THE PERCEPTION OF TELEVISION DISPLAYS

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This is a prepublication draft of a survey and analysis of the basic perceptual determinants that may affect viewers' responses to television as a unique mode of visual stimulation. As the first attempt of its kind, it must undoubtedly be incomplete, and may contain errors of detail or emphasis, but it should provide a foundation that can be filled in further, expanded, and revised with relative ease. It is more difficult to assess the practical importance of many of the factors that are theoretically relevant to the perception of video displays, and areas of research have been suggested where the need for such research has seemed most apparent to us.

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FOREWORD

The Television Laboratory at WNET/13 was formed in early 1972 to research and develop the aesthetic and technological potential of the television medium. Since its beginnings, the Lab has been supported by grants from The Rockefeller Foundation and the New York State Council on the Arts, with special project support coming from the National Endowment for the Arts.

Several years ago, Dr. John Knowles, President of The Rockefeller Foundation, watched a man experience an epileptic seizure which appeared to have been induced directly by the "roll" of his television set. Subsequently, Dr. Knowles encouraged the Lab to extend its research into the area of perception and physiology in an effort to shed new light on the medium as a unique mode of visual stimulation.

In 1973, the Lab commissioned Dr. Julian Hochberg, Chairman of the Psychology Department at Columbia University, to begin major research in that area. The result, "The Perception of Television Displays," written by Dr. Hochberg and his associate Dr. Virginia Brooks, is the first known attempt to survey the mass of individual-related research conducted throughout the years, and to analyze that research.

The paper, as Dr. Hochberg states, is "as a first attempt, undoubtedly incomplete and may contain errors of detail or emphasis; but it should provide a foundation that can be filled in further, expanded, and revised with relative ease." "The Perception of Television Displays" is rich in information. At this point in time, in lieu of rapid technological development, it is difficult to assess the practical value of each point. However, without minimizing the importance of all the information, there are several points covered which seem particularly noteworthy.

Video displays (pictures) have particular characteristics which make them different from cinema and other forms of visual displays. Video displays flicker 60 times per second with each "field." The first field is composed of the odd-numbered "scan lines"; the second is composed of the even-numbered scan lines. A "frame" consists of two fields;

the complete picture of 525 lines occurs 30 times per second (in the American system). The size of home television receivers and the distance at which people sit from them results in the stimulation of the retina over a smaller area compared to stimulation from conventional movies, for instance. These characteristics have interesting consequences (both favorable and unfavorable) when also considering the structure and functions of the human visual system from eye to brain.

One of those consequences is the apparent ability of "flicker" (i.e., lightness changes in the display) to induce, among other physiological responses, epileptic seizures in those few individuals who are particularly sensitive to this type of stimulation. Perhaps even more important than this, Drs. Hochberg and Brooks also ascertained that epileptic sensitivity to flicker-induced seizures can be extinguished or greatly reduced by "teaching" those affected to "unlearn" their sensitivity.

The authors also state that certain measures of brain function, such as alpha-rhythms, can be employed effectively as indicators of attention to video images. And also, the speed and accuracy with which text is read on the video screen can be increased by, for instance, controlling the pictorial images which accompany it.

Of particular interest to video artists may be the information relating to the physiological and psychological effects of different cutting rates (editing rates) and techniques and their relationship to the limited display size and detail of the television receiver; the text also covers points regarding the acuity factors that affect visibility of details in the display, and the effects of moire patterns produced by the interaction of the scan raster with certain other patterns (such as stripes).

Throughout the work, the authors have indicated the great need for more research in specific areas and have also outlined procedures for research in many instances. For example, little is known about the possible undesirable responses of normal viewers to pictures which induce repetitive eye movements; specific effects on the visuomotor system when viewing the world through such a small "window"; viewing distances as related to age groups and socioeconomic strata; and the effects of synthetic visual surfaces, volumes, and edges which can now be effectively created by computers and other related equipment.

The need for more research is undeniably apparent if more is to be learned about the effects the television medium can have on generations of people.

The Television Laboratory is proud to have had the opportunity to sponsor this major step toward further understanding of the television medium as a scientific field of study. We extend our deepest thanks to the authors and hope that "The Perception of Television Displays" will prove a successful foundation for gaining new and more valuable insights.

David R. Loxton, Director
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INTRODUCTION

The simplest prescription for making a picture that is generally recognizable is to make a surrogate display that presents to the eye exactly the same light distribution as does the scene that is to be depicted. Fidelity is the degree of similarity between the light distributions presented by the scene and the surrogate. The various photographic media are designed to produce surrogates automatically, with different kinds of departure from fidelity in each case. Cinema (meaning motion pictures on film) and video (meaning electronically transmitted and stored visual displays, as in TV) are produced by a stroboscopic (uninterrupted) sequence of still pictures. Both cinema and video draw on perceptual mechanisms that are only slightly understood. Stroboscopic techniques (cinema and video) are capable of more fidelity than are still pictures, in the sense that the former permit motion and movement parallax (the strongest depth cue, with the possible exception of binocular stereopsis) to be presented. Two facts associated with video displays can cause major departures from fidelity, however. In both cinema and video, the camera can change its viewpoint while the screen remains fixed. In addition, video displays characteristically further dissect each individual picture in the stroboscopic sequence by means of a relatively coarse, repetitive scanning raster (i.e., into thin horizontal bands that vary in luminance from one horizontal point to the next). In this paper, we consider primarily the perceptual consequence of these facts that are specific to the video media. As we shall see, video displays have some very peculiar features indeed, about whose consequences we know relatively little. (This does not imply that video displays comprise a learned, "visual language," consisting of assemblages of arbitrary symbols, and that the artist and engineer can therefore use whatever techniques they can devise and desire. Instead, it is most likely that the perception of these displays, even though they are quite unnatural, rest heavily on mechanisms evolved or learned in the course of perceiving the natural world, and that any additional departure from fidelity that the video artist may wish to employ should be undertaken with concern about possible losses of intelligibility.)

We consider 1) the factors that are associated with the stroboscopic nature of the display (i.e., repeated interruption, and its potential consequences, both desirable and undesirable); 2) factors that are peculiar to video display contours (largely to do with the raster used in scanning each frame); 3) the acuity factors that affect the visibility of details in the display; and 4) the consequences that limited display-size and display-detail may have for the applications of cutting technique to the presentation of scenes larger than the video screen. Cutting technique per se (as it contributes to the communication of meaning), and the principles that govern piecemeal perception of scenes and events in general, are only touched on lightly in this paper.

(1) Effects of interrupted (stroboscopic) presentation

(1.1) Frame rate and detectible interruption

Stroboscopic interruption is detectible in several different ways, few of which have been separately studied. Such interruption may cause a change in apparent lightness; noticeable discontinuities or jerkiness in any movement that is being depicted; an "activity," busyness or other abnormal vividness. Most research has been directed to the detection of lightness, or flicker.

(1.1.1) Factors affecting flicker-detection

Most sensory (and electrophysiological) flicker studies have varied the luminance of a relatively small (e.g., 2°) sharply bounded patch of light (see Fig. 1), either in an on/off pattern, in a sine wave, or in a combination of frequencies. Thus, a simple contour (between the patch and its background) has been involved in such studies, an immense number of which have been performed (for recent reviews, see 152, 111, 145, 171). But there have been very few studies of flicker as a function of the contour's shape (cf. 112), and no studies (that we know of) of the interruption or "raggedness" of depicted movement (cf. 1.4.1, below, for a related phenomenon).

(1.1.1.1) Frame and scan rates are probably above CFF for most normal conditions and viewers

Nor current theoretical model can fully describe the visual system's behavior, even with the simple cases studied, but there is a great deal of empirical data available.

CFF is the abbreviation for Critical Flicker Frequency, the threshold frequency above which the interruptions are not reliably detected. In general, the following facts are probably generalizable:

(a) CFF varies as the log stimulus amplitude: i.e., with a greater light/dark ratio, flicker can be detected by the viewer at higher frequencies. (b) Above CFF (i.e., where flicker can no longer be detected), the apparent brightness of the screen approximates that of a steady stimulus of same average luminance.

Somewhat less generalizable are the following statements:

Detection is most sensitive in the 5-10 Hz range, falling off sharply at higher frequencies (61, 60, 239). The use of a large, uniformly-flickering field (65°), with blurred as opposed to sharp edges, raises the upper cut-off of detectibility slightly, and decreases the sensitivity to low frequencies more markedly, thus sharpening the curve that graphs the probability of flicker detection against frequency to a peak near 20 Hz (154). The TV display is produced by a rapidly moving spot, of variable brightness, that moves in a horizontal sweep across the screen, and then traces another line across the screen, and so on, until the screen has been filled. This happens twice for each still picture or frame that comprises the stroboscopic sequence, leaving a space between alternate lines on the first set of sweeps, and filling in the remaining spaces on the second set. Thus, although the dot has traversed the screen 60 times per second (i.e., with a 60 Hz rate), the picture can only change 30 times each second. Since detectibility at high and low frequencies are differently affected by the size of the area, and by the number and sharpness of edges in the visual field (153), and because 20 Hz is a peak in the detection curve rather than an absolute limit, it is not automatically safe for us to consider the 30 Hz frame rate and the 60 Hz half-raster rate of TV as being completely above CFF. Moreover, the mutual masking that we would expect to occur between alternate lines of the interlaced raster should complicate the picture theoretically, and the fact that CFF varies with location (and that the CFF of a flickering target region is affected by the interruption rate of the surrounds (172), even if the latter regions are below CFF) on the retina complicates matters still more. To this last point: If we consider that a TV screen as normally viewed subtends an area of about 15° (and a motion picture screen subtends an area of about 45° - see Figs. 2a,b), we can extract rough approximations of the CFF at various parts of the eye from existing data on peripheral sensitivity to flicker (14): 27 Hz at the fovea (the center of the retina); 19 Hz at 15° from the center; and 14 Hz at 40° from the center. Most of the TV screen should therefore fall within a zone having a 19-27 Hz CFF. Although only experiments can answer the question with assurance, however, it does seem plausible that the 60 Hz rate with which adjacent lines of the interlaced raster of video displays are presented, taken together with the fact that (relatively) slow-decay phosphors are used in TV picture tubes, will put the scanning rate past CFF under normal viewing conditions.

But this does not mean that no effects of stroboscopic interruption are to be expected, for 3 reasons:

(1) The interruptions might be undetectible as a flickering brightness-change, yet might still produce physiological effects. This is not a very plausible possibility for two reasons: (a) Because flicker detection appears to have peripheral (but not photochemical) bases (92) so that if the interruption has any effects, it should produce flicker; (b) It would seem reasonable to guess that for flicker to have an effect, it must be consciously detectible by the viewer, because it appears that if we mask a flickering light by adding a steady light, the flicker loses its ability to elicit convulsive seizures (see 1.2.2.3, below).

