THE FORM AND SENSE OF VIDEO

artscanada, 1973

Robert Arn

How then, if formal characteristics are so important, are we to explain the assumption that television is like film? Or the almost total absence, after more than 20 years, of formal descriptions of the television process? The answers are mostly to be found in economic and social rather than artistic history and need not concern us here. The fact remains that to date, television both in production and viewing has been dominated by the conventions and assumptions of narrative film. It is criticized in terms of content of the crudest narrative or logical type. Which is odd, since very few who regard television in this limited way would chance interpreting film purely in terms of the narrative conventions of the novel.

From the first, film has been perceived practically, critically, and theoretically by those whose interest is primarily narrative or content-related, or by those who see its process as opening new forms of perception to the audience and thus new fields of expression to the artist. But of course film did not suffer from a flight of intellectuals at its birth. Born in the Constructivist period of technological optimism, it was immediately the focus of intellectual attention, while television even now faces a technological paranoia which has blocked serious conceptual study of its formal characteristics and has thus enforced an *artistic* triviality as profound as its *social* impact. However, even film criticism is shaky in some of its formal descriptions; some misconceptions about the filmic treatment of time will need to be righted before we can reach an adequate formal description of video (or television-as-an-art-form).

In 1924 film was new and fascinated with itself. Dziga Vertov, out with his camera endlessly walking, created *Man With a Movie Camera* and revealed the new possibilities open to man's cinextended perception. He called this mechanically extended perception "cine eye." Through his viewfinder Vertov saw space expand and contract and perspective shift with lens change. He found that time was under his control: crank the camera a little faster and it all slowed down. Film allowed man to experience what was hitherto beyond his perception – the malleability of space and time. However, others realized the corollary: to say that film extends perception is the same, in one sense, as saying that it distorts perception. Current followers of Vertov – say Jean-Luc Godard and Jim McBride – maintain a reflexive commentary in their films on the distortions of reality introduced by the filming process and our conditioned expectations of it. In fact, the illusion of reality is only achieved by relatively large distortions of actuality. Vertov tells us what now seems obvious – that the matter of film is the manipulation of time and space.

Intuitively, one might expect the manipulation of time to be the dominant formal characteristic of film – the illusion of movement after all is its primary difference from mere photography, and its primary use is in dramatic narrative which exists (barring several attempts at Aristotelian temporal unity such as Agnes Varda's *Cleo de 5 à 7*) by tricking the time sense. Intuition is a bad guide in this case, however, since such a system of temporal illusion is the basis of all narrative art whatever. Much more to the point is the question of how film *differs* from other forms in its use of time. Film's most characteristic means of temporal manipulation, parallel editing (The Maiden on the Railway

Track Rescue at Hand, phenomenon; or, Meanwhile Back at the Ranch) is not intrinsic to film at all but derived from the Dickensian novel by Griffith and developed by Eisenstein. It, like most other conventions of film editing, is necessary to all flexible narrative forms and is found equally in most. The most purely filmic distortion of time – slow or fast motion – is seldom used and relatively obtrusive, a "tic" of certain directors and penchant of the inexperienced.

The basic problem of film editing is easily stated – what shot to use next? Eisenstein saw that the decision was not a purely narrative or temporal one – that certain shots "worked" and some did not and that this was determined not by narrative sequence but by the graphic, compositional relationships of consecutive shots: editing sequence follows spatial relationship. Thus, though film does inevitably alter both time and space, it is primarily space art. A visual Marxist like Eisenstein cut for graphic conflict while most directors cut for graphic similarity to achieve smooth continuity. But composition rules the cut. Graphic space orders time.

Video art, in contrast to film (and also to television which is mostly a feeble narrative reflection of film), has suffered an arrested development. After 25 years of television, video art is entering its adolescence – still looking for its Dziga Vertov and vainly awaiting its Eisenstein. Like film in its earliest period, video is in a phase of self-examination or perhaps narcissism, absorbed in its own processes. The difficulty for the viewer is the fact that these processes – so superficially like those of film – are really quite different; and the responses we bring to film are inadequate and deceptive in relation to video. For example, for a long time I thought that the apparently clumsy editing of video pieces was a mere function of the mechanical difficulties of editing with existing equipment. The low-cost ½″ and 1″ tape recording equipment used by most artists does display its instability particularly in editing. But I now suspect that I have been applying expectations derived from film, where spatial graphic continuity determines editing, to video whose space/time structure makes such criteria meaningless. Classic editing technique *is* to be found among video artists. Andy Mann, for instance, produces tapes of almost vintage Eisensteinian montage. Most video artists who create such work support themselves by producing documentary tapes for business and organizations who demand film-like products; and I suspect film conventions inevitably creep over into their other work. Now when I see video of traditional film editing style it seems slightly out of place. The critics' dilemma: how to avoid seeing "different" as "inferior."

In film the impression of movement is derived from a succession of frozen moments. In contrast, the video image, even if each frame is examined, is all motion. Even a still video image is in motion – a single rapidly moving and constantly changing dot, one dot only, does all the work. The basic *illusion* of film is *motion*. The basic *illusion* of video is *stillness*. A detail of the video image may be located by pointing out where it is (as in film), but also by specifying its distance in time from any other point of the image. Any point on the image is both "where" and "when" or "wherewhen" from any other point. Video is quite literally a space/time machine. In this context the lack of the simple juxtaposition of shots characteristic of film editing is more comprehensible. Continuous motion or metamorphosis is the continuity line of most video art; an art of becoming rather than comparison, an art of time.

Before exploring in more detail the space/time nature of video and its implications in the work of video artists, some of the ways video resembles film in its processing of reality should be considered. Godard has said that film is the truth 24 times a second, which is to say that it is a lie – unless truth really happens at that frequency. Video, then, is a lie 30 frames per second, or rather 60 "fields" a second since each frame consists of two alternate fields of scan lines.* The intermittent nature of both film and

*The repetition rate of video is not determined just by the persistence of vision but also by the line frequency of the electrical power-lines. Hence in North America film on video runs six frames per second faster than in the theater – but in Europe it runs the same speed, since the power-line frequency of 50 cycles per second gives 25 frames per second, which is equal to the established European cine-camera speed.

video gives rise to the stagecoach wheel phenomenon, or "strobing." Combine two periodic motions and you get an apparent motion proportional to the difference in rates. We have accepted this distortion in relation to rotary motion, but cameramen are careful with panning and tilting rates across vertically or horizontally barred fields to avoid strobing effects that might destroy the *illusion of reality*.

In both film and video, achieving realistic color requires some distortion of actuality and here we find a phenomenon of art that would have delighted Yeats. Video has become so widespread that public reality is modifying itself so as to look "real" on television. The announcer's blue shirt was just the beginning. The decor of almost all public events is now chosen with an eye to the sensitivity of cathode ray tubes. The line/scan of the video picture is also an important factor in this context. Horizontal stripes have almost disappeared from public life since they react with the scan lines or "raster" on television to produce a disturbing moiré. A reality which cannot be comfortably facsimiled on television tends to drop out of public life.

The nexus of image/reality is the catalyst of a whole branch of video art that might misleadingly be called documentary, but is, I suspect closer to some sort of reality repair. Because of its low cost and immediate playback capabilities, video is becoming a major tool in psychotherapy and social action. Trapped as we seem to be in the cliché of alienation, we seek corroboration of our existence, and video is on its way to being a mirror for masses. The displacement of reality into the conventions of representation leads us to paraphrase Descartes – I appear on the screen, therefore I am. The key to therapeutic and activist use of video is found in the ambiguity of the word "image". Therapists talk of the difficulty of their patients in generating a body image; activists have found that politics is the art of the body politic image. Glancing through the National Film Board's *Challenge for Change* newsletter you catch a double refrain. People become real to bureaucrats only when they can document themselves within the conventions of television reality. And, even more basically, people only take their own problems seriously and actively after they have been assured of their own reality by seeing themselves on television. Such image/reality inversions are not unique to video. What writer has not felt his self-image enhanced by seeing his work in print?

The ability of video to overwhelm our other reality indices is demonstrated by experiments that require subjects to perform simple tactile tasks while watching a slightly delayed recorded image of the action. Total confusion is the usual result. Even when one can feel an object, the image of the object is convincing enough to make us doubt our tactile sense. In the wider context of social response, few people who have seen a studio television production with live audience have failed to notice the audience preference for watching the action on the studio monitors even though the original is immediately before them. Two notable pieces recently shown in Toronto demonstrate video artists' concern with the power of their medium to dominate reality; both share a major metaphor indicating a basic distrust of such domination. Elsa Tambellini's piece *Cats*, shown at the *international festival of women and film* portrays caged tigers pacing nervously behind 300 bars. Live performers shooting each other with closed circuit cameras and finally stringing rope bars between the audience and its own picture on monitors, imprison first actors then audience in the medium [see p 38]. Juan Downey's piece at the Electric Gallery traces the image of imprisonment, or reality as medium, to its source in Plato's *Myth of the Cave*. The image is somehow more actual than the action it emulates. Is it any wonder that psychiatry and politics talk so much of image? Pygmalion and Dorian Grey admonish from the mythic wings.

However, I doubt that we should regard confusion of image and reality as pathological. That confusion surrounds one of the most paradoxical and contentious issues of art. What is real in art? In film, graininess and greytone degradation – the side effects of low lighting and forced processing of newsreel footage – became conventions of a school of realism, the stamp of vérité on any film image. It is difficult to know to what extent Cinema Vérité looks like newsreel footage because of similar technical constraints, and to what extent it *tries* to produce a grainy and degraded image in the knowledge that the audience associates such an image with recordings of real events. In my experience the two are inextricably tangled. Clearly the convention is totally conscious in Godard's *Le Petit Soldat*, or *Les Carabiniers*, films which dwell on our tendency to confuse conventional representations with the "real thing". The conquering heroes of *Les Carabiniers* return with postcards of conquered wonders as booty. They feel they have plundered the things themselves. The newsreel quality surface of the film presents us with the same dilemma as the heroes – is newsreel really real?

Manipulation of the conventions of representation has by now become almost a cliché – the bread and circuses of intellectuals. Nevertheless, the relation of art, conventional representation, and reality is perhaps the basic theoretical issue of modern art and has been so since the late nineteenth century. Does art imitate reality? Or does it create our very conception of the ultimately unknowable "outthere?" The issue is not substantially different in poetry, fiction, graphic art, film, or video. Video just accelerates this eternal dialectic of art. So Yeats argues:

> That girls at puberty might find
> That first Adam in their thought
> Shut the door of the Popes chapel,
> Keep those children out.
> There on that scaffolding reclines
> Michael Angelo
> With no more sound than the mice make
> His hand moves to and fro
> Like a long legged fly upon the stream
> His mind moves upon silence.

He refers of course to Michelangelo's masterpiece of God creating Adam – *The Touch*. Yeats describes Michelangelo's painting hand in relation to the picture as the same as the relation of God's hand to Adam *in* the picture. Who then is the Prime Mover? Who created Adam? And God? Substitute Chic Young for Michelangelo and a half-tone screen for the brush, and Yeats gives birth to Andy Warhol. Yeats never guessed that crass conventional forms of representing reality would be widespread or powerful enough to create "reality." But further speculation on epistemological problems common to all arts will not bring us closer to a description of those formal processes and possibilities that are unique to video – and just such a description is necessary before we can understand the field of intent and judge the execution of a piece of video art.

It is difficult fully to comprehend that calling video an art of time is not a metaphorical statement but a literal description of the process of generating the video image, any video image. As I mentioned before, the image of video is an illusion; there is only one rapidly moving dot of varying intensity on the screen. In an ordinary television picture the dot scans regularly whether an image is present or not, generating the set of 525 lines called a raster. To produce an image, one introduces a patterned modulation of the dot's intensity as it races across the screen. The varying intensity of the beam is perceived as a range of grey tones from white to black. The critical point here is that the video image is sensitive. It is not fixed but responsive to outside control and alteration at any point in its scan. Thus the essential nature of the video artist is quite different from that of the film artist who seizes discrete frozen images. The video artist controls or intervenes strategically in an ongoing process. Clearly, the aesthetic and critical implications of this distinction, in relation to the typical concerns of most video artists, are sweeping.

Perhaps the simplest and most obvious concern of video art is with the nature of "process" itself, and with the paradoxes and illusions of time on which the concept rests. Consider, for example, the multiple tape-delay environments which have fascinated so many video artists. The simplest form of tape-delay is familiar to broadcast television viewers; the instant replay has transformed sports viewing. But few sports enthusiasts realize how an extension of this technique can break down the conventions of time, and cause and effect.* Video, unlike film, requires no processing; it may record a live event on one machine and play it back simultaneously with varying delays by passing the tape through playback decks at various distances from the recording machine. Moreover, while the tape by its nature must pass in progression from one machine to the next, the displays from these playbacks may be arranged so that the viewer experiences them out of their normal temporal order. Most tape-delay pieces multiply these time-windows and often scramble their sequence so as to attack our conventional sense of time. It requires very little in these environments for the viewer-actor to lose track of the present – even though the screens may be portraying his own actions. Present, past and future become arbitrary, cause and effect absurd. The environmental pieces of Woody and Steina Vasulka pursue the paradoxes of reality a step further. Again, multiple presentation of image is used, but now the same image is displayed moving uniformly across the screen so that it appears to enter at one side and leave the other. Strings of screens placed next to each other give the impression at first that the image is moving from one screen to the next, but soon the images seem to stand still leaving the viewer with the impression that the whole environment is accelerating across the field of the image like the sensation of a train pulling out of a station: a concrete representation of the paradoxes of Einsteinian physics – relativity art. (Michael Hayden has remarked to me that he responded to neon signs and theater marquees in this way and I suspect we can anticipate relativity effects in three dimensions in his projected *Waves* video/computer project.)

Obviously in all such pieces the viewpoint and reactions of the viewer are an essential part of the work itself – these trees make no sound as they fall in an empty gallery. An interlocked loop tends to form of the video process and the viewer's physiological process, and hence a different viewing style is required. The viewer must become part of the process of what he views, and this requires a much longer attention span than the usual scan of graphic art, or the fitful attention of narrative film. Physiological process video operates on a longer time scheme than most other experimental forms and seems merely boring if not pursued to the point of object/observer fusion. (Luckily for artists studying physiological process, videotape is cheap – their work would be prohibitively expensive, even if possible, in film format.) Anyone experimenting with video in any form is likely to chance on physiological interaction patterns incidentally. I have noticed that vivid color hallucinations may be produced by pulsing different parts of a video image at different rates. Many people will see such a black and white picture in vivid (if unpredictable) color. Interestingly, there seems to be some positive correlation between intensity of color hallucination and the incidence of night blindness. Sadly, I don't hallucinate colors at all.

Feedback

In imitation of physiological systems, an image that is responsive to control can become reflexive – self-controlling or regulative. This possibility gives rise to perhaps the purest line of video art: feedback patterning. "Feedback" in this usage is a technical term, designating the procedure of connecting camera and display-monitor in a loop, the camera photographing the display and feeding the result back into the same display. If, for example, a camera is photographing its monitor and projecting this image via its monitor, and the camera is then tilted, the monitor will be receiving a tilted image of itself – but this new image will contain the upright image of the monitor that was already on the screen before tilting the camera: there is no hiatus. The resulting image thus appears as a kind of superimposition; and with every subsequent alteration of the system the image will accumulate, generating an echo-corridor pattern which rapidly transforms itself into the mandala-like imagery typical of much feedback work. It is through step-by-step control of this cumulative property of the feedback system that feed-

• A length of film or tape represents a temporal separation of recorded events. That is, since videotape moves through the playback deck at approximately 7½ inches per second and 16 mm film through the projector at 40/24 feet per second, an event separated in time from another by one second is separated in distance by 7½ inches or 40/24 feet respectively. If we use several playbacks, displayed continuously and simultaneously, of the same tape or film, the distance between the machines will determine the temporal separation between the images. Any image appearing on one display will eventually appear on the next; the intervening time being determined by the distance that point on the tape or film has to travel to the next deck or projector. Film, however, cannot be recorded and played back simultaneously. It must be sent away for processing.

back images are constructed. Images may be injected into the loop from other cameras or tape machines, or by placing objects between the camera and the screen; but even without external image intervention the system is itself a source of almost infinitely varying patterns, merely echoing the shape of the screen and the texture of the scan raster.

Synthesis

In feedback, we reach the limit of talking about the video image as image. A feedback image is not a picture of anything finally; it is a balance of purely electronic forces below the threshold of perception. It is our entrance into that very specialized branch of video called image synthesis, in which the images are not records but creations achieved by manipulating the basic electronic forces at work in video cameras and displays. The term "synthesis" is familiar in the context of electronic music and the Moog synthesizer – or even in relation to chemistry or physics. Before a pure synthesis of anything is possible we must have a set of *basic* forms, forces, or building blocks from which to start. We do not synthesize a house from walls and roof but from board, brick and nails. Only when such basic units are established by analysis can we decide on a system of inter-relation which will lead us to the desired final product. If you don't analyse to small enough basic units you limit the variety of end products – witness the prefab house.

