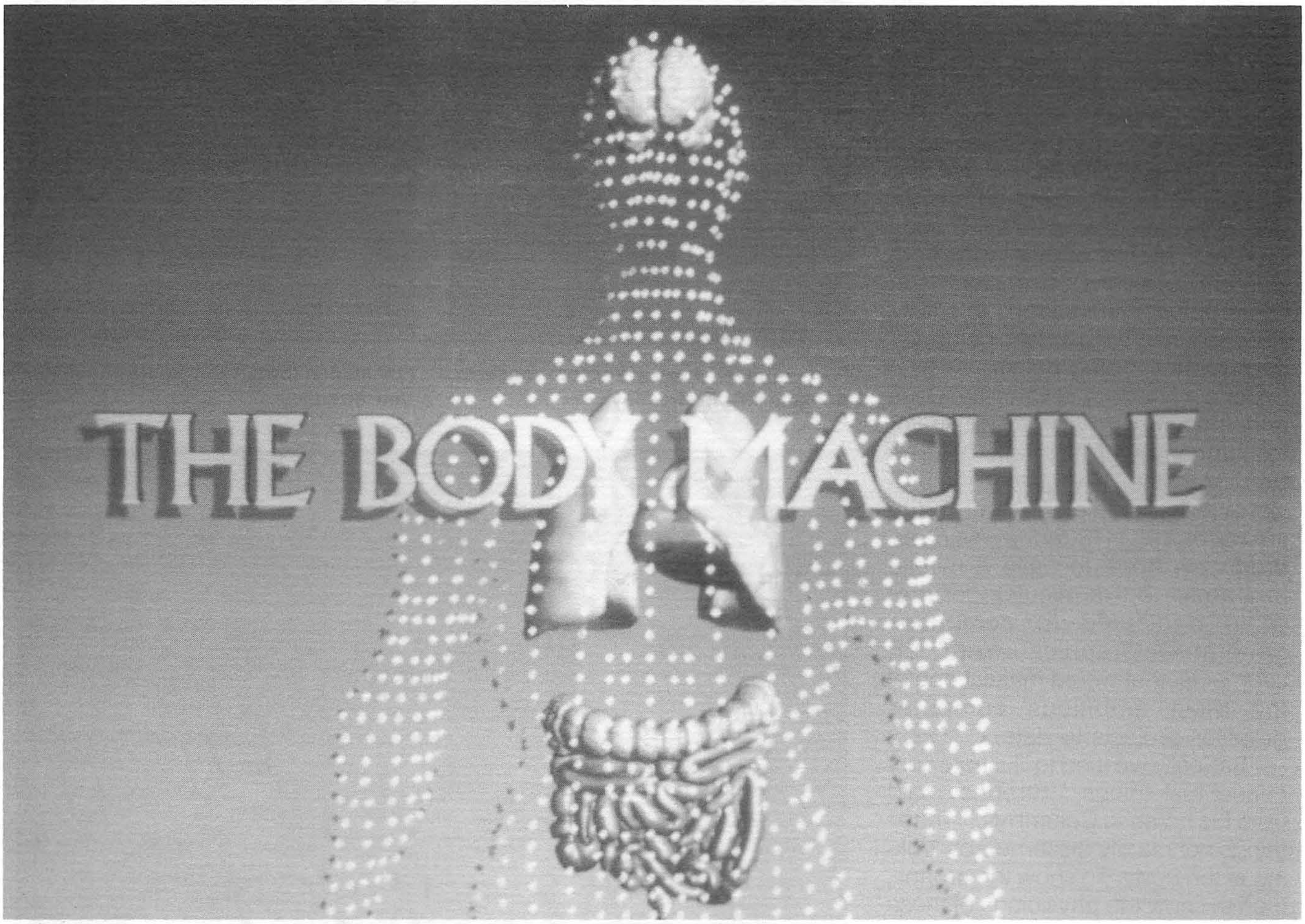
Software expansion

CCPI also is capable of providing computer graphics and developing the customized software that allows clients to work autonomously. In time, research and development will dominate its business. The anticipated trend toward in-house use of computer-generated graphics eventually may see houses like CCPI provide special-purpose hardware and license software to commercial and industrial users.

It's inevitable that the growing use of personal computers and changing public attitudes will lead to general acceptance of computer-generated graphics for a wide range of commercial uses.

There was a time when the majority of people were afraid of computers. By now, most of us are at least comfortable with the thought of them being around. Today's students are the up and coming computer conquerors. They grew up playing with them. And the future-built environment literally will grow up because of them.

COMPUTER PICTURES
A Back Stage Publication
March/April 1984



Title frame to open "The Body Machine" series; shows human body in vector pattern with brain, heart, lungs and intestines in position; Animators: Don Stredney and Jose Garabis

Academy Award-Winning Goldcrest Films Works with Cranston-Csuri to Bring Human Body to Life with Computers

by Roger Armbrust

Back in the early '70s, the Canadian poet Michael Yates said of exercise: "It's taking care of the Machine." Now, a decade later in the age of hi-tech electronic media, that poetic image is being brought to life in a 26-part documentary for television entitled "The Body Machine," and computer graphics will play an important role in demonstrating how a "well-oiled" human machine functions.

The series is being produced by Goldcrest Films of London, the people who co-produced such award-winning feature films as "Chariots of Fire" and "Gandhi," with computer images created by Cranston-Csuri of Columbus, Ohio.

"The program shows the normal workings of the human body," said Karl Sabbagh, writer-producer of the series, "and is not about illness or staying healthy.

"We take the bodily tasks—moving, eating, thinking, reproduction—and break them down into their respective elements. There is live action to introduce the activity, and several real sequences of the human body, supported by computer graphics."

THREE MAIN AREAS

Three special sections of film cover the following main areas:

1. Special filming inside the body, e.g. the use of microscopes.
2. Special modeling devices.
3. Graphics: both simple animated pieces as well as 3-D animation that is computer generated.

"We used computer graphics to take advantage of its 3-D capabilities," Sabbagh said, "enabling us to show the locations and relationships of the organs."

But how did a London film producer connect with an Ohio computer animation studio? Sabbagh learned about Cranston-Csuri at a London communications convention, but Goldcrest looked at many companies before selecting Cranston-Csuri. "Most of the others were dealing with square 3-D figures," said Sabbagh. "Cranston-Csuri were the only ones who had made a start on biological materials which could portray the irregular shapes of the human body.

"In some instances we use the body surface with solid organs inside. We wanted to rotate a 3-D body in order to see the organs inside from different positions. Cranston-Csuri came up with fine images to satisfy this need, and we used the computer graphics for linking points."

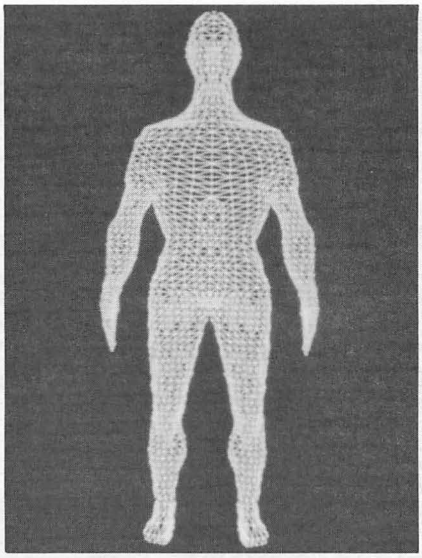
Donald Stredney of Cranston-Csuri is the primary animator and illustrator for the computer elements of "The Body Machine." By the time the project is fully completed—later in the spring of 1984—Stredney said the producers hope to have a minute and a half to two minutes per program dedicated to computer-generated graphics. With 26 segments, that would make it one of the most ambitious computer graphics projects to date.

"Basically we tried to illustrate very conceptual things," Stredney said from his home in Columbus. "Those things not readily discerned by looking at the body. To show the organs, then to show the physiology of those organs."

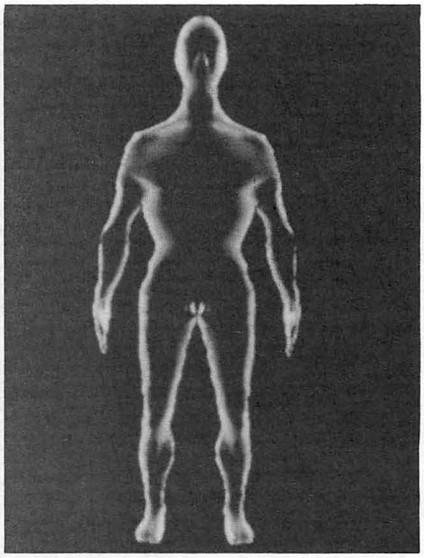
Stredney, along with animators Jose Garabis and Susan Van Baerle, have been creating images of the major organs of the body as well as the body surfaces for both the male and female.

"Those are the major data bases," Stredney said. "There are also some microscopic elements, such as blood cells and nerve cells."

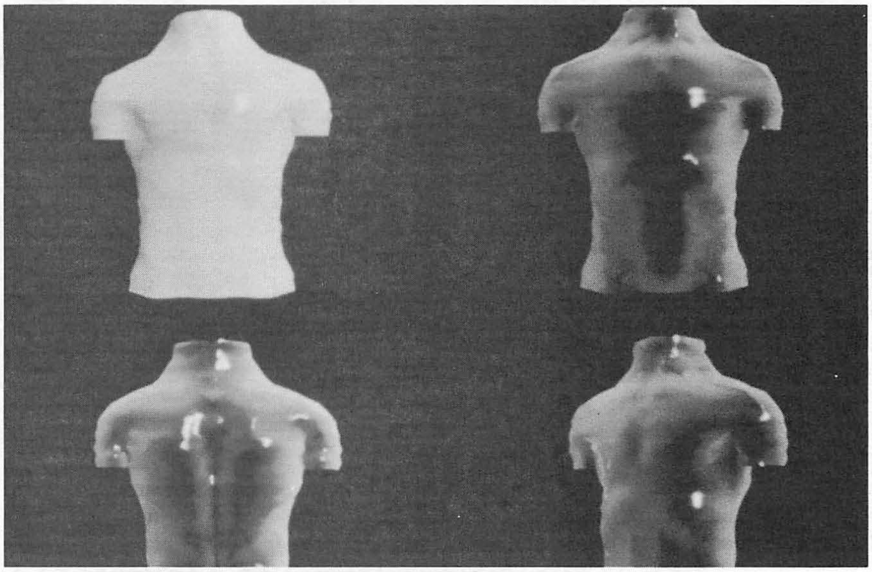
Stredney declined to take credit as the chief producer of the animated material. "In computer graphics, besides the ancillary people—hardware and software—someone may write three lines of code, and someone else may do 100. Someone creates a frame buffer from a long time ago, and you decide to use it now. So there are no lone heroes. It is a team effort."



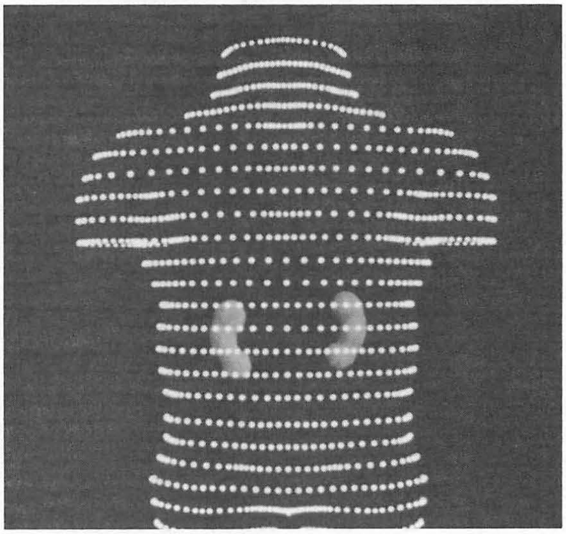
Full human form, vector pattern; Animator: Don Stredney



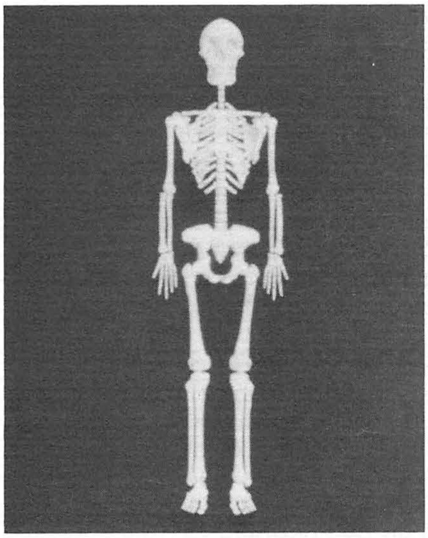
Full human form, transparent; Animator: Don Stredney

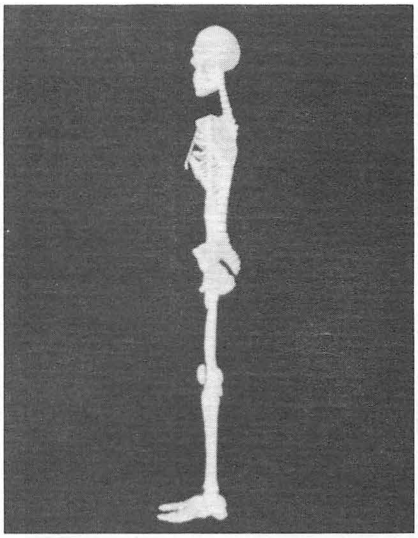


Human torso, opaque and transparent; Animator: Don Stredney

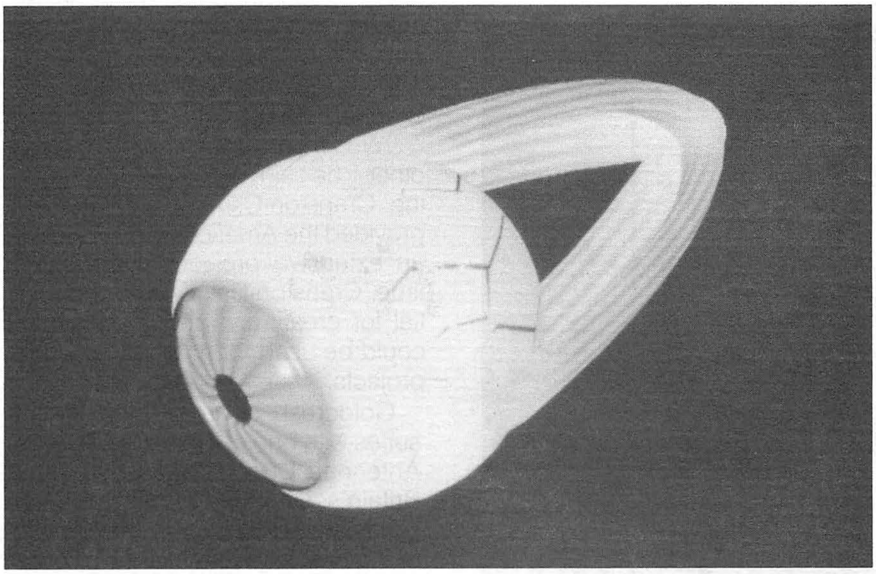


Human torso, vector pattern with positioned kidneys; Animator: Don Stredney

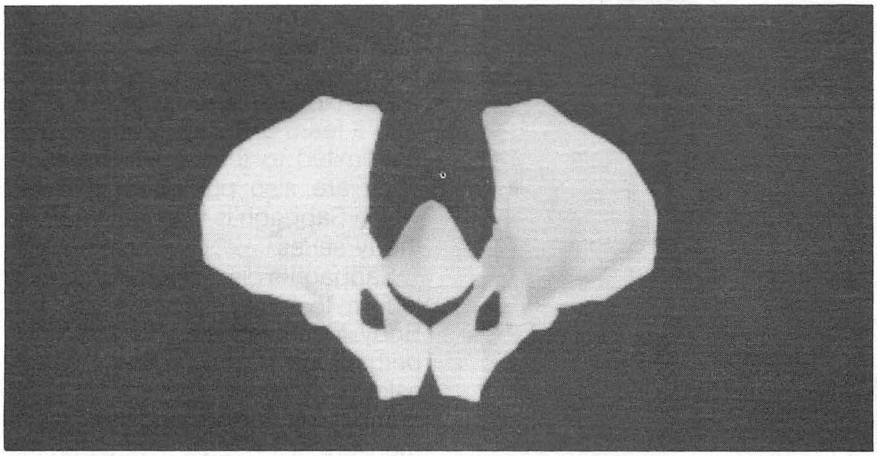




Human skeleton; Animator: Don Stredney



Human eye; Animator: Don Stredney



Pelvis and uterus; Animator: Don Stredney

HARDWARE HEROICS

If pressed on this point, Stredney would probably cite the heroics of the hardware: a VAX11/780 and 11/750 which are the mainframe computers which do the calculations for the databases. He said the frame buffers were built in-house. An Ampex electronic still-store is used for real-time viewing, said Stredney, because the Vax doesn't play back in real time.