(2) There obviously are many sources of flicker in video displays, beside the frame and raster rates, that are well within CFF (especially in sets that are not in perfect adjustment), and we do not know their prevalence or mix.

(3) As experimental video techniques (and particularly, computer-generated displays) are applied to the TV medium, and as higher bright/dark ratios are obtained, we can expect detectible flicker to increase (1.5.2, below).

Research is therefore needed on the conditions of flicker-detection with stroboscopic displays in the frequency ranges to be expected in TV display, with special concern for effects on physiological responses, on affective responses, and on patterns of eye movement.

(1.1.1.2) Stroboscopic enhancement of apparent brightness

Stroboscopic flicker has been shown to affect the conspicuity of a light (i.e., its power to attract and/or hold "attention," measured mostly by such not-very-satisfactory indices as reaction time, apparent brightness, etc.). Bartley (21, 22) believes the enhancement to be a central (as opposed to peripheral) effect, due to "driving" cortical alpha waves (about which, more in 1.2.2, below), a not terribly likely explanation. But enhancement does appear to be maximal at about 10 Hz (1, 9, 18, 20, 21, 22, 170), which means that pulses in this range should have good eye-catching ability - if they can be tolerated, which they may not be (see section 1.2.1, below).

This statement about enhancement cannot be taken as fully established however: for one thing, Bartley found enhancement with reasonably bright light (ca 150 mL), and an actual decrement with dim light, but there are Russion reports (111, pp. 52f.) to the effect that the flashing light's advantage holds only in the threshold region (i.e., for dim lights). (But the balance of evidence seems to support Bartley.) Moreover, a TV screen has most of the characteristics that are normally good eye-catchers (1.3, below), in any case. In general, as we might expect from the CFF data cited above, whereas the fovea can resolve time-differences of approximately 5 milliseconds between adjacent patches of pulsed light, peripheral thresholds are much higher; but the perception of movement is reported to be more precise in the periphery than in the fovea (230), so that the moving contours that are normally present on the TV screen should in themselves provide good conspicuity in the sense that they are readily picked up in peripheral vision; see also 1.3 below. And because the TV screen is probably already an eye-catcher, flicker-enhancement may not be able to raise its conspicuity appreciably in this regard.

(1.2) Affective and physiological effects of stroboscopic lights

(1.2.1) Response to stroboscopic displays: motion pictures and flashing lights

A very few studies have examined broad questions about the effects of film, such factors as the following: the effects on motility during sleep (30, 32); effects on GSR and heart rate while viewing film, as a function of reported subjects' reported interest (33, 34); effects on body temperature (as an indicator of muscular tension; 35). GSR scores measured during the viewing of an abstract film were found to correlate significantly with viewers' ACE (intelligence test) scores (36), and motion pictures have been used as stimuli for arousal in the study of physiological indices of emotion. These are relatively gross measures. Fine-grain frame-by-frame monitoring of GSR (resistance of the skin to electrical current), cardiotachmetric, pupillary reflex, etc., responses to motion picture or video displays, are now feasible, and await only some theoretical reason to be undertaken: gathered on an unguided, exploratory basis, such data can swamp the collector past relief. We here note that a detailed description of apparatus and procedure for recording frame-by-frame GSR responses has been published (173) and the fact that some subjects responded to a flash of light within 100-200 milli-seconds after a stimulus, that is much faster than is usually found with GSRs (177).

The increase was followed by an equally rapid decrease (this much is not surprising: rise times and fall times are correlated in GSRs of the more usual variety, (cf. 177). If substantiated, this rapid GSR response may be of interest in the study of stroboscopic presentations, and particularly in relation to maintaining the visual arousal that results from optimal cutting rate (cf. 4.1, below). In any case, further inquiry here requires specific theories to guide it. We shall mention some of these later on. Of greater interest now than either alpha or short-latency GST activity would seem to be the study of CNV (Contingent Negative Variation), or E-wave (expectancy-wave). This is a slow rise in surface electronegativity of the frontal cortex (246), that seems at present to be the closest correlate of attention, expectancy (122, 159, 246, 182) and of arousal or preference (59). Pupillary response also represents a similar cluster of affective processes (47, 119, 120, 148, 149). The advantage of the latter is that it requires no electrodes to be attached to the subject, but it possesses its own methodological problems which may make it impossible to use (102) in practice. Perhaps cardiac deceleration, which has been theoretically linked to CNV (167), might supplement or substitute for either CNV or the pupillary response. But in any case, it would be important to study how one or more of these measures respond to repetitive view-changes, time-locked to those changes as the latter are varied in rate and abruptness: i.e., to present a display in which some stimulus change occurs repetitively in a systematic fashion, and to average over many such repetitions the time course of the physiological responses after the stimulus change occurrences (see Fig. 3 and section 4.1).

(1.2.2) Electro-Cortical responses to stroboscopic displays

Although much research has been done on brain activity as an index of attention (cf. 72 for a review) and of perceptual processing (cf. 199), the work that is closest to our present interest has been concerned primarily with alpha wave activity. We discuss (1) the general hypothesis that has made these waves of special interest in connection with video displays; (2) its supposed relationship to stroboscopic lights; and (3) the specific phenomenon of photically-driven convulsions in epileptic viewers.

(1.2.2.1) Alpha rhythm and perceptual sampling hypotheses

Once we consider the perception of successive events, and particularly, the perception of events whose temporal distribution have some periodic properties (e.g., the 30 Hz frame rate), the issue of perceptual sampling rate arises: How rapidly in time are events resolved (i.e., separately detected), and with what independence? The most extreme answer to this question is the perceptual moment theory.

This was probably first used in one of G. K. Chesterton's "Father Brown" stories as a general idea. More specifically, Stroud (226) suggested that we can perceive events only in a series of discrete "moments" (of about 100 milliseconds duration), and that the order (and successiveness or non-simultaneity) of any two successive events that fall within the same moment would therefore not be perceived. We cannot ignore Stroud's suggestion: A temporal "grain size" of 100 msec would be large, compared to the 30 Hz frame rate of TV, so it is not a proposal that we can dismiss simply as being on the wrong time scale (i.e., as we could so ignore it if, for example, the perceptual moment were only about, say, 5 msec, which would be far too short to interact with the periodicity of the TV frame rate).

There are, in fact, some phenomena (e.g., subjects' estimates of the "numerosity" of rapidly repeated lights or sounds, the distribution of reaction times, the speeds at which subjects perceive successive events as being simultaneously presented, etc.) that suggest that a moment of 100 msec is indeed in operation (259, 50, 49, 257, 258, 88), and there is some reported relationship between subjects' performance in regard to those phenomena, on the one hand, and the same subjects' alpha rhythm rates. Alpha waves are bioelectrical fluctuations of about 100 msec period, 50 microvolts in magnitude, and an only roughly sinusoidal form, that can be measured under certain "no-load" conditions - notably in inattention, and, especially, when no purposive eye movements are being made (or, perhaps, when no eye movements are being planned). These waves have been proposed to be a sort of "read-out scan" of perceptual content, (analogous to the way in which a TV camera scans a scene), so the temptation of relating them to something like the perceptual moment theory is evident. (In a proposal that is very close to Stroud's, Kristoffersen suggests that there is a minimum time needed to switch attention from one object to another: in fact, he infers a switching time of 50 msec from the analysis of experimental data on subjects' abilities to detect that two stimuli were presented successively rather than simultaneously, and he finds that each individual subject's switching time is quite close to the half-period of his individual alpha rhythm (165, 166).

But there are many problems in the way of accepting these arguments and data (53); there are many other sources of periodicity besides alpha waves (259, 168); and there are other plausible models of perceptual sampling that do not require so drastic an assumption as a discrete perceptual moment. (A particularly interesting one for video purposes is D. Allport's "traveling moment" model, which is a "window" in time that moves forward continuously, rather than discretely; this model correctly predicts how periodic displays within the domain of those used in TV (particularly, within the domain of animated and computer-generated productions) are perceived, whereas the discrete perceptual moment model does not.)

What this line of inquiry does suggest to us, however, is that there are basic cutting-rate limits that should be investigated, and that it pays to experiment with repetitive displays, particularly in the 50 and 100 msec ranges, and to be alert to special perceptual effects that arise under those conditions. And not only perceptual effects can be expected:

A particularly interesting experiment, performed in line of research discussed above, was an attempt (partially successful) to change subjects' alpha rhythms and to measure whether their reaction times (which have previously been shown to be correlated with alpha rates: 229) change accordingly. Alpha was changed by what is known as "photic driving," i.e., by presenting lights that flashed at some rate close to, but different than, the subject's own alpha rate. Very few subjects' alpha rhythms could be changed, and then only by a small amount; in those subjects expected reaction-time effects were obtained. But the possible consequences of the fact that photic driving occurred in even small amounts and for some people, should be considered separately:

(1.2.2.2) Alpha driving and perceptual enhancement

Surwillo's attempt at changing alpha rhythm by photic driving (229) is part of a varied set of attempts to use stroboscopic lights to change or to "lock" brain functions (247, 228,121); in James Bond types of fantasy, photic driving has been used as torture or proposed as weapon (see, by coincidence, Ithaca Journal, Wed., July 25, 1973, p.18). As we noted above (1.1.1.2), Bartley proposed that brightness enhancement occurs with flickering lights in the 10 Hz range because the viewers' alpha waves are driven. However, Kohn and Slisbury (161) measured the EEG at frequencies in which brightness enhancement occurred, and found no relationship between frequency-specific activity of the EEG and brightness enhancement. Nevertheless, photic driving of alpha (and other modes of enhancing alpha: cf. 150) does indeed occur, with effects ranging from drowsiness (2) and "mediativeness" (150) to nausea although one major study found no adverse reactions obtained with "normal" subjects after "long" (approx. 2 hours) exposures to lights that were varied in frequency from 5 to 15 Hz(2).

The nature of the brightness enhancement remains to be determined, and other explanations have been offered (e.g., in terms of the growth of inhibitory processes, etc.). The question of "driving" repetitive physiological processes by the use of repetitive sensory stimuli remains of interest in understanding cinema and video, however, and one well-documented danger must be considered: that of inducing epileptic convulsions.

(1.2.2.3) Stroboscopic triggering of epileptic seizures

As we have noted, something that looks like alpha driving does indeed seem to be possible to some extent. But it is hard to see how such driving could be the *direct* mechanism by which epileptic seizures are triggered by flickering lights when we consider the frequencies (see below) that will trigger the seizures. The flicker rates produced by TV are definitely within the range in which epileptic convulsions are induced (e.g., when poor adjustments produce "flopover," danger appears to be particularly high, perhaps more so because of the strong vertical component). Thus, using EEG indices of seizure, Forster *et al* (81-86) established the sensitivity ranges of their subjects to run from between 1.5-30 Hz for some patients to between 15-45 Hz for others; parts of these ranges are surely beyond alpha rate. Moreover, Forster and his colleagues have shown three things that may make their report particularly important to the video media in general:

(a) Epileptic sensitivity to flicker-induced seizure can be *extinguished* (or greatly reduced) by (among other things) making the flicker unnoticeable by adding brighter nonflickering light to "mask" the flicker and then gradually lowering the nonflickering light's internsity until, after some relatively small number of such conditioning trials, the original unmasked flicker no longer induces convulsions.