In electronic media the basic units are not tangible shapes or forms but forces – electrical energy: complex patterns of energy are built by inter-relating simple ones just as in more concrete forms of synthesis. In this context, however, the methods of inter-relating energy forms are of greater and more critical interest because they bear directly on the fundamental concepts of all art – analogy and metaphor. To control one thing with another is the simplest case of what we call analogy; a successful analogue relationship may result in a fusion which we could call a metaphor. To create complex patterns of energy one simply uses one aspect of one simple form to control or alter an aspect of another simple form. Very complex patterns may be produced by elaborating the stages of control and relationship. Anyone who has used a Spirograph knows how to operate an analogue computer.

A deepening fascination with the processes of analogy is easy to detect in the background of most video artists. Some, of course, came to video from film or the graphic arts, but the majority had some involvement in the lightshow movement of the 60s, and moved through an interest in electronic music before working in video. The drive of lightshows was fairly simple; a quest to give a visual impression of sound. The full significance of that drive, as an exploration of the central mystery of metaphor and symbol, and hence of art, has only become clear in artists' successive absorption in electronic music and video.

The lightshow is a single term analogy; image is controlled so as to be analogous to the music. Eisenstein grapples with this concept in his theorizing on the use of sound in film. He tends to reject simple, positive one-to-one correspondence as too mechanical and prefers a negative counterpoint relationship, not noticing that a negative relationship is equally an analogy as is a positive. It is not the valence of relationship that matters, but its complexity; most metaphors are interlocking analogue systems of great complexity. The search for methods and principles of relationship seems to have intuitively attracted artists to electronic music and the Moog synthesizer, which builds up complex sound patterns out of the inter-action of simple electronic waveforms; and then finally to video synthesis where both image and sound may be analysed according to basic waveforms which in interaction with one another may produce literally any sound/image. Study of artists concerned with the analogue process seems to have led an intuitive critic like Gene Youngblood to create what can be seen as an aesthetic of analogy: he calls most avant-garde video art "synaesthetic." Unfortunately, his aesthetic is partisan and value-based. and fails to reveal the connection between the arts of complex analogy and the more general process of metaphor at work in all art.

Video synthesis proceeds along two lines – direct synthesis, which creates patterns by direct manipulation of time without any external input; and indirect or image-buffered synthesis which modulates input from an external source. Synthesizers developed by Eric Segal and Steven Beck work on the direct system; machines developed by Nam June Paik, Steve Rutt and Bill Etra work on indirect principles. For direct synthesis, imagine the raster of scan lines of the video image as a time track. Switching the beam intensity in varying time intervals will result in basic geometric patterns on the screen. These simple patterns can be elaborated by feedback into ever more complex shapes. Steven Beck's synthesizer starts from the very simple basis of generating two vertical and two horizontal lines, the positions of which may be changed by changing the time constants which determine their positions; and simple logic circuits can cancel the lines, leaving only the dots where they cross. A combination of external control on line position (each line may be made to move in analogy to a separate outside control) and feeding the image back on itself results in both delicacy of control and amazing complexity.

The indirect method of synthesis stems from Nam June Paik's early experiments in magnetic distortion of the video image. Since the raster of scan lines of the video tubes is generated by magnetic deflection of a single beam of electrons, any outside magnetic field will distort the scan field and any image it carries. Paik started by using permanent magnets which introduced a stable distortion to all images displayed on the altered set, but finally tapped into the deflection coils of the set itself so that he could introduce special distortions by means of an external control system. Rutt and Etra's design extends Paik's design by incorporating a separate deflection amplifier designed to permit modulation by outside control signals rather than by tapping into the somewhat crude deflection circuitry of the display monitor. The Rutt/Etra design gives analogue control over size and shape of picture, tonal structure of image, and spatial distortion on three axes. Its capabilities outrun those of the very expensive and inflexible digital computer systems currently in use to produce graphics for broadcast television.

It is tempting to see the technical problems of video synthesis as essentially solved. Combinations of the different synthesizer types give analogue control access to almost all dimensional aspects of the video image. Work remains to be done on electronic color, switching, keying and special effects – some of which is going ahead in Canada in my laboratory at Brock University, St Catharines, Ontario.* Still, when all the technical work is done one has merely established a certain possibility– the equivalent of a brush, a chisel, a musical instrument. It remains for artists to create human and significant metaphors with this analogue capability, and for critics to find descriptive terms that illumine their concerns.

* Anyone wishing a copy of our first technical bulletin, a 30 minute videotape outlining the state of the art in helical scan video equipment, send ½″ or 1″ videotape plus $5 dubbing fee (if no tape is available, send $20) to: Video Support Project, 36 Decew Road, R.R. 1, St. Catharines, Ontario. (Specify English or French version.)

SPACE–TIME DYNAMICS IN VIDEO FEEDBACK

Physica, 1984

James P. Crutchfield*

Video feedback provides a readily available experimental system to study complex spatial and temporal dynamics. This article outlines the use and modeling of video feedback systems. It includes a discussion of video physics and proposes two models for video feedback dynamics based on a discrete-time iterated functional equation and on a reaction–diffusion partial differential equation. Color photographs illustrate results from actual video experiments. Digital computer simulations of the models reproduce the basic spatio-temporal dynamics found in the experiments.

1. In the beginning there was feedback

Video technology moves visual information from here to there, from camera to TV monitor. What happens, though, if a video camera looks at *its* monitor? The information no longer goes from here to there, but rather round and round the camera–monitor loop. That is video feedback. From this dynamical flow of information some truly startling and beautiful images emerge.

In a very real sense, a video feedback system is a space–time simulator. My intention here is to discuss just what is simulated and I will be implicitly arguing that video feedback is a space–time analog computer. To study the dynamics of this simulator is also to begin to understand a number of other problems in dynamical systems theory [1], iterative image processing [2], cellular automata, and biological morphogenesis, for example. Its ready availability, relative low cost, and fast space–time simulation, make video feedback an almost ideal test bed upon which to develop and extend our appreciation of spatial complexity and dynamical behavior.

Simulation machines have played a very important role in our current understanding of dynamical behavior [3]. For example, electronic analog computers in their heyday were used extensively to simulate complex behavior that could not be readily calculated by hand. They consist of function modules (integrators, adders, and multipliers) patched together to form electronic feedback networks. An analog computer is set up so that the voltages in different portions of its circuitry evolve *analogously* to real physical variables. With them one can study the response and dynamics of a system without actually building or, perhaps, destroying it. Electronic analog computers were the essential simulation machines, but they only allow for the simultaneous computation of a relatively few system variables. In contrast, video feedback processes *entire* images, and does so rapidly. This would require an analog computer of extremely large size. Video systems, however, are not as easily broken down into simple function modules. But it is clear they do simulate some sort of rich dynamical behavior. It now seems appropriate that video feedback take its proper place in the larger endeavor of understanding complex spatial and temporal dynamics.

Cellular automata are the simplest models available for this type of complexity. Their study, however, requires rapid simulation and the ability

* Permanent address: Physics Department, University of California, Berkeley, California 94720, USA.

to alter their governing rules. Video feedback does, in fact, simulate some two-dimensional automata and rapidly, too. With a few additions to the basic system, it can easily simulate other rules. Thus video feedback has the potential to be a very fast and flexible two-dimensional automata simulator. The dynamics of cellular automata are governed by local rules, but video feedback also allows for the simulation of *nonlocal* automata. At the end, I will come back to these possibilities and describe how simulations of cellular automata, and their generalization to nonlinear lattice dynamical systems, can be implemented with video feedback.

This is largely an experimental report on the dynamics of a physical system, if you like, or a simulation machine, called video feedback. My intention is to make the reader aware of the fascinating behavior exhibited by this system. In order to present the results, however, section 2 includes the necessary background on the physics of video systems and a very straightforward description of how to start experimenting. An important theme here is that the dynamics can be described to a certain extent using dynamical systems theory. Section 3 develops those ideas and proposes both discrete and continuous models of video feedback dynamics. The experimental results, then, take the form in section 4 of an overview of a particular video feedback system's behavior and several snapshots from a video tape illustrate a little bit of the dynamical complexity.

2. Video hardware

In all feedback systems, video or other, some portion of the output signal is used as input. In the simplest video system feedback is accomplished optically by pointing the camera at the monitor, as shown in fig. 1. The camera converts the optical image on the monitor into an electronic signal that is then converted by the monitor into an image on its screen. This image is then electronically converted and again displayed on the monitor, and so on ad infinitum. The information thus flows in a single direction around the feedback loop. In fig. 1 the image information flows in a counterclockwise loop. This information is successively encoded electronically, then optically, as it circulates.

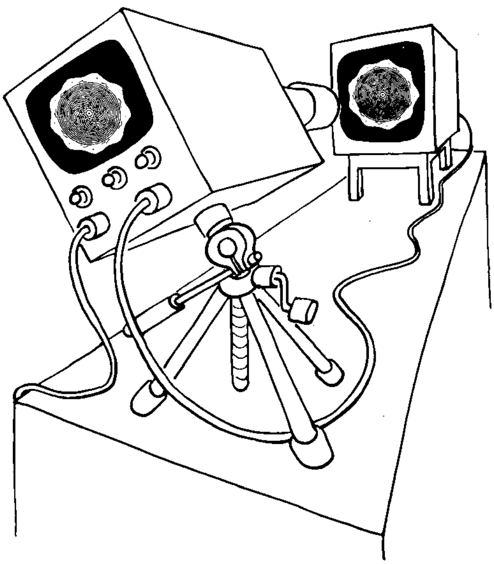

Fig. 1. Single video feedback. Information flows counterclockwise through the electronic and optical pathways.

Each portion of the loop transforms the signal according to its characteristics. The camera, for example, breaks the continuous-time optical signal into a discrete set of *rasters* thirty times a second. (See fig. 2.) Within each raster it spatially dissects the incoming picture into a number of horizontal scan lines. It then superimposes synchronizing pulses to the electronic signal representing the intensity variation along each scan line. This composite signal drives the monitor's electron beam to trace out in synchrony the raster on its phosphor screen and so the image is recontructed. The lens controls the amount of light, degree of spatial magnification, and focus, of the image presented to the camera.

Although there are many possible variations, in simple video feedback systems there are only a few easily manipulated controls. (See table I.)

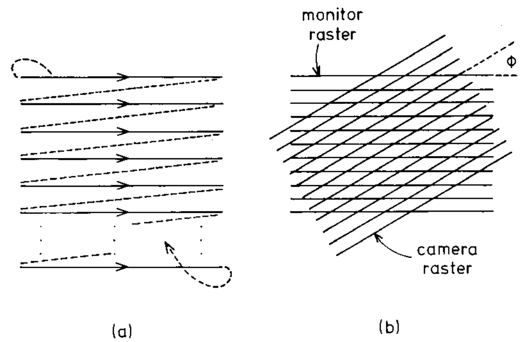

Fig. 2. Video raster with arrows indicating the direction of scanning. Solid lines correspond to when the electron beam is on; the dashed lines when the beam is off during the *retrace* time. (b) Since the raster defines the horizontal, in a feedback system the relative orientation as shown of the camera and monitor is an important control parameter.

The optical controls provide gross spatial transformations of the image seen by the camera. *Zoom*, available on most modern color cameras, conveniently allows for spatial magnification or demagnification. The same effect can be produced using a camera without a zoom lens by moving it closer to or further from the monitor. *Focus* controls image sharpness by moving the focal plane in front or behind the camera tube's image target. The total amount of light admitted to the camera is set by the *f/stop* or iris control. When pointing the camera at the monitor the relative position, or *translation*, of the raster centers and the relative angle, or *rotation*, (fig. 2b) are important controls.

Electronic transformation of the signal occurs in both the camera and the monitor. The sensitivity of the camera's tube is adjusted by a *light level* control. Some cameras also provide for *luminance inversion* that inverts the intensity of the color signals. When switched on, this allows one, for example, to view a color negative print with the camera as it would appear in a positive print. The image intensity can be adjusted again on the monitor with the *brightness*. The *contrast* controls the dynamic range of the AC portion of the intensity signal. On color monitors the amount of color in the image is set by the *color* control and the relative proportion of the primary colors (red–green–blue) is governed by the *hue*.

While the effect of each individual adjustment can be simply explained, taken together they present a formidable number of control variables

Table I
Typical control parameters on color video feedback

Name	Function
Optical	
zoom	spatial magnification
focus	image clarity
f/stop	attenuates incident light level
rotation	relative angle of monitor and camera rasters
translation	relative position of monitor and camera raster centers
Electronic	
Camera	
light level	adjust sensitivity of camera pickup tube
luminance inversion	inverts intensity signal for each color
Monitor	
brightness	varies overall intensity signal
contrast	amplifies dynamic range of intensity
color	attenuates color signals to black and white
hue	relative signal strength of colors

that can interact nontrivially. These problems will be considered in greater detail in the ensuing discussion of TV theory and possible mathematical models of feedback dynamics. This section now ends with a "cookbook" procedure for setting up a feedback system.

Although the detailed and quantitative dynamics will vary with the specific equipment used, my experience indicates that almost all servicable cameras and monitors will give some interesting behavior. This may require some patience as there are a number of controls to be properly set. But once "tuned up" a system will exhibit complex and striking imagery in a reasonably wide control range. For the movie [4] and pictures described later the camera used was a Sony Trinicon HVC-2200 and a Sony Trinitron TV/Monitor KV-1913*.

A typical start-up procedure might be as follows:

1) Connect equipment as shown in fig. 1.

2) Place camera five to six feet from monitor. The distance will depend on the monitor screen size and is not that important if the camera has a zoom lens.

3) Point camera at some object other than the monitor. Adjust camera and monitor controls to give a good image on the monitor. Vary these controls to get a feeling for their effect on the image.

4) Now turn the camera to face the monitor.

5) Again adjust the camera controls, especially the zoom and focus, noting their effect. A warning is necessary at this point: it is not a good idea to let the camera see any steady very bright image for more than 10 to 20 seconds**. Bright, dynamic moving images are generally OK.

6) Adjust camera on its tripod so that it can be tilted about its optical axis.

7) Point the camera again at the monitor, focus on the monitor front, and zoom in enough so that the "first" image of the monitor front fills 90% of the screen.

8) Slowly tilt the camera trying to maintain the camera point at the screen's center. On almost all tripods this will take some fiddling and readjustment. Try zooming in at various rotation angles between 20 and 60 degrees.

Another important element in this is the ambient light level. Some behavior is quite sensitive to, or will not appear at all if, there is any external source of light. Although, a flashlight, candle, or a quick flip of the light switch, can be good light sources to get the system oscillating again if the screen goes dark.

With this short description and a modicum of patience the experimenter has a good chance of finding a wealth of complex and fascinating spatial and temporal dynamics.

3. Toward a qualitative dynamics

In the beginning, I argued that a video feedback system is a space–time simulator. But a simulator of what exactly? This section attempts to answer this question as concretely as possible at this time. A very useful tool in this is the mathematical theory of dynamical systems. It provides a consistent language for describing complex temporal behavior. Video feedback dynamics, though, is interesting not only for the time-dependent behavior but also for its complex spatial patterns. In the following section I will come back to the question of whether current dynamical systems theory is adequate for the rich spatio-temporal behavior found in video feedback.

This section introduces the qualitative language of dynamical systems [5], and then develops a set of discrete-time models for video feedback based on the physics of video systems. At the section's end I propose a continuum model akin to the reaction-diffusion equations used to model chemical dynamics and biological morphogenesis.

* The cost for this space–time simulator is a little over $1000, approximately a cheap home computer.

** Some new cameras incorporate "burn proof" camera tubes. They are much less susceptible than earlier cameras to the image "burn" that can permanently damage the tubes. Caution should still be exercised. Excessively bright images will shorten tube life.

Dynamic, time-dependent behavior is best described in a *state space*. A particular configuration, or state, of a system corresponds to a point in this space. The system's temporal evolution then becomes the motion of an *orbit* or *trajectory* through a sequence of points in the state space. The *dynamic* is the collection of rules that specify the evolution from each point to the next in time. In many cases these rules can be simply summarized as transformations of the state space to itself by iterated mappings or by differential equations.

As will be seen shortly, video feedback is a *dissipative* dynamical system. This means that on the average "volumes" in the state space contract, or in physical terms, that energy flows through the system and is lost to microscopic degrees of freedom. This property limits the range of possible behavior. Starting from many different initial states, after a long time the system's evolution will occupy a relatively small region of the state space, this is the system's *attractor**. An attractor is *globally stable* in the sense that the system will return if perturbed off the attactor. Different initial conditions, even states very near each other, can end up on different attractors. The set of points, though, that go to a given attractor are in its *basin of attraction*. The picture for a particular dynamical system is that its state space is partitioned into one or many basins of attraction, perhaps intimately intertwined, each with its own attractor.

Very roughly there are three flavors of attractor. The simplest is the *fixed point* attractor. It is the analog to the physicist's notion of equilibrium: starting at various initial states a system asymptotically approaches the same single state. The next attractor in a hierarchy of complexity is the *limit cycle* or stable oscillation. In the state space this is a sequence of states that is visited periodically. The behavior described by a fixed point or a limit cycle is predictable: knowledge of the system's state determines its future. The last type** of attractor, that is in fact a very broad and rich class, gives rise to unpredictable behavior. These are the *chaotic attractors*. While globally stable, they contain local instabilities that amplify noise, for example. They also have extremely complex orbit structure composed of unstable periodic orbits and aperiodic orbits.

