# COMPUTER ANIMATION VIA OPTICAL VIDEO DISC

by

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Submitted in Partial Fulfillment

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ABSTRACT

This paper explores the notion of marrying two technologies: raster-scan computer animation and optical video discs. Animated sequences, generated at non real-time rates, then transfered to video disc, can be recalled under user control at real-time rates. Highly detailed animation may be combined with other media in interactive systems. Such systems inherently offer a greater degree of flexiblity to the animator. The implementation of one such system is discussed in detail.

Thesis Supervisor: Nicholas Negroponte

Title: Associate Professor of Computer Graphics

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TABLE OF CONTENTS



A video tape has been submitted with this document.

Specifications:

length 3 minutes

silent

color

width 3/4 inches

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I would like to thank both Professor Nicholas Negroponte, my advisor, and Andrew Lippman, Professor of Media Technology, for their commitment and inspiration.

Finally, Wanda Whitham, whose patience kept me going.

# 1 INTRODUCTION

Computer graphics is a medium of conception and expression. It is not just a means of visualizing computational data. The computer is an artist's tool as well as the tool of the scientist and economist. Computer animation is no longer restricted to the mechanical rendering of a machine; redundant, mass-produced, uniform. Improved human interface has brought the artist's insight into play. It is possible to use "the artist's pictorial imagination to present the basic essentials of the subject..."[1]. The optical video disc extends the range of the computer as a visual tool. Frame generation time, the barrier to the visual complexity and the visual density of each frame, need no longer be a concern of those designing interactive systems.

## 2 THE OPTICAL VIDEO DISC

The optical video disc is a storage device, the video analogue to a phonograph record. At present video discs are most commonly marketed as storage for a video signal, although digital and audio discs will be available soon. Each disc is capable of storing approximately fifty thousand video frames per side. This corresponds to one half an hour of video per side at the standard playing speed of 30 frames per second. On the surface, the video disc appears to be equivalent to two one half hour video tape cassettes. The signal read from the video disc is completely compatible with broadcast television. Analogue image manipulations may be used, such as keying and mixing at real-time rates. The discs are made from thin sheet of aluminum laminated in a transparent plastic. Like a phonograph record, once a master disc is manufactured, duplicates, being mere impressions, can be stamped out in large volume at relatively low cost. Video discs are currently manufactured by Discovision Associates, a joint venture by Music Corporation of America and IBM, Sony Corporation and others with the intent of capturing a share of the home movie market. Hollywood's reruns are being transfered to disc, and sold at prices which undercut the costs of blackmarket and home-recorded video taped versions.

Each of the companies manufacturing optical video discs uses a slightly different scheme for encoding data onto the discs. All of the systems are similar in that they use a laser stylus to detect hundreds of millions of tiny depressions in the surface of the aluminum. A frequency modulation results, which is electronically encoded into a video signal. It is theoretically possible to encode up to 5x10e11 bits of information onto each side of an optical video disc. In reality 10e10 or 2x10e10 bits per side are stored. The standard disc layout is 54,000 concentric tracks, each containing data for one video frame. This tremendous capacity for information storage is where the greatest potential lies for video discs. Data access rates are up to 30 million bits/sec. Video discs offer dense, easily accessed, and very inexpensive data storage.

The optical video disc has may attractive features in addition to dense storage capacity. I am confining this discussion to video applications of video discs, so I will mention three features which lend themselves to applications beyond the normal realm of video: frame freezing, access to individual frames by number (frame search), and frame skipping. This unique combination of features account for much of the interest in video discs. The diversity of playback modes made possible by the optical disc technology enables previously immiscible media: typography, raster-scan computer graphics, vector graphics, drawing, film, video and still photography to be combined in a coherent and highly interactive manner. The optical video disc is the bridge between television, computer graphics and traditional visual and audio media.

The material on the disc need not be played at the standard 30 frames per second. By skipping back to the end of the preceeding track and playing forward the same frame is repeated. This can been done indefinitely, making possible a freeze frame feature. Still images can be stored as a single frame which is viewed repeatedly for any length of time with no loss of resolution. This is radically different from video tape which must resort to use of a periferal frame store, degraded image quality. Alternatively, a signal frame can be stored over many frames, which rapidly deminishes the storage capacity and has a requisite of a predetermined display time. By repeated frame freezing, virtually any playback rate between 30 frames per second and still frame is possible.

The discs can be played with equal facility in either direction. The frame skip feature is used to implement reverse play. Again the process involves interrupting the routine motion of the stylus. By skipping back two tracks between each frame, reverse play is achieved. Almost any reverse playback rate is also possible. Both speed and direction can be changed as often as necessary.

The frame search feature allows the user to jump to any point on the disc accurately and quickly. This feature is implemented by "raising" the stylus, translating it, and then "dropping" it into the new track, much the way one would choose different tracks on a phonograph record by lifting the tone arm. Here too, traditional video techniques fall far short. Comparing random frame search times between video disc and video tape is analogous to comparing random file access times between magnetic disc and tape. Discs are fast enough to be used as pseudo random access, while the tape can only be used for sequential access. The frame search feature will engender the developement of novel editing techinques: loops, cuts, and non-sequential playback.

## 3 INTERACTIVE ANIMATION

The computer graphics industry has exploded over the past 20 years. We began the sixties with Ivan Sutherland and his rubberband lines. As we enter the eighties, we find computers being used as a tool for creating and controlling elaborate visual systems. Computer animation/simulation has progressed hand in hand with the rest of the computer industry.