(b) The extinction described above could be conditioned to an auditory click, which could then be administered to the (discharged) patient automatically by photocell-activated eyeglasses whenever flickering light in the range to which he had been sensitive was encountered.

(c) The subject's sensitivity remains decreased mainly in the region of the frequency that was treated, leaving unaffected the more distant parts of the range of frequencies to which he is sensitive.

All of this sounds sufficiently important that one would want replication before accepting these reports as reliable. Only the conditionability as such has been replicated: (82, 87, 86, 83, 81, 85, 84).

To these phenomena, indicating that seizures can be conditioned and extinguished, add the following: the evidence that the subject's preparation to execute eyemovements is specifically involved in blocking and eliciting alpha (62, 187); that alpha (and alpha-blocking) is readily conditionable (30, 254, 72p. 137, 136); that eyemovements are affected both by flicer and by certain kinds of patterns (190), and that epileptic individuals have been reported who were specifically sensitive to certain visual patterns, but not to the Lambda activity produced by scanning those patterns (260, 30) (that is, not sensitive to the brain waves that are produced by the visual response *per se*: 91). Taken together, these facts suggest to us that it is *via* repetitive eyemovements (or *via* the efferent programs by which such eyemovements are planned and executed, perhaps brain-stem initiated and elicitable by eyeclosure cf. 25, 62, 104, 187, 197, 251), that the stroboscopic light triggers epileptic seizures. This consideration in turn suggests to us that normals will be unaffected, in any way that resembles the epileptic patient's response, by such repetitive stimuli. But it also suggests a new danger for the epileptic:

There is good reason to believe that when one looks at a moving object or surface through a relatively small aperture, repetitive eyemovements are made (10, 100). When a long pan or dolly is shown on a TV screen, a very similar stimulus situation obtains to such aperture viewing, because the screen itself is essentially a small window, or aperture. This is particularly true in cheaper forms of animation in which much of the action consists of pulling a scene past the camera eye. Such displays (particularly those that would induce vertical movements or components) may therefore also be potential triggers for convulsion, directly or by conditioning, even if no flicker is present. We know of no data to this point.

More research is needed in the area, both in relation to the above suggestion, and with regard to the general question of what normal (non-clinical) viewers experience when they are shown photic stimulation that induces either repetitive eyemovements or strong EEG responses. Time-locked computer analyses can now be undertaken, for relatively small investments, in which stimulus periodicity, eyemovements, or some conjoint measure of the two provides the baseline for averaging evoked cortical potentials. The fact that convulsion-sensitivity to flicker can be conditioned (and hence can be extinguished) in susceptible epileptics is both a hopeful sign, and a source of danger in view of the widespread exposure to video displays from cradle on.

(1.2.3) Other physiological responses to repetitive and stroboscopic stimulation

In addition to brain waves, other physiological effects may be expected to occur in response to the repetitive aspects of the TV display (in the 10 Hz range) which may either be desirable, unavoidable or both; and they may occur in response to view-changes (cutting-rate), which may have to be particularly rapid in the video media in general and on the home TV screen in particular (see pp. 57f.), probably in the 10 - 0.2 Hz range.

(1.2.3.1) Conditioning of responses to repetitive stimuli

Conditioning of physiological responses has been demonstrated mostly for operant responses in recent years (108, 115, 109) but Pavlovian conditioning occurs as well. The fact that physiological responses appear to be subject to pervasive conditioning; that some physiological responses are known to occur in the naive organism in response to sensory change (167, p. 211); that the physiological response systems have ample opportunity to become "signals" for each other (167, 109), and that therefore the sensory events that originally elicited those responses can likewise become signals for each other, and hence can become conditioned stimuli for responses with which they had not otherwise been connected; and the fact that the great number of such "conditioning trials" that would occur in the course of a single hour's watching of TV would provide the opportunity for "overlearning" to occur (e.g., 10 x 60 x 60, or 36000 times in an hour for a 10 Hz event) -- these considerations lead us to expect to find that each viewer has a mix of physiological responses that have become conditioned to various stimulus-repetition rates. Questions of timing become critical -- we cannot expect such effects throughout the spectrum of repetitive stimulation. (Moreover, *change* of rate probably also becomes important, in the sense that habituation and extinction can be expected if the time at which the next event will occur becomes well learned (see pp. 7, 51), so that "pace changing" seems likely to be an essential part of such inquiry.)

The method by which to study such effects now seems accessible: the time-locking procedure that we mentioned above in connection with CNV (p. 7), in which each stimulus change becomes the starting point from which a given physiological response is measured, and the sequence is averaged over many cycles at that repetition frequency, bringing out the characteristic sequence of events and reducing the accidental "noise" (Fig. 3).

We know that an *increase* in GSR has been reported to occur with short latency in response to sensory change (see p. 7); if the GSR declines again with the same speed (100-200 msec) with which it increases, stimulus changes at approximately 0.5 Hz should keep the response maximal. With CNV, heart deceleration, etc., the time course is much more complex, and their interactions with each other need be considered. A prime research project here would be to investigate the effects of change-rates in the neighborhood of 0.2 cps (ca. pulse rate) as a recruiting stimulus, with an aim of bringing cardiac accelerations and decelerations under the control of the video display. Periodicity alone is, of course, insufficient to define what will maintain and elicit response: GSR, for example, varies with the physical characteristics of the stimulus and of the change in stimulation as purely *sensory* factors (e.g., size, brightness, etc.). But these factors may, to some unknown extent, themselves be the expression of (or at least be affected by) *cognitive* expectations about what the stimulus will be like (e.g., unexpectedness and "adaptation level"; see also pp. 15, 51). And, of course, GSRs are a function of emotion, of preference and of arousal: emotion-producing words and pictures were among the earliest and the most persistent stimuli to which the GSR was obtained in psychological research. With repeated presentation to the same stimulus, habituation occurs, and the stimulus ceases to elicit the GSR. We know of no systematic study of GSR as a function of flicker. Nevertheless, the following seems plausible: At reasonably slow rates of flicker, each onset and offset should affect GSR, and, because the rate is slow, partial recovery from habituation can occur between flashes. Habituation to the entire cycle will probably eventually occur, but much more slowly than it would occur with a continuous light of the same duration. But at faster rates of flicker, the stimulus changes should occur too rapidly for recovery from habituation to occur between flashes, and therefore habituation to these faster rates should be similar to that which occurs with continuous (non-flickering) stimulation. Regardless of the initial maximal GSR levels, therefore, there should be some range of flicker in which habituation should be slowest to build up, and in which arousal should be maintained longest.

If we assume that it takes arousal level 100 msec to 200 msec to return to baseline, using the extraordinarily low-latency response reported on page 7 as our measure of arousal, then the range in which flicker should be maximally arousing (other factors equal) should be about 5 to 10 Hz: point that may be of considerable importance (see 4.1, below), and towards which research should be directed. Changes in rates should also be effective, and so should a shift in what site or part of the retina is being stimulated by a given flicker rate. Such site-change can either be directly produced by changing the interruption rate separately in different parts of display, or might be produced indirectly by causing the viewer to look at a different part of the display (e.g., by introducing a fixation-catching stimulus which, by causing him to move his fovea to that point in the field, will bring some other part of the retina to some desired part of the display). We don't know that this has been tried at all, either as an artistic experiment, or as a research tool, but it sounds like a potentially effective way of avoiding habituation.

(1.2.4) Effects of attribution and labeling

According to an increasingly popular view, "emotions" and "affect" are not physiological states: They are names or labels that the subject applies to a perceived situation. That situation includes the state of his physiological indicators. If these appear to be in a clearly abnormal state, the subject must explain that fact to himself. For example, Valins _et al_ (244, 242, 241) have shown that, by _changing_ the rate of what subjects thought (erroneously) were their own amplified heartbeats, while they watched some pinup-photos and not others, that the judged attractiveness of those pinups increased. Presumably, the process can be summarized as follows: "If my heart rate changes when I see this girl, it must be because she is more attractive that the others." This line of analysis, which was initiated largely by Schacter and his colleagues (89, 91) and applied to a wide variety of motivational situations (88, 92) (and which is a revitalization of the old James-Lange theory of emotion) is burgeoning today as an important part of "attribution theory" (144) in Social Psychology. We need not take seriously the apparent implication that a conscious decision-making mental process intervenes between stimulus and emotion: perception is full of examples of what look like judgmental or inference-like processes, but are completely "unconscious" and better expressed as "contingent responses." And it may also be that _genuine_ changes in physiological state occur in response to the change in auditory stimulation in Valins' experiment (cf. p. 12, above; also,45) or, alternatively, that the change in the simulated heartbeat stimulation changes the degree and the nature of the viewer's attention (243). But the rubric of "attribution" appears to be good enough at this stage for us to look for similar phenomena in the area of response to repetitive stimulation, with which we are concerned here (although attribution theory's most obvious applications lie at the upper levels of communications theory, in the interpretation of portrayed motives, intentions and interpersonal behaviors -- i.e., in the as-yet untouched research area of the perceptual analyses of charisma, "presence" and acting). If we do attempt to apply the Schacter-Valins model here, the recruited and conditioned physiological indices would seem a good starting place. And even if the latter are not reliable phenomena, the use of spooky music in scary scenes, the use of sudden noise to increase the dramatic effect of the acted content -- these traditional devices may merely be clumsily worked-out precursors of Valin's experiment.

This area demands research with the highest priority.

(1.2.5) Cognitive vs. sensory "surprise"

Change in stimulation (and unexpectedness of change) thus may affect emotion and attention in fundamental ways, regardless of the substantive (story) content of what is being portrayed. But such factors cannot be approached in a simple, mechanical manner: As we note below "unexpectedness" or "change" are cognitive events that are in part separable from purely sensory changes, in that an abrupt sensory change may occur without a change in meaningful content (e.g., a sudden brightness change; or a perfectly comprehensible viewpoint-change within the same scene) -- and *vice versa* (cf. pp. 38, 56). In our normal commerce with the visual world such separation between sensory and cognitive change occurs rarely if ever, but as we shall see it is very easy to separate the two levels of change in cinema and video. Factors that affect the viewer's comprehension of (and cognitive expectations about) a sequence of pictures must therefore be taken into account separately in dealing with video (and with motion pictures in general, although there are special considerations that apply to video displays), and it is very likely that such factors as optimal timing, habituation, duration of effect, etc., are not the same for those physiological responses that are elicited by the cognitively unexpected or incomprehensible changes as they are for those physiological responses that are elicited by purely sensory changes. We will consider possible interactions between these two domains of factors in 4.1 below. But we approach this problem also when we consider the possible effects of regional flicker on comprehensibility, which we do in section 1.5 below.