An important branch of dynamical systems theory concerns how one attractor changes to another, or disappears altogether, with the variation of some control parameter. The motivation for this line of inquiry is clearly to model experimentalists's control over their apparatus. A *bifurcation* occurs when an attractor changes qualitatively with the smooth variation of control parameter. Changing controls corresponds to moving along a sequence of different dynamical systems. In the space of *all* dynamical systems, the sequences appear as *arcs* punctuated by particular control settings at which bifurcations occur. It is now known that these punctuations can be quite complex: continuous arcs themselves or even Cantor sets or fractals. The physical interpretation of these possibilities is very complex sequences of bifurcations. Thus dynamical systems theory leads us to expect not only unpredictable behavior at fixed parameters, but complex changes between those chaotic attractors.

With modifications much of this qualitative picture can be carried over to the dynamics of video feedback. It is especially useful for describing the context in which the complex behavior arises. In the following I also will point out possible inadequacies of the naive application of dynamical systems.

A single state of a video feedback system corresponds to an entire image, on the monitor's screen, say. The state is specified not by a small set of numbers, but rather a function $I(\vec{x})$; the intensity at points $\vec{x}$ on the screen. The dynamics of video feedback transforms one image into another each raster time. The domain of the intensity function $I(\vec{x})$ is the bounded plane, whereas the domain of

* Unbounded or divergent behavior can be interpreted as an attractor at infinity.

** For simplicity's sake, I have not included the predictable *torus* attractor. It is essentially the composition of periodic limit cycle attractors.

the dynamics is the space of functions or, simply, the space of images.

This picture can be conveniently summarized by introducing some notation. The monitor screen is the bounded plane $\bar{R}^2 = [-1, 1] \times [-1, 1]$ where the coordinates of a point $\vec{x}$ take values in the range $[-1, 1]$. With this convention the center of the screen is (0, 0). For the incoherent light of video feedback, there is no phase information and so intensity is all that is significant. The appropriate mathematical description of an image's intensity distribution is the space of positive-valued functions. We will denote the space of all possible images by $\mathscr{F}$. The video feedback dynamic then is a transformation T that takes elements I in $\mathscr{F}$ to other elements: $T: \mathscr{F} \to \mathscr{F} : I \mapsto I'$.

The task of modeling video feedback is now to write down the explicit form of T using our knowledge of video system physics. To simplify matters, I will first develop models for monochrome (black and white) video feedback. With color systems the modeling is complicated by the existence of three color signals and the particular camera technology. Once the monochrome model is outlined, however, it is not difficult to make the step to color.

The construction of the monochrome model requires more detailed discussion of the electronic and optical transformations in the feedback loop. Fig. 3 presents the schematic upon which this model is based. With the physics of these transformations as discussed in the appendix, a relatively complete model can be constructed.

The appendix reviews the operation of the common *vidicon* camera tube, how it (i) stores and integrates images and (ii) introduces a diffusive coupling between picture elements. These attributes impose upper temporal and spatial frequency cutoffs, respectively. The focus turns out to be an easily manipulated control of the spatial diffusion rate. The monitor's phosphor screen also stores an image but for a time negligible compared to that

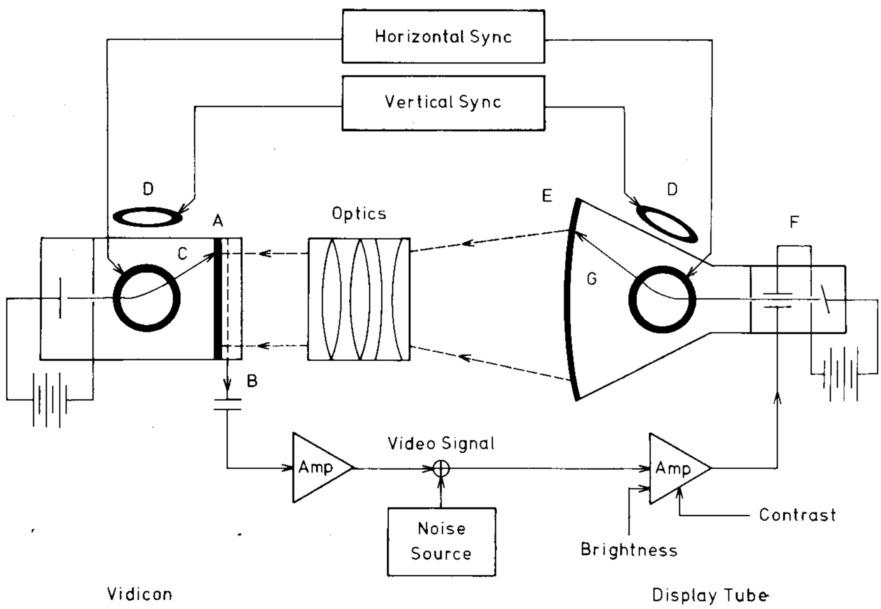

Fig. 3. Idealized monochrome video feedback. A: photoconductive image target; B: pickup for video signal; C: camera electron beam; D: scanning coils for electron beams; E: phosphor screen; F: beam intensity modulator; G: monitor electron beam.

of the vidicon. The appendix indicates various deviations from the ideal video feedback system of fig. 3.

With the physics and electronics of video systems in mind, the details of the transformation T can be elucidated for the monochrome model. The first and perhaps most significant assumption, is that T be taken as a discrete-time transformation of a spatially continuous function, the image I_n,

$$I_{n+1} = T(I_n) .$$

Employing a "bias intensity", the intensity at a point $I_n(\vec{x})$ can be scaled to take values in the range $[-1, 1]$; -1 being black and 1 white. For comparison at the end of this section, I consider how a continuous time and space model can be applied to video feedback using reaction–diffusion equations.

The new image I_{n+1} consists of two parts: the first, the "old image" stored in the photoconductor, and the second, the "incoming image" from the monitor screen. This, and the process of successive feedback of images, can be expressed as an *iterated functional equation*. The first model of the dynamic T is the following

$$I_{n+1}(\vec{x}) = LI_n(\vec{x}) + sfI_n(bR\vec{x}) , \qquad (1)$$

where $\vec{x}$ is a point in $\bar{R}^2$. The first term represents the old image whose intensity at the point $\vec{x}$ has decayed by a factor of L each time step. Thus L is the intensity dissipation of the storage elements, including the monitor phosphor, but dominated by the photoconductor. The second term represents the incoming image that is possibly rotated by an angle ϕ and spatially magnified by a factor b. R is then a simple rotation,

$$R = \begin{pmatrix} \cos(\phi) & \sin(\phi) \\ -\sin(\phi) & \cos(\phi) \end{pmatrix},$$

due to the relative raster orientations; b corresponds to the zoom control. If $\vec{x}' = bR\vec{x}$ lies outside of $\bar{R}^2$ then $I_n(\vec{x}') = 0$. The parameter $f \in [0, 1]$ corresponds to the f/stop. For a system with luminance inversion black regions become white and vice versa. To take this into account the parameter s is set to -1, rather than its normal value of unity.

Spatial diffusion due to the photoconductor, but largely controlled by focus, contributes to the intensity at a point. It produces a spatial coupling to neighboring pixels that can be represented continuously by the following convolution integral:

$$\langle I_n(\vec{x}) \rangle_x = \int_{\bar{R}^2} \mathrm{d}\vec{y} I_n(\vec{y}) \exp\left(\frac{-|\vec{y} - \vec{x}|^2}{2(\sigma_f + \sigma_v)^2} \right), \qquad (2)$$

assuming a Gaussian shape for the diffusion profile. The denominator in the exponential controls the width of the smoothing with σ_f representing the focus control and σ_v the intrinsic smoothing in the vidicon.

A more complete model including the major features of video feedback systems is the following:

$$I_{n+1}(\vec{x}) = LI_n(\vec{x}) + L' \langle I_n(\vec{x}) \rangle_x + sfI_n(bR\vec{x}) , \qquad (3)$$

with the parameter L' setting the magnitude of the intensity signal contributed (or leaked) to that at $\vec{x}$ during one raster time.

Furthermore, the first term in eq. (3) can be modified to include the temporal storage and integration of images and their successive decay. This can be effected by a weighted sum of past images,

$$\langle I_n(\vec{x}) \rangle_\tau = \sum_{i=0}^{\infty} I_{n-i}(\vec{x}) L^i ,$$

where the decay parameter L is the same as above. This gives equations corresponding to the video feedback system as laid out in fig. 3,

$$I_{n+1}(\vec{x}) = L \langle I_n(\vec{x}) \rangle_\tau + L' \langle I_n(\vec{x}) \rangle_x + sfI_n(bR\vec{x}) . \qquad (4)$$

For a color system the scalar intensity becomes a vector of red, green, and blue intensities, $\vec{I}(\vec{x}) = (R(\vec{x}), G(\vec{x}), B(\vec{x}))$. There are also couplings between the colors caused by a number of interactions and imperfections, such as

1) incorrect convergence of the monitor electron beams on the screen phosphor color dots;

2) non-ideal color filters and differential diffusion rates for the photoelectrons in the vidicon;

3) aberration in the optical system;

4) electronic cross-talk between the color signals in pickup, amplification, and reconstruction, of the image.

A model for color feedback can be developed as an extension of eq. (4) based on the evolution of a vector intensity $\vec{I}$,

$$\vec{I}_{n+1}(\vec{x}) = \bar{L}\langle\vec{I}_n(\vec{x})\rangle_\tau + \bar{L}'\langle\vec{I}_n(\vec{x})\rangle_x + sf\vec{I}_n(bR\vec{x}) , \quad (5)$$

where $\bar{L}$ and $\bar{L}'$ are matrices. Their diagonal elements control the color intensity decay, while their off-diagonal elements the coupling of the color signals. In a first order approximation, this model summarizes the various couplings only linearly although it is clear that nonlinear couplings could be added.

Along the same lines a continuous-time model can be developed that for many purposes is easier to study. This also allows for the comparison of video dynamics to other work on spatial complexity in biological and chemical systems. The type of model proposed here is generally called a reaction–diffusion partial differential equation. A.M. Turing introduced this kind of system in 1952 as a model for biological morphogenesis [6]. The general form of these equations is

$$\frac{\mathrm{d}\vec{I}}{\mathrm{d}t} = \vec{F}(\vec{I}) + D\nabla^2\vec{I} \quad (6)$$

for the evolution of the "field" $\vec{I} = (I_1, I_2, \ldots, I_k)$ of concentration variables. The function $\vec{F} = (F_1, F_2, \ldots, F_k)$ represents the local "reaction" dynamics of these variables without diffusion. D is a matrix describing the spatial coupling and diffusion rate of the concentration variables. For linear $\vec{F}$, Turing showed that this system gives rise to spatial patterns that can oscillate temporally. He also considered the addition of a noise term and its effect on the selection of spatial patterns.

These equations naturally take into account spatial diffusion with the Laplacian operator on the RHS of eq. (6). Furthermore, the continuous time derivative and the local reaction dynamics can be used to implement a temporal low pass filter. Thus. reaction–diffusion models can be constructed that satisfy the basic criteria already laid down for video feedback. Video feedback differs from Turing's reaction–diffusion models because of a nonlocal spatial coupling resulting from the spatial rotation and magnification. In direct analogy with the previous arguments, the proposed reaction–diffusion equation for color video feedback dynamics is

$$\frac{\mathrm{d}\vec{I}(\vec{x})}{\mathrm{d}t} = \bar{L}\vec{I}(\vec{x}) + sf\vec{I}(bR\vec{x}) + \sigma\nabla^2\vec{I}(\vec{x}) , \quad (7)$$

where the parameters s, f, b, $\bar{L}$, and R, are as before, and σ is a matrix summarizing the spatial diffusion rate. The first term on the RHS of eq. (7) is the "old image", the next term is the nonlocal "incoming image", and the last is the diffusion coupling. For spatial structure and temporal behavior well below the spatial and temporal frequency cutoffs discussed above, this model should be valid. As will be seen in the next section, video feedback dynamics has very similar phenomenology to that of chemical and biological systems described by this type of model. The reaction–diffusion model provides a conceptual simplicity as well as simpler notation. In fact, video feedback can be used to experimentally study this widely used class of models for spatio-temporal complexity.

The previous iterated functional equation model eq. (4) can be derived from eq. (7) upon discretization. Eq. (7) is the differential form of eq. (4), an integro-functional difference equation. A digital computer simulation of this continuum model naturally involves spatial and temporal discretization. Thus, as far as verifying the models by digital simulation, it is a moot point as to which is better, the iterated functional equation or reaction–diffusion model.

Having constructed these models, the burning question is whether their dynamics describe that actually found in real video feedback systems. For the very simplest behavior there is hope that the equations can be solved analytically. In general, though, simulating the models in a more controlled environment on a digital computer, for example, seems to be the only recourse [7]. After describing the dynamics typically observed in a real video feedback system in the next section, I will come back to the results of just such a digital simulation.

4. Video software

The models and discussion of video physics in the last section may have given an impression of simplicity and straightforwardness in understanding video feedback dynamics. The intent in this section is to balance this with a little bit of the richness found in an actual color video system. An overview of the observed dynamics will be presented initially from a dynamical systems viewpoint. I will also address the appropriateness of this framework for some of the more complex dynamics. Then a brief description of a movie on video feedback follows. Stills from the movie illustrate some of the curious features of video feedback dynamics. And finally, these "experimental" results will be compared to those from preliminary digital computer simulations.

Video feedback dynamics can be roughly categorized as in table II. For the simplest temporal behavior, descriptive terms from dynamical systems seem appropriate as in the first four behavior types. At first, let's ignore any possible spatial structure in the images. When a stable time-independent image is observed, it corresponds to a fixed point in the image space $\mathscr{F}$. Much of the behavior seen for wide ranges of control parameters falls into this category.

Thus on the large scale video systems are very stable, as they should be in order to operate properly in a wide range of environments. For extreme parameter settings, such as small rotation, low contrast, large demagnification, and so on, equilibrium images are typically observed. For example, when the zoom is much less than unity then one observes an infinite regression of successively smaller images of the monitor within the monitor within .... The image is similar to that

Table II
Video feedback dynamics

Observed	Attractor in image space
equilibrium image	fixed point
temporally repeating images	limit cycle
temporally aperiodic images	chaotic attractor
random relaxation oscillation	limit cycle with noise-modulated stability
spatially decorrelated dynamics (e.g. dislocations)	quasi-attractor with local temporal dynamics: fixed point, limit cycle, chaotic attractor
spatially complex image	spatial attractor: fixed point, limit cycle, chaotic attractor (?)
spatially and temporally aperiodic	nontrivial combination of the above

seen when two mirrors face each other. With a bit of rotation the infinitely regressing image takes on an overall "logarithmic spiral" shape that winds into the origin.

When the parameters are set to moderate values, one of the first non-trivial dynamics to appear is a simple oscillation. This would be a limit cycle in image space: a sequence of dissimilar images that after some time repeats. Because entire images repeat, individual points on the screen exhibit periodic behavior. Consequently, the values of intensity at a point cycle repetitively.

At parameter values nearby often lie temporally aperiodic image sequences. Chaotic attractors in image space are most likely a good description of this behavior type in the simplest cases*. When non-repeating images are reached from limit cycles with the change of a parameter, the bifurcation occurs in one of (at least) three ways:

1) Simple lengthening of the limit cycle period, until it is sufficiently long to be effectively aperiodic: for example, going from a limit cycle of 10 seconds to one of hours. New images are introduced, but are not sufficiently similar to be considered as close "recurrences".

2) The introduction of subharmonics at frequencies lower than that of the original limit cycle: these subharmonics are small modulations of the image's geometric structure. The overall image sequence remains the same, but differs in the modulated detail.

3) Suddenly at some critical parameter value, the limit cycle disappears and aperiodicity set in.

A very telling indication that complex behavior lies at nearby parameter settings comes from slightly perturbing the system. This can be done most conveniently by waving a finger between the monitor and camera. Once perturbed, the nearby complexity reveals itself by long and convoluted transients as the system settles down to its original simple fixed point or limit cycle. The closer in parameters to aperiodic behavior, the longer the transients. The simple dynamics discussed so far are globally stable in just this sense of returning to the same image(s) when perturbed. Of course, one can perturb the system too much, knocking it into another basin of attraction and so losing the original behavior. It is a common experience, in fact, that hand-waving perturbations will leave the screen dark, with the system requiring a "positive" stimulus of light from some source to get back to its initial attractor.

At large zoom, or spatial magnification, the system noise is readily (and exponentially) amplified. This regime is dominated by bursts of light and color. Depending on the controls, the bursts can come at regular intervals or at random times. Also, the particular features of the bursts, such as color, intensity, or even the pattern, can be the same or aparently randomly selected. This behavior is quite reminiscent of a limit cycle with (noise) modulated stability [9].