Computer animation can be categorized as either passive or interactive. Passive animation, such as the cigarette comercials produced by Gary Demos's group at Information International Incorporated are seen by the viewer in a entirely premeditated and prescribed manner. We have no control over what we see or when we see it. We can only close our eyes. Interactive animation, such as the "Nova-View" flight simulator built by Evans and Sutherland is meant to engulf the user. What we see is dependent upon what we input to the system. We see something new everytime we enter our "aircraft". My concern in this paper is real-time interactive animation. I will discuss the limitations of many such systems currently implemented, and the implications of video disc technology, how it may be applied to circumvent many of the limitations.

The trend in the industry has been towards more visual detail and a greater degree of freedom in interaction. The oriention of interaction with computers is changing, modelling itself after natural methods of communication. Voice recognition systems are replacing keyboards, gesture recognition replacing joy sticks. There has been a move away from black and green vector graphics to full color raster-scan displays. The potential scope of computer generated images is increasing, as the hardware and software strive forward. Algorithms describing texture mapping, shading, and stotastic modelling (the latest craze) provide the animator with tools capable of virtually any level of visual density.

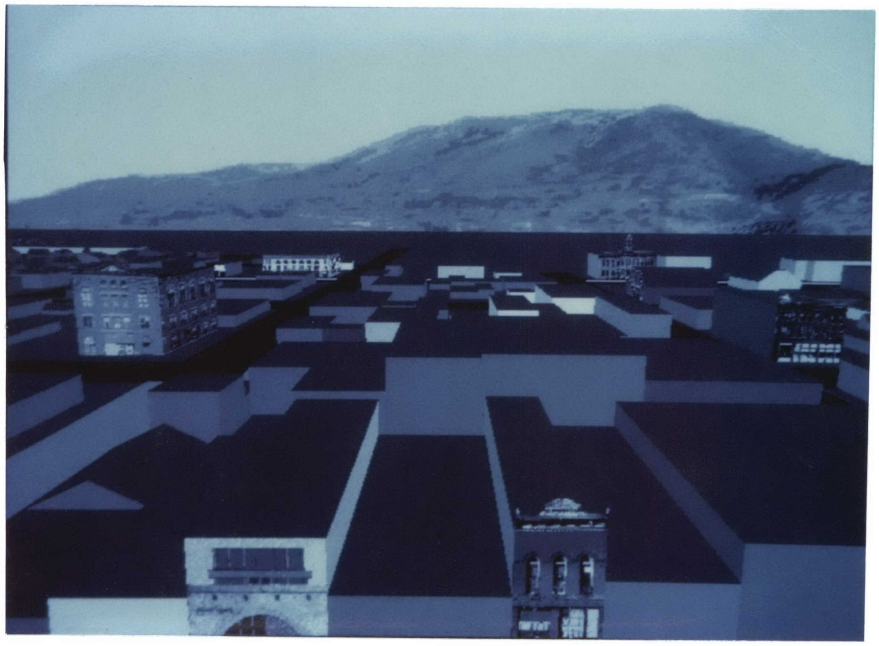
Animation houses spend several days generating highly detailed film shorts for television commercials and cinema. The details of these films are scripted in the studio before production. Each frame takes up to several minutes to generate. Occasional frames often take several hours to compute. The final product is seen in a linear sequence at a fixed frame rate and from a fixed point of view, an intentionally passive experience. This application can be contrast with the interactive systems built by Evans and Sutherland and others. Their flight simulators require constant human attention at the controls. The trainee is able to interact with an environment in real time (a minimum of 24 frames per second). He has freedom to move about a virtual space, changing his speed, direction and position at will. He is only restricted by the extent of the database defining the simulated environment. Care must be taken not to fly off the edge of the world.

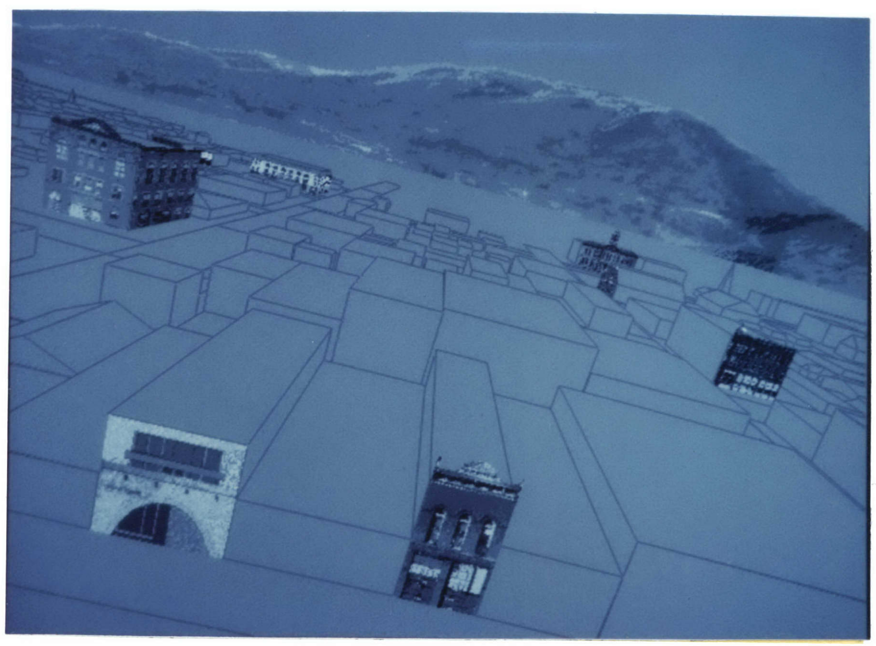
In real-time interactive systems, time constraints severely limit the visual density of the image. Since real-time necessitates image regeneration rates of upwards to 30 frames per second, the time consuming techniques used by the animation houses are not applicable. Precomputing, then storing the images for recall at play time is a possible solution. There would be no restriction on frame generation. As long as the stored images could be retrieved quickly, any degree of visual density can be achieved. Until the advent of the optical video disc, there has not been a practical means of storing the images, except when inordinately few frames can suffice. For elaborate systems, magnetic disk storage is often too slow, and has a too limited capacity. A 300 megabyte disk can hold fewer than a few thousand images. Less than a minute of animation. It would be an expensive, as well as bulky proposition to use magnetic discs for interactive animation systems.