Writer-producer Sabbagh started the project in 1982. He feels it should be finished by May, during which time Goldcrest will be doing "a trickle of small post-production work."

But he admits that, like all projects, there have been some hurdles to overcome.

"The computer graphics have been delaying the project somewhat," Sabbagh said, adding quickly that minor delays are understandable. Creating a data base and then using it to produce images may sound simple and easy. But in reality, it is a painstaking process when creating human organs that must function properly.

Because of the vastness of the project, Sabbagh was forced to cut back on some of the computer graphics images he had originally called for in the script.

A great deal of the computer work has already been done: the skeleton, the digestive tract; the liver, pancreas, kidneys, the brain, the beating heart and reproductive organs. "Don Stredney's literally working day and night to finish up," Sabbagh said.

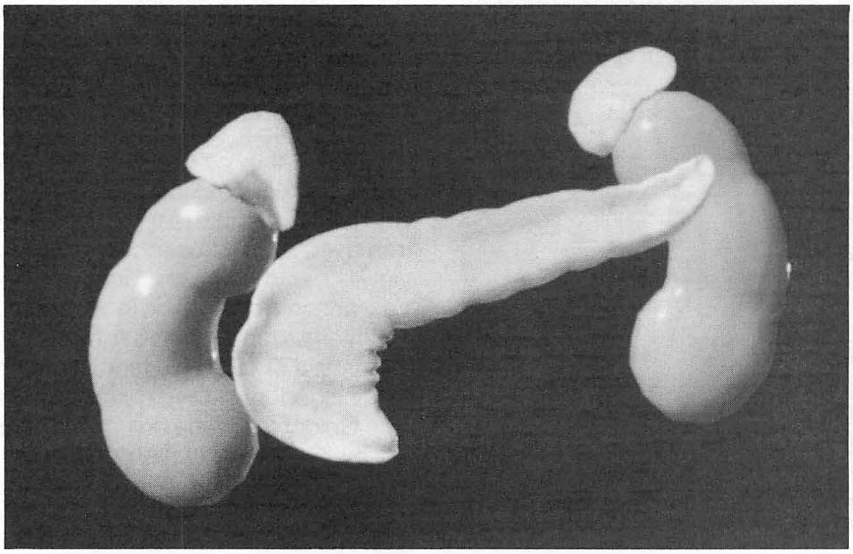
"We had hoped to put in data for all the major organs, but some parts created technical problems," Sabbagh said. "The circulation of blood is such a fiendishly difficult thing to do, and so we decided not to do it:"

Still, they did manage to come up with one or two separate types of blood flow which also allowed them to infuse other elements or molecules into the blood.

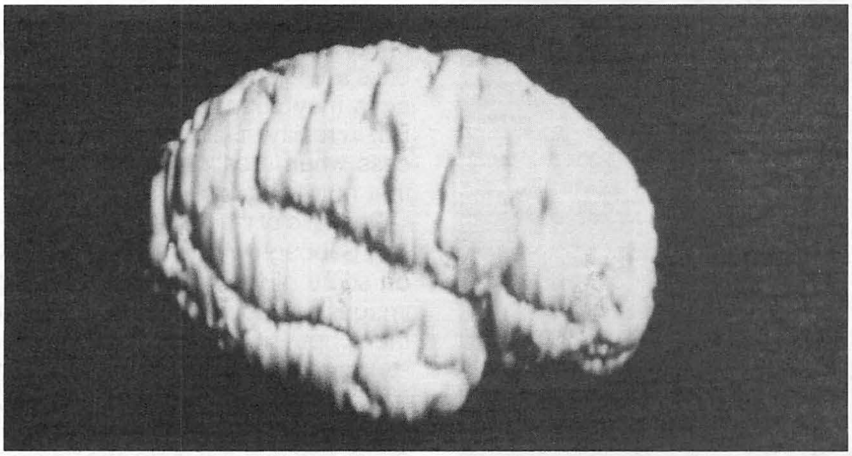
Sabbagh seemed especially pleased with Cranston-Csuri's creation of a beating heart.

"It's more than a scaling process," he said. "We actually reproduced the twisting movement of a beating heart."

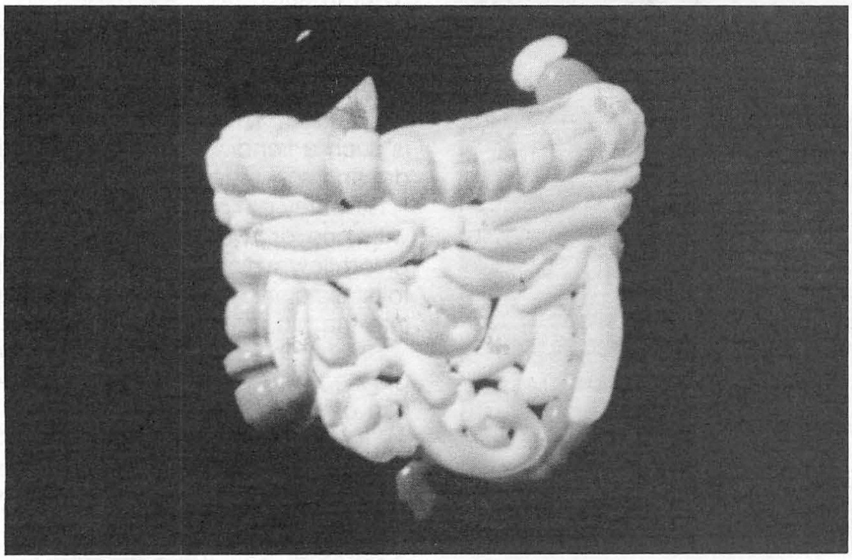
Sabbagh said the shape and color of the brain were good, but in-



Pancreas and adrenal glands; Animator: Jose Garabis



Human brain, opaque; Animator: Don Stredney



Small intestine, large intestine and liver; Animator: Jose Garabis

dicated it was difficult to create the exact surface he wanted.

"The brain took us about a month to put together," Stredney commented. "It depends on the data base involved. It takes the computer about 15 minutes a frame to calculate an image as complex as the brain." He suggested that it's not worth the time or money to spend any more than that on a frame.

COST CONSIDERATIONS

"Even when you've got the data in," Sabbagh agreed, "it's still difficult getting it out in the way you want. And the expense in doing six, seven, nine or ten minutes a frame can be considerable."

Speaking of expense, Sabbagh said the budget for the entire project is 2½ million pounds—just under $4 million in American dollars. He declined to discuss what portion of that budget went into the computer graphics work.

"We have been helping each other," he said, indicating that, by hiring Cranston-Csuri, Goldcrest had provided the American firm with quite an extensive project. At the same time, Cranston-Csuri saw the potential for creating a data base which could be used for a variety of future projects.

Goldcrest is co-producing the series with one of France's channels: Antennae Duo. Sabbagh said that Britain's Channel 4 will carry the series, and discussions are currently being held with potential sponsors in the United States and Japan.

"Of course, when you're talking this kind of money we have to give them a finished program to show them what it will be like," Sabbagh said.

At Goldcrest, Sabbagh is working with a team of 12, and their work is not limited to the television series. They are also publishing a book, which Sabbagh is writing, based on the tv series.

Sabbagh's discussion of the book led him to point out that the title "The Body Machine" may be changed, perhaps to "The Living Body". When asked why, he replied, "For a number of reasons too tedious to mention." One reason might be the likeness of the title to "The Body

Human," an excellent tv series hosted by Jonathan Miller.

While the idea of mass education through a tv series is highly exciting to the people both at Goldcrest and Cranston-Csuri, both Sabbagh and Stredney are also deeply aware of the great potential the computer graphics data bases have for medical education.

"This potential has a special place in the heart of Stredney, whose talents are not limited to creativity at Cranston/Csuri computers. He taught anatomy at The Ohio State University after receiving his undergraduate degree in medical illustration.

"Most people are 3-D illiterate," Stredney said bluntly. "It's hard for them to understand how organs develop. There are so many twisting and turning structures which make the organs extremely complex.

"Too, the basic tools for teaching anatomy haven't changed over the last 200 years. It's usually gross anatomy. We were teaching the body in static form. What we really want to get across is the function of the anatomy and how the organs serve us."

Stredney feels that, with the new technology, there is now a tool which allows educators to expand and improve their methods to not only show anatomical structure, but bring it to life with motion and function.

"The big thing we see is the use of videodisc technology on systems where people can learn anatomy at their own rate," Stredney said.

Working with Sabbagh, Cranston-Csuri published a position paper titled "A Unique Tool in Human Biology." Besides the discussion of using its databases for television documentary, it also reviews the potential of using them for the following areas:

—**Anatomy teaching**: The database uses a body surface made up of tiny points through which solid organs and stystems can be seen. This "point body" or portions of it, such as the torso, can be rotated with organs located in 3-dimensional space inside, giving a view of human anatomy that can be portrayed in no other way.

Through this image, the system can show the complex relationship of the heart to the lungs or the pancreas to the stomach. By making the human brain's surface semi-transparent, 3-dimensional pictures can be projected of sub-surface structures such as the ventricles, the limbic system, the hypothalamus, and the pituitary.

—**Physiology teaching:** The database allows a simple and clear representation of such processes as oxygen and carbon dioxide transport in the blood; nerve transmission along myelinated and unmyelinated (sheathed and unsheathed) fibers; excitation and inhibition at nerve synapses; the action of hormones on target cells; the generation and transmission of heat throughout the body; the emulsification of fats by bile; the release of glucose from the liver, and many other basic physiological processes.

—**Patient education**, to be used in both hospital and office settings, for physicians to use video in discussing with patients the aspects of their illnesses or their bodies.

Although primarily dealing with the normal healthy human body, the computer data can be adapted to show the location and extent of pathological processes: the area of a myocardial infarction or a lobar pneumonia; the location of a brain hemorrhage leading to paralysis, or the location of phlebitis in the legs could all be illustrated on video tape.

Stredney cited these examples:

"First, the patient: If you showed a heart patient a film of a heart operation, he'd probably have a heart attack. Graphics can clean it up and explain it succinctly.

"Second, in teaching surgery, a doctor doesn't want a clouded view. He wants the specific objects of his concern.

"To put it simply, computer graphics adds animation and dimension to the traditional medical illustration. An artist can do anything we can. But we add to it the speed and accuracy of the computer."

What Cranston-Csuri sees in the future expansion of the databases is research leading to a continuous surface representation similar to skin, as well as the display of aspects of neurology and dermatology; portrayal of a variety of body postures instead of the current anatomical position, as well as a display of the peripheral nervous system and detailed circulation.

"We're talking about a video library," said Stredney. "A kind of 'Gray's Anatomy' (the Bible of anatomy textbooks). It will be on video discs. That's the medium of the future because of the power of interaction. That's the main attraction."

Sabbagh agrees, but he feels it may be a while before such computer-generated videos can be used extensively for education.

"A major project like this ('The Body Machine') can afford to do it," said Sabbagh, "but educationally, they'll have to become much more flexible and user-friendly before you can use it inexpensively enough for education."

Still, Sabbagh recognizes the unlimited potential of Cranston-Csuri's database, of bringing computer animation to anatomy and its use in the medical profession.

"This is something that is being studied world-wide," he said. "Three-dimensional data can be valuable world-wide. If Cranston-Csuri can crack that, they'll have a very competitive edge on the market. If they end up able to work off the shelf, it will be great."

And we assume Sabbagh means not only great for the production company's bank account and prestige, but for mankind as well.

THE 26 SEGMENTS OF THE BODY MACHINE

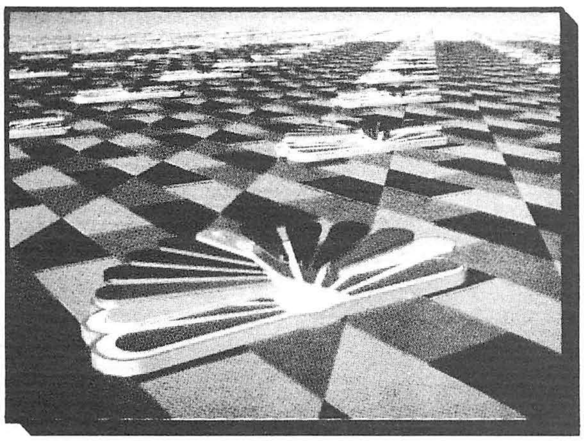
"The Body Machine" consists of 26 separate 26-minute segments for television, divided into the following components:

1. An introduction to the series
2. Surface senses–touch, taste and smell.
3. Eyes and ears–the incredible accuracy of vision and hearing.
4. Eating–why we need food and how it reaches the stomach.
5. Digesting–the transformation of our food into ourselves.
6. Water in the body–thirst, and the amazing abilities of the kidneys.
7. Growth–how we change shape and size.
8. Nerves–the cells that make us behave.
9. Brain-maps–how brain organization helps us to understand our world.
10. Consciously human–the complex brain activity that makes us uniquely human.
11. Muscle power–how muscle cells produce power and movement.
12. Joint activity–how joints and nerves produce the smoothness of human movement.
13. The depth of sleep–the surprisingly active body during a night's sleep.
14. Hot and cold–how the body copes with extremes of temperature.
15. Hormones–the body's chemical messengers.
16. Breath of life–how breathing works.
17. The heart–two pumps in one.
18. The circulation–blood pressure and the versatile network of blood vessels.
19. Accident–the body's own repair kit.
20. On the defensive–how we protect ourselves from foreign invaders.
21. Spare parts–replacing or compensating for parts of the body that go wrong.
22. Puberty–the body prepares for adulthood.
23. Coming together–genetics and sex.
24. A new life–nine months in the womb.
25. Ageing–how the body's systems change with age.
26. Looking forward–how the human body might evolve in the next million years.

On Location®
THE FILM & VIDEOTAPE
PRODUCTION MAGAZINE

Cranston/Csuri Creates Computer-Animated Logo for NBC Fall Promo

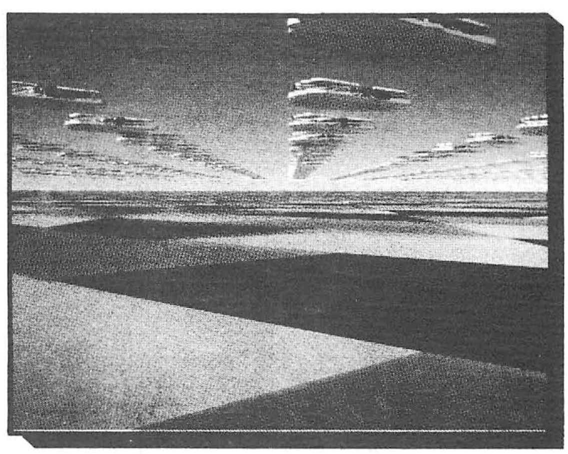
Airing nationally for the past two months has been **NBC**'s fall promotion series titled "Be There," which features computer-generated graphics by **Cranston/Csuri Productions Inc.**, Columbus, Ohio. Working through **Teitzel Film Inc.**, Los Angeles, Cranston/Csuri provided the background animation for sequences used throughout the campaign by the network itself as well as all the NBC affiliates nationwide.