(1.3) "Eye-catching" effects (peripheral conspicuity) and eye deployment

(1.3.1) The functional division of the eye and its relation to eye movement

We should note that the eye is spatially differentiated into two functionally separable regions, and that the field of view must also be so analysed because these regions respond differently to one and the same stimulus pattern. The fovea (the center of the retina), that is highest in acuity and most complete in color-receptors, and which is normally considered to be of 2° - 4° in extent, is used for detail vision. The periphery, the remainder of the field of view, has much lower acuity (acuity falls off very rapidly outside the fovea: 212, 157), has much more in the way of interactions between adjacent regions (i.e., the induced contrast between dark and light regions appears to extend over wider ranges in the periphery: 243), and has only partial color sensitivity (the retina is divided into zones that are decreasingly sensitive to full color differences as we go into the periphery, 34). These differences between fovea and periphery are not noticeable in our normal perceptions because the eye moves with great ease to bring whatever one is next interested in looking at from the periphery to the fovea: The very impulse to know what a given object in peripheral vision looks like brings it to foveal vision. Because the fovea is so small compared to the total visual field the normal perceptual process requires the eye to sample the field by bringing successive parts of it to the fovea. It does this, not by a systematic and invariant scanning raster, but by using information received in the periphery to guide the succession of saccades (the information-gathering glances) that are made until the viewer has received enough information about the display to satisfy whatever perceptual-cognitive task he has set for himself (or that the visual display has set for him). Such saccades are ballistic in nature: i.e., the eye movement is preprogrammed to fixate some point in the periphery, so the limitations of peripheral vision, and perceptual habits of using it, are the primary determinants of visual information pickup. Although the periphery is so important to visual perception, we know little of what and how it makes its contribution, and of the special requirements of TV, which uses the periphery in a special way: The normal field of view is about 180° ; the motion picture theater presents a field of view that varies very widely, but one of about 25° - 45° seems a reasonable expected value; whereas the video field of view (assuming a screen of say 1.5 feet, and a viewing distance of about 6 to 12 feet) may be about 7° - 14° . (We really need information very badly about what viewing distances we can expect to encounter with what screen sizes; and with what age of viewer and socio-economic status, since these will affect this figure, and the possible consequences of different viewing distances recur throughout this survey -- cf. pp. 29, 32, 59). We don't know much about the behavior of the visuomotor system when viewing the world through such a small "window" as a 7° - 14° display, or smaller. There is some reason to believe that the eye does move around a great deal, even within such a small confined area (a point to which we return later, p. 55ff.), but it is surely not safe to assume that it does so in the same way that it does in free gaze or even that it behaves as it does in viewing projected motion picture films (cf. p. 59). In any case, it is clear that a great deal of what the periphery normally contributes to help guide the gaze, and that keeps at least the gross outlines and relative location of an object in view even after the fovea has stopped looking directly at it, is missing from normal video viewing. We must expect that there will be differences in whatever perceptual functions would be affected by these facts (cf. pp. 58f.).

(1.3.2) Peripheral conspicuity

Although CFF is even lower for peripheral than it is for central vision (see p. 4), flicker rates produced by poor TV set adjustment, by edge effects, and by special effects (cf. 1.4, 1.5, below) should be well within detectable flicker range. Studies of conspicuity (cf. p. 5) have mostly investigated such factors as the time it takes to pick out a flashing light from among steady ones (or from among other flashing lights). We need research on the extent to which a TV screen, viewed peripherally, forces fixation to occur as a consequence of flicker, and how central that forced fixation is. (And we should note that 15° is a very small part of the effective visual world, so that if chance were the only determinant of whether or not we look at the TV screen it should usually be well outside of central vision.) In any case, even without flicker, the TV screen (with its internal luminosity and movement) fulfills most of the prescriptions for catching the eye that are listed by advertising psychologists (cf. 114), so that it might be that there is little to be done to a display that will additionally enhance its conspicuity. Those advertising prescriptions, however, are based largely on the old Cornell work on attensity (reviewed in 44), and on recall studies which test whether subjects have attended to advertisements by how well they remember them, a very dubious measure for our purposes, and may not therefore be directly applicable to this question. A concealed VTR camera (optically sited at the center of the video display by half-silvered mirror, or other beam-splitter) should permit sampling of when a free observer, with no constraints on posture or movement, looks toward the screen.

About 1° accuracy is all such a situation would require. Sampling of the VTR tape would permit us to assess the degree to which actual gaze-capturing is affected by various display factors. Presumably, the greater the peripheral conspicuity of the display, the higher the proportion of time that the display is fixated, regardless of its substantive interest. However, we have no knowledge at present of habituation and fatigue factors, nor of the degree to which peripheral conspicuity may be counterproductive (because of irritating or optically disappointing effects when the peripherally-viewed displays are brought to foveal vision). Research would be easy to implement and inexpensive in apparatus, but might be expensive with respect to any large-scale reduction and analysis of data.

(1.4) Interactions with eyemovements

Even well above CFF, stroboscopic interruption should interact with eyemovements, in ways that make such displays detectably different from uninterrupted ones, and that may give them special significance in more disturbing ways.

(1.4.1) The effects of persistence

The motion and continuity that are perceived in stroboscopic pictures (which are successive static displays, alternating with short dark periods), are, of course, "illusions," a fact that we tend to overlook because of the familiarity of the medium. We do not know the visual mechanisms by which that "illusion" is achieved. "Visual persistence" is often invoked as an explanation, but it will not do: Although persistence might indeed by used to account for the fact that the dark periods are not separately detected as such at high enough rates (i.e., at rates high enough so that flicker will not be seen with alternating black fields), persistence cannot account for the integration of successive displaced contours into smooth movement. Indeed, all that persistence would do is to superimpose the successive frames to form an incomprehensible multiple exposure. That is, with stationary eyes, persistence (which is real, and important, and particularly important to any eventual understanding of flash frame effects (cf. 3.2.2, below) and to an understanding of why the following kinds of interference do <u>not</u> normally occur) would merely produce adjacent multiple images. With moving eyes, that fact becomes clear: If the eyes move relative to a stroboscopic (interrupted) display, when the eye has stopped the afterimages of each point at which the light impinged on the retina will have left a track of persistent points separated by gaps that correspond to the times at which the light was interrupted. Thus, a moving luminous point that appears to the stationary eye to be in smooth motion will be "dissected" into a set of static points if the eye moves (cf. 38, 67, 158, 240). Some form of inhibition must normally suppress these multiple images. (There is some period of suppression of vision before and during a saccade. The extent and basis of that suppression is not clear, however, (176, 185, 186, 225, 137, 245); it may not apply to smooth pursuit movements at all (225); and we are here discussing afterimages which persist after the eyemovement has stopped, and the eye has come to rest, in any case -- a point often overlooked in connection with this issue.) If we knew the distance past which the inhibitive effect (if it holds in a moving eye) breaks down, and if we know the velocity of the eye, and the interruption-rate of the display, we should be able to say precisely the sizes and distance at which the dots would appear. The effect is somewhat like an uncontrolled version of McLaren's Pas de deux, if the field is relatively uncluttered so that each afterimage is not overlaid by contours produced by other objects. Whereas a set of contours that overlay each other (for example, the gridwork of the raster pattern) will, if they are regular (or if they have any regular component, as appears to be true of "snow" -- cf., McKay) cause successive moire patterns, which will themselves appear to move. All of this is something like "picket fencing" under strobe lights, except that it is dependent on the eyemovements of the observer. Computer-generated displays should be particularly prone to such effects: The representation of rapidly moving objects, that are displayed with high-contrast on otherwise-empty fields, which induce tracking movements of the eye, should be avoided if this form of visual "beats" is to be minimized. More difficult to avoid is a similar effect, on a smaller scale, that we discuss in 2.1 and 2.4, below.

(1.4.2.) Interference with oculomotor coordination

Saccadic movements are preprogrammed rapid excursions of the eye that bring some point in peripheral vision to the fovea (p. 17). Although the excursion itself is very rapid (ca. 50 msec), a minimum of about 150-200 msec preparation time is needed before the saccade can be made, and therefore saccades cannot be executed with a frequency greater than 4-5 Hz. If unrelated visual stimuli are flashed before the eye at 4-12 Hz, normal saccades stop occurring and the eye appears to freeze (52, 203) presumably because insufficient time is then provided for planning the next saccade (and for assimilating the information of the previous one). In fact, if we assume that an interruption or discontinuous change in scene will immobilize the eye for 100-200 msec above normal 150-200 msec response time, a possible explanation of the photic driving phenomenon (p. 9) suggests itself, without recourse to brain-wave hypotheses. Within the range of 10-30 Hz, let us first consider the lower frequencies: Each time the eye prepares to move, it may receive a signal that the scene has been interrupted (because the light has come on and gone off), and the intended saccade is aborted in accordance with the movement-freeze hypothesis discussed above. Consider next the higher frequencies: Whenever an eyemovement is undertaken, and the eye has moved, it will have received a new view from its new position, but with a dark period intervening, and both views will be superimposed because of the persistence (i.e., afterimages of both views will be seen). There is reason to believe that the eye does not immediately take its own shift into account for some period after shifting (possibly up to 500 msec: 180); there is reason to believe that a continuous visual framework is necessary for the saccadic "suppression" to occur (43); and, in any case, if the eye's movement straddles the dark period, it will confront multiple images (cf. 1.4.1, above) and have no way to distinguish the final image from the ones previously received. If the visual system makes a wrong choice about which one is currently being received (and therefore about which way the eye is currently looking, inasmuch as its nonvisual sources of information about where the eye is pointed may be inoperative for some time after the movement has occurred), the confusion would only be increased by the time the next saccade is executed. Severe interference with the normal coordination of eyemovements, and with the integration of successive inputs into a single unified scene, should then result.

In short, stroboscopic lights in the 10-30 Hz range, having detectable and substantial dark times between the flashes, may affect purposive eyemovements similarly to the way in which DAF (Delayed Audio Feedback) is known to disrupt purposive speech. And this interference should occur whether or not there is any photic driving effect on brain waves. To the uninformed and unpracticed subject, the results might well be disorientation, dizziness, nausea and worse (including effects on middle-ear function).

Research should be relatively easy and inexpensive in this area. For one thing, the disruptive effects of interruption in this range should be reduced or eliminated by producing a stable, nonflickering surround (which may at least in part account for the amelioration of epileptogenic seizure-driving described by Forster *et al* in Section 1.2.2.3, above).