The advent of the optical video disc presents new possibilities for the production of interactive systems. Fifty four thousand frames can be generated in the labratory to be stored on video disc for later use. Thus animation, whether generated in real-time or not, can be used in real-time interactive situations since the recall of images from the disc need not be strickly sequential as in the case of film and standard video. As mentioned above, real-time interactive situations from preconstructed images have been simulated in the past by such techinques as storing a series of images on magnetic disc or drum, yet never on the same scale.

Precomputation and storage on video disc is not always a viable solution. The 54,000 frames allow for quite a latitude of material, yet one is still restricted to some finite path. The system must be such that there are a finite number of possible configurations or points of view required. Evans and Sutherland's flight simulators, with the range of freedom available in all directions would be difficult, if not impossible to duplicate by means of precomputation and storage on disc. But in those cases where motion can be confined somewhat, the algorithm is quite successful.

Using QADAS, the quick and dirty animation system developed by the author to model Aspen Colorado, I was able to produce a series of sequences simulating a drive through





Figures 1 & 2: The Quick and Dirty Animation System.

town. Photographs of select buildings are mapped onto their corresponding polygonal representations in the model of the town, a cheap but effective way of selectively increasing the density of detail [greater than computationally possible in real-time given the equipment in the lab]. Generation of each frame took approximately 30 seconds. I then transfered the footage to optical video disc, where under computer control, one is able to drive through the town. The traveller is restricted to travel down the center of each street, but he may travel around the lattice of streets with complete freedom. [This material was produced in conjunction with the Movie Map project described in section 4 of this document.] Only by using the optical video disc was I able to achieve both a high level of detail and user interaction.

Several years ago, Nelson Max made a beautiful film on topology entitled "Turning a Sphere Inside Out". Dr. Max unravels a very complex mathematical process in visual terms. He shows us a half dozen different models of the sphere doing it's thing, each emphasizing a different aspect of the dance. We are shown wire mesh models, vector animation, exploded polygons, and transparent skins sliding apart. Each model is shown from a different point of view. These varied representaions follow one another, each richer than it's predecessor. "ooohs" and "aaahs" resound. At the end of the film, even the most skeptical viewer is convinced that computer animation is a (pregnant) medium. Unfortunately, only the most clever of observers has any more than a vague understanding of how a sphere can be turned inside out. [I have seen the film three times. I have found that if I really concentrate, I can follow the transformation about half way through before getting lost.] Dr. Max has provided a frame work of multiple views and styles of represenation, yet the film is not wholely successful in elevating audience awareness of the process depicted. I believe it is because of the linear and passive manner in which the material is presented. If we were allowed to step through the film frame by frame, and jump between the various modes representations, while maintaining temporal correspondence between sequences (that's a mouthful), we would have an opportunity to thoroughly examine any aspect of the process which is confusing. The use of video discs now makes interaction with a process as complicated as Dr. Max's sphere possible. Professor Nicholas Negroponte presents a case for what he calls "interactive movies" in his paper "The Imapct of Optical Videodiscs on Filmmaking". He exemplifies the power of viewer interaction, taking note of an MCA Discovision demonstration of knot tying and a card trick. "Only through speed variation (user controlled) is the sequence of the knot clarified and the slight of hand in the trick revealed."[2] This kind of interaction, although not unique to optical video disk animation [for example, in the case of Dr. Max's film, somehow lining up a half dozen analyst projectors with a centralized control unit might work.] is easily implemented with video disks.

Ideally, the animator should be free from any constraints of the hardware. Through imaginative software he is able to affect high resolution imagery. The optical video disc frees the animator from time constraints when considering real-time interaction. The fluidity of Disney, the ingenuity of McClaren, the complexity of Max and the responsiveness of Evans and Sutherland will be grand experience.

## 4 WHY ANIMATION?

Video discs provide the ability to "edit on the fly". Taking advantage of the frame search feature, sequences may be pieced together at play time. This can be done in a precalculated or interactive manner, either stretching the virtual storage potential or enhancing the playback with personalized flexibility.