The animation consisted of an infinity field of peacocks flying in rapid motion over a solid form, with the peacocks then turning in a vertical move to float up the screen in a wallpaper-type effect.

The project was especially difficult because of the speed of the animation, which was calculated at 60 fields per second, the maximum playback rate for television. "The results are unusually dynamic because the rapid motion across the screen causes the viewer not only to be compelled to watch but to 'be there' or be drawn into the field of infinity," said Patricia Moore, senior public relations executive.

The three-dimensional solid/shaded raster graphics were created using a **Vax** 11/780 host computer, **IMI** 500 display for designing data and producing vector animation, frame buffers for storing color information and image mixing, **Ampex** ESS2 electronic still storer for editing and mixing of live video, plus a series of smaller hardware.



Director of production for the sequence was Dr. Wayne Carlson. Director of animation was Michael Collery.

In addition to the NBC campaign, Cranston/Csuri has produced computer-generated animation for **ABC** and **Goldcrest Films** (London) as well as for commercials promoting 7-Up, Clairol, SmithKline and CBS Electronics.

Reprinted from the September, 1983 issue of "ON LOCATION" The Film & Videotape Production Magazine, with permission from the Publisher.

Los Angeles Times
Sunday, October 2, 1983

Computers Become Graphic Artist's Brush and Canvas

From the Associated Press

COLUMBUS, Ohio—When artist Charles A. Csuri started teaching himself about computers 20 years ago, his stock in trade was paint and canvas.

Today, the computer-generated graphic designs created by his company are seen by millions of people nationwide every night.

Csuri, a West Virginia native, didn't start out with a business career in mind. He studied and taught art at Ohio State University. He successfully exhibited for 10 years in New York. Pop artist Roy Lichtenstein was best man at his wedding.

Now Csuri rarely picks up a paintbrush. "I pick up a phone," he said, laughing, during an interview at Cranston-Csuri Productions Inc., the computer graphics company he helps direct. "I jog. I guess that's creative."

Designs Titles for TV

Csuri, who is executive vice president, picks up the phone for business calls a lot these days. Cranston-Csuri—the Cranston part coming from the Columbus investment firm Cranston Cos.—has been in business less than a year. But its successes are many.

The company has designed promotions and opening titles for ABC-TV's "World News Tonight," "20-20," "Nightline," "The Last Word" and "This Morning." Cranston-Csuri designers are putting the finishing touches on the logo ABC will use for its coverage of the 1984 Olympic Games.

A Cranston-Csuri promotion for the L.A. Express of the U.S. Football League received an award from the Broadcast Designers Assn. An ad for a popular cold-relief capsule is by Cranston-Csuri.

The company also sells a low-cost "station image package" of promotions for independent television stations and network affiliates.

The company's creations are realized in a 36,000-square-foot glass-and-brick contemporary structure at the end of a sycamore-lined street of Victorian houses near the Ohio State campus. The building once housed a think tank that dealt with contemporary social issues.

Cranston-Csuri shares space with Cranston Enterprises but may soon take over the whole building if growth continues. The company started with five employees, but now has 26.

Since the company is privately held, it discloses little financial data. James W. Kristoff, president, says Cranston-Csuri is aiming at sales of $75 million to $100 million a year within the next five years.

Kristoff says one reason for the firm's success has been its ability to finish jobs quickly, something important in a field with a reputation for being expensive.

"We seem to be able to make decisions faster and better than most people," Csuri said.

"I saw the importance of it, and that's why I stayed with it," Csuri said of his early efforts with computers. "I saw it as an incredible art tool."

That artistry has been expanded to applications in architecture, medicine, simulation, training and games.

Takes Design Ability

Csuri insists that the creativity of the people is paramount and that the computers are only as good as the people who program them. "It takes a design ability," he said.

The computers used to create artistic images are programmed automatically to apply the laws of perspective and the physics of light. Thus, these ordinary artistic problems are quickly solved.

Cranston-Csuri prides itself on the high resolution of its three-dimensional images, and the viewer notices the clear edges and soft surfaces with a full range of values. Colors come in every hue.

Csuri, who says when asked his age that he was born "a day before God," has lived in Ohio 43 years. He says he is grateful for the business backing and expertise he has received from Cranston Cos.

"What does a college professor do?" Csuri asked. "Where am I going to get all that money?"

Csuri still works half time at Ohio State. For 13 years, his research was supported by the National Science Foundation. He has attended international conferences and sits on the editorial board of the IEEE Computer Graphics & Applications magazine.

BusinessWeek
AUGUST 13, 1984 A McGRAW-HILL PUBLICATION $2.00

THE ECCENTRIC WIZARD OF GLOSSY GRAPHICS

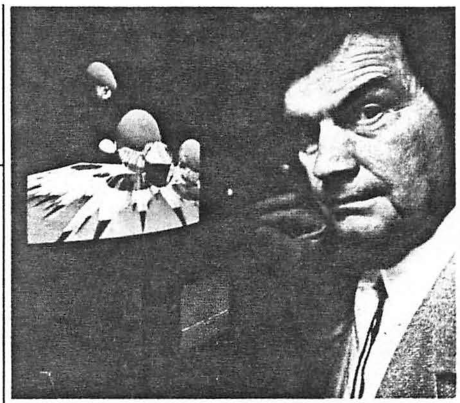
Even by Hollywood standards, computer-generated graphics that cost $4,000 a second are pricy. But those fees for advertisements or promotions are just business as usual for Cranston/Csuri Productions, a beehive of computer "tekkies" and animators in Columbus, Ohio. It spins out glossy computer graphics for major television networks as well as—for less astronomical fees—medical and educational institutions.

Within the normally competitive graphics industry, the mention of Cranston/Csuri evokes awe and respect. Trade shows open with vivid films of the company's three-dimensional animated magic. National Broadcasting Co. turned to Cranston/Csuri for its fall 1983 promotional series.

WAR GAME. The eccentric genius behind the three-year-old venture is Charles A. Csuri, an art history professor and surrealist painter whose life was changed when he discovered computers. With his bowl-shaped haircut, Csuri, 61, a former All-America football tackle who won a Bronze Star in World War II's Battle of the Bulge, more closely resembles a Franciscan monk than a high-tech wizard. A faculty member for the past 37 years at Ohio State University, Csuri started experimenting with computer animation in the 1960s.

In an early *tour de force,* Csuri computerized images of toy soldiers and programmed the computer to distribute them on a battlefield. Then he entered the names of faculty and students at Ohio State and wrote a program that determined randomly whether they survived or were killed. For Csuri, the work evoked his own combat experience: "It was a game of roulette—good friends died, I lived." Prizes and several million dollars in grants from organizations such as the National Science Foundation followed.

In 1982, Csuri decided to commercialize his increasingly sophisticated animation techniques. He co-founded Cranston/Csuri, of which he is executive vice-president in charge of research. The company is already making a profit, Csuri says, and over the next



SURREALIST PAINTER CSURI: COMPUTERS PERMANENTLY CHANGED HIS LIFE

year may double its current staff of 50. Commercial TV accounts for 75% of revenues, while applications in medical education, training, and simulation account for the rest. Csuri expects this ratio to reverse itself within five years. Cranston/Csuri is also developing software it hopes to sell to graphic designers, architects, and TV stations that want to create their own weather maps and logos.

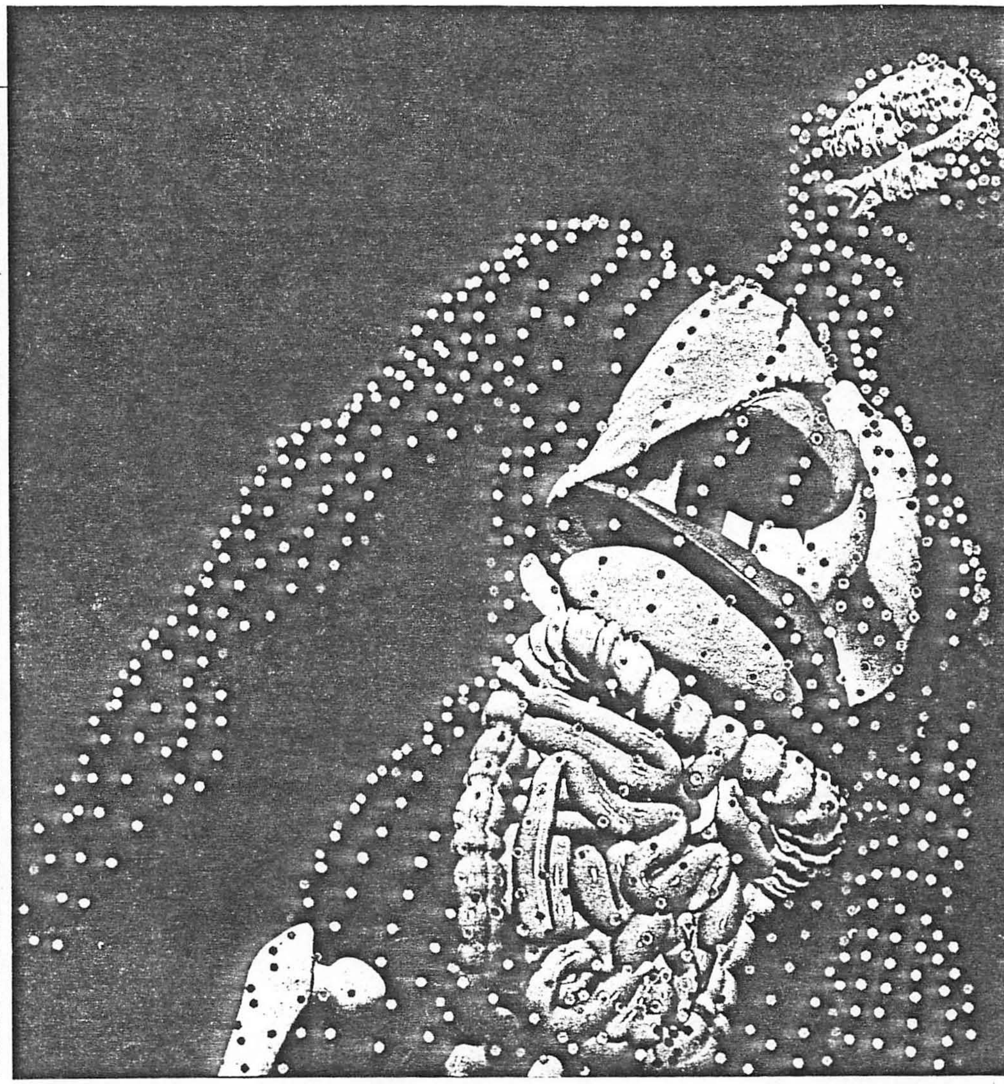
While Csuri continues to manage the company's R&D, he has returned to creating his own computer art. "I'm plain disappointed with [the computer art] that's out there," he says. "It's all so damn serious and boring."

THE SUNDAY TIMES magazine SEPTEMBER 16, 1984

How well do you know your body?

1 The human liver is situated
(a) above the waist
(b) at waist level
(c) below the waist
2 The average adult heart weighs
(a) six ounces
(b) 10 ounces
(c) one pound
3 A cornea is
(a) a transparent outer layer of the eye
(b) a painful growth in the joints
(c) an enlargement of a valve in the heart
4 How much blood does the human body normally contain?
(a) six pints
(b) 12 pints
(c) four pints
5 The length of the large intestine is
(a) five feet (b) 10 feet (c) 13 feet
6 While resting, a long-distance runner's heart, compared to that of an untrained person, beats
(a) more slowly
(b) at the same speed
(c) more quickly
7 Your kidneys purify in one hour
(a) two pints of blood
(b) eight pints
(c) 12 pints
8 The heart and lungs fit inside the ribs. The lungs (a) both touch the heart
(b) are separated from it by one inch
(c) are separated from it by three inches
9 Alcohol in the bloodstream is slowly destroyed by
(a) the lungs
(b) the kidneys
(c) the liver
10 How many different tastes can the tongue recognise?
(a) four (b) 11 (c) 23

Answers on page 25



CRANSTON-CSURI PRODUCTIONS

TAKING A CLOSER LOOK AT YOUR INNER SELF

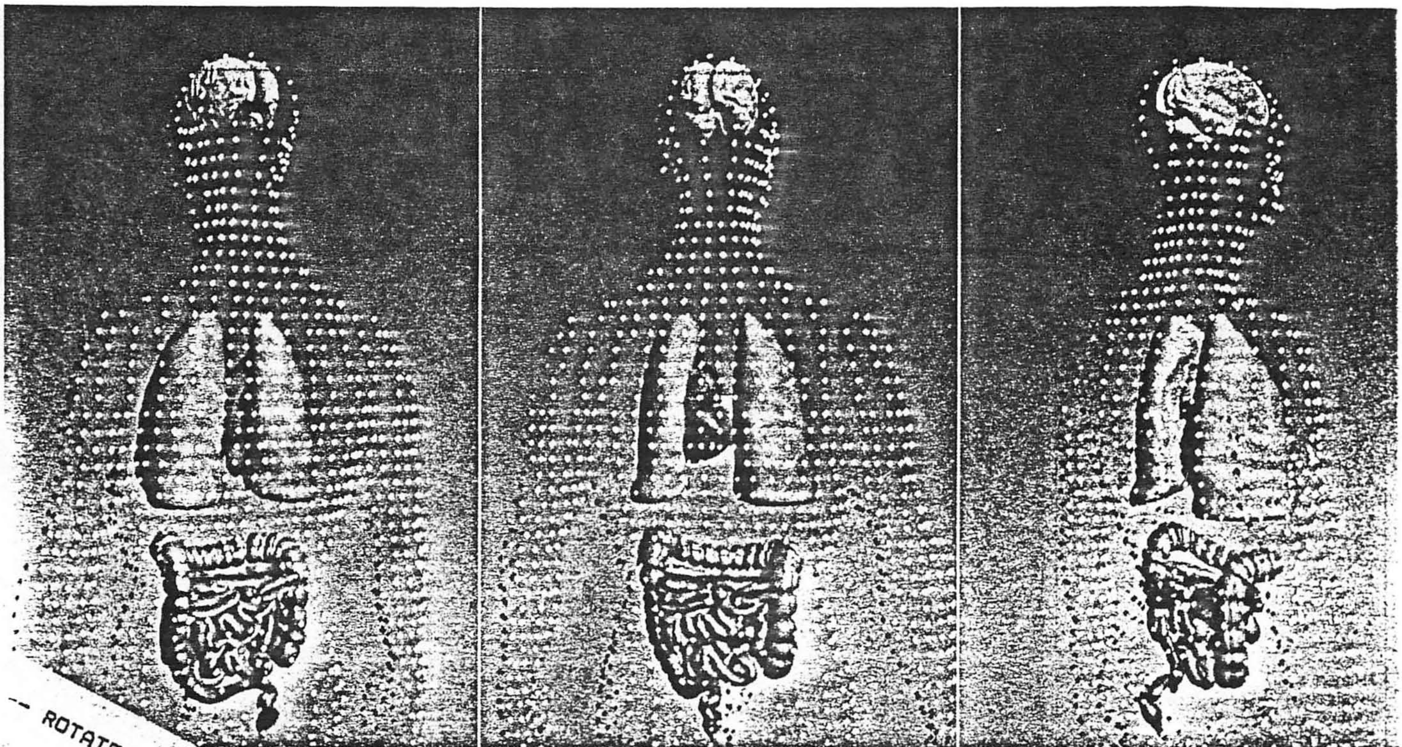
You can, no doubt, put your hand on your heart. But can you put it on your spleen? Do you even know what your spleen does? Most of us know so little about our bodies (see quiz, above) that doctors find it difficult to explain what is wrong or what an operation will do. In future they may be helped by a remarkable new use of computer graphics – the images are three-dimensional and rotate – which will be seen on Channel 4's *The Living Body* series which begins on Wednesday. *Tony Osman* visited the American company who made them

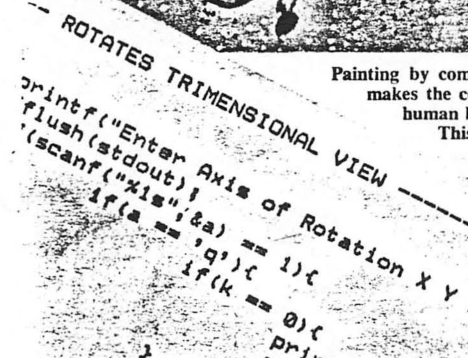
Our ignorance about our bodies can have far-reaching effects when something goes wrong. Doctors find it difficult enough to explain to a patient why his gall bladder, for example, isn't functioning properly or why an operation may be necessary. It is even more difficult to spell out the incidental consequences of an operation – how and why other parts of the body might be affected. Yet, without such knowledge, the patient can be totally unprepared for the little things that go wrong, the things that make him uncomfortable or unnecessarily anxious, at the post-operative stage.