The dynamics discussed so far is simple in the sense that its temporal features are the dominant aspect. No reference was made to spatial structure as the temporal dynamics was readily distinguished from it. A more precise way to make this distinction is in terms of whether the behavior at a suitably chosen point captures the dynamics [8]. Using intensity data from this point, if a simple attractor can be reconstructed, then the behavior is of a simple type that can be *decomposed* into temporal and spatial components. The last entries in table II are an attempt to indicate that there is much more than this simple decomposable dynamics. Indeed, the spatial structure and its interaction with the temporal dynamics are what makes video feedback different from other systems with complex dynamics, like chaotic nonlinear oscillators. But this difference presents various (intriguing) difficulties, especially because a dynamical system description does not exist for spatial complexity [10]. Nonetheless, a qualitative description is possible and, hopefully, will lead to the proper theoretical understanding of spatial dynamics.

* In this case, given a time series of intensity values at a point, it is possible to "reconstruct" a state space picture of the attractor [8].

Much of the following description, and the categorization used in table II, is based on *observed* similarities in spatial structure. While it may be very difficult to unambiguously state what a complex image is, we as human beings can easily discern between two images and can even say some are "closer" than others in structure. I am not currently aware, however, of any mathematical definition of "closeness" for spatial structure that is of help with the dynamics observed in video feedback. Such a concept would be of immense value in sorting out complex dynamics not only in video feedback but in many other branches of science.

To denote images that are observed to be similar, but different in spatial detail, I introduce the phrase "quasi-attractor" for the associated object in state space. These state space objects appear to be globally stable to small perturbations and it is in this sense that they are attractors. Once perturbed, the video system returns to similar images, although in spatial detail they may be slightly altered from the original.

A good example of quasi-attractors is the class of images displaying *dislocations*. This terminology is borrowed from fluid dynamics, where dislocations refer to the broken structure of convective rolls in an otherwise simple array. Dislocations are regions of broken symmetry where the flow field has a singularity. The formation of this singularity typically requires a small, but significant, energy expenditure*. In video feedback, dislocations appear as inter-digitated light and dark stripes. The overall pattern can be composed of regular parallel arrays of alternating light and dark stripes with no dislocations, and convoluted, maze-like regions where stripes break up into shorter segments with many dislocations. The boundaries between segment ends form the dislocations. They can move regularly or wander erratically. Dislocations form in pairs when a stripe breaks in two. They also annihilate by coalescing two stripes. Dislocations make for very complex, detailed patterns whose temporal evolution is difficult to describe in terms of dynamical systems because of their irregular creation and annihilation. Nonetheless, when perturbed very similar images reappear. A quasi-attractor would be associated with global features, such as the relative areas of regular stripe arrays and dislocation regions, the time-averaged number of dislocations, or the pattern's gross symmetry.

Dislocations fall into the behavior class of *spatially decorrelated dynamics*. Moving away from one point on the screen, the spatial correlations decay rapidly enough so that eventually there is no phase relationship between the behavior of different regions. The governing dynamics in any one area is similar to that of other areas. The local behavior, however, can take on the character of a fixed point, limit cycle, or chaotic attractor. Thus while globally stable, the entire image cannot be described by a *single* attractor in the conventional sense of dynamical systems theory. This behavior type has been studied quantitatively in simple nonlinear lattice models [13]. Spatially decorrelated dynamics apparently is the cause of heart fibrilation that results in sudden cardiac death [14].

The existence of *spatial attractors* that describe an image is another useful notion in classifying video dynamics. Intensity values as a function of a "pseudo-time" can be obtained by following along a simple parametrized curve on the screen. These values then can be used to reconstruct a "state space" picture [8] that captures some features of an image's structure. These features naturally depend on the type of curve selected. For example, data from a circle of fixed radius elucidates the rotational symmetry in an image. Similarly, data from along a radial line allows one to study radial wave propagation caused by magnification. The reconstruction of spatial attractors has been carried out for the above-mentioned lattice models [13].

* Both Couette flow [11] and Bénard convection [12] exhibit this phenomenon. In nematic liquid crystal flow these are called *disclinations*. Similar structures appear in spin systems, such as magnetic bubble devices, and in the formation of crystals. Turing's discussion [6] of "dappled patterns" in a two-dimensional morphogen system is also relevant here.

The rough classification is not yet complete. There are also image sequences that appear to be combinations of spatially-decorrelated dynamics and complex spatial attractors. The latter entries in table II indicate these possibilities.

The interaction of spatial and temporal dynamics makes it very difficult to describe the more complex behavior in any concise manner. To alleviate this problem a short video tape was prepared to illustrate the types of behavior in table II [4]. The movie is particularly effective in giving a sense of the temporal evolution, stability, and richness of video feedback dynamics. An appreciation of the spatial complexity can be gleaned in a few stills from the movie. (See plates 1–7.) This will compensate hopefully those readers who do not have access to a video feedback system or who have not seen the movie.

The examples have a few common features. Regarding parameter settings, they were all made at rotations of approximately 40 degrees and with spatial magnifications slightly less than unity, unless otherwise noted. The discreteness caused by the finite resolution is apparent in each figure. Note that the spatial structures are typically many pixels in extent, so that the discreteness does not play a dominant role.

Plate 1 presents a typical nontrivial equilibrium image, or fixed point. It has an approximate nine-fold symmetry that comes from the rotation angle: $360/40 = 9$. The intensity at each point as a function of angle is periodic, with periods not greater than nine. The overall spatial symmetry as a function of rotation ϕ exhibits a "symmetry locking" highly reminiscent of that found in temporal frequency locking in nonlinear oscillators [3]. One noteworthy similarity is that the parameter window for which a given symmetry dominates decreases in width with increased order of the symmetry. For example, spatially symmetric images of period 31 occur for a much smaller rotation range those with period 9 symmetry.

* One evening this cycle was allowed to oscillate for two hours with no apparent deviation from periodicity before the power was turned off.

One image out of a long limit cycle is shown in plate 2. The limit cycle period was approximately 7 seconds. Initially, a green disk nucleates at the center of a homogeneous light blue disk. The green disk grows to fill 80% of the illuminated area leaving a blue annulus. A red disk then nucleates inside the green disk, along with an outside ring of nine dots. The oscillation consists largely of the radially outward moving red disk, that intercepts the inward propagating dots. The still is taken at the moment of collision. The disk expands engulfing the dots and the green annulus, then itself is over taken by the inside boundary of the blue annulus that moves inward. The outer boundary of the red disk then recedes before the blue annulus. The screen then eventually becomes entirely light blue, at which moment the center nucleates a growing green disk, and the cycle repeats. This limit cycle was stabilized by a very small marking near the screen's center*.

Plate 3 shows a still from a sequence of images with slowly moving dislocations. Toward the outside there is a "laminar" region of stripes. Moving inward from this, the first ring of nine dislocations is encountered. These were seen to move smoothly counter-clockwise. The center, however, periodically ejected thin white annuli that propagated out radially, only slowly acquiring clockwise rotation. The interface between the inner and outer regions caused the intervening maze-like dislocation pattern. The entire image shows a high degree of nine-fold symmetry although in the dislocation region it is quite complex.

Spiral patterns are quite abundant, as one expects from a transformation with rotation and magnification. Plate 4 illustrates a *logarithmic spiral* that dynamically circulates clockwise outward. Temporally, the behavior is periodic with color and structure flowing outward from the center. The rotation here is $\phi = -30$ degrees. The logarithmic spiral can be easily described as a parametrized curve with angle ϕ and scaling b controls as follows

$$(x, y) = (bt \cos(\phi \log t), bt \sin(\phi \log t)),$$

with $t \in [0, 1]$. Such structure and periodic coloring occur often in organisms, such as budding ferns and conch shells.

With relatively high zoom, or large spatial magnification greater than unity, noise in intensity and spatial structure is exponentially amplified. A common manifestation of this is periodic or random bursts. Plate 5 shows a snapshot of a developed burst that had spiralled counterclockwise out of the center in about one second. After a burst the screen goes dark with faint flickering, until another fluctuation occurs of sufficient magnitude to be amplified into a spiralling burst. The video system's finite resolution can be seen as a graininess on a scale larger than the intrinsic discreteness.

Luminance inversion stabilizes images by amplifying contrast. Black regions map into white and colors map to their opposite. This sharpens boundaries between dark, light, and colored areas in an image. Section VI of ref. 2 discusses this stabilizing effect in more detail. Plate 6 shows an example of the "pinwheels" that dominate the images found with luminance inversion*. The rotation for this photo was $\phi = -90$ degrees. By adjusting the rotation, focus, and/or hue, controls the pinwheels are seen to move either clockwise or counterclockwise. Winfree discusses similar "rotating waves" of electrical impulses that cause the heart's coordinated beating. Plate 6 should be compared to the figure on page 145 of ref. 14.

Plate 7, also made with luminance inversion, is a snapshot of outward spiralling "color waves". These are very reminiscent of the ion concentration waves found in the Belousov–Zhabotinsky chemical reaction [15]. The rotation parameter here is roughly $\phi = -40$ degrees. As in the above pinwheels, every point in the image has a well-defined temporal phase, except for the center where there is a phase singularity.

A digital simulation based on eqs. (4) and (7) captures some of the gross features of video feedback. To this extent the proposed models are correct. It is still an open question as to whether they reproduce the detailed spatio-temporal dynamics. Such comparison is a difficult proposition even in modeling temporal chaos alone. Digital simulations are many orders of magnitude slower than the space–time analog simulations of video feedback. And for this reason it is difficult, given model equations, to verify in detail and at numerous parameter settings their validity. To date digital simulations [7] have reproduced the following features typical of video feedback:

1) equilibrium images with spatial symmetry analogous to Turing's waves [6];

2) fixed point images stable under perturbation;

3) meta-stability of fixed point images: sufficiently large perturbations destroy the image;

4) logarithmic spirals;

5) logarithmic divergence when the rasters are not centered.

At this preliminary stage of digital simulation it is not possible to discuss much in detail. In fact, it may be a long time until extensive digital simulations are carried out on the proposed models. The construction of, or use of pre-existing, special purpose digital image processors to simulate video feedback may be more feasible than using conventional digital computers. The next and final section comes back to address these questions of future prospects for understanding video feedback.

5. Variations on a light theme

Video feedback is a fast and inexpensive way to perform a certain class of space–time simulations. It also provides an experimental system with very rich dynamics that is describable in some regimes by dynamical systems theory, while in other regimes it poses interesting questions about extending our current descriptive language to spatial complexity.

One goal in studying video feedback is to see whether it could be used as a simulator for dynamics in other fields. Turing's original proposal of reaction-diffusion equations for biological mor-

* Bob Lansdon introduced me to these pinwheel images. See also ref. 2.

phogenesis comes to mind, as well as the image processing [16] and hallucinogenic dynamics [17] of the visual cortex. Naturally, the first task in this is to understand video feedback itself as completely as possible. Toward this immediate end, I have proposed models based on video physics and presented an overview of the possible behavior in a particular color video system. The next steps in this program are to make a more quantitive study of the attractors and bifurcations with calibrated video components. Data from these experiments would be analyzed using techniques from dynamical systems to (i) reconstruct state space pictures of the simpler attractors, and (ii) quantify the unpredictability of the simple aperiodic behavior.

A second approach to understanding video feedback dynamics is to study other configurations of video components. The possibilities include:

1) masking portions of the screen to study the effect of boundary conditions;

2) optical processing with filters, lenses, mirrors, and the like;

3) using magnets to modulate the monitor electron beam scanning;

4) connecting two camera–monitor pairs serially, thus giving twice as many controls;

5) nonlinear electronic processing of the video signal;

6) inserting a digital computer into the feedback loop via a video frame buffer.

The possible modifications are endless. But, hopefully, they will help point to further understanding and lead to applications in other fields.

Variations (5) and (6) may lead to the most fruitful applications of video feedback. For example, they allow one to alter the governing rules in simulations of two-dimensional local and nonlocal automata. In this process an image is stored each raster time. Each pixel and its neighbors are operated on by some (nonlinear) function. For rapid ("real-time") simulation this function is stored in a "look-up" table. The pixel value and those of its neighbors form the input to the table. The table's result then becomes the pixel's new value that is stored and displayed. This is a very general configuration. With video feedback one has simple control over the nonlocality of the rules using rotation and spatial magnification, and over the number of neighboring pixels using the focus.

A monochrome system, employing an intensity threshold to give crisp black and white images, could be used to simulate binary cellular automata. This restriction on the intensity range falls far short of the possible pixel information in video systems. Indeed, as discussed in the appendix, color systems are capable of transmitting roughly 20 bits of information per pixel. This includes a random "noise floor" for small signals. Generalizing cellular automata, from a few states per site to many, leads to lattice dynamical systems [13]. This corresponds in the video system to removing the above thresholding. Thus this video configuration will be especially useful in the experimental study of lattice dynamical systems and in the verification of analytic and numerical results, such as spatial period-doubling, found in some nonlinear lattices [13].

A number of video image processors are available, both analog and digital. Many have been constructed solely according to their aesthetic value by video artists. Certainly, among this group there is a tremendous amount of qualitative understanding of video dynamics. At the other extreme of the technical spectrum, some of the emerging supercomputers have adopted architectures very similar to that of video feedback systems. These machines would be most useful in detailed quantitative simulations. And, in turn, video feedback might provide an inexpensive avenue for initial study of simulations planned for these large machines.

Physics has begun only recently to address complex dynamical behavior. Looking back over its intellectual history, the very great progress in understanding the natural world, with the simple notions of equilibrium and utter randomness, is astounding. For the world about us is replete with complexity arising from its intimate interconnectedness. This takes two forms. The first is the recycling of information from one moment to the next, a temporal inter-connectedness. This is feedback. The second is the coupling at a given time between different physical variables. In globally stable systems, this often gives rise to nonlinearities. This inter-connectedness lends structure to the chaos of microscopic physical reality that completely transcends descriptions based on our traditional appreciation of dynamical behavior.

From a slightly abstract viewpoint, closer to my personal predelictions, video feedback provides a creative stimulus of behavior that apparently goes beyond the current conceptual framework of dynamical systems. Video feedback poses significant questions, and perhaps will facilitate their answer. I believe that an appreciation of video feedback is an intermediary step, prerequisite for our comprehending the complex dynamics of life.

Acknowledgements

I am particularly indebted to Ralph Abraham for introducing me to video feedback a number years ago. Special thanks are due to Doyne Farmer and the Center for Nonlinear Studies, Los Alamos National Laboratory, for the support and encouragement of this project. Larry Cuba generously loaned his video equipment for Plates 6 and 7. Elaine Ruhe was especially helpful in the preparation of the video tape and stills. I would also like to thank the Automata Workshop participants who played with the video feedback demonstration and discussed their ideas with me. Particular thanks go to Bob Lansdon, Alice Roos, Otto Rössler, and Art Winfree, for useful discussions on video feedback.

Appendix A

Video physics

There are many types of camera pickup tubes, but for concreteness I will concentrate on the common vidicon tube and describe how it converts an image to an electronic signal. The vidicon relies on the photoconductive properties of certain semiconductors (such as selenium). When light is incident on these materials their electrical resistance is reduced. Photoconductors can have quite large quantum efficiencies, approaching 100%, with virtually all the incident photon energy being converted to mobilizing electrons in the material. Once energized these electrons diffuse in an ambient electric field.

The vidicon takes advantage of these mobile electrons in the following way. (Refer to fig. 3.) An image is focused on a thin *photoconducting layer* (A) approximately one square inch in size. Spatial variation in an image's light intensity sets up a spatial distribution of mobile electrons. Under influence of a small bias field these diffuse toward and are collected at the transparent *video signal pickup* conductor (B). During operation the photoconductor/pickup sandwich acts as a leaky capacitor with spatially varying leakage: the more incident light, the larger the local leakage current. The *electron beam* (C) from the vidicon's cathode scans the back side of the photoconductor depositing electrons, restoring the charge that has leaked away, and hence, bringing it to a potential commensurate with the cathode. The coils (D) supply the scanning field that moves the electron beam over the photoconductor. They are driven synchronously with the horizontal and vertical raster timing circuits (top of diagram). The output video signal corresponds to the amount of charge locally deposited by the beam at a given position during its scan. This charge causes a change in the leakage current and this change is picked up capacitively and then amplified.

The important features of this conversion process, aside from the raster scanning geometry already described, are

1) the diffusion of electrons as they traverse the photoconductor; and

2) the local storage and integration of charge associated with the light incident during each raster time.

The diffusion process directly limits the attainable spatial resolution. This places an upper bound on the number of horizontal lines and the number of *pixels* (distinct picture elements) within each line. The effect on spatial patterns is that there can be no structure smaller than this diffusion limit. Another interpretation of this is that, over the period of several rasters, there is a diffusive coupling between elements of an image.

The high spatial frequency cutoff can be easily estimated. The electron beam forms a dot on the photoconductor's backside approximately 1 to 2 mils in diameter. Diffusion then spreads this out to roughly twice this size by the time these electrons have traversed the layer, yielding an effective 3 to 4 mils minimum resolution. For a vidicon with a one inch square photoconducting target, this results in a limit of 250 to 300 pixels horizontally and the same number of lines vertically. These are in fact nominal specifications for consumer quality cameras. Additionally, although the raster geometry breaks the image into horizontal lines, the resolution within each line is very close to that given by the number of scan lines. It will be a reasonable approximation, therefore, to assume that the spatial frequency cutoff is isotropic.