Both of these concepts of non-linear sequencing are being explored at the Architecture Machine Group at M.I.T. In a research project entitled "Personalized Movies", the user is shown a selection of sequences which has been optimized according to a user profile. Innumerable personalized sequences are produced from a single disc by applying a variety of editing principles. In the "Aspen Movie Map" project, the user drives himself through the town of Aspen, Colorado, choosing his own path through the town as he travels. Although the user is restricted to those streets which were filmed and placed on the disc, and in an order which corresponds to the physical layout of the town, he is not hindered by the order in which the streets were filmed or by the the layout of the film on the disc. In both projects, the optical video disc is used to provide visual density to interactive systems. "Systems that have the responsiveness and controllability of computer systems, but use the visually complete and detailed imagery of the television world."[3]

The basis for exploration into the use of the optical video disc in interactive systems has been unmanipulated photographic imagery. Both "Movie Maps" and "Personalized Movies" capitalize upon the novelty of interaction with such images. However, synthesized images have merit in interactive situations. The remainder of this paper discusses my investigation of the use of video discs in interactive animation as opposed to or in conjunction with interactive film.

Human interface is an important consideration in any system which attempts to instruct a human user. The inputing / outputing of information and the configuration of the information itself are necessary considerations. All such systems, inorder to successfully educate must be simultaniously rich in content and conducive to long term retention of the the information. My aim in the discussion which follows is to expound upon a variety of applications where education systems are expediated by use of animation.

Perhaps the most obvious reason to employ animation is because it allows you to see what you normally cannot see, either because of some physical or practical limitation, or because you want to represent something which normally can't be seen. Aerial animation generated by QADAS for the Movie Map of Aspen is an example of animating something for convenience. It was possible to use a helicoptor to film the sequence, but impractical. Dr. Max's topology film is an example of a visualization of a concept rather than an object. It would be impossible to actually film a sphere turning itself inside out. Animation can fill in where practicality or reality leave off.

Animation differs from photographic imagry in that it is schematic rather than pictorial. It is a controlled abstraction rather than a virtual window to some reality. "Nature was not fashioned by a designer. It's visual appearance is only an indirect by-product of it's physical being."[4] Unlike photography which derives it's character from nature directly, animation is characterized by funtional, systematic selection. Animation is capable of providing an overview of objects, places and procedures. Relevent attributes can be emphasised. Indiscriminate attention is not given to minute parts, exposing internal or external structure and flow. At every level each element in the image has been knowingly and functionally placed. The animatior is an editor who has the ability to produce images discrimiating visualization of any intrinsic constiuent or quality. Stimulation derives from contrast and change.

Animation is a tool which gives us complete control over this contrast. Thus we are able to direct attention, and retention towards those aspects of a system which facilitate the learning process.

I have previously taken a cursory glance at both the Quick and Dirty Animation System and the Movie Map System, developed at the Architecture Machine Group. I reiterate by saying that QADAS was developed as a suppliment to the Movie Map. The remainder of this section is a discussion of the relationship between the animation and the photographic footage in the context of Movie Maps. The map is an attempt to provide a means of familarizing one with a spacial environment with out necessitaing a visit to the environment. Aspen, Colorado, was chosen as the test site. The backbone of the project is a lattice of "truck footage", film shot from the top of a truck while driving down all of the streets in the town. This material was shot a frame every 10 feet, the cameras beging triggered by a fifth wheel. The film is played back at less than real time rates, anywhere from 15 to 0 frames per second. I refer the reader to an article by Andrew Lippman in the 1980 SIGGRAPH Proceedings entitled "Movie-Maps: An Application of the Optical Videodisc to Computer Graphics" for additional information about Movie Maps.

SELECTION

The animator has the opportunity to edit the content of each frame. By resorting to digital or analogue image processing techniques or manual intervention, it is possible to eliminate any aspect of an image which is misleading, redundant, distracting, irrelevent, or counter to whatever the system is attempting to elucidate. Too much detail or misplaced detail can distract the viewer. An example from the Movie Map typifies misleading hence detremental detail:

Because it was not possible to have a camera everywhere in town simultaniously (this would require approximately 30,000 cameras) it was not possible to film the entire town at the same moment in time. Hence there are temporal discontinuities. Several problems arise because of these discontinuities: They are most evident in the transitory traffic patterns. Cars and pedestrians are constantly popping in and out of frames. Turning a corner, one can come face to face with a truck, materialized from the nothingness. The same pedestrians can be seen repeatedly throughout town. While travelling in reverse, cars and people move backwards also. All of this commotion is quite a distraction, especially to cautious or nervous drivers. Even worse, there is a constant danger that some transitory object will be used

Figure 3: Main Street, Aspen Colorado.

Figure 4: Animated Main Street. [Note lack of traffic!]

as a navigational cue. The ephemeral nature of such objects increase the possiblity that they will be noted, and remembered. A white station wagon which pops in suddenly while turning onto Main Street serves well as a cue that Paepke Park is coming up ahead, but it is of little use when one is trying to negotiate the streets of Aspen in situ. There is one street in the residential part of town I identify from a man in a wheelchair who is crossing the street ahead of us as we drive. With QADAS, I am able to discriminately eliminate detail (a good trick). Fortunately, while animating the town, I was able, with little extra work on my part, to leave out automobiles and wheelchairs from my database.

Selective elimination of detail is a powerful tool for the animator.

Selective inclusion or exclusion of detail can be used by the animator as a visual cue to indicate importance. Detail can be added to flag important aspects of a process, and the image can be degraded in less important areas. Contrast in detail can direct the viewer's attention towards those things he should notice and retain. QADAS employs several levels of detail to establish various overt and more subtle landmarks and navigational aids. Landmark buildings

Figure 5: Facade with tree and auto.