Sir John Stallworth, former professor of obstetrics at Oxford, believes there is a lot of needless suffering because of the "breakdown in communication" between doctor and patient and that this is largely caused by the patient's lack of knowledge. At its most extreme, it can lead to litigation, says Sir John, who has served for 20 years with the Medical Protection Society, one of the major bodies concerned with protecting doctors against litigation.

In America, where litigation is the medical profession's nightmare, the conviction that patients should know more about the way their bodies function is growing. Which is why a remarkable new use of computer graphics is being hailed as a breakthrough in patient education.

Some of these graphics will be seen for the first time in Britain in the Goldcrest production, *The Living Body*, which starts next Wednesday on Channel 4. The animated graphics are both three-dimensional and rotating so that ⟶





Painting by computer: The program (left) that makes the computer rotate the image of the human body (above) is strikingly simple. This is because the computer already has in its memory 3-D images of the anatomy and information about the colours of the organs and their shininess. As the computer executes the program, the sketched body revolves and we can watch the heart beating and the lungs inflating and deflating. The rotation gives the viewer the best view for the action of each of the realistic organs. The images look as if a real model has been filmed. Below: close-up of a heart beating

the viewer can see clearly how the parts of the body relate to each other and what effect the movement of one part has on the others.

The graphics come from one of the world centres of computer art, Cranston-Csuri Productions, at Columbus, Ohio. It is run by Chuck Csuri, an acknowledged master of realistic computer graphics. He is an artist who has had regular exhibitions in New York and he has been head of the department of art education at the gigantic Ohio State University for nearly 20 years.

Csuri firmly believes that people need to know more about their own bodies. Too many patients, he says, are surprised by the results of surgery. "We need the graphics for patient education," says Csuri. "We even get women who are stunned by the consequences of a hysterectomy: they didn't realise they would be sterile afterwards. There is a lot of litigation based on 'inadequately informed consent'."

Cranston-Csuri Productions was set up only three years ago but it is based on Csuri's long-standing interest in computer graphics: his department at the university has studied the topic for the past 17 years. The company makes a wide range of video material using computer animation. As Csuri says; "Our main source of income comes from animations to introduce news and sports programmes. But the medical side is building up."

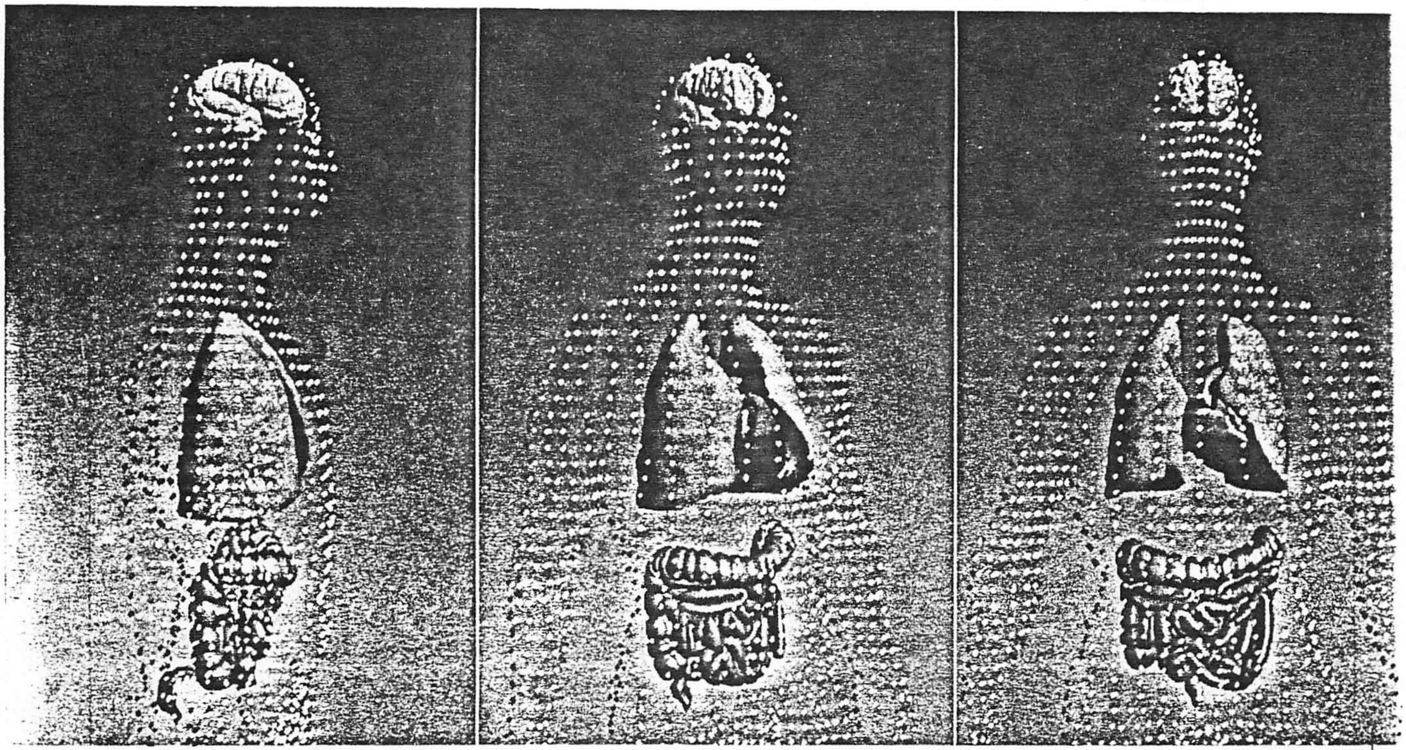
The company has in fact already built up an unrivalled collection of computer images of the anatomy of the human body. A key person in this has been Don Stedney, who started as an anatomical illustrator. "Even in school, I wanted to be a medical illustrator. I was very interested in science, and then I developed an interest in art, and found I had some ability. Then my father said, 'Do you know that there is a profession engaged in medical illustration?' So I started in medical school. But I never liked the idea of learning anatomy from static pictures." Which led him into the realistic, three-dimensional computer animation used in the TV series.

Realism in computer graphics is a complex study needing elaborate mathematical research. The expense certainly would not have been justified for medical illustrations alone nor even by the more financially rewarding demands of the giant television companies. The original work was carried out for the US Air Force.

The air force needed to train pilots to fly near the ground at supersonic speeds. It could hardly let the pilots learn in the aircraft, where a mistake would cost many millions of pounds, not to mention a valuable life. It could use flight simulators but these really simulated only instrument flying. What was needed was a simulator that would give at least a fair representation of the ground, changing in response to the controls. Computer graphics could be the answer.

But, as anyone who has played a computer game knows, such graphics are generally crude and unrealistic. They were originally designed to show regular shapes: natural shapes are irregular and demand a different approach.

A crude shape can be "drawn" on a computer screen as a picture. Most home-computer owners have done this. Points and shapes and lines are placed at mapped positions, and the picture is built



up by eye. But because a computer can, generally speaking, work to any rules that can be clearly specified, there is another approach.

First, you give the computer the rules for constructing an object from plans: then you write in the plans. For a three-dimensional object, you will need a ground plan, an end view and an elevation. The computer is then told to put a three-dimensional object, based on the plans, into its memory. After this, you can call up the object and get the computer to rotate it: you can make additions and enlarge parts of it if you wish.

For geometrical objects, or relatively regular shapes like the body of a car, this process is difficult enough. But natural objects such as hearts and lungs and kidneys are very irregular indeed. Whole new realms of mathematics have had to be devised for computer programs that will lead to realistic images of natural objects. One of these involves "fractals" – a way of adding as much irregularity as is needed to a regular shape: and there are others. As our pictures show, the result can be images that are disturbingly realistic. They are, though, entirely drawn by keyboard and computer and stored in the computer's memory.

Putting an image into the computer's memory is a lengthy process since the image must be described fully to the machine. Then a simple instruction to the computer – as shown on the left – will rotate the image. The computer works out which parts of, in this case, the human body are hidden and become visible as the body rotates. With another set of instructions, the computer can be told what movements of the human joints are possible. The elbow and the knee, for example, bend in only one plane, while the ankle and the hip have much more movement. Once these rules have been put into the computer, a simple instruction will make the body move.

To those who are not experts in computer graphics it is astonishing that realistic images are produced by working with the keyboard only. Yet the operator – even the programmer – does not have to make a single artistic judgment about, for example, perspective. The computer does this for him.

It also solves the problem of how the object will appear. The "computer artist" tells the computer where the light is coming from and whether it is falling on matt or shiny surfaces and where the viewer's eye is. Then the computer produces an image, based on the laws of reflection of light that have been programmed into it. For some images, the laws of refraction can be built in, so that the computer image shows what happens as an object moves through slabs of glass, or is submerged in water.

Though the computer makes everything *seem* easy, there is a prodigious amount of computing involved. In the animation of human anatomy, *each single frame* needs 20 minutes of computer time to produce. You can stand in front of the screen and watch the picture build up. Television runs at 25 frames every second demanding more than eight hours of computer time per second.

To cut time, Cranston-Csuri considered using a Cray supercomputer. The company was deterred partly by the fact that these supercomputers are astonishingly expensive: the talk was of $1 million a year just for maintenance and service. And it seemed unwise to put all its eggs into one basket, albeit a giant computer, so the company uses several smaller machines, each operating on a different aspect of the animation.

It has built up a library of images of human anatomy, a "databank", which is available for explanations of human anatomy and physiology in great detail. They can produce pictures of extremely high resolution, defining a total of a million points – a thousand each way.

The result is a spectacular system for explaining how the body works. We know that when we see something frightening, our heart begins to pound. But how does a message that starts at the eyes produce an effect on the pacemaker of the heart? The databank contains a set of pictures of the body with the heart beating. On to this, the computer superimposes the various processes: the message from the brain to the glands on the kidneys that produce the adrenalin and the way in which the adrenalin agitates the heart.

Most of us are a bit vague about what goes on when we breathe: what makes the lungs expand? An animation shows how the diaphragm moves down, lowering the pressure in the cavity of the chest so that the lungs are inflated. This sequence immediately explains why a heart-lung machine is needed if the chest is opened for an operation on the heart.

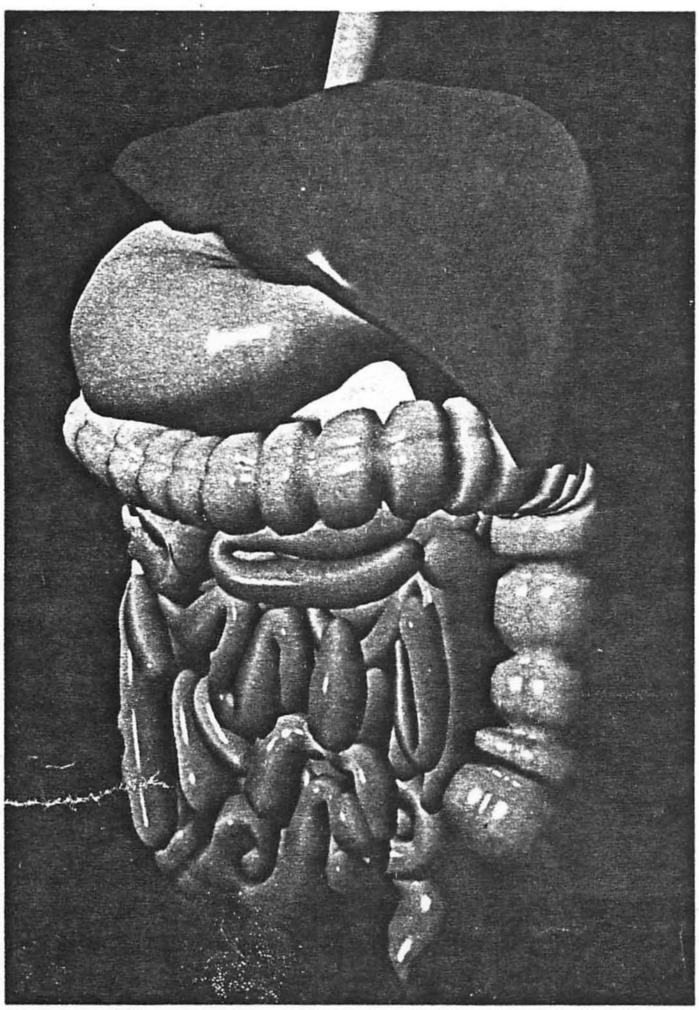
Realistic computer animation is a marvellous way of explaining what is going on in the body because, despite its complex processes, it produces an image that is remarkably simple. While medical cinematography has achieved marvels, non-medical people find it difficult to understand what is going on. Some processes, such as the release of adrenalin are invisible and cannot be filmed.

For those who have to explain an operation to a patient, computer animation portrays the operation clearly, yet in a cleaned-up version. It is at least interesting to know what has happened when our coronary artery has become blocked – a "heart attack" – and fascinating to know how by-passes will be fitted. But it would be confusing and possibly alarming to see a film of the actual operation, with the clamps and the pipes and the heart-lung machine all visible. Similarly, it is helpful to patients to show them how a hip joint can be replaced; but it is unnecessary to show the instruments used in the operation.

Explaining operations to patients will probably be the main use of the databank at Columbus. Educational applications could probably never justify the cost in programming and the computer time to generate the images. But as Csuri has said, there is an immense demand for ways of explaining surgery to patients, and, perhaps even more, to those who are forced to make decisions for patients. People who are very old and unsure in their minds, and the very young who cannot give valid permissions for operations, must have decisions made for them. Anyone placed in the position of making so important a decision for someone else will welcome the clarification that realistic computer graphics can give ●

The Living Body *starts on Wednesday, on Channel 4, at 6.30pm. An associated book.* The Living Body *by Karl Sabbagh with Christiaan Barnard, will be published on October 11 by Macdonalds at £12·95.*

Answers to quiz: 1 (b); **2** (b); **3** (a); **4** (a); **5** (a); **6** (a); **7** (c); **8** (a); **9** (c); **10** (a).



23 A closer look at your inner self

Enter the world of computer graphics – remarkably realistic 3-D animated images which are playing an important part in medical education (left: liver and intestines). Tony Osman, our Science Editor, explores this new application of technology in Ohio, where the images originated.

Columbus Business Journal®
Central Ohio's Business, Industrial, and Financial Newspaper July 1983

Cranston-Csuri Perfects Three-Dimensional Graphics

Journal Report

Special effects sell movies like "Return of the Jedi." Cranston-Csuri Productions of Columbus is trying to sell WCMH-TV to its viewers in much the same way.

Millions of mathematical equations create the computer-generated three-dimensional graphics on "WCMH-TV" and "Newswatch" that blaze across the Channel 4 screen.

Station Manager Gary Robinson says the station is very proud of the graphics. "It is a good crisp, clean look," he says.

The formal name for that look is "computer-generated three-dimensional solid-shaded raster graphics."

Charles A. Csuri, and Ohio State University professor who has been researching computer-generated graphics for 18 years, says developing the technology for three-dimensional animation has been a cumulative effort of many researchers.