(1.5) Masking, lustre and new "surface colors" subjective colors

(1.5.1) Masking

The range of succession times employed in stroboscopic video displays is within that in which a host of poorly understood phenomena, variously called *masking*, *metacontrast*, contour-assimilation, etc., may occur. In these phenomena, shapes or patterns (or areas of color) that would have been perfectly visible had they not been preceded or followed by some other display, fail to be perceived. Such masking phenomena may turn out to be undesirable side effects in artificially-assembled video displays. Recent reviews and papers (146, 181, 202, 252) reveal a complex array of findings, not amenable to a general summary. At this stage, all that can be offered is a warning that sequentially-produced scenes, especially those produced in alternational on the same or adjacent areas, may result in perceptual blanking of some of them, and that displays that are built up from frame to frame (e.g., stop-action and flash frames) or that vary from frame to frame, should be carefully inspected with this warning in mind.

Closely related to at least some of the masking phenomena are those that occur with equal-flux and "lustrous" displays, which we consider next.

(1.5.2) Lustre and uniform (ambiguous) lightness displays

When lights are flashed in close temporal and spatial contiguity, a number of unusual phenomena occur. In particular, if a given pattern is presented on the same site in reversed luminance distributions (e.g., a black pattern on a white ground, which alternates with its photographic negative), it is perceived as a lustrous, pearly white or gray ground, both figure and ground being very vibrant and compelling.

This phenomenon does not look totally unfamiliar: In binocular vision, a similar simultaneous presentation (and, perhaps, an alternation of dark and light via binocular rivalry) occurs when one looks at a specular (glossy) surface, since such surfaces characteristically reflect a highlight to one eye and not to the other eye at the same point on the object. The same thing occurs in miniature at each of the very small facets that make up a lustrous or irridescent surface (e.g., mother-of-pearl; brushed aluminum; etc.) in normal binocular viewing. Thus the lustrousness that appears in response to an alternating negative-positive display may occur because such displays simulate the binocular rivalry that occurs during binocular vision of lustrous surfaces. (And although this has never been studied, a similar effect also may occur, with head tremors, to produce the same effect in monocular vision. We should also note that brightness-enhancement is known to occur at the edge or contour of a flickering field (207, 208), in a manner that seems closely related to the enhancement discussed in 1.1.1.2, above; this brightness enhancement effect is far more pronounced when the two eyes receive different luminance levels (207).) It may thus not be a really "new" surface color that we see with such alternative video displays. But it is new insofar as controlled presentations are concerned, and we have much to learn about how to produce the effect, and about what its consequences are.

As far as production of the phenomenon is concerned, the "temporal modules" open to the normal video display (the units in terms of which sequences can be constructed) are based on a minimum full-raster cycle of 30 msec. We do not know what the required times for alternative negatives and positives should be, nor do we know (as we shall see) whether the same phenomenon can be achieved by alternating a pattern with a blank (patternless) field of the proper luminance and timing; we do not know whether the second field can have a different pattern on it, nor whether the two fields can consist of dot-matrices in negative-positive alternation (perhaps with some phase difference from one part of the field to the next) with the contours being produced between those sets of dots that co-vary. (Such displays, if they produce visible pictures at all should be strikingly "active" and irridescent.) Most of the detailed research we have on the effects of cyclical temporal luminance changes on surface-color has been directed at two problems: one is the attempt to discover the conditions for generating what is called "subjuctive color" (i.e., hues that appear when only sequences of black and white or light and dark are actually being presented; see 78 for a recent theory and review). The other is the important study by Sperling, 91, which has not been really followed up, on the luminance and temporal conditions under which a pattern of light, alone, cycling at about 500 msec, followed by a black field, will produce one of the following: either the positive image of the pattern is seen; both a positive image and its negative afterimage are seen to alternate; a negative image appears alone (which is what most interested Sperling); or an image of ambiguous brightness-distribution appears, which sounds very much like the lustrous condition we are discussing in this section. Sperling reports that the relationship between the conditions (of luminance and timing) that produce these alternative percepts is invariant over a variety of patterns (although the actual luminance and time values may be different with different patterns). This seems to us to be an extremely important area of future research, particularly in view of the possible consequences of the use of displays that alternate within these ranges. Other consequences are considered in 1.2, 2.4, and 2.5 One concern we must have, of course, is the possibility that these displays are epileptogenic.

(2) Video contours

The world contains objects' surfaces, edges and corners, not outlines nor contours, although it is by the use of the latter that those surfaces, edges and corners must be represented in pictorial displays: Outlines and contours in a picture serve to mark off the two-dimensional projection of an object, in the scene being portrayed, from the rest of the visual field. In a high-fidelity surrogate (e.g., a good photograph), the contours are produced by changes in texture-density; by abrupt differences in surface color, or in surface texture; or by cast shadows. In drawings, which are extremely low-fidelity surrogates, objects' edges and corners are "represented" by luminance-difference contours or by lines (which are doubled luminance-difference contours, very close together). Although outlines are nothing at all like objects' edges, we are so familiar with their use that it is hard to remember how different from edges they are; but although they are so different, they probably share certain essential stimulus features with objects' edges, and are not merely arbitrarily-learned symbols (129, 130). Video, as we shall see (3, below) is probably a relatively low-fidelity medium for most things other than closeups (even though it can approximate the very high fidelity of photography, for certain combinations of camera distance, subject, screen-size and viewer-distance), and computer graphics certainly rely heavily on lines and outlines. Most of what we know about contours, we have learned in the study of luminance-difference contours. But in addition to these, there are varieties of contours encountered in video displays that are rarely encountered elsewhere, whose perceptual properties are largely unknown. We first discuss luminance-difference contours briefly, then the other varieties.

(2.1) Luminance-difference contours

A prerequisite for seeing shapes, objects, distances or anything substantial, is the existence of luminance-difference contours in the visual field. (E.g., if 2 regions differ only in their hue, and are equal in brightness, the contour that separates the regions does not in general have a clearly discernable shape (176; cf. however 31)). Moreover, the luminance must change abruptly (204). Because of this need for sharp change, if we defocus the image, or blur it in any other way, or increase the incident light to both of the regions that are bounded by the contour, the detectability of the contour (69, 193, 194, 195, 235) is decreased, and the apparent brightness of the stimulus also decreases (although some of these effects may disappear at short exposures: 132). Thus a sharp focus, reduced incident light falling on the video tube face, increased contrast (and any electronic amplification of the abruptness of the change in luminance gradient each side of the contour) -- all of these increase the apparent brightness of the objects, and increase the visibility of their contours, on the TV screen.

But a luminance-change may be well above the degree of abruptness that is normally *sufficient* for a contour to be seen, and yet the contour may not be perceived: Luminance-difference contours mask or inhibit each other when they are presented successively with intervals between their onsets that range up to about 150 msec (255), with a maximum masking effect between them at about 50 msec (20 Hz) reported by some (13, 163, 181, 253). Neither is an abrupt luminance change *necessary* in order to see a contour, as we will see in connection with *subjective contours* (2.3, below), except in this sense: even subjective contours depend on groupings or arrangements of elements (e.g., dots) that are themselves bounded by well-defined luminance-difference contours even though those contours do not themselves bound or outline the object being represented.

So luminance-difference contours are essential to perception despite these qualifications. And sharpness of focus is important to obtaining well-perceived luminance-difference contours. Nevertheless, the visibility of overall patterns, and of larger shapes, are probably actually *increased* by blurring (as we shall see in 3.3, below).

(2.2) Moire and border effects

When the eye moves rapidly, a stationary point of light at which the viewer is looking will stimulate a path or line on the retina, rather than a point (p. 19), yet our eyemovements do not normally cause us to see a tangle of lines -- a fact that is usually attributed to suppression of vision during eyemovements (see p. 20). Some researchers question the degree to which vision is suppressed immediately before and during voluntary and involuntary eyemovements (240), but in any case the aftereffects of having exposed the same part of the retina to two different luminance distributions result in partially overlapping "afterimages." This should occur with each tremor that the eye makes; it should bypass the suppression phenomenon; and it should have a wide variety of effects, some of which may be important in video displays.

(2.2.1) Border effects

Consider a small eyemovement which causes a luminance-difference contour (henceforth abbreviated l.d.c.) to be displaced on the retina so that a strip which previously lay on the dark side of the contour is now exposed to the bright side. The strip that is freshly exposed to the bright side will look brighter than any of the surrounding region, because in effect the afterimage will be added to that of the incident light itself. This super-bright stripe will move as the eye moves, producing a fluctuating brightness pattern of brightness bordering on, and interacting with the perception of the l.d.c. The width of such border effects depends (among other things) on the eye tremors. We do not know what the latter are under TV-watching conditions. When an observer tries to keep his gaze steady under laboratory conditions, a number of different kinds of movement occur (7, 57, 190, 205): a high-frequency tremor (30-100 Hz, with a median amplitude at about 17 seconds of visual angle); slow drifts (1 minute of visual angle per second) over about 5 minutes of angle; rapid unperiodic flicks, from 1 to 20 minutes of visual angle in extent. The area which includes the center of the eye about 50% of the time is about 10 minutes of visual angle (63), so we are talking about movements some of which are several times the width of a raster line at what we have taken to be the normal viewing distance (p. 4). It seems plausible that such tremors will occur with video displays at least as much as they do in laboratory conditions: There is reason to believe that the last two movements are corrective in purpose (57, 190), and if that is so, the minor perturbation or jitter that is characteristic of video (and especially TV) displays might mislead the visual system into acting as though drifts have occurred and therefore as though corrections are necessary (even though it is the display and not the eye that has moved). Alternatively, it might be that eyemovements decrease in the presence of jitter.

Research on these problems will need precision eyemovement recording procedures, and cannot be undertaken inexpensively nor in a casual setting. Perhaps the apparent brightness of a display could be measured as a function of the degree of jitter electronically introduced into the overall display, without attempts to measure the effects on tremor directly. We should note that the relative movement of the image over the retina is an essential part of the visual process: When the retinal image is stabilized by optical methods (involving contact lenses), so that there is no visual consequence of tremor and small saccades, vision ceases. It is apparently the low-frequency components (10Hz and below) that are needed to maintain vision, and the higher frequencies merely blur the image (164). The normal movement is within the frequency range available to, and possibly inherent in, TV displays: So it is not implausible on the face of it that the jitter of the video display, in this frequency range, should be accepted by the visual system as being part of the system's own perturbation (an effect which seems more plausible to occur in a dark room than in a lit one, and with a large display than a small one).

(2.2.2) Moire effects

A moire is produced when a spatially repetitive pattern of l.d.c's (luminance-difference contours) is displaced relative to its previous position and relative to the afterimage that it has left there. This is so because the displacement (whether by display-jitter or by eyemovement) results in the superposition of the new stimulus input and the old afterimage, slightly displaced relative to each other. The points of intersection between the two displaced sets of contours provide the repetitive elements for a new set of lines, which is present in neither set considered separately. The pattern formed by the new set of lines is the moire pattern (Fig. 4). The castellations and harmonics produced as side-effects by, say, chroma-keying, and the repetitive elements of the raster themselves, would seem to provide sufficient basis for us to expect moire patterns will be generated in the TV display. These moire patterns will move as the eye moves and trembles relative to the display, or as the display itself moves slightly as a whole. The moire patterns will move even more so (and much more than the eye moves) when the display itself contains a periodic movement, as is almost inevitable in video. (The purely subjective patterns that McKay (184) describes as being visible is visual noise or "snow" are probably examples of the interaction of eyemovements, afterimages, and nonrandom l.d.c. changes in the snow.)