In a similar manner the charge storage and integration during each raster time places an upper limit on the temporal frequency response of the system. In fact, this storage time τ_s can be quite a bit longer than the raster time τ_r of 1/30 second. A rough approximation to this would be $\tau_s \approx 10\tau_r \approx 1/3$ second. Thus the system's frequency response should always be slower than 3 Hz. And this is what is observed experimentally. Even the simplest (linear) model for video feedback must contain spatial and temporal low pass filters corresponding to the above limitations.

The optical system that forms the image on the photoconductor has spatial and temporal bandwidths many orders of magnitude greater than the vidicon itself. Hence these intrinsic optical limitations can be neglected. The optical system controls, however, are quite significant. The focus, for example, can affect an easily manipulated spatial diffusion by moving the image focal plane before or behind the photoconductor. In addition, by adjusting it to one side of exact focus the diffusion orientation can be inverted. Very small changes in the zoom, or spatial magnification, can have quite large qualitative effects because the image information repetitively circulates in the feedback loop. A spatial magnification greater than unity increases exponentially with the number of passes through the loop. Similarly, adjusting the admitted light with the f/stop can cause the light in an image to dissipate completely when set below some intrinsic threshold.

The image intensity can again be adjusted with the brightness control on the monitor, perhaps to compensate for the camera's f/stop setting. The brightness adjusts the DC intensity level of the video signal, while the contrast amplifies its dynamic range, or the AC portion of the video signal. High contrast will amplify any noise or spurious signal into an observable flickering of the image. A monochrome monitor's screen (E) is coated with a uniform layer of phosphor that emits light when struck by the electron beam (G). Using the monitor's driving coils (D), the raster synchronizing circuits move the beam to the appropriate position on the screen for the incoming video signal. This signal modulates the beam's intensity (F). The screen's spatial resolution is effectively continuous with a lower bound significantly less than that imposed by the vidicon resolution and by the finite number of scan lines. Additionally, the phosphor stores each raster for a short time to reduce flickering. Thus there is another image storage element in the feedback loop. The phosphor's *persistence* is typically a single raster time and so it can be neglected compared to the vidicon's storage time.

There are a number of sources of error, or deviations from the idealized video feedback system. Here I will briefly mention a few that could be taken, more or less easily, into account in the modeling, but for simplicities sake will not be included. The first omission that I have made in describing the functioning of video systems, is that the bulk of them transmit two *interlaced* half-rasters, or *fields*, every sixtieth of a second. A complete raster is still formed every thirtieth of a second, but the successive images appear to flicker less than without interlaced fields. Since the time scale of this is much less than the image storage and integration time of the vidicon it can be neglected.

A second and important error source is the intrinsic noise of the intensity signal. A number of physical processes contribute to this noise. The discreteness of the quantum processes and the electron charge produce resistive noise in the photoconductor. The electronic amplifiers for the signal also introduce noise. The net effect though is a signal to noise ratio of about 40 db. This translates into about 10 mV white noise superimposed on the 1 V standard video signal, or into about 1% fluctuation in the intensity of pixels on the monitor's screen.

The photoconductor's monotonic, but nonlinear, current output i_0 as a function of light intensity I_i adds a third error. For vidicons $i_0 \sim I_i^\gamma$, with $\gamma \in [0.6, 0.9]$. Furthermore, this response function saturates above some intensity threshold I_{sat}. Vidicon photoconductors also exhibit a nonuniform sensitivity of about 1% over the target region.

When the camera is very close to the monitor, there is significant geometric distortion due to the screen's curvature. Geometric distortion also arises from other errors in the system, such as the adjustment of the horizontal and vertical raster scanning circuitry. These distortions can be reduced to within a few percent over the image area. Finally, within the monitor there are saturating nonlinearities in its response to large intensity signals and high brightness or high contrast settings. This list is by no means exhaustive, but at least it does give a sense of the types of errors and their relative importance.

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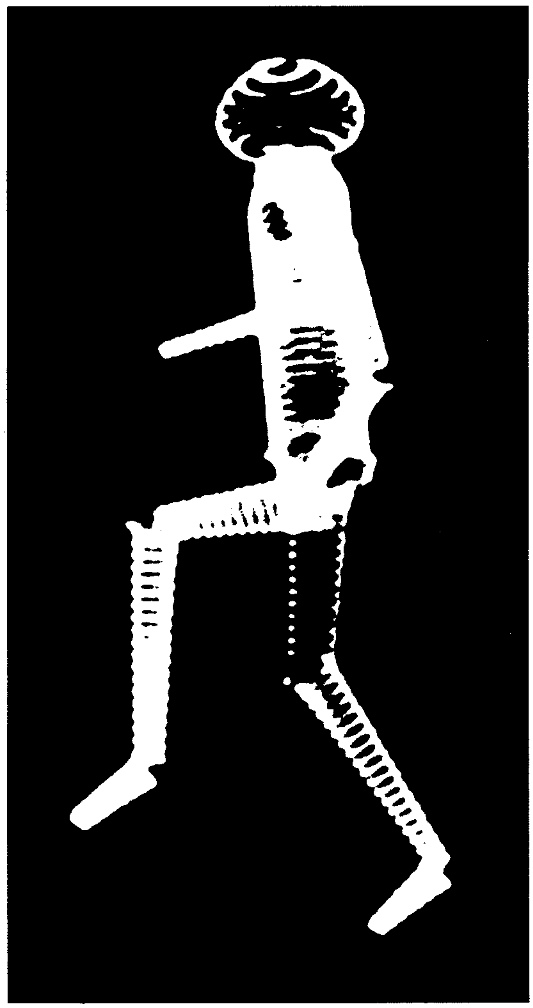
NOTES FOR AN EARLY ANIMATION DEVICE

Lee Harrison

The following paper is reprinted in facsimile form as the most primary and authentic source of Lee Harrison's original concept for electronic animation. These notes eventually materialized as the ANIMAC animation system. —D.D.



TODAY DEC. 29, 1961 N.A.C., 44

THE CLOCK OR MASTER OSCILLATOR, IS A STABLE, VARIABLE-FREQUENCY WAVEFORM GENERATOR

~~THE OUTPUT OF THE CLOCK~~

THERE ARE TWO SIGNAL OUTPUTS OF THE CLOCK OR MASTER OSCILLATOR. ONE IS A SQUARE WAVE ⊓⊔⊓, THE OTHER, A SINE WAVE. ∿∿. THE OUTPUTS ARE AT THE SAME FREQUENCY.

THE FUNCTION OF THE CLOCK IS TO FURNISH THE "DRIVING-SIGNALS" TO THE DEVICE. IT IS ALSO A MEANS BY WHICH THE INNER WORKINGS OF THE DEVICE ARE "TIME-SYNCHRONIZED."

WE REFER TO THE OUTPUT OF THE CLOCK AS "HIGH FREQUENCY," BECAUSE WE COUNT DOWN (BY MEANS OF A COUNTER TO BE DESCRIBED LATER) TO THE "FRAME FREQUENCY", THUS ESTABLISHING A FRAME RATE. FRAME RATE IS THE RATE AT WHICH WE DRAW ONE COMPLETE FIGURE OR PICTURE ON THE DISPLAY SCOPE.

BECAUSE THE COUNTER PERFORMS A FIXED-RATIO COUNTDOWN, THE LOW FREQUENCY IS ALWAYS A LOWER MULTIPLE OF THE HIGH FREQUENCY.

THUS, BY VARYING THE HIGH FREQUENCY, WE AUTOMATICALLY VARY THE LOW FREQUENCY OR FRAME RATE.

DURING THIS DEVELOPEMENTAL PERIOD, WE ARE OPERATING AT FRAME RATES BETWEEN 24 AND 30 CYCLES PER SECOND (CPS). 30 cps IS DESIRABLE AT THIS TIME BECAUSE

a.) THE LIGHTING IN OUR WORKSHOP IS SUCH THAT AT A LOWER FRAME RATE, WE SEE A BOTHERSOME FLICKER, and

b). IT IS VERY EASY TO SYNCHRONIZE THE FREQUENCIES TO "60-CYCLE LINE FREQUENCIES (JUST TWICE THE FRAME RATE) WITH A HAND ADJUSTMENT AND THEREBY ELIMINATE WHAT IS KNOWN AS "HUM" OR LINE NOISE, WHICH IF NOT SYNCHRONIZED CAUSES A SLOW WOBBLE OF THE PICTURE.

IN THE FUTURE, WE WILL INSTALL A FEEDBACK TIMING CONTROL IN THE COUNTER CIRCUIT WHICH WILL AUTOMATICALLY SYNCHRONIZE ALL FREQUENCIES TO THE LINE (60CPS) AND

Witnessed by ... 12/29/61

page 2

THUS ELIMINATE THE NECCESSITY OF HAND ADJUSTMENTS AND ALSO ASSURE AN EXACT 24 CPS FRAME RATE.

THE SQUARE WAVE OUTPUT IS FED INTO AND IS DIRECTLY INTO THE COUNTER. IT IS ALSO THE DRIVING SIGNAL FOR THE HORIZONAL DEFLECTION GENERATOR OF THE SKIN SCANNER (TO BE DECRIBED LATER.)

THE SINE WAVE OUTPUT IS FED INTO TWO OF THE SAMPLERS (SAMPLER GATES) TO BE DESCRIBED LATER, ALSO INTO A 90 DEGREE PHASE SHIFTER WHOSE OUTPUT NOW BECOMES A COSINE WAVE (IN RELATION TO THE ORIGINAL SINE WAVE) WHICH IS SUBSEQUENTLY FED INTO THE OTHER SET OF SAMPLERS. ALSO BOTH SINE AND COSINE WAVES ARE FED INTO MODULATORS (TO BE DECRIBED LATER)

THE FUNCTION OF THE CLOCK MAY BE TAKEN OVER BY THE TAPE RECORDER, WHERE THE CLOCK SIGNALS ARE RECORDED ON ONE OF THE CHANNELS, AND USED AS DRIVING SIGNALS OF THE DEVICE, THUS SYNCHRONIZING ALL RECORDED SIGNALS WITH THE "TAPE CLOCK".

COUNTER & TIMING CONTROL

THE COUNTER IS A CHAIN OF BISTABLE MULTIVIBRATORS. THE INPUT TO THE FIRST BSMV IN THE CHAIN IS THE HIGH FREQUENCY SQUARE WAVE FROM THE CLOCK. THE OUTPUT OF THE FIRST BSMV IS A SQUARE WAVE WHICH IS EXACTLY ½ THE FREQUENCY OF THE INPUT. THUS EACH BSMV IN THE CHAIN HALVES ITS INPUT FREQUENCY.

AT THE PRESENT TIME WE HAVE 9 BSMV'S IN THE COUNTER CHAIN. THIS GIVES A COUNTDOWN RATIO OF 512:1. THUS FOR A FRAME RATE OF 24 FRAMES/SEC, THE HIGH FREQUENCY MUST BE 12,288 CPS

THERE IS NOTHING MAGIC ABOUT THIS SELECTED RATIO OF 512 TO 1. THE CHOISE OF IT AT THIS TIME WAS GOVERNOD BY THE EASE WITH WHICH WE ARE ABLE TO USE THE HIGH FREQUENCY IN THE FUNCTION (SINE-COSINE) GENERATOR NETWORK. IF THE FREQUENCIES USED IN THAT NETWORK GET TOO HIGH, THE GENERATOR DOES NOT PERFORM AS WELL AS WE'D LIKE IT TO. WE HAVE NOT HAD TIME TO REDESIGN THE NETWORK. HOWEVER IT WORKS WELL UP TO 16 OR 17 KC. EASILY ALLOWING A 30 FPS FRAME RATE.

OF COURSE, THE HIGHER THE FREQUENCY WE USE, THE GREATER "BONE & SKIN" RESOLUTION WE MAY HAVE (THIS WILL BE EXPLAINED LATER.)

THE OUTPUT OF THE FIRST BSMV, BESIDES BEING FED INTO THE 2nd BSMV, IS ALSO FED INTO THE DELAY MULTIVIBRATORS IN THE AFORE-MENTION SINE-COSINE FUNTION GENERATOR NETWORK, AND ACTS AS A DRIVING SIGNAL FOR THOSE DELAY MVS. IN OTHER WORDS, IT CAUSES THE DELAY MV'S TO ALLOW A SAMPLING OF THE SINE-COSINE WAVES IN THE SAMPLERS AT ½ THE FREQUENCY OF THE SINE-COSINE WAVES IN THE SAMPLERS, i.e. there ARE 2 CYCLES TO SAMPLE FROM.

(1 COUNTER, WILL PRODUCE 24 CPS (AS ACCURATELY AS THE LINE FREQUENCY IS 60 CPS) AT THE BACK END OF THE COUNTER. FOR USE WITH A TAPE RECORDER, THE OSCILLATOR WOULD BE REPLACED BY A MOTOR SPEED GOVERNOR, WHICH WOULD ACCURATELY REGULATE THE TAPE SPEED AND THUS THE FREQUENCIES COMING OFF THE TAPE.)

page 4

THE SIGNIFICANCE OF THIS IS THAT WE CAN GET MORE THAN A 360° ROTATION OF A BONE. (TO BE DESCRIBED MORE FULLY)

THE TIMING CONTROL IS A FEEDBACK NETWORK WHICH AUTOMATICALLY SYNCHRONIZES ALL OF THE DRIVING FREQUENCIES (i.e. HIGH & LOW) TO THE 60 CPS LINE-FREQUENCY, THUS ASSURING AN EXACT 24 FPS FRAME RATE.

[HUM: THE ELECTRONIC EQUIPMENT OPERATES BY POWER RECIEVED FROM A 60 CYCLE SUPPLY LINE. THIS POWER AT 60 CPS IS PRESENT IN WIRES AND CABLES NEAR & THRU THE EQUIPMENT, AND HAS A TENDENCY TO RADIATE A CERTAIN AMOUNT OF THIS POWER TO ADJACENT PARTS. THE RESULT IS THAT THERE IS ALWAYS PRESENT A SLIGHT VOLTAGE RIPPLE ON THE LINES, IN THE AMPLIFIERS, AND EVEN IN THE D.C. REGULATED-VOLTAGE SUPPLIES. THIS MAY BE ELIMINATED BY SHIELDING AND FILTERING OF THE SUPPLIES, OR IT MAY BE COMPENSATED FOR BY SYNCHRONIZING ALL OF THE OPERATING FREQUENCIES TO AN EVEN MULTIPLE OF THIS HUM. FOR EXAMPLE, LET US SUPPOSE WE ARE OPERATING AT 23.999 FRAMES PER SECOND, AND THE LINE RIPPLE IS AT 60 CPS, THE PICTURE WILL TEND TO SLOWLY UNDULATE BECAUSE OF A BEAT SET UP BY THE TWO, NON-MULTIPLE FREQUENCIES. HOWEVER, BY MAKING THE FRAME RATE EXACTLY 30 FPS, WE WILL DRAW 1 COMPLETE FRAME FOR EVERY 2 CYCLES OF HUM.]

THERE ARE 2 INPUTS TO THE TIMING CONTROL: ONE IS THE 24 CPS FROM the counter, THE OTHER IS 60 CPS FROM THE POWER LINE. THE 24 CPS FRAME RATE IS FED INTO A BSMV WHOSE OUTPUT IS THEREFORE 12 CPS. THE LINE FREQUENCY (60 CPS) IS FED INTO A 5:1 COUNTER (BINARY FEEDBACK TYPE) AND ITS OUTPUT IS 12 CPS. THESE 2 FREQUENCIES ARE THEN FED INTO A PHASE-COMPARATOR. THE OUTPUT OF THE PHASE-COMPARITOR (A D.C. VOLTAGE) IS FED INTO A D.C.-CONTROLLED OSCILLATOR WHOSE MEAN OUTPUT FREQUENCY WILL BE THE HIGH FREQUENCY WHICH WHEN FED INTO THE FRONT END OF THE

ELECTRONIC GATE-COMMUTATOR OR MONOSTABLE MULTIVIBRATOR CHAIN (MSMV)

THE CHAIN OF MONOSTABLE MULTIVIBRATORS IS AN ELECTRONIC COMMUTATOR WHICH OPENS AND CLOSES A SERIES OF "BONE" GATES IN A SEQUENTIAL MANNER. IN OTHER WORDS, THE MSMV'S FURNISH THE DRIVING (OPENING & CLOSING) SIGNALS TO THE GATES.