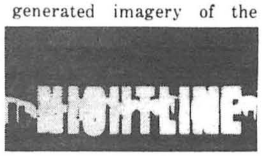
"What we have been able to do is perfect the technique," he says.

Csuri established Cranston-Csuri Productions in September 1982 with Robert Cranston Kanuth Jr., chairman of Cranston Cos. To date, the firm primarily has created animation for television and films.

In addition to its work for WCMH, Cranston-Csuri has produced commercials and promotions for NBC Television, ABC Sports, the United States Football League, and Kircher, Helton & Collett in Dayton for Huntington Bank.

In the Huntington Bank commercial, the firm produced a graphic of Cleveland's Union Commerce turning into a graphic of Huntington Bank, symbolizing the merger between the two.

Cranston-Csuri is currently working on a series of films for Goldcrest Multimedia Television in London, the major financial backer of the Academy Award-winning "Chariots of Fire" and "Gandhi" films. This project will include computer-generated imagery of the human body and its functions.



ABC Network

Video games are another facet of the business. For CBS Electronics, Cranston-Csuri has created "Solar Fox" and "Tunnel Runner," two video games soon to be released.

Computer-generated animation also is of use to architects and developers. The firm created a three-dimensional graphic of the Huntington Center unders construction in downtown Columbus. Prospective tenants can see how the building will look—inside and out—through animation.

Csuri says in the future the firm will more actively develop computer-generated graphics for the medical field—in education and X-ray technology.

Also, he expects more use of graphics by the military. The firm is already developing software for defense document transmission—or the sending of pictures over telephone lines.

Marketing Director Patricia Moore says Cranston-Csuri's billing has been "substantial." The business and technical staff has doubled since fall to 17, and Moore expects it to double again soon.

Csuri says the computer-generated graphics market is growing at a rate of 20 percent a year. "That's faster than the computer industry itself," he says. "The opportunities are very exciting."

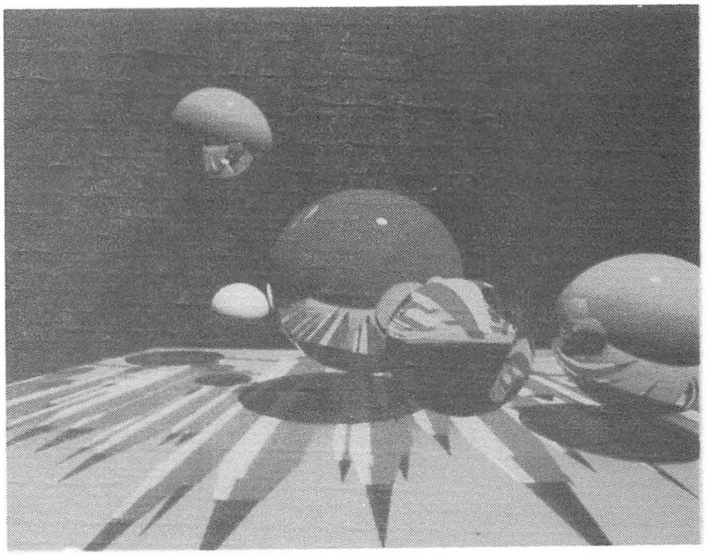
CUPPING—Computer-generated graphics illustrate the three-dimensional quality of Cranston-Csuri Productions. The firm is blazing a new graphic image for WCMH-TV in Columbus, as well as building an impressive repertoire for clients around the world. See stories on pages 10 and 11.

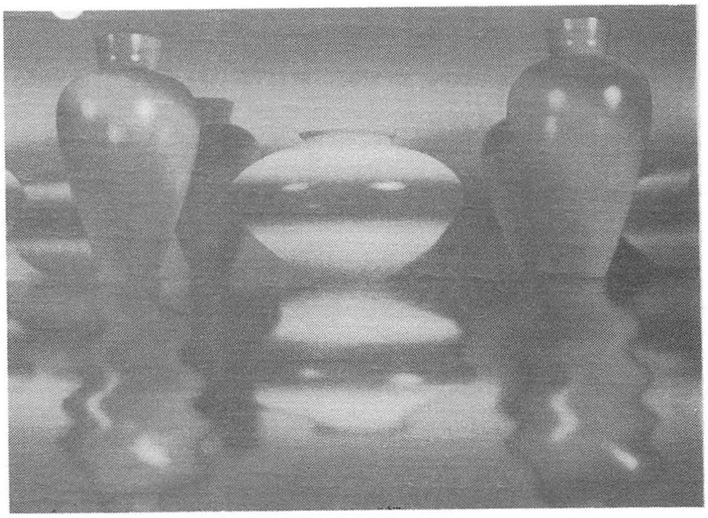
IEEE Computer Graphics and applications

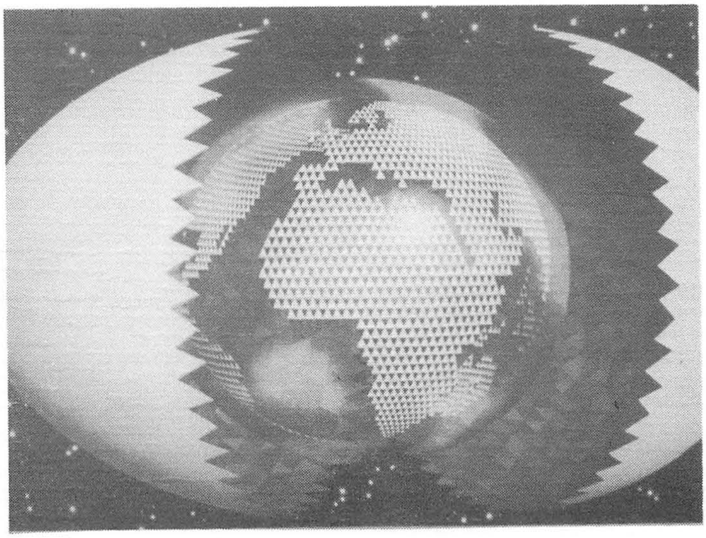
August 1983 Volume 3 Number 5 (ISSN 0272-1716)

DISPLAYS ON DISPLAY

Editors:
Frank Crow and Charles Csuri







Welcome, one and all, to Pencil City

Working at Cranston-Csuri Productions, Inc., in Columbus, Ohio, Hsuen-Chung Ho and Michael T. Collery produced "Pencil City and Balls" (top right) on a VAX 11/780 and displayed the image on a 640 × 484 × 32-bit frame buffer. The image was created through the use of polygon-based and ray-tracing display algorithms. (Ho developed the ray-tracing algorithm with an improved antialiasing method.) The reflection and refraction on the balls, as well as the perspective view of the ground image, were calculated during the ray-tracing process.

Using the same hardware, Collery also produced our other two images: "Vases on Water" (center) and "Rebirth" (bottom). The "Vases" raster image was created by layering three-dimensional images. Frame buffer averaging was used to defocus selected image layers, and the illusion of water was achieved by translating pixels based on random sign waves. The vases themselves were created using software developed by Wayne Carlson; the display software was the creation of Frank Crow, Ho, and Collery.

"Rebirth," which made use of the same display software as "Vases on Water," utilizes polygon-based coloring techniques. The cloud layer was created by transforming a frame buffer image into a vertex color file. The continents were created by reading an image from a frame buffer and developing a flat polygonal surface, which was then mapped onto a sphere.

C/C.P.
Cranston/Csuri Productions, Inc.

RECEIVED
MAY 24 1985

May 21, 1985

Mr. Oliver Strimpel
The Computer Museum Store
300 Congress St.
Boston, MA 02210

Dear Oliver:

As you requested, I have enclosed one color and three black and white stills of Snoot & Muttly. Please return at your convenience.

Thanks for your interest.

Cordially,

CRANSTON/CSURI PRODUCTIONS, INC.

Patty Moore

Patricia A. Moore
Corporate Communications Director

Enclosure: (3) 5x7, B&W, (1) 4x5, color

PAM/bdf

Cranston Center
1501 Neil Avenue
Columbus, Ohio 43201
614/421/2000

October 24, 1984

AIRBORNE

Mr. Oliver Strimpel
Curator
The Computer Museum Store
300 Congress St.
Boston, MS 02210

Dear Oliver:

As we discussed, I have enclosed our recent demo reel and information kit containing updated fact sheets. Please discard any past fact sheets you've received.

Thanks for your interest.

Cordially,

CRANSTON/CSURI PRODUCTIONS, INC.

Patty Moore

Patricia A. Moore
Communications Director

PAM:vrb

Enclosures: Demo Reel
Information Kit

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FACT SHEET/EQUIPMENT 10/17/84

HOST COMPUTERS:

VAX-11/780 with 4 megabytes of main memory, 3 300 megabyte disks, 6250 BPI tape drive, 32 bit frame buffer and 32 terminal lines.

VAX-11/780 with 4 megabytes of main memory, a 67 megabyte disk, a 484 megabyte disk, high speed tape drive, 32 bit frame buffer and 16 terminal lines.

VAX-11/750 with 3 megabytes of main memory, one 484 megabyte Winchester disk, 1600 BPI tape drive and 16 terminal lines. (Serves as the controller for the Megatek).

Two VAX-11/750 with 3 megabytes of main memory, 2 521 megabyte disks and 16 terminal lines.

Pyramid Technologies - 8 megabytes of main memory, data cache, 3 484 megabyte disks, a 6200 BPI tape drive and 16 terminal lines.

GRAPHICS DEVICES:

Evans & Sutherland 330, a vector-display work station.

Two IMI-500 Display for designing data and pencil tests as well as to produce vector animation; comprised of a 68000 based microprocessor with a 20 megabyte Winchester disk and 8" floppy disk.

Megatek 7200 vector device for designing data and pencil tests with a 36" x 48" digitizing tablet for data input.

Two custom-built frame buffers, or raster color display devices, used to store color information for each pixel and information for digital mixing of images. Also includes arithmetic processing capabilities.

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Eikonix camera digitizing system used to scan imagery and make an associated computer data base.

EAS 770 and EAS 300, printer circuit board layout system for designing in-house hardware.

HP7580B Drum plotter.

WORKSTATIONS:

Two Sun Micro Workstation I

One with file server with 24 bit frame buffer, one 484 megabyte Winchester disk, 2 megabytes of main memory, 1K bitmap display devices.

One diskless with 8 bit frame buffer, 2 megabytes of main memory, and 1K bitmap.

Seven Sun Micro Workstation II

One file server with 3 megabyte main memory and 2 484 megabyte disks.

Six diskless with 2 megabytes of main memory, 24 bit frame buffers and 1K bitmap display devices.

Four vector drawing terminals, one with 11" x 11" digitizing tablet.

RECORDING EQUIPMENT:

Ampex ESS-2 Electronic Still Store with three 200 megabyte disks with the ability to save and edit in real time up to 81 seconds of animation and/or live footage.

Celco CFR 4000, optical film recorder offering 16mm, 35mm, 70mm, Vistavision, 4" x 5" stills, 35mm slides, and Polaroid formats.

PDP-11/23 used as the control for the ESS-2 and a one-inch C format videotape recorder.

Camera station with Mitchell 35mm stop frame camera and color filters for multi-pass filming of vector animation from the IMI-500.

All equipment connected by an Ethernet network.

FACT SHEET 061884

Cranston/Csuri Productions was incorporated on July 1, 1981, and has been in a production mode since September 1, 1982. It is based on 17 years of computer graphics research at The Ohio State University.

Cranston/Csuri Productions develops and produces computer-generated animation based upon its state-of-the-art software and hardware technology. Its software system has been developed entirely by its own personnel. It is one of the few companies in the world that can generate high complexity three-dimensional, computer-generated images.

Computer generated animation has been produced for television commercials and promotion sequences for the following:

- ABC Sports, New York
- ABC News, New York
- CBS Sports, New York
- NBC Sports, New York
- ARD German Television
- CBC, Canadian Broadcasting Corporation
- STV, Scottish Television
- MTV, New York
- McCall/Coppola at FilmFair, New York, for 7-Up & Clairol
- Lofaro & Associates and Wunderman, Ricotta, Kline, New York for CBS Video Games; Ogilvy & Mather, New York for SmithKline
- Callner/Shapiro, Los Angeles
- Caesar´s Palace, Atlantic City
- HBO/Cinemax, New York
- L.A. Express/U. S. Football League, Los Angeles
- Marcus Advertising, Cleveland for Ohio Lottery
- COMAP, Consortium on Math Applications, (American Mathematical Association), Boston
- Kircher, Helton & Collett, Dayton, Ohio for Huntington Bank
- Gannett Broadcasting System, Atlanta
- Bay Cable, San Francisco/ J. Walter Thompson
- Diseno Grafico, Murcia, Spain for Spanish Department of Tourism

KCNC, Denver	WCVB, Boston	WTAE, Pittsburgh
KOVR, Sacramento	WFLD, Chicago	WTTG, Washington, DC
KTXA, Dallas	WFTV, Orlando	WTTV, Indianapolis
KTXH, Houston	WISN, Milwaukee	WWL, New Orleans
WCMH, Columbus, OH	WPEC, West Palm Beach	

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Syndicated animation packages have been provided for the following:

KBHK, San Francisco	KUTV, Salt Lake City	WISN, Milwaukee
KCNC, Denver	WCFC, Chicago	WTAE, Pittsburgh
KCOP, Los Angeles	WCMH, Columbus, OH	WTTG, Washington
KPTV, Portland	WDZL, Miami	WWL, New Orleans
KTXA, Dallas	WEVU, Bonita Springs	WXNE, Boston
KTXH, Houston	WFTV, Orlando	CNP Telephone
KSNF, Kansas	KSNW, Kansas	KSNT, Kansas
WHEC, New York	WVIA, Penn.	KTBC, Texas
WNYT, New York	KFVS, MO	WKBD, Michigan

Feature film markets also are presently being developed. Current clients:

Goldcrest Multimedia Television, Ltd., London, England
Project: computer generated animation for a series of 26 medical films on the human body. (Goldcrest was the producer of "Chariots of Fire" and "Gandhi").

Other market development in process:

Video games
Medical imagery for research, patient education, and computer-aided medical equipment
Architectural and engineering design systems
Educational/medical learning systems
Government/military sponsored research

FACT SHEET 061984

Awards

1984 Creativity 84 Awards, Art Direction
ABC News Globe
Cinemax

1984 Broadcast Designers Association (BDA):
Best of Show, CBS Super Bowl XVIII, CBS Sports;
Gold Award of Excellence, CBS Super Bowl XVIII, CBS Sports.

1984 CLIO Award Finalist, ABC World News Tonight, ABC News.

1984 Monitor Awards:
Best Achievement in Computer Animation, ABC World News Tonight, ABC News;
Best Computer Animator, Michael Collery, ABC World News Tonight, ABC News.

1984 ADDY Award, Columbus Advertising Federation:
Excellence in Computer Animation.

1984 DESI Award, Graphics Design/USA: Excellence in TV Graphics, ABC World News Tonight, Gannett Broadcasting, KCNC-TV Denver.

1983 Nicograph, Tokyo, Japan:
Grand Prix, Excellence in Computer Graphics.

1983 International Film & TV Festival of New York:
Medalist winners: USFL/LA Express, ABC World News Tonight, ABC Nightline, KCNC-TV Denver and Demo Reel.

1983 London Animation Festival, London, England:
Two top awards: Best Showreel and State-Of-The-Art Computer Animation.

1983 Broadcast Designers Association (BDA):
Gold Award of Excellence, USFL/LA Express, 30-second spot.

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FACT SHEET/MEDICAL 361584

Cranston/Csuri Productions, Columbus, Ohio, produces three-dimensional, computer-generated animation used for medical, scientific, and educational applications, as well as for feature films and advertising.

Based on over 17 years of research conducted at The Ohio State University, the company is staffed with professional animators and technical specialists trained in medical illustration; industrial and graphic design; computer science; mathematics and electrical engineering. Specialized hardware and software are custom-designed in-house.