Video contours (and particularly those produced by special effects) therefore can offer space-time "beats," which can be of higher contrast than is otherwise available on the video display, and whose frequencies can be considerably lower than the stroboscopic interruption rates with which video displays are actually presented. These "beats" may have several consequences -- in physiological and affective effects (see 1.2, 1.5), in subjective color (note that the conditions at what we will call active contours are often right for generating "subjective color"), etc. -- consequences that may be of considerable importance, although that importance can only be assessed by research: It may turn out after all that these effects are basically nondetectable, or, if they are detectable, that the perceptual system adapts to them without effects of any importance. Research methods here are not obvious. They will themselves require further thought.

The moires and border effects described above should occur whenever the subject's fixation is *relatively* constrained, when his eyes are well focused, and when the display luminance is high relative to the ambient room illumination. The first two conditions may or may not be met in normal video viewing (cf. 3.3 and 4.4, below); the latter probably is usually met. Let us consider the consequences of these effects that may occur at video contours.

(2.3) *"Active contours" and their possible effects*

Because they depend on interactions between the nature of the display, the eyemovements that are executed, and the structure of the retina of the eye, the following flicker effects depend on the size of the elements in the *proximal* stimulus pattern (i.e., on the visual angles subtended at the eye) rather than on the *distal* stimulus object (i.e., the physical size of the display *itself*). For this reason, the vibrancy and contour-activity that we will discuss should be a function of the viewer's distance from a given display. Furthermore, the fovea (or center) of the retina and the periphery of the retina respond differently to these factors, if only because of acuity differences (but also because of their different sensitivity characteristics), and the extent of the picture that falls on each (on fovea and on periphery) will also change with viewing distance. As noted in reference to pointillism and subjective contours (2.4, below), this means that there may be several different "optimal" viewing distances to consider, and to compare with the actual average distances at which viewers tend to sit (when these are known; we do not now know them, nor how they differ for different age groups and socio-economic strata). Thus active contours should be studied separately under 3 viewing conditions: when they fall in far periphery; when they fall in near periphery, and when they fall in central vision. We consider possible effects of each of these separately, and then their interactions.

(2.3.1) Far periphery

There is an old belief to the effect that movement and change, peripherally-viewed, evoke reflexive fixation movements of the eye and head -- i.e., that movement and change serve to catch visual attention. Active contours would appear to be more attention-catching in this regard than normal static ones, but it seems unlikely that they will be effective in the far periphery (especially because the poorness of peripheral vision is due not only to the way the retina is organized, but to poorer optical performance of the eye's optical system in the far periphery). But under normal viewing conditions, TV displays must be much too small to fall into far periphery when the observer is looking at the set, and there usually is sufficient gross movement on the screen anyway to attract the observer to the screen when he is not looking at it. I.e., active contours are probably not particularly important as far as extreme peripheral vision is concerned.

(2.3.2) Near periphery

If the active contour falls close enough to the fovea to be detectably active (and it may turn out that this is true within the visual angle subtended by the whole TV screen, given normal viewing size and distance), then some or all of three consequences may occur: (1) The eye will be drawn to fixate that contour more strongly than it would be with an ordinary contour (e.g., than it would be attracted to a line on paper).

(2) The apparent luminance and saturation of the two regions that are bounded by an active contour may be much higher than would be true if they were bounded by an ordinary contour: something of a jewel-like or stained-glass effect may occur (heightened by lustre-color, discussed above (1.5)), that resembles some of the descriptions of drug-induced visual effects (as may other aspects of contour-activity: cf. the next two points discussed below). What suggests that such heightening of the entire bounded region will occur is the evidence that the color of a given region of the visual field is set by the contour, and is at least in a part a "construct," filled in over the entire area but really determined only by the processes that occur at the contour (cf. 164). This point has to be tested by color-matching research using active contours; if it is true, it should be of considerable interest in creating experimental displays. The research procedures here seem relatively straightforward.

(3) The contour activity may stimulate the same analyzing mechanisms or receptive fields as are activated by real movement of contours in peripheral vision. There is some evidence that receptive fields of this sort exist, i.e., that our visual nervous system contains analyzing mechanisms that are stimulated by moving contours in the retinal image. Such contour movements normally occur on the retina for any or all of three reasons:

First, because the eye trembles and shifts continually by small amounts (see p. 26). Fixation is normally maintained and corrected on the basis of visual information. If the amplified contour-activity is interpreted by the fixation maintaining machinery of the visual system as being due to eye movement and as a signal that fixation is not being adequately maintained, the system may take steps to stop what it interprets as being eye tremor. Automatic attempts by the visual system to stop that tremor will not, of course, stop the visual activity at the contour, under these conditions, and the attempts to do so may result in increased difficulty of maintaining fixation (see also p. 47). That is, it may be easier to maintain in a somewhat defocused fixation than to maintain perfect, focused fixation, when active contours are presented.

Second, movement in the retinal image obviously may occur for either of two reasons: because an object moves relative to the eye and/or because one object moves relative to another object or to the object's background. If active contours have the same effect on motion "detectors" as does real movement in the retinal image, such contours may indeed trigger fixation "reflexes." The periphery is particularly sensitive to movement, and might be sensitive to the pseudomovement that we are discussing here, as well.

Third, because active contours may be strongly interpreted as being an edge between surfaces at different distances. This point is less evident, but may be of importance: With slight head movements, movement parallax (i.e., the difference in views from two station points) will produce slight movements at the edges of objects where an abrupt change in distance occurs (e.g., objects as they are normally distributed in space around us: cf. 123). In addition, binocular parallax may produce an apparent alternating motion or activity in the combined (both eyes') view at an object's edge, in that two binocularly viewed contours in close proximity (ca. 15 min.

of visual angle or less) generate a piecemeal alternation that may resemble videocontour activity, and may activate the same perceptual mechanisms.

(4) If the viewer has moved his eye to fixate an active contour on a CRT with an "expectation" that movement and/or depth-at-an-edge will be found for reasons discussed above, that expectation will of course be disconfirmed. That is, when the eye fixates an active contour, after having viewed that contour in near periphery, the absence of consistent parallax and movement-information should then become clear to the visual system (and our acuity is extremely keen with respect to such information, detecting parallax down to about 2 seconds of visual angle). With active contours present on the video screen, depth and movement may thus be interpreted as being present wherever one doesn't look, and absent where one does look. (Something of the sort may happen with all pictures, particularly with pointillistic pictures and gross-screen halftones, but video may provide a more vivid and active form of the phenomenon.) These displays may therefore maintain a restless visual search activity within the confines of the video field (say, over a field of about 15%), quite independent of the search activity that the visuomotor system normally undertakes under the press of intrinsic and extrinsic perceptual tasks (44, 102, 190). Something much like this presumably is achieved, at much greater pains and with much more talent, by the use of composition to keep visual search activity (and visual interest) alive beyond the intrinsic demands of the subject matter or the extrinsic demands of the task that has been set the viewer. If we apply attribution theory (see section 1.2.4) to this circumstance, we would expect the viewer to consider any material that causes him in this manner to search more than he can explain, as being more interesting than he would otherwise consider it to be.

Alternatively, it may be that such disconfirmed visual expectations are soon extinguished. Eyemovement research, using such displays, is clearly needed. It is particularly important to determine whether such a spurious search process does occur; whether it persists indefinitely or finally extinguishes; if it does extinguish, what kinds of schedules of presentations will maintain it; and how the search activity that occurs with active contours compares with the search that occurs with compositions composed of normal luminance-difference contours. Gross eyemovement records would suffice for such study, and can be obtained unbeknownst to the viewer.

(2.3.3) Fovea

Another possible source of visuomotor conflict remains, especially likely when the fovea fixates an active contour. The eye can only focus at one distance at one time. Accomodation (focus of the eye's lens) is most probably a visually-guided action (7; although it is not a well-understood behavior). The repetitive "busyness" at active contours may (like certain kinds of type-face that are difficult to keep in focus) provide cues that lead the system to treat the contours as though they are out of focus even when they are perfectly well focused. This may produce an accomodative "hunting," or (alternatively) it may lead the eyes to defocus down to some compromise level at which the "busyness" is no longer detectable because the blur at that level of defocusing masks it. (There is evidence (57) that the eye is normally kept somewhat defocused, anyway, but we are here proposing a more marked state of mis-accomodation.) Another reason for the defocusing to occur is the conflict that may occur between periphery and fovea in terms of tremor signals (cf. the discussion of this point above), which can only be resolved by defocusing the eye enough to obscure the contour activity. (There are still other reasons for the eye to defocus while watching video displays: see 3.3, below.)

A possibility of further visuomotor peculiarity (and possible conflict) then arises from the above consideration as follows: The degree of accommodation that the eyes maintain, and the degree of binocular convergence that is needed to bring an object to single vision (binocular fusion) are normally closely coupled to each other in the visual system. If a defocusing of accommodation occurs, that should either entail a convergence of the two eyes at some point other than the surface at which the viewer is looking, or should entail decoupling of accommodation and convergence. It is not generally thought that accommodation and convergence are decoupled in normal seeing, so it seems most likely that convergence would be deliberately out of adjustment, also.

The effects of contour-active displays on accommodation can conveniently be measured by laser scintillation technique (17, 118) although probably not without the viewer's knowledge that such is being done; convergence changes would require much more elaborate methods (and ones which would interfere drastically with normal viewing habits, whatever they are).

(2.3.4) Possible effects of the above differences

In one way or another, therefore, watching active-contour video may elicit visuomotor anomalies or conflicts whose effects may range from causing the viewer not to look clearly at what he is watching attentively (!), to causing him to maintain an active and repetitive (and perhaps purposeless and basically uninterested) scan of a small viewing area. Some form of visual disorientation seems likely, and we already know that visual disorientations often have affective and even emotional consequences: There are the undocumented but well-known effects of flickering and dazzling lights used in the Electric Circus and "psychedelic light shows," which themselves deserve formal research; there are the effects on orientation that tilted and moving fields can produce (64, 261); there are the hypnagogic and possibly hypnotic effects of the Ganzfeld, which is any visual field that is blank and homogeneous enough to prevent accommodative and convergent fixation from being maintained (15, 131); and there are the reports that defocusing normally accompanies "withdrawal" and fantasy or daydreaming (11), which suggests that a display that elicits defocusing for optical reasons may, by conditioning or circumstance, encourage the fantasy activity. Research on these effects would be valuable to undertake, but the research methods are not self-evident, and require thought and development. (Note that the heightened color, the active contours, the visuomotor conflicts, and the heightened visual attention to a single area are also all anecdotally features of may psychoactive drug states. These video phenomena may be or more value (perhaps reminiscent) to those who have had experience with such states, experiences that were rewarding. It is even conceivable, if far-fetched, that the reverse is also true: that the early experience with electronic displays are predisposing to later enjoyment of psychoactive drugs which produce similar perceptual effects.)