THE INPUT TO THE FIRST MSMV IN THE CHAIN IS A FRAME-RATE FREQUENCY PULSE (SAY 24 CPS) WHICH COMES FROM THE COUNTER. WHEN THE PULSE ARRIVES, IT CAUSES THE MSMV TO FLIP INTO ITS OTHER (UNSTABLE) STATE, FOR A LENGTH OF TIME AS DETERMINED BY ITS INTEGRAL RC NETWORK. BY VARYING R, THE LENGTH OF TIME DURING WHICH THE MSMV IS IN ITS UNSTABLE STATE MAY BE VARIED. ~~WHEN THIS TIME HAS LAPSED, THE~~ DURING THIS "OPEN" TIME, A CHANGE IN VOLTAGE OCCURS ON ONE OF ITS OUTPUTS. THIS VOLTAGE IS USED TO OPEN A NUMBER OF GATES CONNECTED TO IT. WHEN THE "OPEN" TIME HAS LAPSED, THE MSMV AUTOMATICALLY FLIPS BACK INTO ITS ORIGINAL STATE (STABLE) AND CHANGES BACK THE OUTPUT VOLTAGE DRIVING THE GATES, THUS CLOSING THEM. DURING THE FLIP-BACK, A PULSE SIMILAR TO THE ONE THAT CAUSED THE ORIGINAL FLIP IS GENERATED AT ANOTHER OUTPUT POINT, AND THENCE IS SENT TO THE NEXT MSMV IN THE CHAIN WHERE A SIMILAR OPERATION OCCURS, THUS OPENING THE NEXT GROUP OF ASSOCIATED GATES FOR A TIME DESCRIBED BY THE R ASSOCIATED WITH THAT 2nd MSMV. THIS COMMUTATING ACTION CONTINUES UNTIL ALL THE MSMV'S IN THE CHAIN HAVE GONE THRU THEIR INDIVIDUAL CYCLES.

THE "DRIVING OUTPUT" OF THE MSMV'S (SHOWN IN FIG 1.) IS USE TO PERFORM A NUMBER OF TASKS. FOR EXAMPLE, THIS OUTPUT MAY BE USED TO CLOSE THE ELECTRONK SWITCHES ACROSS THE

page 6

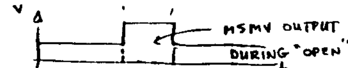


FIG 1

Lee Harrison III

INTEGRATING CAPACITORS, THUS CAUSING THE DISPLAY BEAM TO "FLY BACK" TO ITS STARTING POINT. THESE SIGNALS ARE USED THEREFORE AS INPUTS TO THE FLYBACK CIRCUIT, AND THE ACTION WILL BE DESCRIBED LATER IN MORE DETAIL. ANOTHER USE OF THE MSMV OUTPUT IS TO DIM OR BLANK-OUT THE DISPLAY BEAM. BY APPLYING THE MSMV OUTPUT TO THE GRID OF THE DISPLAY CRT, THE BEAM IS "TURNED-OFF" DURING THE "OPEN" TIME OF THE MSMV SO ENGAGED. IN THIS MANNER, FLYBACK RETRACES, AND CERTAIN BONE-PLACING RETRACES - (AS IN THE ARMS, WHERE THE BEAM MUST MOVE FROM THE STARTING POINT, UP TO THE SHOULDER AND THENCE PROCEDE TO DRAW THE ARM, AND DURING THAT "PLACEMENT" BONE DRAWING, THE BEAM IS BLANKED OUT) MAY BE BLANKED OUT AS DESIRED.

AS MENTIONED BEFORE, THE LENGTH OF TIME THAT AN MSMV REMAINS IN ITS OPEN POSITION IS DETERMINED BY R OF THE INTEGRAL R.C. NETWORK. THUS BY VARYING EACH OF THE RESISTANCES ASSOCIATED WITH EACH MSMV-RC-NETWORK, AN OPERATOR IS ABLE TO "SET-UP" A FIGURE OR CHARACTER TO HAVE THE DESIRE "BONE" LENGTHS, AND OVERALL STRUCTURE. HE ALSO, IN THIS SETUP PROCEDURE, DETERMINES THE SEQUENCE IN WHICH THE PARTICULAR BONES WILL BE DRAWN. IN DETERMINING THIS SEQUENCE HE MAKES THE NECCESSARY CONNECTIONS, BETWEEN THE MSMV'S AND THE FLYBACK AND BLANKING CIRCUITS IN ADDITION TO DETERMINING AND SETTING UP THE DESIRED BONE LENGTHS.

THE MSMV CHAIN IS A SWITCHING, COMMUTATING NETWORK WHICH REGULATES THE OPENING AND CLOSING OF THE BONE GATES. THE VARIOUS TASKS WHICH IT PERFORMS COULD BE DONE IN OTHER WAYS, SUCH AS (a) MECHANICAL SYSTEMS (b.) BINARY COUNTER SYSTEMS WITH AND/OR DIODE NETWORKS c.) OTHER ELECTRONIC ARRANGEMENTS d.) electro MECHANICAL SYSTEMS.

BONE GATES.

ASSOCIATED WITH EACH BONE, AND BEING DRIVEN BY A MSMV OF THE MSMV CHAIN, ARE A NUMBER OF ELECTRONIC GATES. THE GATES ARE NORMALLY CLOSED, BUT ARE OPENED BY THE RECTANGULAR WAVE FORM RECEIVED FROM THEIR DRIVING MULTIVIBRATOR. THERE IS AN OUTPUT FROM THE GATE ONLY DURING THE "OPEN" PERIOD, AND THE NATURE OR CHARACTER OF THIS OUTPUT IS ~~A FAITHFUL REPRODUCTION OF THE~~ GOVERNED BY THE INPUT SIGNAL. IF THE INPUT IS A D.C. SIGNAL, THEN THE OUTPUT WILL BE A CORRESPONDING D.C SIGNAL, (SIMILARLY IF THE INPUT IS A SINE WAVE OR OTHER SHAPED SIGNAL, THE OUTPUT WILL LOOK LIKE THE INPUT.) IN OTHER WORDS, THE GATE PASSES OR ALLOWS TO PASS THRU IT ANY SIGNAL THAT IS PRESENT AT ITS INPUT DURING THE "OPEN-PERIOD" OF THE GATE.

THE GATES FOR EACH BONE ARE IN PARALLEL, AND OPERATE SIMULTANEOUSLY, AND SEND SIGNALS TO DIFFERENT PARTS OF THE DEVICE IN ORDER TO "MAKE" BONES AND CONTROL THEIR VECTORIAL POSITIONS IN SPACE. A GATED D.C WAVEFORM (AS WILL BE SHOWN LATER) MAKES A STRAIGHT BONE. A GATED "SHAPED" WAVEFORM WILL MAKE A BONE WHOSE AXIS IS NOT STRAIGHT, BUT HAS THE INTEGRATED, VECTORIAL DIRECTION (OR SHAPE) PRESCRIBED BY THE SHAPED INPUT.

BY VARYING THE D.C. VOLTAGE APPLIED TO THE FIRST GATE, THE ANGLE (Θ) THAT THE BONE MAKES WITH THE X-AXIS OF THE DISPLAY IS VARIED. A VARIABLE POTENTIOMETER MAY BE USED TO VARY THE INPUT VOLTAGE, OR OTHER MEANS MAY BE USED, OF COURSE). THE SECOND GATE IS USED TO CONTROL THE ANGLE THAT THE BONE MAKES WITH THE X-Y PLANE, IN SIMILAR FASHION

page 8

BY VARYING THAT D.C. INPUT. THE THIRD GATE IS USED TO CONTROL THE ANGULAR POSITION (OR MAY BE CALLED "ROTATIONAL POSITION") OF THE SKIN ON THE BONE.

ADDITIONAL GATES MAY BE USED IN SIMILAR FASHION TO CONTROL OTHER PARAMETERS OF THE BONE — SUCH AS INTENSITY, TEXTURE ETC.

THE FIRST TWO GATES CALLED "Θ" AND "φ" SEND THEIR OUTPUT SIGNALS TO SIMILAR, AND OTHER GATE, ANGLE-PRODUCING NETWORKS. THESE SIGNALS MAY ALSO BE SENT TO CORRESPONDING CHANNELS OF THE TAPE RECORDER, SO THAT DURING PLAYBACK THESE MULTIPLEXED SIGNALS WILL DRIVE THE BONE AND SKIN PRODUCING MECHANISMS OF THE DEVICE, THUS AUTOMATICALLY PRODUCING THE PREVIOUSLY RECORDED MOVEMENTS OF THE BONES & ASSOCIATED PARTS.

THE OUTPUTS OF CONSECUTIVE Θ GATES ARE ALL FED INTO THE Θ - SINE-COSINE FUNCTION-GENERATOR AND SIMILARLY THE OUTPUTS OF φ GATES INTO THE φ SINE COSINE FUNCTION GEN.

[redacted] - COSINE FUNCTION GENERATOR

THERE ARE 2 SINE-COSINE FUNCTION GENERATORS. ONE RECEIVES ITS INPUT FROM THE Θ-GATES, THE OTHER FROM THE Φ GATES. EACH GENERATOR HAS 2 OUTPUTS FOR EACH INPUT. THE RANGE OF VOLTAGES AT THE INPUT REPRESENT [redacted] ANY DESIRED ANGULAR POSITION OF THE BONE, AND THE TWO VOLTAGE OUTPUTS HAVE THE RELATION OF THE SINE AND COSINE RESPECTIVELY [redacted] (SEE GENERAL THEORY)

IN ORDER TO PRODUCE THE RELATIVE VALUES OF THE SINE AND COSINE, SAMPLES OF SINE AND COSINE WAVES ARE TAKEN AT REGULAR INTERVALS, AND THESE SAMPLES ARE FED INTO CAPACITORS WHICH HOLD THE [redacted] SAMPLED VOLTAGES TO PRODUCE D.C. VOLTAGES ACROSS THE CAPACITORS WHICH ARE AT THE LEVELS BEING SAMPLED.

A [redacted] SINE-COSINE FUNCTION GENERATOR HAS IN ITS NETWORK A DELAY MULTIVIBRATOR, A NARROW-OUTPUT MONOSTABLE MULTIVIBRATOR, [redacted] 2 WAVE-SAMPLING GATES AND A HOLDING CAPACITOR ON THE OUTPUT OF EACH SAMPLING GATE.

THE DELAY MULTIVIBRATOR HAS TWO INPUTS. ONE INPUT COMES FROM THE 2nd STAGE OF THE COUNTER, AT ½ THE HIGH FREQUENCY AND IS OF THE SQUARE WAVE TYPE. THIS INPUT CAUSES (TO FLIP) THE DELAY M.V. TO CHANGE STATES. IT WILL REMAIN IN THIS STATE UNTIL IT FLIPS BACK AUTOMATICALLY INTO ITS ORIGINAL STATE. THE LENGTH OF TIME THAT IT REMAINS IN THE UNSTABLE STATE IS DETERMINED BY THE 2nd INPUT. THIS 2nd INPUT (WHICH COMES FROM THE GATES) IS A D.C. VOLTAGE WHOSE VALUE DETERMINES THE LENGTH OF TIME THE DELAY M.V. WILL DELAY. [redacted]

[redacted] DRIVING INPUT [redacted] THE COUNTER, [illegible] IS AT [illegible] THE HIGH FREQUENCY. THIS MEANS THAT THE DELAY M.V. PERFORMS ITS FUNCTION ONCE FOR EVERY 2 CYCLES OF THE HIGH FREQUENCY. THIS ALLOWS A SAMPLING OF THE SINE & COSINE WAVES TO BE TAKEN EVERY 2 CYCLES OF THE WAVES, WHICH ALLOWS FOR A BONE-ANGLE SWING OF MORE THAN 360° [illegible].

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page 10

THE OUTPUT OF THE DELAY M.V. IS DIFFERENTIATED AND CLIPPED, SO THAT ONLY A NARROW PULSE REPRESENTING THE TRAILING EDGE OF THE CHANGE-OF-STATES IS SENT ON TO THE NARROW-PULSE MSMV.

THE INPUT TO THE NARROW PULSE MSMV IS A NARROW TRIGGER PULSE COMING FROM THE DELAY MV. THE OUTPUT OF THE MSMV IS A VERY NARROW, STRAIGHT SIDED PULSE WHICH IS USED TO DRIVE (OR OPEN) 2 SAMPLING GATES. THE GATES ARE VERY FAST ACTING. [redacted] ANOTHER INPUT TO [redacted] GATES IS A SINE WAVE (TO ONE) AND A COSINE WAVE (TO THE OTHER) COMING FROM THE SINEWAVE GENERATOR (CLOCK) AND FROM THE PHASE-SHIFTER RESPECTIVELY. THUS THE OUTPUT OF THE GATES IS A VERY NARROW PULSE WHOSE HEIGHT (OR VALUE OF VOLTAGE) IS DETERMINED BY THE TIME AT WHICH THE SINE AND COSINE WAVES WERE SAMPLED, WHICH TIME WAS DETERMINED BY THE TRAILING EDGE OF THE DELAY M.V., WHICH TIME WAS DETERMINED BY THE D.C. VOLTAGE IMPRESSED UPON IT, THIS VOLTAGE [redacted] HAVING BEEN DETERMINED BY THE OUTPUT OF THE BONE GATES. THE NUMBER OF SUCH PULSES FOR ANY GIVEN D.C. VALUE IMPRESSED UPON THE DELAY M.V. IS DETERMINED BY THE LENGTH OF ANY GIVEN BONE.

BECAUSE OF THE HOLDING CAPACITOR ASSOCIATED WITH THE OUTPUT OF EACH SAMPLING GATE, THERE APPEARS ACROSS EACH CAPACITOR A D.C. VOLTAGE [redacted] REPRESENTING A PARTICULAR VALUE OF SINE OR COSINE. FOR A NORMAL-LENGTH BONE, THE HOLDING CAPACITOR MAY RECEIVE 15 OR 20 SAMPLING PULSES DURING THE TIME THE BONE IS BEING GENERATED.

THERE ARE OTHER WAYS OF GENERATING THIS SINE-CONSINE FUNCTION. ONE SIMPLE WAY WOULD BE TO LET THE OUTPUT OF THE BONE GATES SUPPLY VOLTAGE TO ASSOCIATED SINE-COSINE POTENTIOMETERS BUT THESE POTS ARE EXPENSIVE AND *

* WOULD BE REQUIRED THAT THERE BE ONE FOR EACH GATE, AND CONTROLLING INPUTS WOULD NEED TO BE ESSENTIALLY MECHANICAL.

BONE INTEGRATORS

THE INTEGRATOR IS A HIGH GAIN AMPLIFIER WHICH HAS A FEEDBACK CAPACITOR TO ITS INPUT. ITS FUNCTION IS TO PERFORM CONTINUOUS INTEGRATION OF THE SIGNALS PRESENTED TO ITS INPUT. THERE ARE THREE INTEGRATORS IN THE BONE GENERATOR, ONE FOR EACH COORDINATE (ie X, Y, Z) OF 3 DIMENSIONS.

IF THE INPUT TO AN INTEGRATOR IS A D.C. VOLTAGE, THE OUTPUT IS A RAMP FUNCTION. THE INITIAL CONDITIONS (STARTING VOLTAGES ON THE OUTPUT WHICH DETERMINE THE STARTING POINT OF EACH BONE ON THE DISPLAY) ARE DETERMINED BY THE VOLTAGE ACROSS THE FEEDBACK CAPACITOR. IF THERE IS NO DISCHARGE OF THAT CAPACITOR, THEN THE BONES GENERATED BY THE INTEGRATION OF A SEQUENCE OF D.C. VOLTAGES WILL BE "JOINED TOGETHER". WHENEVER THE CAPACITOR IS DISCHARGED OR "SHORTED OUT", THE INITIAL CONDITION VOLTAGES ARE ZERO AND THE DISPLAY BEAM RETURNS TO A "ZERO" OR "STARTING" POSITION. (THE FLYBACK CIRCUIT TO BE DESCRIBED PERFORMS THE FUNCTION OF SHORTING OUT & DISCHARGING THE CAPACITOR AS DESIRED OR REQUIRED TO DRAW A FIGURE OR IMAGE.)

THE COMBINATION OF OUTPUTS OF THE ANY TWO OF THE INTEGRATORS WHEN PRESENTED ONE TO EACH OF THE VERTICAL AND HORIZONTAL DEFLECTION CIRCUITS OF THE DISPLAY CRT, WILL GIVE THE PROJECTION OF THE FIGURE (OR IMAGE BEING DRAWN) ON THE PLANE DETERMINED BY THE COMBINATION. FOR EXAMPLE, IF THE X AND Y INTEGRATOR OUTPUTS ARE USED, THEN THE DISPLAY WILL BE A VIEW WHICH IS THE PROJECTION OF THE FIGURE ON THE X, Y PLANE. SIMILARLY, IF THE Y AND Z OUTPUTS ARE USE, THE VIEW WILL BE A PROJECTION OF THE FIGURE ON THE Y, Z PLANE.

page 12

INTERMEDIATE VIEWS MAY BE OBTAINED BY COMBINING ALL THREE INTEGRATOR OUTPUTS IN PROPER AMOUNTS; THUS ALLOWING AN OPERATOR OF THE DEVICE TO VIEW THE OBJECT OR FIGURE FROM ANY POSITION, THE FUNCTION OF COMBINING THESE INTEGRATOR OUTPUTS IN A PROPER FASHION IS CARRIED OUT BY THE "CAMERA ANGLE NETWORK" TO BE DISCUSSED LATER.