Cranston/Csuri has completed the production of an extensive data base of the human body, to be used for disseminating medical information. The animation demonstrates the dynamic qualities of the body through representations of major organs, several histological studies, cells and their organelles.

Separate sets of data portray detailed physiological processes and detailed workings of the body such as the heart beating, the lungs breathing, eye movements, blood flow and microscopic functionings, such as absorption of oxygen into blood cells and the operations of the nervous, endocrine and urinary systems. The intricate interaction of organs, tissues and cellular components can be elucidated through multiple viewpoints, color control, texture, transparency and highlighting of detail afforded by the use of Cranston/Csuri´s computer graphics and animation.

Cranston/Csuri´s representation of non-regular, three-dimensional solids combined with surface biological textures and colors, allows the production of vivid descriptions of human anatomy and physiology. Cranston/Csuri´s commitment to research is continuing to provide further advances in computer graphics applications in science, medicine and education.

Current Client Projects:

Goldcrest Multimedia Television, London--extensive animation for a series of 26 films for broadcast throughout Europe.

Additional applications for computer-generated animation include:

Professional Education: New forms of treatment, new breakthroughs in research and the latest surgical techniques and to better train future health-care professionals.

Patient/Student Education: Preparatory procedures for surgery or human fetal development; detailed explanations on the body and its systems for academic settings.

Advertising: Video and film formats for training and education; single frames for publicity and promotion in brochures and publications. Planned flexibility for the integration of client products and services with the medical animation.

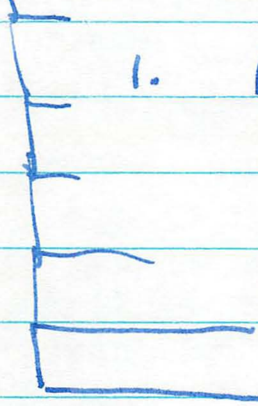
Sales Training: Simulating the effects of new drugs/products on the body to aid pharmaceutical sales and also to inform medical professionals.

Snoot & Mottly

Snoot & Muttly
Animation: Susan Van Baerle and Douglas Kingsbury, The Ohio State University.

Susan Van Baerle

Tron done this way:



__Motion__ 3 types

1. Neck, tail + neck - interpolation

Leg — inbetweening on data file

Change 1st pt on 1st leg

Animate data itself, not just position

Linear motion; one step would be 5 data files; 5 shapes — Input points

Reg k f is rotation; changed shape of leg; extended; bending at joints 3D tubular object. Hip knee ankle

2. Head, Feet; regular key-frame

+ Eyes — __event__-driven animation

+ Beaks — system

Only looks like one parameter being set in each frame

Rotation; Reg key frame animation

1. Legs all way through
2. Body
3. Neck

3. Bubbles; program control bubbles on grid.

12-15 points on grid: Randomly moved + systematically

Randomly place bubbles

Move all bubbles together, but move from vertex to vertex randomly on grid.

Grid control points.

Bubble spheroid to smooth motion.

Body : ellipse
Neck tail, leg : cylinder tubular objects
Beak : tubular object knifed
Head : Sphere + holes.

Rainbow backgrounds : Random vortex colour program.
Specify different ranges.
Goes through range & assigns random
color at each point
~~Ext~~ Interpolate across each surface

Hardware VAX 11/780
Megatek Vector Display
In-house frame buffer for raster
Electronic ~~still~~ store used to drop frames on to tape
still
Holds 780 x 3 frames ; dumps onto tape
1" Musha
Used existing software in C
Members of Ohio State

Art Educ Dept Computer Graphics Art
Masters.

Undergrade in film.
Animator

6m
1. Specific software written for this by Doug Kingsbury.
Feet left behind.
Objects had to remain attached.

Reposition
2. Character walking straight ahead.
Put path for curved walking. Circle walking.

6 months for software, background, create characters
5 months to animate

~~Felt~~ 1½ person-time ¾ time each.

Adventures of André & Wally B.

THE ADVENTURES OF ANDRÉ & WALLY B.
Summary

Alvy Ray Smith

Computer Graphics Department
Computer Division
Lucasfilm Ltd.
August 20, 1984

SUMMARY

The Adventures of André & Wally B. is a demonstration of several things:

First is full classic *character* animation - as opposed to effects animation - the animation being fully 3-D and designed by a professional animator, Disney-trained in this case.

Second is articulated motion blur. In particular, the two characters, André (the android) and Wally B. (the bee), are always motion blurred.

Third is very complex 3-D background sets, realized here with particle systems.

Fourth is laser input scanning, the background cards for the credits being some of the first input scans from the new Lucasfilm laser scanner.

The sound track was partially produced using the ASP, the Lucasfilm digital audio system.

Since this is a demo, it is rendered at only 500-line video resolution. We plan to output the completed piece on the laser scanner but the current version is filmed directly from a video monitor.

The completed piece was premiered at the International Animtaion Festival in Toronto, August 17.

THE ADVENTURES OF ANDRÉ & WALLY B.
Credits

Alvy Ray Smith

Computer Graphics Project
Computer Division
Lucasfilm Ltd.
August 15, 1984

FILM CREDITS

Forest design and rendering: William Reeves.

Character design and animation: John Lasseter.

3-D animation program: Tom Duff, Eben Ostby.

3-D rendering: Rob Cook, Loren Carpenter.

Concept/direction: Alvy Ray Smith.

Andre and Wally models: Ed Catmull, Tom Duff, John Lasseter, William Reeves, David Salesin, Alvy Ray Smith.

Laser scanning: David DiFrancesco, Tom Noggle, Don Conway.

Computer logistics: Craig Good.

Sound design: Ben Burtt (Sprocket Systems).

Texturing/compositing software: Steven Baraniuk, Sam Leffler, Tom Porter, John Seamons.

Cray XMP-2 and Cray XMP-4, Cray Research Inc.: Bence Gerber, Steve Perrenod, John Aldag, Janet Low, Tom MacDonald.

10 Digital Equipment Corporation VAX 11/750s: Project Athena, Massachussets Institute of Technology.

SOFTWARE

gt ("Get picture"): Picture retrieval program (from disk) by Thomas Porter.

gtxt, svtxt ("Get Texture, Save Texture"): Texture formating programs by Sam Leffler.

hv ("Horizontal, Vertical"): Filtered size changer by Alvy Ray Smith.

md ("Motion Doctor"): 3-D animation program by Tom Duff, with extensions by Eben Ostby and William Reeves.

me ("Model Editor"): 3-D modeling program by William Reeves.

mg ("Merge"): Compositing program by Thomas Porter.

mi ("Model Instantiator"): Inbetweening program by William Reeves.

mktree ("Make Tree"): Tree, grass, and flower generator by William Reeves.

mp ("Model Previewer"): Animation pencil testing program by Steven Baraniuk and Loren Carpenter.

paint: 2-D painting program by Thomas Porter.

reyes ("Renders Everything You Ever Saw"): 3-D rendering program with motion blur, hidden surface removal, texture mapping, bump mapping, etc., by Rob Cook and Loren Carpenter.

td ("Terrain Dicer"): 3-D database subdivision program by Eben Ostby and William Reeves.

HARDWARE

Adage/Ikonas 32-bit framebuffers and microprocessor.

Evans & Sutherland Picture System II vector display.

Hitachi tablets.

Fujitsu Eagle winchester disk drives.

Control Data Corporation removable disk drives.

Digital Equipment Corporation VAX computers: Three 11/750s and one 11/780 at Lucasfilm, ten 11/750s at Project Athena of MIT.

Cray Research Inc. computers: One Cray XMP-2 and one Cray XMP-4

LUCASFILM Ltd

18 June 1985

Mr. Oliver Strimpel
The Computer Museum
300 Congress Street
Boston, MA 02210

Dear Mr. Strimpel:

Per your request Alvy Ray Smith has agreed to send you the following image for the next issue of your quarterly publication:

Andre & Wally B. slide

The slide is enclosed along with a description. You have permission of the Lucasfilm Computer Graphics Division to use the slide listed above. It must not be used for any other purpose or otherwise duplicated without express written permission.

Complete and proper credit must be given for the image with its presentation. Please sign and return the copy of this letter indicating agreement with these conditions and return the slide to us as soon as possible after its use.

I apologize for the delay in getting this to you; hopefully it has arrived in time for use. If so, I'm sure Alvy would appreciate receiving a copy of the publication.

Sincerely yours,

Lynn DeKeyser

Lynn DeKeyser
Computer Research and Development

I agree:

____

P. O. Box 2009, San Rafael, California 94912 Telephone (415) 457-5282

Telex: 330499 LFL SRFL

THE MAKING OF ANDRÉ & WALLY B.
***** DRAFT October 8, 1984 *****

Alvy Ray Smith

Computer Graphics Department
Computer Division
Lucasfilm Ltd.
August 21, 1984

INITIAL CONCEPTS

Upon returning from SIGGRAPH 83‡ in Detroit, Ed Catmull and I decided we would push for a big show at SIGGRAPH 84. This would include publishing many of the results developed by the Graphics Department personnel since its inception and finishing the prototype Pixar compositing station hardware and displaying it. We would also make a short demonstration of 3-D character animation to show at the SIGGRAPH 84 film show.

The production group was to consist of Bill Reeves and Tom Duff for modeling and animation and Rob Cook and Loren Carpenter for rendering. The purpose of the piece was to center our software and algorithm development efforts on a definite goal. Bill and Tom had already developed the rudiments of a modeling/animation system as part of their contribution of a 3-D "holographic" display device to *Return of the Jedi.* Rob and Loren were to implement their new rendering algorithms in software to simulate future hardware developments (the Pixar 3D) anyway. This project seemed to be a natural extension of efforts already underway. Furthermore it provided a chance to do a small piece of production. Members of the Graphics Department (formerly the Graphics Project) tend to find short productions stimulating, and it had been over two years since the last one involving the whole group, the Genesis Demo for *Star Trek II: The Wrath of Khan.* The piece this time was to be strictly an in-house production for demonstration purposes only.

My original proposal to the group was very simple. An android would wake up in a woods, get up, turn around, see a beautiful scene, and be happy at seeing it. The goal as stated in the meeting notes of July 31, 1983, was "to render a showable sequence of 3-D articulated animation, with edits, in a rich setting. Motion blur very desirable, texture/bump mapping mandatory." The piece was meant to be symbolic: A computer-animated 3-D character wakes up and sees the world.

The original storyboard consisted of nine crude thumbnail sketches with the following captions:

1. Dark forms.
2. Sunlight breaks through in shafts. Establish that light is breaking through in several places.
3. X-diss (cross-dissolve) to highlit area which is forest-like but moves occasionally.
4. Android, camouflaged, sits up. Hard to distinguish him from forest.

‡ SIGGRAPH is the Special Interest Group on Computer Graphics of the Association for Computing Machinery (ACM). It holds an annual conference; SIGGRAPH 83 is the conference held in 1983. Each conference has technical paper presentations, tutorials, panel discussions, an art show, a film/video show, and an equipment show. SIGGRAPH 84 was held July 25-27 in Minneapolis. Approximately 20,000 people attended.

5. CU (closeup) from below. Yawn. Stretch. Camouflage begins to melt in face.
6. Medium shot to watch arising android. Less and less camouflage; more and more skin.
7. He arises. More sun. Less and less camouflage; more and more skin. He smiles and reaches out.
8. Cut to CU of smile. Full day attire. Sunrise and mountains reflected in face.
9. Cut to glorious back view long shot. Pull away a bit during shot.

The motivations were several. First, we wished to show *articulated* animation as opposed to rigid-body animation so popular with most computer graphics houses. Second, we wanted a *character.* This was the reason for the android stipulation. My first drawings of him were nothing more than a stick figure with long skinny ellipsoids instead of sticks, but he had definite arms, legs, torso, and head. Third, I wanted to show filmmakers, particularly within Lucasfilm, that our group knew about editing and other cinematic techniques.

The forest set was motivated by talks earlier in the year with a group from Walt Disney Productions. The group was considering producing an animated piece to be called *The Brave Little Toaster* and wanted to know if we could produce a computer-generated 3-D forest set through which conventionally animated characters would move. One member of this group whom I quite liked was John Lasseter. As will be seen, John figures prominently in the remainder of this story. At the time, however, I quickly volunteered that we could do an elaborate forest set, a belief based on my predilection for rendering plants and trees. So, having already convinced myself that we could do a forest, it was natural that a forest set was what I first thought of for the new piece.

I had referred to the android as "André" in early presentations of the storyboard, and the name stuck. We stumbled over several names for the piece-to-be such as *Androids Awake* before settling on a joke name, *My Breakfast with André,* in honor of a film many of us admired, as our internal name. Perhaps the most interesting parts of this story are how the initial concepts outlined above transformed into the finished piece, *The Adventures of André & Wally B.*

INTERESTING TWISTS

Two important events occurred during the early stages of the production. I count these as two of my best moves as director and don't want to imagine what the piece would have been without them.

First, I suggested to Bill Reeves that he might apply the particle systems he used so successfully for fires in the Genesis Demo of *Star Trek II: The Wrath of Khan* to make trees. This took a little ego-eating on my part because up until that time I had been the only member of the group who had made pictures of plants. There is an unwritten "law" that forbids any of us from stepping into territory already claimed by other members of the group. The strength of our group depends on such respect for the other members and their sensitivities. Now I'm sure Bill had already thought about making particle system trees but he needed an okay from me to do so. Whether he did or not, I gave it to him. I did not have time to build forests in addition to my other responsibilites, and he needed something to turn his considerable creativity to. The success of the final forest sets attests to the "wisdom" of this early decision.

Second, I heard that John Lasseter was between jobs at Disney and urged Ed Catmull to hire him as a consultant. Ed and I had visited John at Disney since his original visit to Lucasfilm. He had shown us through the Disney archives, a tremendous treat to both of us. He continued to impress me with his willingness to consider using the computer in animation. He had already helped in a test with MAGI of Elmsford, New York, which used a computer generated camera move in a 3-D background as a guide to conventional animators for creating the foreground action for *Where the Wild Things Are.* He was one of the handful of conventional animators we had met over the years who seemed to see the same promise of computer-mediated animation that we saw.

In November 1983, Ed called me from the Queen Mary in Long Beach where he was giving a talk. During the course of our conversation, he mentioned that he had run into John at the meeting and that John was between jobs at Disney. He had finished the MAGI test and was waiting for further developments on *Toaster*. Without hesitation, I quickly and strongly urged Ed to find John and offer him a consultant's position with the Graphics Department immediately. Luckily, I had put just such a slot in my most recent budget. Ed did it, and John joined us for what was to be a fine collaboration. He was officially a consultant hired to advise us - particularly Tom Duff - on our 3-D animation program interface, which we realized would suffer without such professional input.

A third event which was to have a major impact on the project was the involvement of Cray Research Inc. in it. It had been clear to Ed and me for some time that we were greatly lacking in graphics computation power. We had begun a search - still underway - for cost-effective computers to replace our reliable but very slow VAX's. The so-called supercomputers, those of Cray Research and Control Data Corporation, were immediate candidates. This fit in exactly with the desires of Bence Gerber, our local Cray sales representative, who was looking for placement of a Cray in a commercial environment. It turned out that Cray allowed us to use our rendering software in the production of *André & Wally B.* as a serious benchmark of real code running on their machine. The piece would have been impossible without this involvement.

In all, we used five VAX's at Lucasfilm, ten VAX's at Project Athena at the Massachusetts Institute of Technology, and two Cray's at Cray Research in Mendota Heights, Minnesota, for the 1.8-minute piece. The Cray machines used were a two-processor Cray XMP-2 and a four-processor Cray XMP-4, the most powerful machine in the world at the time (four cpus working in parallel), and just announced.

NAILING IT DOWN

The production now began to take definite shape. Bill began a search for effective ways to generate complex trees. I brought in all my tree books for inspiration as well as pages torn from my home state's magazine *New Mexico Magazine*. John brought a stack of *Arizona Highways* magazines from the Disney reference collection for further ideas. Before long, the Graphics Room monitors were displaying very nice evergreen trees which Bill modeled after red spruces.