(2.4) Subjective contours

We have seen that luminance-difference contours are in one sense essential to the perception of objects and scenes -- to the perception of anything other than fog. But that does not mean that the objects or shapes that we perceive must be bounded (or outlined) by luminance-difference contours: In fact, whenever TV is viewed from a distance at which the raster is clearly visible, all representation is achieved by means of subjective contours -- contours that are not coincident with luminance-differences, but are somehow "filled in" by the "mind's eye." Such contours are not only essential to perception under those conditions of viewing video: They are also uniquely easy to produce in electronically-generated displays, so that their characteristics, advantages and disadvantages should be better understood than they are at present.

(2.4.1) Completion contours

The classic forms of subjective contours are:

(a) Those in which a set of repeating (or, at any rate, densely distributed) lines or elements are all interrupted colinearly; the line along which they are occluded or interrupted is thus perceived to delineate a superimposed shape, whose implicit edges appear to occlude the interrupted set of elements (cf. 123, p. 431).

(b) A set of dots placed on a piece of paper usually appear to group together forming one shape or another, in accordance with so-called principles of *Gestalt* organization (123, p.431).

(c) More striking than either of these two classical examples are the contours that can be produced in random dot-fields by parallax: In binocular vision, two displays made up of random sets of dots, neither of which, when viewed separately, show anything but the random texture, will be seen as an object in front of a background if the two displays are identical (albeit effectively random), except that a subset of one display has been displaced relative to the other (e.g. Julexz patterns, reviewed in 143).

(d) A similar effect can be obtained monocularly if some subset of dots is moved with a common vector, relative to the rest (127). In both cases, the object that is perceived appears to be bounded by a more or less sharp edge, which is usually peculiarly vibrant in character, even though the entire field is of homogeneous luminance and (except in the sense that each dot has a luminance-difference contour that makes the dot itself visible) no luminance differences are needed in order for the object's shape to be perceived.

Coren (54) has recently proposed that the first kind of subjective contour (*a*, above) is really a case in which the visual system has assumed that one surface is interposed in front of another, and that the contour that we perceive is a perceptual reconstruction of the object's occluded edge. This sounds right. The more general rule may be this: that the conditions that lead the visual system to "expect" that the edge of an object's surface will be found to lie at a given locus of points in the visual field, will elicit the perception of a contour at that locus. Contour-perception would thus become a special case of the more general perceptual process of surface-perception.

(2.4.2) Pointilliste pictures, halftone and "snow"

The use of cross-hatching, dots, texture, or small brushstrokes to ontain shades of color and lightness is almost as old as art itself. The process seems simple enough, at first glance: If we make the points of black and white (or of different colors) so small that the eye cannot resolve them, they will be averaged into a single blended area. This indeed happens, and is of course responsible for the mixture processes that underlie the perception of color in color TV. But this cannot possibly be the whole story: The cross-hatching, the dots, the raster (or whatever) can be perfectly discernible, yet the shades of gray will still be seen: we can detect both the shading, and the individual dots on whose blending or averaging the perception of the shading presumably depends. We propose that this process, like that of completion-contours discussed above, depends on the two-stage nature of vision, that is, on the fact that a vague peripheral glimpse is followed by detailed foveal inspection: When a set of dots (or cross-hatching, etc.) falls in peripheral visions, the low acuity of the periphery causes the dots to be averaged to form what is perceived as an apparently homogeneous area which has a true luminance-difference contour to set it off from other peripherally-viewed areas that have a different average luminance, etc. When the eye moves so as to bring the same set of dots to the fovea, however, the dots are seen as the group of discrete elements they are, if the observer is sufficiently near the display to resolve them. From the right viewing distance, therefore, such displays should have this particularly vibrant and dynamic property: contours, edges and surfaces alternately form in peripheral vision, and dissolve into individual points at the center of the fovea as the viewer moves his eyes about. The vibrancy, and the existence of an optimal viewing distance, has been noted in the case of pointilliste and impressionist painting (cf. Grosser, 105; Taylor, 233), although we believe that the reasons have not hitherto been clearly understood.

The same principle should be operative either when poor reception imposes a blanket of visual noise (snow) on the TV screen, or when the viewer sits so close to the screen that he can discern the individual "lines" of the raster in foveal viewing: recognizable contours and shapes should be clearly visible in peripheral vision (see also 3.3, below), whereas in a small area at the center of gaze (an area whose size depends on the viewer's distance and on the size of the TV tube), those shapes should dissolve into bands or points of color. And there should therefore be an optimal viewing distance to obtain such effects, if the consequences of such pointillistic vibrancy are desirable.

(2.4.3) Subjective surfaces and edges which are particularly accessible to video technology

Viewing distances are probably great enough in most cases, and reception good enough, that neither raster nor snow is an important cause of subjective contour -- i.e., it seems plausible that many viewers sit so that true, uninterrupted luminance-difference contours delineate objects' shapes, even to foveal viewing. But there are resources available to video technology that make it particularly easy to generate" synthetic surfaces" whose edges are subjective contours.

There are two electronic ways of generating such "synthetic surfaces" that are readily available to video programming (and therefore also motion pictures) that cannot be achieved at all in other media. These are (1) textures and patterns of elements whose distribution and movements are designed and executed by computer; and (2) rapid and pre-programmed changes (and reversals) of light and dark (e.g., from negative to positive) and of complementary colors. We know a little about each of these exotic stimulus conditions, but not enough to comprise a well understood palette for the video artist to use.

(2.4.3.1) Dot-defined surfaces and volumes

The visual system can extract what is common and ordered about the distribution of a large number of separate elements (like points of light, the bits of a texture, etc.). Examples here: Small lights that are worn at actors' joints as the actors shake hands, embrace, walk around in an otherwise totally dark room are sorted out by the visual system into the perception of a group of behaving people, and are not simply perceived as a wild array of moving dots (140); the extraction of surface planes (93, 140, 141, 142, 190) and volumes of space (cf. the logo for Startrek) out of a sea of moving points of light, etc. Some of the principles that determine and limit this extraction procedure for static displays have been studied under the heading of grouping (123, 160, 256), and a very little experimental data have been gathered (23, 24; Attneave, 12). More important are the dynamic grouping factors, and what looks like a powerful theoretical analysis and some preliminary experiments have been undertaken but have not yet been pursued very far (32, 139, 140). It is probably worthwhile to try to apply these rules to computer graphic programming.

It is now possible to program display-generating computers to depict volumes, surfaces, etc., in three dimensions (e.g., by the flow-patterns of elements or dots that result from relative motion of observer and scene -- i.e., by dolly and tracking shots). It should also already by possible, at our present state of knowledge, to program such computers so as to choose just those patterns that will most readily be correctly perceived by the viewer, and to avoid those views or configurations which will be most difficult to perceive as the filmmaker desires them to be seen. In effect, this means that the computer can not only carry out the laborious work of rotating and dollying with respect to scenes and objects, once it is programmed to do the job -- it can also pick out the most effective ways of doing so. Research here is not difficult in principle (although it is probably quite expensive, to the degree that it depends on the services of commercial computer-graphics companies for exploratory and trial-and-error work). The research questions here are (a) To what degree can we now effectively design synthetic visual surfaces, volumes and edges; (b) What are the properties of the contours that are thus created (see 2.5, below).

(2.4.3.2) Surfaces constructed of alternating colors, which are particularly easy to produce by electronic means, are discussed as perceptual effects in 1.5, above.

(2.4.4) Subjective contours and their probable effects on comprehension

When our gaze shifts from one object to another while we are looking at the real world, we know where one object lies relative to the other because (1) we ourselves have moved our gaze, and because (2) the first object may remain in peripheral vision when we regard the second (and vice versa). When it is the camera that has shifted its direction, of course, the first of these sources of information is unavailable, and if there is any overlap between two successive views that can serve to provide peripheral indication of the relative directions in which the two views lie, the overlap must then be an important factor in comprehending the scene that is being de picted by the successive shots. Although we do not have direct information to this point, it seems very likely that the patterns of light and dark, in peripheral vision, are important to the comprehension of successive views.

In the case of equal-flux displays, in which lustrous objects are produced on lustrous backgrounds (see 1.5, above); in displays in which regions of the visual field differ from each other mainly in hue but are of equal lightness; and in dot-pattern displays of essentially equal density over the field of view: -- in all of these, the viewer has no masses of different lightness in peripheral vision to enable him to decide rapidly where one view lies relative to others. That is, the viewer should lose track more readily of where he is when views change in equal-flux (or high- or low-key) displays. Computer graphics would seem to be particularly prone to this source of comprehension slow-down.

Moreover, it should take longer for the viewer to detect when the scene has changed, when such equal-flux displays are used. Thus, these displays provide a good example of a separation between <u>cognitive change</u> and <u>sensory change</u> (cf. 1.2.3, and 4.1): That is, the scene may change drastically, but there are no lower-level brightness changes in peripheral vision to signal the lower levels of the processing system that the scene has changed. In these circumstances, the visual system does "know" that a change in view has occurred only after the observer grasps that the meaning of the new scene is different from that of the old. This is a relatively high-level process that may take considerable time (e.g., 500 - 1500 msec) and should be added to the time that it takes to discover what the new scene contains. In such equal-flux displays, it should therefore take longer than in formal displays to comprehend a new scene, and this should make visual understanding a more demanding task. It may be neither desirable nor undesirable, in itself, to increase the difficulty of comprehending the flow of scenes: As we shall see below, if we want to maintain a particular change rate (or cutting rate), and we don't want the viewer to grasp each view and tire of it before it is replaced by another view (this is a particularly important goal, yet probably difficult to achieve in relatively uncluttered montages or in closeups), such equal-flux pictures as we here describe may help maintain comprehension at the desired level of slowness. Research is needed on such consequences of using flicker, lustre-color, and other approximations to equal-flux displays.

Comprehension time is a rather abstract concept, and a method of measuring it is not immediately evident. Because the eye appears to "freeze" until a scene is visually comprehended to some minimum degree, the time needed for the eye to start to move again after a scene has changed (i.e., eyemovement latency and frequency), is probably a particularly promising avenue of research on comprehension time. But research with other indices of change, such as GSR, would also seem worthwhile to explore.

(3) Acuity factors and information limits

A TV display can of course provide only a very small fraction of the field that the eye itself can look at directly: If the viewer sits close to the screen, or if a large set is used, so that the display fills a large part of the visual field, then the scanning raster is extremely coarse compared to what the eye can resolve. Conversely, if the distance from the screen (or the screen's size) is such that the scanning raster is not much coarser than the eye's resolving power, then the size of the screen's image must be very small -- say, about 5 °. These considerations place constraints on what can be shown the TV viewer, and how it can be shown.