Figures 6 & 7: Cleaned up facades and mountains used by QADAS have photographic detail mapped on to them. Other buildings are represented either by simplified polygonal shapes or outlines. The billboarded buildings help the traveller get a fix on his location. Also, he is made conscious of a controlled subset of identifiers. The billboarded buildings actually have more detail than the corresponding filmed buildings, since I am able to employ image processing techniques inorder to remove obscuring snowbanks and trees. This is a practical procedure since the offending elements are removed only once, from a master image. All subsequent occurrences of the billboards are all mapped from this master. In the case of the film, each frame would have to be examined individually to identify and remove the offending branches and banks.

## HYPERBOLE

Hyperbole is perhaps the animator's most powerful tool. Changes in physical scale, time frame, and impact do much to reinforce or elucidate. In the QADAS footage, the YELLOW stripe down the center of main street has been exaggerated both in scale and saturation. This tag distinguishes it from all the other streets in town, both making it easy to distinguish Main Street from the others (search in a busy field) and making it difficult to forget that one is

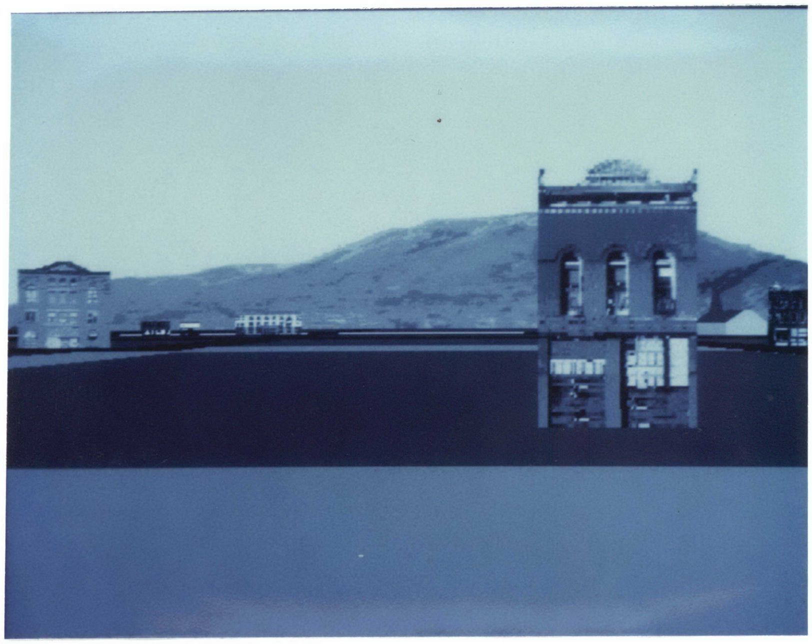


Figure 8: Selection of landmark facades only.

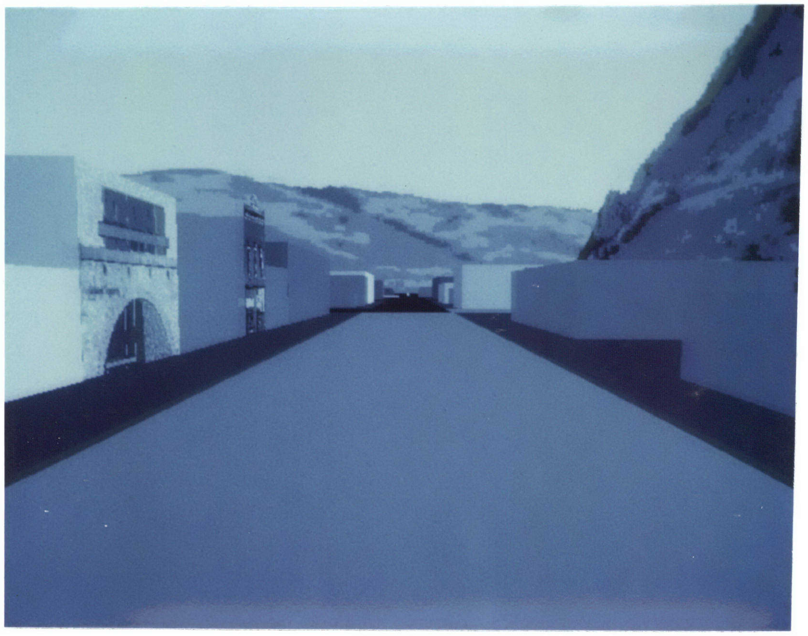


Figure 9: Aspen with undistorted mountains.