Bill also began modeling the forest environment for the animation - i.e., the set. We originally planned a Grand-Canyon-like landscape with a forested cliff. André was to run to the edge of the cliff to see a very elaborate scene. Bill used his model editor program **me** for this task. He soon had large forest floor plans covering the walls and tables of the Graphics Room. These proved themselves very valuable in later planning of camera moves and character placements.

One of the original storyboard ideas was that of a camouflage texture on André which disappeared with the increasing light at sunrise - a substitution of day texture for night texture. This required a leaf-strewn forest floor into which André could be camouflaged. We chose aspens as our deciduous species. This should not be surprising considering the magazines we were using for inspiration.

Bill designed a special rendering system to make his trees. It was based on the line-drawing software of Tom Porter. He added subtle coloring schemes to his program's capabilities so that it could handle non-real lighting schemes. One of John's first suggestions was that we use a Maxfield Parrish lighting model. The production staff had trooped down to San Francisco to see an exhibit of Parrish's works to understand his colorful backlighting. Rob Cook helped Bill design a method for simulating the internal shadowing so important to effective plant rendering and also a method for mutual shadowing of the trees.

Tom Duff was very inspired by the presence of a professional animator who would use his 3-D animation system. He immediately added many of the features John requested after his first few tries at the new system. For example, computer scientists always number from 0 but animators always number from 1. So Tom changed his 0-origin displays to 1-origin displays.

When I showed John the crude storyboard described above, I encouraged him to use it only as a guideline. In particular, the stick figure André could look entirely different so long as he remained an android. I told him that, although we would eventually be able to model complex plastic shapes, it would be far easier for us if he would try to stick to modeling from simple primitives such as ellipsoids and cylinders. I also showed him a little figure I had always admired and hoped to be able to computer generate someday. It is an airbrush picture by Charles White III called "Running Chrome Man" which I saw in a book called *Air Powered: The Art of the Airbrush* produced by Richard Childers for Random House, New York, 1979. The picture is an apparently 3-D cartoon man made entirely of chrome.

John took this input back to Los Angeles for a few days; he was working only occasionally with us at first while he finished up a few projects. He sent us some sketches of his first ideas for André in many different poses. He had carefully adhered to the restrictions we had imposed. The first response of most of us to his designs was one of mild surprise at the cartoon-like quality of the figures. But I reminded the group that we had given John great design freedom and he had designed in the Disney tradition with which he was very familiar. In fact, one of the things we wanted to stress to people was that the new medium of computer imagery carried the "look" of the artist using it, not that of the computer. John must have sensed that we would respond this way because he asked rather tentatively whether the cartoon-like influence was okay. I assured him it was, though a surprise to us. It shouldn't have been a surprise to me, considering the running chrome man. By the end of the project, everyone had forgotten they ever questioned John's designs.

I took John's sketches of André and began realizing them as a computer model. This was done by writing a description of the model in a language designed by Bill Reeves and Tom Duff called, appropiately enough, **model**. The language is very powerful and extensible. In other words, all the usual primitive forms - spheres, ellipsoids, cylinders, points, lines, patches, polygons, cones, etc. - used by computer graphicists are available in the language, plus it can be extended to handle new forms invented as we go along. André's model required two such extensions, so the extensibility capability turned out to be of basic importance. The final model required 26 pages in this language. It resembles a program written in a C-like programming language and requires the same kind of care.

One of the first attempts at the model used a sphere capped by a cone to realize André's torso. The cone was articulated about the sphere to model bending at the waist but John felt this was just too sterile. All his early thumbnail sketches of the character had a more plastic shape, in the expressive style inherited from Disney's Fred Moore. Ed Catmull claimed he could make a new primitive shape which would fill the bill, and he proceeded to invent it. It is a shape called the "teardrop" which allows a fluid bend between its top and bottom rounded forms. This shape was added to the **model** language and got used in a variety of ways in the final piece.

Other shapes which we just could not successfully model with the original primitive forms were André's eyelids and mouth. David Salesin, aided by Ed Catmull and Loren Carpenter, invented a new form to solve this problem and it was added to the model language and to André's model. This was called the "bound" and consisted of a spline-bounded area confined to the surface of a sphere. These two extensions were key to John's ability to give André convincing character.

John drew up a complete storyboard of about fifty panels which helped us tighten up the story considerably. He labeled the final panel "the most complex scene ever rendered by computer graphics". His storyboard drawings joined Bill's forest floor plans to decorate the walls of the Graphics Room for the duration of the production.

John arged that we needed a motivation to move André to the edge of the cliff. He suggested a second character to interact with André, a large bee with a nasty streak in him and a sharp stinger. Homage to the same movie as before dictated that his name be Wally. A production crew brainstorming session modified this into Wally B. The working title changed to "André & Wally B.". "The most complex scene ever ... " eventually bit the dust as did several others in the mad rush for the SIGGRAPH 84 deadline.

John's design for Wally included four teardrops as "feet" to be animated as if they were water balloons. His animation skill was admirably demonstrated by pulling this off, using the computer, of course. Two visitors who were quite impressed by this feat were animation masters Frank Thomas and Ollie Johnston, two of the great "nine old men" who made Disney famous (see *Disney Animation: The Illusion of Life* by these two gentlemen for Abbeville Press, New York, 1981). The basic animation laws of squash and stretch, anticipation, overlap, and follow through *(ibid,* p. 47) were all demonstrated by this piece of animation. Most importantly to us, they saw a convincing demonstration that none of this was alien to computer animation.

By animating early versions of the André and Wally models, John got used to Tom Duff's animation program md (for "motion doctor"). He not only suggested many improvements to the program during this period but also to the models. Animation controls were added to the model as John needed them - another form of extensibility which proved to be very important. The final form of the André model had 547 animation controls, and the final form of the Wally model, by Bill Reeves, had about 252 controls. One of the successes of the animation program was a presentation of this large number of controls to John in such a natural way that he was unaware of the complexity. The large number of controls required for these apparently quite simple cartoon characters reinforced our belief that animation of characters of human-like complexity will be tremendously difficult, even with the addition of constraints such as gravity and fixed musculature.

John created a set of pastels for background and color inspiration. He and Bill Reeves began one of the most productive collaborations of the piece at this time, sharing thoughts on colors, lighting, tree and rock placement, and the long trucking shot through the forest as the opening. This was to be the one animation of the camera through the background in the film to clue the audience into its 3-dimensionality. All other depth information was carried by the foreground characters in order to save computation time. We had originally planned a funny "helicopter" pull-away shot at the end but it got cut in the squeeze for time and computer cycles.

Bill used John's pastels as guides for the elaborate background sets featured in the final piece. They are all 3-D even though the camera does not animate through any of them except the first. The pastels themselves ended up in the final film as background cards for the credits. They were filmed as slides which were then scanned into the computer by laser team members Tom Noggle and Don Conway using the new laser scanner just completed under the direction of David DiFrancesco.

Meanwhile, Rob Cook and Loren Carpenter were perfecting the rendering software which would be used to turn the animated models into finished, fully colored and textured elements to be composited into each frame over Bill's backgrounds. Sam Leffler helped them by writing special purpose texture storage and retrieval programs. Two papers on motion blur had been presented at SIGGRAPH 83 which did not fully solve the problem so Rob and Loren set out to find a complete solution. Without motion blur, animated characters and sets tend to "strobe". This means that each image doubles up - a distracting departure from real-world motion. The solution is to blur every part of an object in the direction of its motion as if it were moving with the camera shutter open. In conventional animation, this is impossible so animators have invented some techniques to approximate motion blur. A familiar trick is the addition of "speed lines" to indicate the blur of a fast-moving character. Another is to show several positions of a character along its path of motion, only the last of which is fully rendered - like a multiple exposure. Sometimes these two tricks are combined. In computer graphics, the problem can be completely solved although no one had done so until Rob and Loren, aided by Tom Porter, turned their attention to it. What makes the problem hard is the fact that objects become visible and invisible *during* a motion - a 4-D problem.

Ed Catmull also made an attempt at this problem. This created a situation of friendly competition in the group which resulted in both teams producing a better result than either would have found without the rivalry. It turned out that Ed solved the problem too, but the group thought that the solution by Cook, Porter, and Carpenter (a paper of the proletariat!) was of more general applicability than Ed's. Nevertheless, both groups published their solutions at SIGGRAPH 84. These were two of seven papers by the Graphics Department published at SIGGRAPH 84, 23% of the technical papers at the conference.

Rob and Loren implemented their solution in a program called **reyes** (for Renders Everything You've Ever Seen), with Rob principally responsible. Thus André and Wally are always motion blurred in the film. Rob included in the program his new technique for specifying and controlling texturing and shading, called "shade trees", the subject of another of the Lucasfilm papers at SIGGRAPH 84. **Reyes** is our principal rendering system, consisting of about 45,000 lines of code in the programming language C. One of the main purposes of *André & Wally B.* was to test the algorithms realized in this program, some of which will eventually be committed to hardware in the Pixar 3D picture computer. One of the major accomplishments of the project was the completion of a piece which relied on totally new algorithms and their realizations in software.

THE MIDDLE MONTHS

While Bill was developing his tree and grass program **mktree**, John was animating several shots, and Rob and Loren were implementing **reyes**, several changes occurred in our internal makeup. Tom Duff, who had been with some of us for eight years, decided to leave and join Bell Labs. Being the sensitive and honorable person that he is, Tom did not make his move until his animation program **md** was fully functional and solid. It was the animation workhorse for *André & Wally B.* Fortunately, Eben Ostby wanted to move over from the Computer Division Systems Group to the Graphics Department. We brought him over and he immediately made some additions to the animation program with Bill's assistance. These had been requested by John Lasseter, as usual, to ease the animation task.

Another person, Craig Good, moved into the Graphics Department at this time. Craig had been helping us a great deal anyway in the seemingly infinite logistics problems, so we just made him official. He took charge of all logistics: backups, filming, optical house negotiations, camera rental, tape and disk management, etc. This is one of the most important parts of any animation, particularly computer animation, but it tends to be unsung. He joined Eben in immediately becoming strong members of the production team.

I heard that Tom Duff was attracted to Bell Labs by - among other things - the possibility of working on a Cray supercomputer. He did not know that we would soon be involved with Cray in a substantial way. None of us did at the time he left. Cray Research Inc. agreed to let us implement **reyes** on their in-house machines as a serious benchmark of our production software. This began a generous contribution of computer time and software assistance by Cray Research. Rob, Loren, and Eben were to spend many, many hours at the Mendota Heights facility running this test. Steve Perrenod, a Cray software analyst, in particular, gave us much help in adapting our software to the Cray machines. John Alldag, Janet Low, and Tom MacDonald made life easier for the group who spent many sleepless nights in Mendota Heights; the most readily available slots on the big machines were at night in the wee hours.

THE BIG PUSH

As SIGGRAPH 84 neared, and since we had chosen this as our deadline, the effort to finish *André & Wally B.* intensified. Bill began using all five VAX computers at Lucasfilm. Three of these are used by other groups during the work day, so Bill made sure that they were computing backgrounds for the piece during the night. He also arranged with a friend of his to use idle time - again at night - on the ten VAX 11/750s which form the Project Athena network at MIT. These were all employed to compute the opening trucking shot across Bill's forest of 46,254 trees, all different. Bill invested immense amounts of time in the effort of mananging all these disparate computing resources while continuing to develop the details of the individual backgrounds. Eben Ostby, again with Bill's assistance, implemented a hidden surface solver for this shot and the backgrounds.

Rob and Loren began spending more and more time at Cray in Mendota Heights, mastering a different operating system environment and helping Cray to debug its new C compiler. Later Eben joined the Mendota brigade. These three were to demonstrate superhuman powers of endurance in the final race against the clock. During the last week of computations before

SIGGRAPH 84, Rob got four hours of sleep in a week and Loren got six! They literally hand scheduled the four processors of the Cray XMP-4 and the two processors of the Cray XMP-2 to keep all six cpus operating at close to 100% capacity. They not only generated nearly all the André and Wally elements but also composited them against Bill's backgrounds at Cray. Occasionally one of the three would return to Marin County for a two or three day breather. Each would arrive carrying the latest results and would return carrying the latest changes.

A sound track was clearly needed to bring the piece together. I had approached several members of the Digital Audio Project asking for help, but they were gunning for their own deadline on the digital mixers for Lucasfilm's Skywalker Ranch and could not help. As sort of an afterthought - never believing he would even hesitate before saying No - I approached Ben Burtt whose studio is in our building at Lucasfilm. Ben is the Academy Award winning sound designer for such films as *Star Wars* and its sequels and *Raiders of the Lost Ark* and its sequel. Much to my surprise and delight, he said he had nothing creative to do for a week or so and besides he was rather intrigued by the weird project upstairs anyway. Arrangements with Jim Kessler, manager of Sprocket Systems, our post-production division, went smoothly and Ben did our sound track! This was the last of the surprising twists to which I attribute the success of *André & Wally B.* Together these twists turned a test into a piece.

John, Craig, and I shot pencil tests and edited them into a locked print for Ben's audio effort. We used a program for rendering pencil tests by Steven Baraniuk, an MIT student working with us for the summer. Visits to Ben's studio found him blowing through stretched rubber bands and swinging toy jets around his head to find a sound for Wally. He eventually used a cousin of the Bronx cheer mixed with a "thhip - thhip - thhip" sound (a tribute to *Apocalypse Now* he says) for Wally made with his own tongue. Other sound sources used were a ricocheting bullet recorded in Utah, a thump on a balloon, and reverberations of a sheet of plastic. These were combined with cartoony music Ben selected from a sound library in San Francisco for the final track. Parts of the track were processed with the ASP (Audio Signal Processor) by our Digital Audio Department.

Ben had some discomfort with the "story" as we first presented it to him. This inspired John to change it slightly for a cleaner ending. This suited me fine since it required less animation and less rendering, both of which we had no time for. Furthermore it was a better story.

Craig made all the arrangements for camera rental from Alan Gordon Enterprises in North Hollywood and with Monaco Labs in San Francisco for negative cutting and prints. Monaco agreed to work overtime so that we could compute every last minute before show time in Minneapolis at the Electronic Theatre of SIGGRAPH 84. As it turned out, I got the answer print from him the morning it was to show in Minneapolis and never got to see it until it went on the screen that night.

Craig, Bill, John, and I were also not sleeping during the last week, but I don't believe any of us matched Rob's or Loren's effort. Another person who unexpectedly joined in for the final push was John Seamons, from the Systems Group, who cracked a magtape from Cray when several others had failed to do so. John's effort was greatly appreciated; it saved us many hours, every one of which counted at this point. Another who helped in the last push was David Vezie who backed up our precious frames onto magtape as they arrived from Cray. We had five disk crashes during the last two weeks - after having none for over a year - so such precautions were mandatory.

SIGGRAPH 84

Much to our surprise, George Lucas announced almost at the last minute that he was going to the SIGGRAPH 84 the night of the Electronic Theatre. When Cray Research heard this, they gave us one final day's worth of computing which we didn't expect. But even with this fine gesture, we were not quite able to finish all the necessary computations. We decided that it should be shown anyway, since it was so near completion. Because Bill had completed all the backgrounds, we decided to put pencil-test line drawings over the backgrounds for the two shots (about six seconds) which were incomplete. The sound track was complete and delightful. We believed the SIGGRAPH people would like to see the mechanics of the production. Furthermore, after the valiant efforts expended by the group to show the piece to our colleagues at SIGGRAPH, I could not dare suggest that it not be shown!

The big week arrived. The Lucasfilm Graphics Group made a big showing with seven technical papers, four tutorials, two panels, the presentation of the Pixar 2D, and, of course, *The Adventures of André & Wally B.* We announced just prior to showing it that it would be completed and premiered in three weeks at the International Animation Festival in Toronto. We also announced that it would eventually be laser scanned onto film. George came to our champagne celebration afterwards and offered his congratulations. He was lost in a room full of bright red tee shirts featuring André and Wally. These were designed by John Lasseter as one of his last creative efforts before departing for Los Angeles to co-direct *The Brave Little Toaster.*

FILM CREDITS

Forest design and rendering: William Reeves.