THE VALUE OF VOLTAGE PRESENTED TO THE INPUT OF AN INTEGRATOR DETERMINES THE RATE OF CHANGE OF VOLTAGE AT THE OUTPUT. (SLOPE). IF THE INPUT D.C. VOLTAGES TO THE X AND Y INTEGRATORS REPRESENT THE COS Θ AND SIN Θ RESPECTIVELY THEN THE OUTPUT OF THE INTEGRATORS WHEN FED INTO THE HORIZONTAL AND VERTICAL AMPLIFIERS ON A DISPLAY SCOPE WILL CAUSE THE BEAM TO DRAW A LINE ON THE SCOPE WHOSE ANGLE TO THE HORIZONTAL IS Θ.

Lee Harrison III

DEC 2 1961 W

BACK NETWORK.

THE FUNCTION OF THE FLYBACK NETWORK IS TO SHORT OUT OR DISCHARGE THE CAPACITORS (C) ASSOCIATED WITH THE INTEGRATORS AT DESIRED TIMES DURING THE SEQUENCE OF BONES AND AT THE END OF EACH CYCLE OF BONE GENERATION. DISCHARGING OF THE CAPACITORS CAUSES THE BEAM OF THE DISPLAY CRT TO FLY BACK TO THE STARTING POSITION.

AN ELECTRONIC SWITCH DISCHARGES THE CAPACITOR. PULSES WHICH CLOSE THE SWITCH COME FROM AN AMPLIFIER WHICH IS IN TURN FED BY PULSES (WHICH ARE SELECTED AS DESIRED) COMING FROM SELECTED MULTIVIBRATORS OF THE MVB CHAIN. ALSO, A PULSE WHOSE DURATION IS DETERMINED BY THE TIME OF THE CLOSING OF THE LAST MSMV TO THE BEGINNING OF A NEW CYCLE OF THE FIRST MSMV IS GENERATED BY A BISTABLE MULTIVIBRATOR. THIS FLYBACK BI-STABLE MV RECEIVES A PULSE FROM THE LAST MSMV AS IT CLOSES. THIS PULSE FLIPS THE BSMV AND IT'S OUTPUT CAUSES THE SWITCHES TO CLOSE. THIS BSMV STAYS IN THE "CLOSED" STATE UNTIL IT RECEIVES ANOTHER INPUT PULSE WHICH THIS TIME COMES FROM THE COUNTER, THE SAME PULSE WHICH STARTS THE CHAIN OF MSMV'S.

DIODES CONNECT ALL OF THE PULSE INPUTS TO THE AMPLIFIER WHICH ACTIVATES THE SWITCHES SO AS TO PREVENT PULSES FROM FEEDING BACK INTO THE GATES AND THUS CAUSING THEM TO OPERATE OUT OF SEQUENCE.

THE ELECTRONIC SWITCHES REMAIN CLOSED DURING THE DURATION OF A PULSE, BE IT LONG OR SHORT.

page 14

Lee Harrison III

SKIN NETWORK.

THE FUNCTION OF THE SKIN NETWORK IS TO ALGEBRAICALLY COMBINE THE VARIOUS VOLTAGE REPRESENTATIONS OF $\sin\theta$, $\cos\theta$, $\sin\phi$, $\cos\phi$, K_1t_x, K_1t_y, K_1t_z, $\sin K_2t$, $\cos K_2t$ AND the VIDEO signal "A", TO GIVE THE PROPER FORMULAMATIC REPRESENTATIONS OF THE GEOMETRIC PROJECTIONS OF THE FIGURE OR OBJECT BEING GENERATED. FOR QUICK REFERENCE, A TABULAR EXPLANATION OF THESE VARIOUS SIGNALS IS GIVEN BELOW.

Kt_x — K_1t_x — signed

DEC 2 1961

$\sin\theta$:, $\cos\theta$: } D.C. VALUES OF VOLTAGE WHOSE RELATIONSHIP IS AS THE SINE AND COSINE OF THE ANGLE θ

$\sin\phi$:, $\cos\phi$: } DC. VALUES OF VOLTAGE WHOSE RELATIONSHIP IS AS THE SINE AND COSINE OF THE ANGLE ϕ.

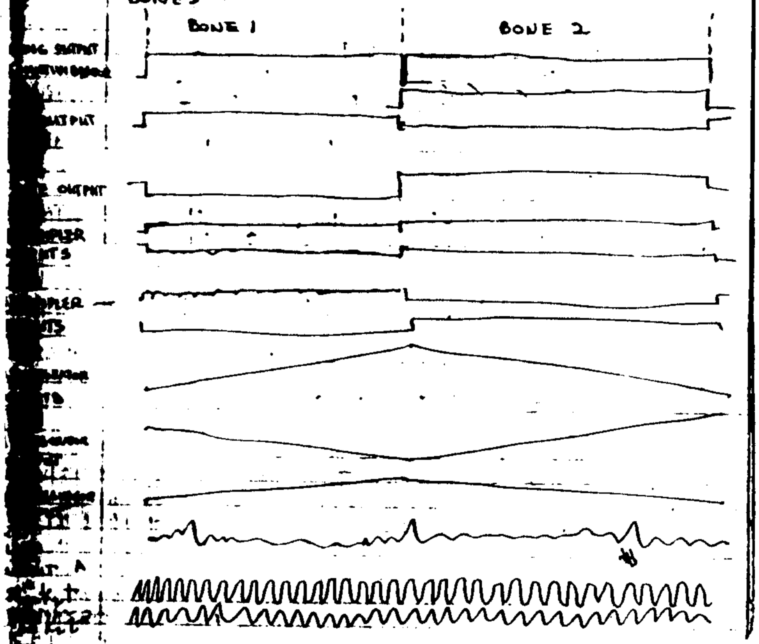
K_1t_x, K_1t_y, K_1t_z } RAMP FUNCTIONS OF VOLTAGE, THE OUTPUTS OF INTEGRATORS X, Y AND Z RESPECTIVELY, WHERE THE CONSTANT K_1 IS A SCALING FACTOR, WHICH IS A DEVICE FUNCTION OF THE GAINS OF DISPLAY AMPLIFIERS OF THE GAINS OF THE INTEGRATING AMPLIFIERS AND ALSO A FUNCTION OF THE AMPLITUDE OF THE INPUT SINE AND COSINE WAVES TO THE INTEGRATORS. FOR SIMPLICITY THESE EFFECTS ARE ACCOUNTED FOR BY THE USE OF THIS "LUMPED CONSTANT" K_1.

$\sin K_2t$:, $\cos K_2t$: } SINE AND COSINE WAVE FUNCTIONS WHOSE FREQUENCY (THE HIGH FREQUENCY) IS DETERMINED BY K_2, AND WHOSE AMPLITUDE IS CONSIDERED TO BE EQUAL TO 1 (ONE UNIT). (FOR A NORMAL MATHEMATICAL REPRESENTATION WE'D HAVE TO USE "$a \sin K_2t$" TO DENOTE THIS WAVE, BUT WE SIMPLIFY THE EXPRESSION BY LETTING $a = 1$ unit, (which may = about 10 volts p-p

Lee Harrison III

A } CAPITAL A IS USED TO DENOTE THE VIDEO SIGNAL WHICH COMES FROM THE SKIN SCANNER. THIS IS A WIDE BAND SIGNAL WHOSE UPPER FREQUENCIES ARE VERY HIGH.

TO SHOW THE INTER-RELATIONSHIP OF THE VARIOUS SIGNALS, A PICTOGRAPH IS GIVEN BELOW FOR 2 BONES



page 16

Lee Harrison III

TWO ALGEBRAIC FUNCTIONS ARE PERFORMED BY THE PORTION OF THE DEVICE WHICH WE CALL THE SKIN NETWORK, NAMELY MULTIPLICATION AND ADDITION.

ASSOCIATED WITH EACH MULTIPLIER ARE INPUT AND OUTPUT AMPLIFIERS, WHICH ARE ELECTRONICALLY NECESSARY TO ALLOW AN ANALOGUE MULTIPLIER TO PERFORM THE TASK OF MULTIPLICATION. MULTIPLIERS REQUIRE A "CENTER TAP" INPUT, THUS THE THREE INPUTS TO THE MULTIPLIERS. THE IMPORTANT THING HERE IS NOT HOW WE PERFORM THE PARTICULAR TASK, BUT THAT WE DO PERFORM IT.

DEC 29 1961

ADDERS ARE MERELY RESISTOR NETWORKS WHICH ADD THE VARIOUS SIGNALS PRESENTED TO IT.

ALGEBRAICALLY SPEAKING, THE SKIN NETWORK TAKES THE PREVIOUSLY MENTIONED SIGNALS AND COMBINES THEM SO THAT

$$x = k_1 t_x \cos\theta \cos\phi + A \cos\theta \sin\phi \cos k_2 t - A \sin\theta \sin k_2 t$$

$$y = k_1 t_y \sin\theta \cos\phi + A \sin\theta \sin\phi \cos k_2 t + A \cos\theta \sin k_2 t$$

$$z = k_1 t_z \sin\phi + A \cos\phi \cos k_2 t$$

HERE, x, y AND z REPRESENT THE x, y AND z VECTORIAL COMPONENTS OF THE 3 DIMENSIONAL FIGURE. BY PRESENTING ANY 2 OF THESE SIGNALS TO THE X AND Y CHANNELS OF A DISPLAY CRT, THE RESULTING DRAWING WILL BE A PROJECTION OF THE 3 DIMENSIONAL FIGURE ON THE PLANE DETERMINED BY THE COMPONENTS SELECTED.

BY THE GEOMETRIC SELECTION AND COMBINATION OF ALL THREE OF THESE COMPONENTS, ANY VIEW OR PROJECTION OF THE 3 DIMENSIONAL FIGURE MAY BE SH page 17 — Lee Harrison III

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CAMERA-ANGLE NETWORK

THE FUNCTION OF THE CAMERA ANGLE NETWORK IS TO ALGEBRAICALLY (AND THUS GEOMETRICALLY) COMBINE THE X, Y, AND Z COMPONENTS OF THE THREE DIMENSIONAL FIGURE IN SUCH A MANNER AS TO ALLOW FOR THE PRESENTATION OF ANY 2 DIMENSIONAL PROJECTION OR VIEW OF THE FIGURE WHEN THE OUTPUTS OF THIS NETWORK ARE PRESENTED TO THE X AND Y CHANNELS OF A DISPLAY CRT.

2 ALGEBRAIC FUNCTIONS ARE PERFORMED. THE FIRST IS MULTIPLICATION BY A CONSTANT, THE SECOND IS ADDITION.
THE "MULTIPLICATION BY A CONSTANT" IS, IN EFFECT THE "TAKING OF THE SINE AND COSINE" OF THE VECTOR AND IS ACCOMPLISHED BY A NETWORK OF VARIABLE "SINE-COSINE" POTENTIOMETERS. ADDITION IS PERFORMED USING A FIXED RESISTANCE NETWORK.

ANGLES Θ' (THETA PRIME) AND Φ' (PHI PRIME) REPRESENT THE ROTATION OF THE XY PLANE ABOUT THE X AXIS AND THE XZ PLANE ABOUT THE Z AXIS.

2 SIN-COSINE POTS GANGED TOGETHER (WITH WIPERS ON A COMMON SHAFT) IS THE MECHANISM FOR PERFORMING THE PROPERLY-RELATED MULTIPLICATION BY CONSTANTS, IE TAKING THE SINES + COSINES IN THE PROPER RELATIONSHIP.

THERE ARE TWO SUCH MECHANISMS. ROTATION OF THE SHAFT OF ONE, CONTROLS THE VIEWING ANGLE Θ'. THE OTHER CONTROLS Φ'. AMPLIFIERS ASSOCIATED WITH THE NETWORK OF SINE-COSINE POTS ARE AN ELECTRONIC NECESSITY.
THE TWO OUTPUTS OF THIS NETWORK ARE FED INTO THE X AND Y CHANNELS OF THE DISPLAY CRT, AND REPRESENT THE BEAM-POSITIONAL INFORMATION NECESSARY TO DRAW THE FIGURE

page 18 — Lee Harrison III

EVENTUALLY, WE'LL USE CONTROLING SERVO-MOTORS TO POSITION THE SHAFTS Θ' + Φ', SO THAT THE CAMERA ANGLES MAY BE RECORDED ON THE CONTROL-TAPE RECORDER ALONG WITH OTHER CONTROLLING INFORMATION. IN OTHER WORDS, WE'LL RECORD SIGNALS TO WHICH THE SERVOS WILL REACT, THUS RECORDING THE CAMERA ANGLES.

DEC 29 1961 AM

page 17 — Lee Harrison III

SKIN GENERATOR.

GENERAL

THE FUNCTION OF THE SKIN GENERATOR IS TO GENERATE A VIDEO SIGNAL; THE MAGNITUDE OF WHICH REPRESENTS THE ORTHOGONAL DISTANCE (OR THICKNESS) BETWEEN THE BONE (VECTOR) AND THE SURFACE (OR SKIN) OF THE OBJECT OR FIGURE BEING DRAWN.

THE SKIN GENERATOR IS A FLYING SPOT SCANNER WHICH SCANS A SPECIALLY PREPARE PHOTOGRAPH, THE DENSITY OF WHICH CONTAINS THE DESIRED "THICKNESS" INFORMATION.

THE SKIN GENERATOR IS A HIGH SPEED COMMUTATOR WHICH CONVEYS IN PROPOR SEQUENCE AND SYNCHRONIZATION THE THICKNESS INFORMATION WHICH IS RETAINED IN A CONVENIENT FORM OF INFORMATION STORAGE DEVICE OR MEDIUM.

THE FLYING SPOT SCANNER IS A SPECIAL (SHORT PERSISTANCE) CATHODE RAY TUBE IN WHICH THE BEAM SWEEPS OUT A PRESCIBED RASTER (PATERN OF LINES). THE BEAM PRODUCES A SHORT PERSISTANCE SPOT OF LIGHT ON THE FACE OF THE TUBE. THIS SPOT OF LIGHT IS OPTICALLY CONDUCTED AND FOCUSED ON THE PHOTOGRAPHIC TRANSPARENCY WHICH TRANSMITTS VARYING AMOUNTS OF LIGHT ACCORDING TO THE FILM DENSITY. THUS THE PHOTOGRAPHIC TRANSPARENCY MODULATES THE INTENSITY OF THE LIGHT, AS THE SPOT SWEEPS OR SCANS ACROSS IT. THIS MODULATED LIGHT IS COLLECTED BY A CONDENSING LENS AND ROUGHLY FOCUSSED ON A PHOTO-MULTIPLIER TUBE WHICH CONVERTS THE MODULATED LIGHT INTO A VOLTAGE SIGNAL (VIDEO). (IN GENERAL THIS SYSTEM ACTS AS A HIGH SPEED COMMUTATOR, COMMUTATING MANY PIECES OF INFORMATION IN THE DESIRED STREAM

page 20 — Lee Harrison III

OR SEQUENCE.)

THE VIDEO SIGNAL IS THEN ADDED (VECTORIALLY SPEAKING) TO THE BONE SIGNAL, GIVING THE POSITIONAL INFORMATION TO THE DISPLAY BEAM WHICH REPRESENTS THE THICKNESS OF THE OBJECT OR FIGURE BEING DRAWN.

THE MOVEMENT OF THE FLYING SPOT IS CONTROLED BY DEFLECTION AMPLIFIERS IN SCANNER. THE CONTROLING DEFLECTION WAVE FORMS ARE GENERATED IN THE HORIZONTAL AND VERTICAL DEFLECTION GENERATORS (SAWTOOTH GENERATORS), WHICH ARE SYNCHRONIZED AND DRIVEN BY AN INPUT FROM THE CLOCK.

THE RASTER (PATTERN OF MOVEMENT OF THE SPOT) OF THE SCANNER BASICALLY RECTANGULAR, WITH SOME LOCALIZED MODIFICATIONS IN THE PATTERN FOR SPECIAL, SKIN-DISTORTION EFFECTS AS IN LIP, EYE & OTHER FACIAL AND PLASTIC-TYPE MOVEMENTS. (SUCH AS WRINKLE EFFECTS WHICH WOULD BE AUTOMATICALLY DEVELOPED AS A FUNCTION OF ASSOCIATED BONE ANGLES.)

THE SKIN GENERATOR MAY ALSO BE USED TO DEVELOPE OTHER SKIN INFORMATION SUCH AS COLOR, TEXTURE & SHADING. (THIS WILL BE DISCUSSED LATER.)