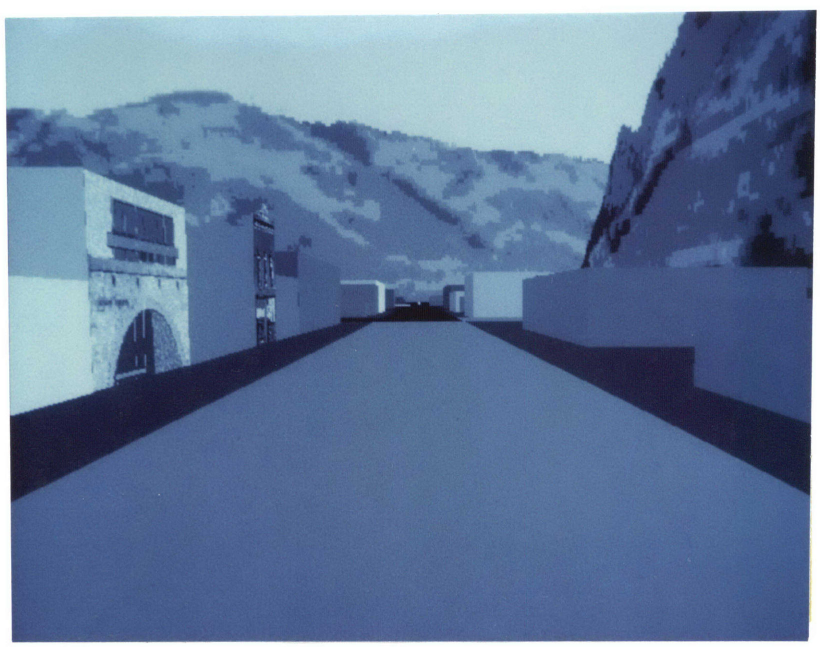


Figure 10: Aspen with exaggerated mountains.

travelling on Main Street. The pedestrian mall is paved in red bricks, exaggerated in the animation. The MALL is given landmark status. The transition from the grey pavement alerts the traveller to take note. To my knowledge, none of our test subjects have been issued citations for driving on the mall, though many have had trouble staying off the dividing line on Main Street.

Exaggeration can also be used to circumvent some of the physical limitations of conventional photographic optics. It was difficult to choose a lens for the filming of Aspen. We wanted to encompass a 360 degree view at all points in town. Since we were using four cameras, we had to choose a lens with an angle of view of 90 degrees or more. This is a wide lens. A problem arises when filming a location such as Aspen with such a wide lens. Objects in the distance appear smaller than they actually are. The mountains which envelope the town have little impact in the film, either as navagational cues or in atmopsheric effect. The animator doesn't have this problem. Spacial distortion is a standard animation tool. Distances and scales are arbritary. With a quick manipulation of the database, the mountains are suddenly larger than life. The mountains in QADAS are about 50% larger than they should be. They "feel" like the looming mountains of Aspen. Temporal distortion is also common in animation. It is possible to slow important passages down, thin out less important passages. Changing to other time frames is another viable option. Aspen in 1880 is no more of a problem to film than 1980. (Crazy)

CLASSIFICATION

Classification is the last tool I'll discuss here. (wheh!!) Color and texture can be assigned by the animator arbitrarily. Objects can be color coded by any relevent or irrelevent classification. Once again, I am using QADAS to illustrate methodology available to animators. (sorry folks, but it's the only video disc I've made). Downtown is distinguished from suburbia by hue and saturation. Also, a standard urban planning color scheme has been used: orange means retail, green residencial... Status of an operation can be indicated by a color. Color can be used to indicate simultaneity, helping one maintain temporal or spacial correspondance between points of view.

I have rambled on about the flexibility of animation. Yet, I have neglected to mention that perhaps the most important characteristic of animation is that it is fun. To animate or "give life to" something means that that something will be stimulating, and motivating. If the user fatigue is low, and he doesn't get bored then the chances of his absorbing and synthesizing the information he strives to grasp is greatly improved.

## 5 CONCLUSION

A fool sees not the same tree that a wise man sees.

- W. Blake Marriage of Heaven and Hell

The optical video disc and computer graphics have a bright future. Together, they greatly expand the range of interactive graphic systems. But, what are the liabilities? The animator, irregardless of any technological advances, is not relieved of his principal task, that of intelligent selection. Indeed this task is more burdensome because of the greater flexibility alotted him. The animator must ask himself, does the subject matter merit such abstractions? Both context and content are concerns. Care must be taken that a suitable mode of representation be selected. It is too easy to over simplify, misdirect, or weed out potentially useful material, altering the process. In any control situation, information is pruned and reshaped. The resultant system is only reliable to the extent that the editor is attuned to the cognitive attributes of the users.

Animation should be looked upon as a support system; part of a multi-channelled system, giving the user the widest range of interaction, and freedom in those interactions. Then, with luck, and persistance, he will learn.

## APPENDIX

### The Quick and Dirty Animation System

QADAS, the Quick and Dirty Animation System, has been developed the past two years at the Architecture Machine Group. It was originally developed to explore the possiblity of either replacing or augmenting the process of filming Aspen on location. It was hoped that computer animation would be able to provide some or all of the film footage necessary to simulate a drive through Aspen Colorado. The Quick and Dirty Animation System was designed about the premise that a large quantity of images of a static database (the town of Aspen) must be generated from a restricted point of view (from the street).

Briefly, this is how it works:

Animation of static objects, such as the buildings in a town, allows for an uncomplicated description of such objects in terms of a numerical model from which to generate the animation. Since nothing moves except for the view point, there is no need for continuous run-time modification the database. The model can be arranged in manner which always reflects its actual physical attributes. Because there is a simple correspondance between the model and reality, and because this correspondance never changes, the model is easy to construct, easy to examine, and easy to modify. It took approximately one man week to enter the entire Aspen database.