Character design and animation: John Lasseter.

3-D animation program: Tom Duff, Eben Ostby.

3-D rendering: Rob Cook, Loren Carpenter.

Concept/direction: Alvy Ray Smith.

Andre and Wally models: Ed Catmull, Tom Duff, John Lasseter, William Reeves, David Salesin, Alvy Ray Smith.

Laser scanning: David DiFrancesco, Tom Noggle, Don Conway.

Computer logistics: Craig Good.

Sound design: Ben Burtt (Sprocket Systems).

Texturing/compositing software: Steven Baraniuk, Sam Leffler, Tom Porter, John Seamons.

Cray XMP-2 and Cray XMP-4, Cray Research Inc.: Bence Gerber, Steve Perrenod, John Aldag, Janet Low, Tom MacDonald.

10 Digital Equipment Corporation VAX 11/750s: Project Athena, Massachussets Institute of Technology.

SOFTWARE

gt ("Get picture"): Picture retrieval program (from disk) by Thomas Porter.

gtxt, svtxt ("Get Texture, Save Texture"): Texture formating programs by Sam Leffler.

hv ("Horizontal, Vertical"): Filtered size changer by Alvy Ray Smith.

md ("Motion Doctor"): 3-D animation program by Tom Duff, with extensions by Eben Ostby and William Reeves.

me ("Model Editor"): 3-D modeling program by William Reeves.

mg ("Merge"): Compositing program by Thomas Porter.

mi ("Model Instantiator"): Inbetweening program by William Reeves.

mktree ("Make Tree"): Tree, grass, and flower generator by William Reeves.

mp ("Model Previewer"): Animation pencil testing program by Steven Baraniuk and Loren Carpenter.

paint: 2-D painting program by Thomas Porter.

reyes ("Renders Everything You Ever Saw"): 3-D rendering program with motion blur, hidden surface removal, texture mapping, bump mapping, etc., by Rob Cook and Loren Carpenter.

td ("Terrain Dicer"): 3-D database subdivision program by Eben Ostby and William Reeves.

HARDWARE

Adage/Ikonas 32-bit framebuffers and microprocessor.

Evans & Sutherland Picture System II vector display.

Hitachi tablets.

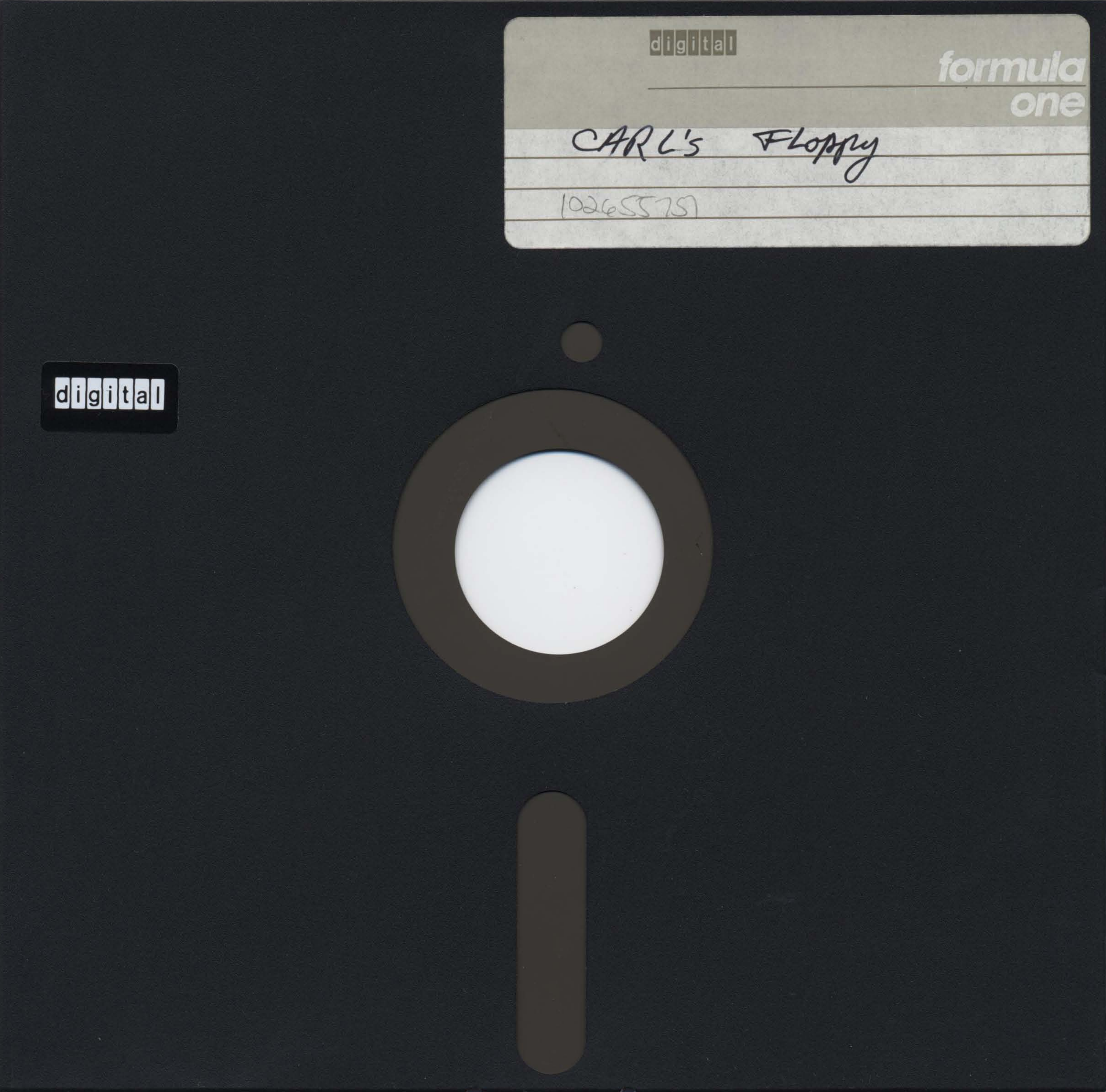
Fujitsu Eagle winchester disk drives.

Control Data Corporation removable disk drives.

Digital Equipment Corporation VAX computers: Three 11/750s and one 11/780 at Lucasfilm, ten 11/750s at Project Athena of MIT.

Cray Research Inc. computers: One Cray XMP-2 and one Cray XMP-4

See How They Ran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03 2:55 → 7:50 Eniac

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13 13:15 → 19:40 Whirlwind

20 19:40 → 24:45 FORTRAN

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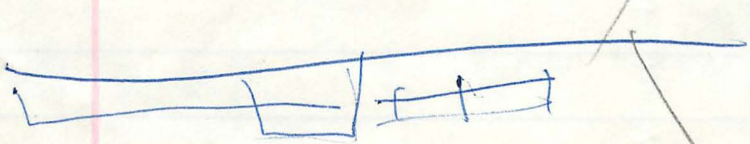
31 31:10 → 37:25 Kropotechev

37 37:25 → 41:00 STRECH



Call

Bill

Bilker

271-3252

SEE HOW THEY RAN

Sixty Years of Computers on Film
From The Computer Museum Collection

IBM PUNCHCARDS

Circa 1920

ENIAC

1946

Narrated by Dr. Arthur Burks
For The Computer Museum 1983

AUTOMATIC COMPUTING
WITH THE EDSAC

1951

Cambridge University
Mathematical Laboratory

Narrated by Dr. M. V. Wilkes
For The Computer Museum 1976

WHIRLWIND I
PROGRAMMING AT 3:00 A.M.

1953

From "Making Electrons Count"

MIT Digital Computer Laboratory

FORTRAN

1957

IBM Department of Education

TX-0 WRITES A WESTERN

1961

From "Tomorrow:
The Thinking Machine"

CBS News

With David Wayne
and Dr. Jerome Weisner

ELLIS D. KROPOTECHEV
AND ZEUS
A MARVELOUS
TIME-SHARING SYSTEM

1967

By Arthur Eisenson

Stanford University
Computer Laboratory

STRETCH: THE IBM 7030

1981

From "Stretch: The Technological Link
between Yesterday and Tomorrow"

Produced by Brigham Young University
For The Computer Museum

Produced by The Computer Museum

Edited by Carl Sprague

Hunger

LA FAIM/HUNGER

Un film de Peter Foldès

Une production de
l'Office national du film
du Canada

Film by: Peter Foldès

Produced by
The National Film Board
of Canada

This scene is from a
NATIONAL FILM BOARD OF CANADA
production: Hunger

Photo tirée du film La faim
Production de l'OFFICE NATIONAL DU FILM

10-45-5717

S13334

Photo tirée du film *La faim*
Production de l'OFFICE NATIONAL DU FILM

This scene is from a
NATIONAL FILM BOARD OF CANADA
production: *Hunger*

The
Computer
Museum

300 Congress Street
Boston, MA 02210
(617) 426-2800

May 16 1985

Katherine Riordon
Chief Scientist
Ontario Science Centre
Don Mills
Ontario

Dear Katherine

I expect you are well into the crazy phase, so I am reluctant to ask you for anything now, but perhaps you can respond to this.

I'm writing an article for The Computer Museum Report on the films we show in our computer animation theater. I'd like to show a sequence from Hunger, rather like the lady turning into an ice-cream cone that you have on page 14 of the booklet for the summer show. Do you know where to get permission to use this - I could probably work directly from a xerox of your images if this was acceptable. The New York Canadian film board people are sending me some images but they don't sound as good.

I would also like to have a little more information on how the film was made. Are you in touch with Peter Foldes or Marcelli Wein?

Sorry to trouble you in this hectic period, but this is for the next issue, and I have to complete it soon.

All the best with your project.

Yours sincerely

Olivi

Oliver Strimpel

National Film Board of Canada
Office national du film du Canada

16th Floor
1251 Avenue of the Americas
New York, N.Y. 10020-1173

Telephone: (212) 586-5131

RECEIVED
MAY 22 1985

17 May 1985

Mr. Oliver Strimpel
Computer Museum of Boston
300 Congress Street
Boston, MA 02210

Dear Mr. Strimpel:

Enclosed are the stills I mentioned in our telephone conversation yesterday.

Please return them to my attention when you are finished, along with a copy of the publication for the files.

Thank you.

Sincerely,

John Rowe
Marketing Assistant

enclosures

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(Running Time: 11:22)

HUNGER

LC# 75-700187 **Code #EX951**

SUMMARY: In this wordless allegory from the National Film Board of Canada, animator Peter Foldes indicts affluent nations and individuals for selfish consumerism and greed in a world where many starve. His moralistic tale exposes a man who leaves his office and must stop at a delicatessen before indulging in a huge dinner. Growing more corpulent and repulsive, he goes on to devour an enormous midnight supper, which leads to enormous indigestion during the night and a nightmarish descent into a hell of emaciated bodies. The man's over-stuffed body provides a meal for these desperate beings. Through clever, metamorphosing images and powerful line drawings, the filmmaker not only criticizes unchecked food consumption, but in a larger sense he ponders an attitude toward life that destroys the exploiter as well as the exploited. The symbolic hero is obsessive, compulsive, and insatiable. The film makes imaginative use of sound and solarization, and is the first film to combine computer and traditional animation.

USES OF THE FILM:
1. To stimulate discussion of the exploitation and compulsiveness beneath the consumerism of affluent individuals and nations.
2. To show how individual relationships—symbolized by the man and the waitress—can be viewed as part of this cultural attitude.
3. To create awareness of the ever-increasing global interdependence of nations and to focus on the problems of world-wide hunger and poverty.
4. To allow those interested in film technique to study a new type of animation process that combines computer animation with traditional animation techniques.

GENERAL DISCUSSION QUESTIONS:
1. What is the filmmaker indicting beyond the fact that the affluent consume too much of the world's food? What is consumerism? Discuss some of the psychological or sociological factors that cause people to overindulge themselves with food or material goods.
2. How does the film put man-woman relationships in the context of its general theme? (Look at specific images: e.g. woman turning into an ice cream cone which the man consumes, her turning into pots and pans when he squeezes her, etc.)
3. Certain groups among the poor in the United States have particularly acute hunger problems, either because of special nutritional vulnerability or due to their exclusion from food assistance programs: the elderly; migrant laborers; the American Indian and Alaskan natives; nutritionally vulnerable mothers and children.
   —Classroom teachers might ask students to go without one meal per day for a week, and at the end of the week assess their physical strength and mental creativity.
   —Students can be asked to plan meals for a week on a welfare-poverty diet of $1. per day per person. What can they buy, and how nutritious will the meals be?
   (*Reading Suggestion: Hunger USA Revisited,* A Report by the Citizens' Inquiry into Hunger and Malnutrition in the United States, published in cooperation with The National Council on Hunger and Malnutrition and the Southern Regional Council, Washington, D.C.)
4. The United States has 6% of the world's population, yet it has 34% of its wealth. What is the responsibility of the United States towards the rest of the world?
5. Many people living in Western societies resent the fact that the peoples of India and South America don't make a greater effort at birth control because of cultural and religious factors. They feel that societies that control their populations can't really help those societies that won't "help themselves." Discuss.
   (*Reading Suggestions:* Paul and Arthur Simon, *The Politics of World Hunger,* New York, Harper and Row, 1972; Jayne Millar Ward, *Focusing on Global Poverty and Development: A Resource Book for Educators,* Washington, D.C., Overseas Development Council, 1974.)

QUESTIONS FOR FILM STUDY:
1. This is the first film that combines traditional animation with computer animation. The animator provided the first and last cells for a shot, and the computer filled in the intermediate frames. For more information on the technique contact the National Film Board of Canada.
2. What was the artistic purpose of the solarization sequence in which the waitress did a dance? Did it seem to have a connection with the rest of the flim?
3. Much of the delight of the animation depends on the imaginative, metamorphosing images. Which ones do you immediately recall? (A film project might include doing a scene in which the characters' thoughts are shown by having things in the shot continually metamorphose.)

June 7 1984

Ken Shere
National Film Board of Canada
1251 Avenue of the Americas
New York
NY 10020

Dear Mr Shere

Further to our telephone conversation today I am writing with further information as to how The Computer Museum would like to use the film Hunger by Peter Foldes.

The Museum has recently moved into a new site in downtown Boston where it will reopen to the public on 14 November 1984. I enclose the latest issue of The Computer Museum Report to give you some background. We are a non-profit organisation and rely on donations from individuals and industrial corporations for our funding.

Within one of our new exhibits will be a small theatre capable of seating about 15 people. We plan to show a 30 minute program composed of computer-generated films on a variety of topics. Hunger would be one of about 4 - 5 short films in this program. It would illustrate computer-generated intermediate images. Other films would show realistic computer-synthesised images, simulation and animation.

The program would be shown regularly on the half-hour during opening hours (11-8 Wednesday-Sunday) or on demand by push-button depending on the number of visitors.

We would like to use only 16mm in the theatre to preserve image quality. However, to increase reliability and allow for unattended operation, we will use a modified 16mm projector from Museum Electronics, Toronto. The orginal films will all have to be copied onto a Kodak ESTAR film which is suitable for continuous loop operation.

The duration of the exhibit will be about 5 years but we may not wish to show Hunger for the full duration of the exhibit. We would like to make 2-3 ESTAR copies of the film so as to have back-up should the film break. We would show the film in its entirety and show the credits. We would also be prepared to make an acknowledgement on the program listing and description at the entrance to the theatre.

Visitors would not pay to get into the theatre but they would have to pay to gain admission to the Museum as a whole (or be members).

I hope this gives you sufficient information to work on and that we can work out a scheme to our mutual advantage. Please do not hesitate to contact me should you require further information. I look forward to hearing from you soon.

Yours sincerely

Dr Oliver Strimpel
Curator

enclosure

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