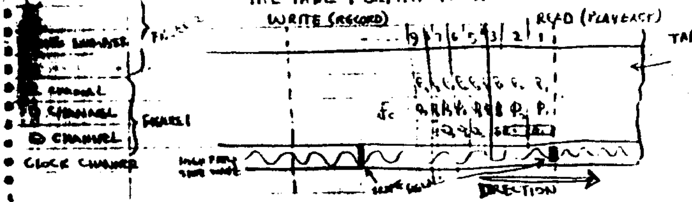
DEC 29 1961

…#21

…cording Network. (Tape Recorder)

The Function of the RECORDING NETWORK IS
TO RECORD THE JOINED-together GATE OUTPUT
SIGNALS (MULTIPLEXED ANGLE-SIGNALS) AND
ALLOW FOR THE PLAY-BACK OF THESE SIGNALS,
THE RECORDER IS A MULTI-CHANNELED RECORDER.
ON ONE CHANNEL IS RECORDED THE CLOCK (signal) AND FRAME-
SIGNALS FOR SYNCHRONIZATION. Sound is recorded on another
SELECTIVE RECORDING OF INDIVIDUAL GATE-OUTPUTS
OR GROUPS OF GATE-OUTPUTS IS ACCOMPLISHED
WITH RECORDING GATES, WHICH ARE ACTIVATED (OPENED)
BY THE (MS) MULTIVIBRATORS ASSOCIATED WITH THE
BONE GATES DESIRED TO BE RECORDED. A SWITCH
MAY BE EMPLOYED TO HOLD THESE ~~GATES~~ RECORDING
GATES OPENED IF IT IS DESIRED TO RECORD ALL OF
THE BONES. (AS AN OPERATOR MAY DO AT THE BEGINNING OF AN …)
~~THE TAPE MOVES ACROSS~~ THE "WRITE" HEADS ARE
~~OF THE TAPE RECORDER FIRST, THEN ON TO THE~~ (PLAYBACK)
SITUATED "UPSTREAM" FROM THE "READ" HEADS
AS FAR AS TAPE MOTION IS CONCERNED, THE SIGNALS
WHICH ARE PASSED BY THE RECORDING GATES ARE,
THENCE RECORDED ON THE TAPE BY THE WRITE HEADS.
THE SIGNALS THUS RECORDED ARE ALMOST IMEDIATELY
READ BY THE "READ" HEADS FROM WHICH THE
SIGNALS ARE AMPLIFIED AND SENT INTO THE
BONE GENERATION NETWORK.

THE TAPE FORMAT IS SHOWN BELOW



page 22

THE CLOCK CHANNEL HAS RECORDED ON IT THE HIGH FREQUENCY
SINE WAVE PLUS THE INTERMITTANT FRAME PULSE.
THESE SIGNALS ARE (ELECTRONICALLY) SEPARATED ~~…~~ AFTER READING,
AND THE SIGN WAVES ARE SENT TO THE BONE
GENERATOR & THE FRAME PULSES ARE SENT TO
THE COUNTER CHAIN.
AFTER THE θ AND φ (TAPE) CHANNELS ARE FILLED WITH
RECORDED SIGNALS, SELECTIVE RE-RECORDING IS
ACCOMPLISHED BY MAKING CONNECTIONS BETWEEN
~~THE~~ SELECTED MSMV's & THE RECORDING GATES,
SO THAT THE (THAT) GATES ARE OPENED ONLY DURING
THE TIMES OF OCCURRENCE OF THE OPENING OF
THE ~~…~~ θ + φ GATES ASSOCIATED WITH
THE SELECTED MSMV's, (THE INITIAL RECORDING SWITCH IS OPENED,)
FOR EXAMPLE, SUPPOSE AN OPERATOR WISHED TO
RE-RECORD THE ANGULAR ACTIONS OF THE 4th +
5th BONES. HE'D CONNECT THE PULSED OUTPUT OF
MSMV's # 4 + 5 TO THE ~~RECORDING GATE ACTUAT~~
ACTUATING INPUT TERMINAL OF THE RECORDING GATE.
THUS THE ONLY TIME RECORDING WOULD TAKE PLACE
WOULD BE AT THE EXACT SPOTS ON THE TAPE
THAT CORRESPONDED TO THE PREVIOUSLY RECORDED
ACTIONS OF BONES 4 + 5. THE WRITE HEAD ~~IN~~ BEING
ACTIVATED AT THOSE TIMES WOULD OBLITERATE THE
PREVIOUSLY RECORDED SIGNALS AND LEAVE THE
NEWLY DESIRED SIGNALS ON THE TAPE. THE REST
OF THE (TAPE) TIME, THE RECORDING GATES ARE CLOSED.
~~AND~~ THE READ HEADS PICK UP THE OLD AS WELL AS
THE NEW SIGNALS, AND TRANSMITT THEM THROUGH
THE DEVICE TO STIMULATE THE DESIRED ~~…~~ ACTION
ON THE DISPLAY.
OTHER TAPE CHANNELS ARE USED IN SIMILAR FASHION TO
~~CONTROL~~ RECORD AND CONTROL OTHER PARAMETERS OF
THE BONE. FOR EXAMPLE, THE ρ (RHO) CHANNEL IS
USED TO CONTROL THE ROTATIONAL POSITION (OR TWIST) *.

page 23

CONTROL OF MOTION & OTHER PARAMETERS

~~OF THE ... RELATIVE TO THE BONE AXIS~~

BY CONTROLING THE VOLTAGE INPUTS TO THE BONE GATES, THE POSITIONS, ATTITUDES, PLASTIC DISTORTIONS AND OTHER SPACIAL PARAMETERS ARE CONTROLLED. THE FUNCTION OF THE CONTROLS IS TO GENERATED THE DESIRED SIGNALS FOR THE VARIOUS MOTIONS. IN GENERAL, THE CONTROLLING SIGNALS ARE VERY LOW FREQUENCY AND IN SOME CASES PRACTICALLY D.C. (THE SAMPLING RATE FOR EACH BONE SIGNAL TO BE MULTIPLEXED IS 24 TIMES PER SECOND. IN ONE SECOND, UNLESS THE ACTION OF A BONE IS VERY SWIFT, THE VOLTAGE VARIATION FROM THE BEGINING TO THE END OF ONE DRAWING CYCLE ($\frac{1}{24}$ sec) OF ONE BONE ($\approx \frac{1}{5} \cdot (\frac{1}{24})$) IS VERY SLIGHT. THAT IS TO SAY, SUPPOSE THE VOLTAGE VARIES 5 VOLTS IN ONE SECOND DUE TO THE TURNING OF A POTENTIOMETER, THEN THE VARIATION FROM THE BEGINNING TO THE END OF A BONE IS ABOUT $\frac{1}{5}$ VOLTS WHICH IS SUCH A SMALL CHANGE THAT THE BONE APPEARS STRAIGHT.)

NETWORKS OF VARIABLE RESISTORS AND VERY LOW-FREQUENCY GENERATORS MAY BE USED TO GENERATE INTERRELATED BONE-GROUP ACTIONS OR MOTIONS. AS THE MANIPULATION OF THE POTENTIOMETER INPUTS IS SIMPLIFIED, IT MAY BE CONSIDERED THAT THE 'CONTROLS' MAY BECOME MORE AND MORE COMPUTER-LIKE, WHERE MANY BONE-MOTION FUNCTIONS ARE GENERATED AUTOMATICALLY.

BONES OTHER THAN STRAIGHT MAY BE PRODUCED BY APPLYING HIGHER FREQUENCIES TO THE BONE GATES. SHAPED WAVEFORMS IN PLACE OF D.C. INPUTS WILL GIVE BONES OTHER THAN STRAIGTH. FOR EXAMPLE, A SAWTOOTH CONTROL INPUT WILL MAKE A WIGGLY ∿∿

page 24

DEC 29 1961

BONE; A SINOSOIDAL INPUT (IF AT THE PROPER PHASE & FREQUENCY) WILL MAKE A CIRCULAR BONE; A SQUARE (TYPE) WAVE INPUT WILL MAKE A ZIG ZAG ∧∨ OR SAWTOOTH TYPE BONE; A RAMP INPUT TO THE BONE GATES WILL MAKE A CURVED OR ARCHED BONE.

SPECIAL CONTROLLING WAVEFORMS MAY ALSO BE INSERTED EITHER BEFORE OR AFTER THE INTEGRATOR, WITHOUT PASSING THROUGH THE SAMPLING NETWORKS, IN ORDER TO PRODUCE DESIRED MUTATIONS ON THE BONES (TECHNIQUES SUCH AS THESE HAVE BEEN DISCUSSED ON MANY OCCASSIONS AND WILL BE EXECUTED WHEN TIME ALLOWS.)

JOY-STICKS & FINGER CONTROLS HAVE BEEN DESIGNED FOR EASY, MECHANICAL MANIPULATION OF THE CONTROLS & MAY BE THE SUBJECTS OF LATER PATENTS. SPECIAL CONTROLLING INPUTS FOR FACIAL EXPRESSIONS MAY BE ~~THESE TECHNIQUES INCL~~ TRANDUCED FROM ACTUAL FACIAL & LIP MOTIONS USING A NETWORK OF STRAIN GAGES

SHADING (AND COLOR) NETWORK

Lee Harrison III
12/29/61

THE ELECTRONIC SIGNALS COMING OUT OF THE CAMERA ANGLE NETWORK ARE BEAM-POSITIONING SIGNALS; (just as FINGERS CONTROL THE POSITION OF A PENCIL ON PAPER). THE FUNCTION OF THE SHADING (AND COLOR) NETWORK IS TO GOVERN THE BEAM INTENSITY AS IT DRAWS THE FIGURE OR OBJECT, (HIGH FREQUENCY) VARIATIONS IN INTENSITY ASSOCIATED WITH SKIN SHADES & SHADOWS, Textures etc. which arise from the surface VARIATIONS IN THE SKIN. (COLOR VARIATIONS IN THIS SENSE ARE THOUGHT OF IN TERMS OF A two or THREE-COLOR (MULTI-COLOR) PROCESS WHERE, FOR EXAMPLE THE IMAGES OF THREE DISPLAY SCOPES (IMAGES IDENTICAL ON EACH), ARE OPTICALLY SUPPERIMPOSED, AND EACH SCOPE HAS A COLOR FILTER ON ITS FACE. BY VARYING THE INTENSITIES OF THE 3 BEAMS, THE OPTICAL IMAGE HAS FULL SPECTRUM COLOR CAPABILITY. THUS THIS TOPIC IS CALLED "SHADING (AND) COLOR NETWORK.)

THE "SKIN" VIDEO SIGNAL CONTAINS THE INFORMATION ABOUT THE ORTHAGONAL DISTANCE BETWEEN BONE AND SKIN. IN THE FULL BASIC FORMAT, THE RATE OF CHANGE OF THE VIDEO SIGNAL IS USED TO CONTROL THE BRIGHTNESS (SHADING) & HIGH FREQUENCY SKIN VARIATIONS TO ACCENTUATE SKIN FEATURES WHICH OCCUR BETWEEN THE EDGES OF THE OBJECT BEING DRAWN IN THIS FORMAT. BY DIFFERENTIATING THE SKIN VIDEO A RATE-OF-CHANGE SIGNAL IS OBTAINED. A THRESHOLD NETWORK DETECTS ALL RATES OF CHANGES ABOVE A PRESCRIBED ABSOLUTE VALUE. THE CLIPPED OUTPUT OF THE THRESHOLD NETWORK IS AMPLIFIED AND SCALED, thence used to modulate beam intensity

ROUNDING, EDGE EFFECTS (EDGE SHADOWS etc)

page 26

Lee Harrison

ARE PRODUCED IN ACCORDANCE WITH THE SKIN VECTOR POSITION WHICH IS A FUNCTION OF THE PHASE OF THE HIGH FREQUENCY SINE WAVE FROM THE CLOCK.

IN ADDITION, A HIGH FREQUENCY WOBBLE OR A FOCUS-FLARE MAY BE EMPLOYED TO HEAVY-UP OR THICKEN THE EDGES, this ACTION ALSO BEING SYCHRONOUS WITH PHASE OF the High freq. Sine WAVE.

FLAT COLOR EFFECTS, OR GRAYS OR TEXTURES WHICH DO NOT VARY WITH BONE POSITION, MAY BE PRODUCED BY GATING IN THESE INTENSITY-MODULATING SIGNALS USING THE BONE GATES DESIGNED FOR THAT PURPOSE. THE INPUT TO THE GATES "MAY BE" A HIGH FREQUENCY OF A CERTAIN PATTERN WHICH WHEN APPLIED TO MODULATE THE BEAM INTENSITY DURING THE DRAWING OF A PARTICULAR BONE WILL GIVE A TEXTURED PATTERN. MORE SPECIFICALLY, VIDEO SIGNALS OF PRESCRIBED DESIGNS MAY BE APPLIED IN THIS MANNER TO GIVE THE DESIRED EXTERIOR APPEARANCE OF AN OBJECT AS A SOAP BOX OR OTHER CONSUMER PRODUCT, OR A SHIRT PATTERN (ON A HUMAN FIGURE) OR A FUR PATTERN (ON AN ANIMAL CHARACTER) (TO GENERATE THIS INTENSITY VIDEO, ANOTHER SCANNER WOULD BE REQUIRED, OR A SPLIT-IMAGE SCANNING TECKNIQUE WHERE OPTICAL MEANS (2-WAY MIRRORS) ARE USED TO HAVE THE SKIN-SCANNING RASTER OF THE FLYING SPOT FOCUSED ON TWO (OR MORE) FILMS - WHERE ONE FILM CONTAINS THICKNESS INFORMATION AND ANOTHER CONTAINS SURFACE COLOR, PATTERN OR TEXTURE INFORMATION.

OVERLAP PREVENTION AND SCAN CONVERSION

BECAUSE THE DISPLAY BEAM IS DRAWING A 2-DIMENSIONAL PROJECTION OF A 3-DIMENSIONAL IMAGE IN A CONTINUOUS MANNER IT IS NECESSARY TO PROVIDE A MEANS OF PREVENTING THE BEAM FROM DRAWING OVER A PORTION OF THE IMAGE WHICH HAS ALREADY BEEN DRAWN. THUS A SPECIAL DEVICE FOR "OVERLAP PREVENTION" HAS THE FUNCTION OF DOING AWAY WITH "GHOST" IMAGE OR OVERLAP.

OVERLAP MAY BE CLASSIFIED INTO TWO TYPES. ONE TYPE OCCURS WHEN THE "BACK PART" OR PART OF THE IMAGE ON THE SIDE AWAY FROM THE VIEWER IS DRAWN. THIS OVERLAP IS PREVENTED BY TURNING OFF THE INTENSITY OF THE BEAM ACCORDING TO THE VECTORIAL POSITION OF THE SKIN VECTOR WHICH IS A FUNCTION OF 1) PHASE OF THE HIGH FREQUENCY, AND 2) THE CAMERA ANGLE (WHICH GOVERNS THE POSITION OF THE PLANE OF PROJECTION).

THE 2nd TYPE OF OVERLAP OCCURS WHEN ONE PART OF AN OBJECT OR FIGURE OVERLAPS ANOTHER PART, OR WHERE ONE FIGURE IS INFRONT OF ANOTHER. BY USING A SPECIAL DISPLAY TUBE WHICH HAS IN IT, TWO OR MORE ELECTRON GUNS, ONE OF WHICH IS A "WRITE" GUN, ANOTHER OF WHICH IS AN "ERASE" GUN (HAVING SELECTIVE ERASURE CAPABILITY). AND HAVING THE ERASE GUN PRECEDE THE WRITE GUN BY EMPLOYING A SLIGHT DELAY IN THE "WRITE" SIGNALS (BOTH GUNS GETTING THE SAME POSITIONAL DISPLAY SIGNALS HOWEVER) OVERLAP MAY BE PREVENTED, AS LONG AS THE OBJECT OR PART OF THE OBJECT WHICH IS TO BE DISPLAYED IS DRAWN IN SEQUENCE COMPATIBLE WITH THIS METHOD (NAMELY, LAST

A MULTI-GUN SCOPE THUS EMLOYED WILL CONTAIN THE IMAGE THUS DRAWN FOR A LENGTH OF TIME NECESSARY FOR PHOTOGRAPHING OR SCAN CONVERTING. A SCAN CONVERSION TUBE MAY BE USED TO TRANSFORM THE DRAWN IMAGE INTO A SCANNING PATTERN WHICH IS COMPATIBLE WITH TELEVISION TRANSMISSION OR A CLOSE-LINE RASTER WHICH WOULD BE COMPATIBLE FOR THE SUPERPOSITION OF FIGURES ON A BACKGROUND.

AT THIS POINT IN THE GENERATION OF ANIMATED PICTURES IT IS NECESSARY TO CONSIDER PICTURE QUALITY IN TERMS OF RESOLUTION. THE PROBLEM OF RESOLUTION BECOMES ACUTE WHEN HIGH SCANNING SPEED NECESSITATES HIGH BANDWIDTH REQUIREMENTS. THUS IT IS CONTEMPLATED THAT THE SPECIAL PICTURE TECKNIQUES (SUPPERIMPOSITION-OVERLAP PREVENTION-SCAN CONVERSION) WILL BE CARRIED ON AT A RELATIVELY SLOW RATE — ie not AT THE SAME SPEED AT WHICH WE ANIMATE. AN OPERATOR MAY DO HIS ANIMATION IN REAL TIME (WHERE THE DEVICE PUTS THE CONTROL SIGNALS INTO A 24/FRAME/SEC FORMAT) BUT THE EVENTUAL FILM-RECORDING OF THE ANIMATED SEQUENCES WILL BE AT A SLOWER RATE, AND OF COURSE ALL AUTOMATICALLY CONTROLED BY THE PRE-PROGRAMMED ANIMATION.

WITH LOW REPRODUCTION SCANNING RATES, HIGH RESOLUTION (CATHODE RAY TUBE DISPLAY COMPATIBLE WITH 35MM. FILM GRAIN) MAY BE ATTAINED.