The stability of the database also simplifies the task of actual generation of the animation. One of the more difficult aspects of three dimensional animation is that of determining the relative position of objects to the view point. What objects are obscured by others? A brute force algorithm which can provide an answer to this question is to compare every object with every other object, sorting by distance from the view point. This can be a tedious operation for large numbers of objects. (N+1)*(N/2) comparisons must be made for N objects. It is also redundant, since, for example, objects to the north are always behind objects to the south whenever the view point is in the south. Also, since the databse is static, the relative position of the objects is constant. If the data were prearranged in some fashion reflecting their position in three space, the determination of which objects lie in front of which other objects can be simplified. A finite number of zones can be defined for which the relative position of the objects does not change. A list of relative object positions for each zone can be pregenerated. At run time, one need only calculate which zone is appropriate for the current point of view. Determining the relative position of the objects becomes the matter of a table lookup.

The sort algorithm described above can get out of hand for large numbers of objects. N [from N!/(N-1)! ] lists of length N will be needed to completely determine the sort. For large or detailed models, the number and size of lists becomes prohibitive. There are several ways to limit the number and length of lists needed. By restricting the view point the number of possible zones can be reduced. For example, if the view point is restricted to the south, all zones in the north can be eliminated. All those lists in which the buildings in the north are in front of the buildings in the south are eliminated. Reduction in the length and number of lists required is possible if one thinks of the objects falling into clusters or groups. If adjacent objects are grouped together in such a manner as to eliminate overlap, then determining the relative position of these clusters determines the position of all objects in a cluster relative to all objects in any other cluster. Note that we have a set of lists for the clusters, and a set of lists for the objects in each cluster. We've come from the (N+1)*(N/2) run time comparisons per frame to less than 2N lookups per frame.

The elementary object defined in the Quick and Dirty Animation System is a polygon. Groups of polygons form clusters which are analogous to buildings. The building modules have been designed so that each has a pregenerated sort which in combienation with backfacing [a method of determining visiblity by crossing the normal vector of a surface with the direction of view] always assures a satisfactory order of the basic elements. Buildings are gathered into clusters analogous to city blocks. Aspen has a consistent system lot assignment within blocks. There are always 18 lots per block, in the same relative positions. Thus one set of 18 pregenerated sorts which are applicible to any block. This taking advantage of Aspen town planning is the key to the quick and dirty in QADAS.

Objects in Quick and Dirty Animation System are displayed as solid or textured polygonal shapes. These polygons are sorted by distance from the point of view, then drawn from "back to front". Thus, objects closer to the viewer are draw on top of (after) objects which are farther away. This method of hidden surface removal is known as the painter's algorithm. It is applicable in systems such as QADAS where there is no overlap or intersection of objects. The advantage of the algorithm is in the elimination of the need for any point by point "z-buffer" examination, often a costly proposition in terms of image generation time.

QADAS makes use of a combination of perspective rendering of a three dimensional database and mapping of two dimensional images onto the screen. Photographs of selected buildings are digitized. These facades are then cleaned; deep shadows eliminated, snow plowed to the side, bushes pruned, trees defoliated. At run-time, these images are mapped onto the screen. The facade mapping algorithm can be summed up as follows: The perspective transformation [mapping the view coordinate space to the screen coordinates], the inverse view transformation [mapping view coordinates into world coordinates] is used to project back through the screen into object space. Each point on the screen lying inside the target polygon is mapped back onto the surface of the building in world coordinate space. The relative coordinates on the surface are used to index into the facade data. The point retrieved is drawn onto the screen. (ugh!)

QADAS affords complete freedom in selection of point of view. The model of Aspen may be viewed from the ground, the air, or even underground. The focal length is arbitrary, and both perspective and axonometric transformations are available. The database is flexible. Buildings can be added, deleted, stretched and shrunk. Coloring is arbitrary, and there are several modes of representation, vector and polygonal.

QADAS is used to generate a variety of sequences through Aspen. Each frame is generated on a Ramtek 9200 frame buffer, than recorded on 35 mm. film off of a Matrix Color Graphics Camera. The film is subsequently transfered to optical video disc. The animated material is encorporated in the Aspen Movie Map, an interactive mapping system.

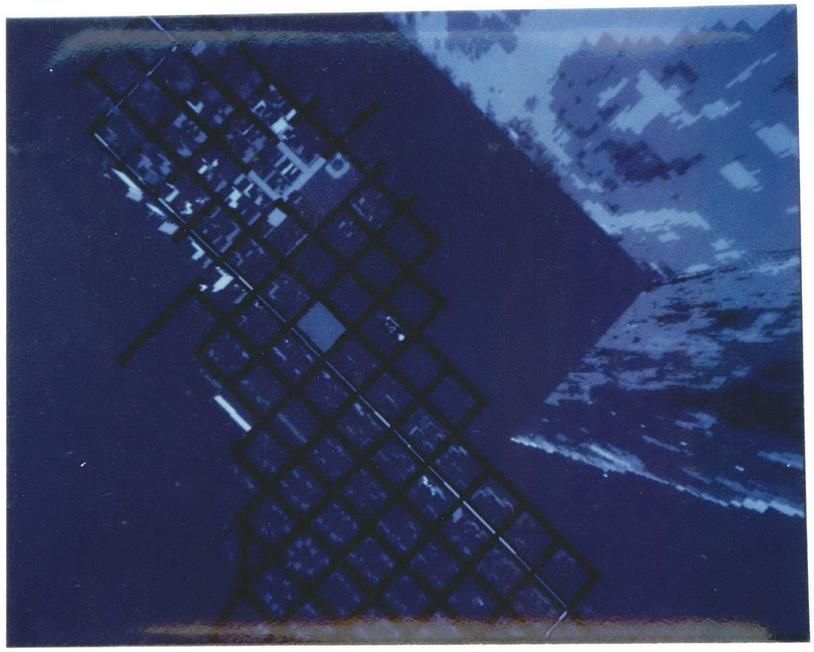


Figure 11: Aerial Animation.

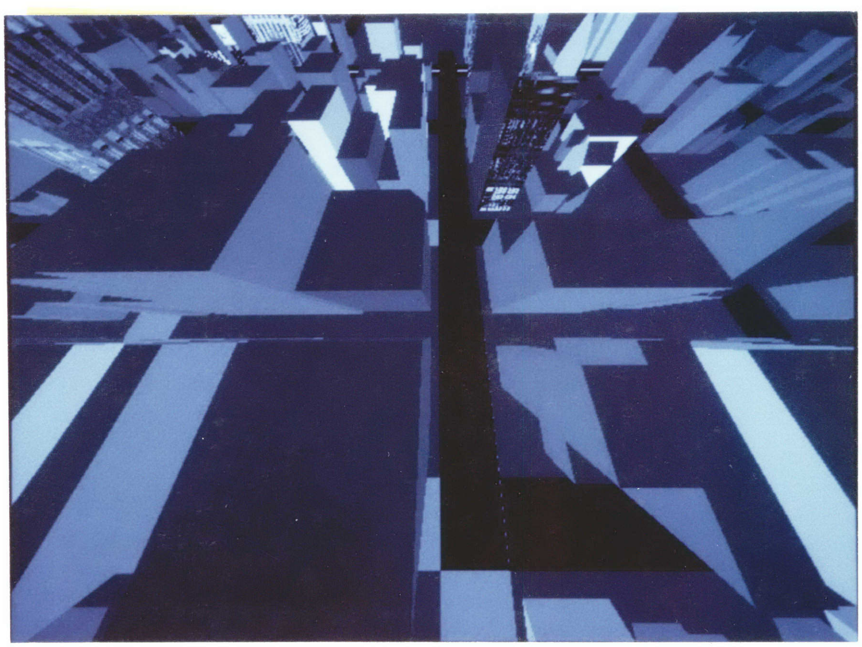


Figure 12: Wide Angle Lens.

Figure 13: QADAS multiple window.

REFERENCES

[1] Arnheim, Rudolf. Visual Thinking. Berkley: University of California Press, 1969. p. 306.

[2] Negroponte, Nicholas. "The Impact of Optical Videodiscs on Filmmaking", The Architecture Machine Group, Department of Architecture, M.I.T. 1979. p. 16.

[3] Lippman, Andrew. "Movie-Maps: An Application of the Optical Video Disc to Computer Graphics", SIGGRAPH'80 Conference Proceedings. New York: The Association for Computing Machinery, 1980. p. 32.

[4] Arnheim, Rudolf. Visual Thinking. Berkley: University of California Press, 1969. p. 302.

BIBLIOGRAPHY

American Institue of Graphic Arts. Symbol Signs. United States Department of Transportation, November 1974.

Andrews, Harry C. "Digital Image Processing", IEEE Spectrum, April 1979.

Arnheim, Rudolf. Visual Thinking. Berkley: University of California Press, 1969.

Ingrid Carlbom and Joseph Paciorek. "Planer Geometric Projections and Viewing Transforms", Computing Surveys, Vol 10,No. 4,Dec 78.

Courant, Richard and Robbins, Herbert. What is Mathematics? Oxford: Oxford University Press, 1941.

Dreyfuss, Henry. Symbol Sourcebook. McGraw Hill, New York, 1972.

Finch, Dennis. "Hyperbolic Geometry as an Alternative to Perspective for Constructing Drawings of Visual Space", Perception, 1977, Volume 6, pages 221-225.

Heuston, Dustin H. "The Promise and Ineveitability of the

Videodisc in Education", submitted to the National Institute of Education, Sept 1977.

Hochburg, Julian, and Brooks, Virginia. "The Perception of Motion Pictures", Handbook of Perception, Vol. 10, Academic Press Inc., New York, 1978.

Lippman, Andrew. "Movie-Maps: An Application of the Optical Video Disc to Computer Graphics", SIGGRAPH'80 Conference Proceedings. New York: The Association for Computing Machinery, 1980.

McCarty, John. "Information", Scientific American, Sept 1966.

Neisser. "The Processes of Vision", Scientific American, September 1966.

Negroponte, Nicholas. "Books without Pages", IEEE 1979.

Negroponte, Nicholas. "The Impact of Optical Videodiscs on Filmmaking", The Architecture Machine Group, Department of Architecture, M.I.T. 1979.

Newman and Sproull. Principles of Interactive Computer Graphics. McGraw Hill, New York, 1979.

Pangaro, Paul, Steinberg, Seth, Davis, Jim, McCann, Ben. "EOM: A Graphically-Scripted, Simulation-Based Aniamtion System", Unpublished, Architecture Machine Group, Department of Architecture, M.I.T., 1977.

Shahn, Ben. The Shape of Content. Vintage Books, New York, 1957.

Sutherland, Sproull, and Schumacker. "A Characterization of 10 Hidden Surface Algorithms", Report sponsored by the Office of Naval Research. Contract number N 00014-72-C-0346.

Wallach, H. "The Perception of Motion", Scientific American, July 1959.

Weinzapfel, Guy. "Mapping By Yourself", DARPA Interim Report. Contract Number MDA 903-78-C-0039, December 1978.