(3.1) Measures and determinants of acuity

Optical resolution can be measured in various ways, some (but not all) of which are interchangeable. Video resolution sets some limits on the total information transmittable through the CTR display, with a particularly rigid form of redundancy being set by the horizontal lines of the scanning raster. Assume a line width of 1 mm., and a viewing distance of three meters, or a visual angle of approximately 1 min. of arc. That visual angle is usually taken as the minimum detectable separation for the average observer (4.2.1, below), but we shall see that from the viewer's standpoint, this measure cannot be assigned too mechanically. Perceptual acuity (the psychological counterpart of optical resolution) has various measures for different purposes and circumstances, measures which are only slightly interchangeable. The most widely used measure is the minimum separable: a gap of about 1 minute of visual angle is taken as the approximate measure of detectability (e.g., for a _c_ to be distinguishable from an _o_, the gap in the _c_ must be at least 1 minute wide). The TV raster is marginally detectable from about 3 yards, by that measure, and the redundancy that this imposes should make letters indistinguishable that would otherwise normally be just barely distinguishable to direct vision. This statement must immediately be qualified however, in several ways.

(i) Acuity falls off rapidly from the center of the retina. The fovea is generally considered to be a region of maximum acuity of 2° to 4° in extent, but even within that small region, acuity varies (143). If a video display of 40 cm in horizontal extend is centrally fixated from a distance of 3 meters, its horizontal margins fall 4° each side of the center of the fovea. Assuming that the eye remains fixated at the center of the screen, at the edges of the screen the gap in a letter _c_ will have to be much more than 1 minute of arc in order for the _c_ to be detectably different from an _o_.

(ii) The perceptual machinery does not respond independently to each point in a matrix, or raster, but is affected by redundancies in the stimulus display. Thus, the acuity for an offset or a "jog" in a straight line is only about 2 _seconds_ of arc -- much finer than the minimum detectable separation of 1 minute. A more appropriate measure to apply to video displays might be the m.t.f. (or _modulation transfer function_), a Fourier analysis of grating acuities. (Grating acuity is a measure of the spacing that a number of lines must have before their directions of orientation can be detected (cf. 4.2.1).) Grating acuity would vary as a function of the grating's spacing, its orientation with respect to the raster, and the distance from which the set is viewed. This measure would be particularly useful with respect to learning the limits with which texture-density gradients can be represented in TV, a problem to which we refer below (3.2). Under optimal conditions, subjects can resolve gratings of lines that are about 35 - 40 seconds wide (56), but we know of no research applying this measure either to the perception of texture gradients or to video. Such research is needed, but two precautions should be noted now:

(a) Moire between the test grating and raster pattern is an artifact which will affect the measure of grating detection, and must be separately assessed. (b) We do not know how well grating acuity (and the _modulation transfer function measure_ to which it is ideally suited) predicts other kinds of acuity. In particular, we do not know how well grating acuity measures will predict the detectability of the various patterns that are used in graphic communication, since the latter have distinctive features some of which are (in terms of these measures) at low frequency, some of which are high frequency, and some of which are broadband. (A dramatic example of this point is discussed in 3.3, below.)

Research is needed to determine the applicability and generalizability of this measure of visual acuity to video displays.

(3.1.1) Increasing acuity by temporal integration

Because the eye can integrate information over time in various ways the acuity limits imposed by the spatial "grain size" of the display may be surmounted by drawing on those integrative abilities. One way of doing so that has not been explored is to treat the raster like a screen or picket fence, behind which the scene to be shown moves in some systematic manner. As a rough analogy, consider a grainy motion picture (or the "snow" of low signal/noise ratio in a video display): In any one frame, the grain imposes a measurable information loss; but the grain is randomly distributed and changes from frame to frame, whereas the components of the original scene itself remain unchanged (or change systematically), so that the grain "averages out." It may be that a continuous pan or dolly achieves the same effect (in addition to serving other and more obvious functions) by moving the details that are obscured by the dark lines of the raster in one frame to an unobscured location in the next frame (this discussion ignores horizontal resolution limits), resulting in a spatial distribution whose peaks define the details. One assumption here is that the visual system can store up partial detail from view to view, even when the views do not fall in registry (if they fell in registry, the whole issue would be a trivial one); there are recent data (65, 106, 107, 113) that can be interpreted as supporting this assumption.

(3.1.2) Pattern sensitivities

The fact that the perceptual system makes use of stimulus redundancies (cf. 3.1, ii) necessarily implies that it also responds to more than one point at a time (i.e., that it responds to <u>patterns</u> and not merely to the aggregate of individual, stimulated points), and therefore, implies the use of sensitivities outside of the fovea.

What is more, it seems likely that different kinds of training result in different sensitivities to patterns (e.g., it is possible that near-sighted viewers are sensitive to different features of objects than are normals; 228). We do not know what these pattern-sensitivities are, how far they extend over the retina, nor how they differ with age, education and purpose of viewing. But we do know at least this: that letters (and presumably other shapes as well) can be recognized as patterns (or as packets of characteristic distinctive features, which may not be quite the same thing); that larger familiar collections of letters (e.g., familiar words) can be recognized as units by use of features that are probably larger than the individual letters (i.e., by "word features"; cf. 262). It is a reasonable assumption that the shapes of printed letters and words have so evolved in use that they make good use of the features that are available to the normal visual nervous systems, and that they will therefore be good measures of pattern-acuity, over and above the more local acuity measures discussed in the previous section (i.e., letter legibility should be a good measure for pictorial use, as well as for text). Letters and words are readily varied as stimuli; they are readily scored as responses; and we have a great deal of experience with using letters and words as experimental materials, so they are good measures to use in the operational sense. What the actual features are by which we recognize letters and words is not known with any assurance at present; but while it would be helpful to know them, if we intend to generalize from reading-acuity in video displays to other forms of video acuity, we need not await such knowledge in order to use readability as a measure of video display characteristics.

(3.2) Reading as shape perception in video displays

There are 3 reasons for studying reading in video displays: (1) Most important, the recognition of printed materials is in many ways a better index of the medium's perceptual effects and capacities than the more "objective" tests used to measure and define video resolution. (2) As symbols, printed text has emotional effects, as well as informative value, that are different from spoken words and from pictures, and the video media are in some respects exceptionally well-suited to exploit those effects. (3) Text is an important part of the video display, whether in overt or covert display (e.g., text and subtitles vs. labels on pictured products).

(3.2.1) Legibility studies

There is a large body of legibility studies, most of those through 1963 having been indexed by Cornog and Rose (55) and somewhat less extensively by McCormick (183). The former provide an index of studies on the legibility of alphanumeric characters and other symbols. These are classified in terms of the presentation techniques, the typography, the response measures, etc., that were used. A few principles are probably quite general to the reading process: In skilled reading (as opposed to letter-by-letter decoding), responses are made as readily and as quickly to familiar words (and even to familiar phrases) as to individual letters (262); such responses are made on the basis of partial information (e.g., beginnings or ends of words; word length; perhaps word-pattern features), and on expectations of what the writer is likely to say next, etc. Letters are more readily detected than the closed shapes that are often used as symbols in electronic displays (200; but cf. 116). The higher the familiarity of a word, the lower the duration required to recognize it (133, 134, 221): In fact, familiarity, frequency, expectability, meaning -- these affect all measures of legibility: they affect the speed of recognition, the exposure duration required for recogntion, the distance at which the word is legible, etc. (236). Upper halves of words are more legible than the lower halves (236), lower case letters are more legible in the context of meaningful words than they are as individual letters (71, 236). And for this reason, words can be partially missing or wrongly spelled, and that fact will go effectively undetected (the "proofreader's effor") as long as one reads for meaning and not merely to check letters (262). In contrast, meaningless strings of letters require much longer exposures to recognize, and unfamiliar nonsense shapes have to be dealt with piecemeal, each identifiable element by element. (Similar phenomena occur in hearing as in vision, in that missing phonemes are "heard" as long as some noise (a burst of white noise, a cough) is presented at the time in which the phonemes should have occurred (248, 249); whereas strings of meaningless sounds, even if they are as few as four in number and the listener knows what they will be, cannot be recognized as to the order in which they occurred (250).) And this in turn means that the eye is picking up features of the words, other than each specific letter of which each word is composed, and must be picking up such features outside of the central fovea. Estimates may vary of how far outside of the fovea features are picked up, and by the nature of the fact that different kinds and levels of cues (some of them sentence-wide in nature) are used to determine what response the subject makes, the precise figure cannot be fixed. (A useful line of research would be this: to vary the number of words-at-a-time in which a message appears, and to study the effects of that variable on the recognition of a given word in that message. This measure will tell us how much is being picked up peripherally in a given context. And in any case, we don't know just how many words are needed to achieve a decent reading rate on something like a TV display.) But regardless of what the precise figure turns out to be, it is clear now that word-recognition draws on larger and on more peripherally-visible features than are measured by the 1 min. figure for visual acuity. What those features are, is not presently known.

A promising line of inquiry is suggested by what may be an important finding by Erdmann and Neal (71): They varied the vertical and horizontal resolution of letters, using a digital scanning device; they also varied character size and familiarity. In a previous study (70), they had examined the legibility of letters as a function of the first two of these factors. Familiar words and familiar individual letters were consistently more legible than were unfamiliar words at all sizes, which is of course what all other research has led us to expect. But their most important finding was this: Words were more legible than lower-case letters alone <u>only</u> in the case of familiar words at high levels of legibility. For familiar material, the average legibility of words was equal to or higher than the average legibility of the individual letters; for unfamiliar material, word-legibility is <u>less</u> than it is for individual letters. But since correlation coefficients were high for all words (.93 - .98), it seems that it is still useful to know the legibility of the individual letters, since one can use that information to predict (approximately) the legibility of words that are constructed from those letters. Furthermore, these data seem to imply that the effects of degradation on the features by which words are recognized are pretty much the same as the effects of degradation on the features by which individual letters are recognized.

As far as individual letters' legibilities (and symbol-identifiability) in video displays are concerned, 6 lines per symbol seem to suffice (155, 156), although Bell (1967) and Shurtleff and Owens (216) recommend a minimum of 10 lines per character; and the curious fact appears to be true both for non-alphanumeric symbols (16, 116) and for alphanumeric symbols (216, 217) that, in order to achieve a given degree of legibility, decreasing the number of raster lines that compose the image may be compensated for by increasing the visual angle that the figure subtends, up to about 16 min. of arc: Further decreases in raster lines cannot be compensated for by increasing the visual angle that the figure subtends. With fixed raster and viewing distance, legibility decreases with size, of course. Specifically, the x height is the important feature of lower case letters, with a minimum of about 1.1 mm., in printed text, or about 10 min. of visual angle. Giddings (99), however, also finds a decline in legibility as character height is increased past an optimum of about 18 min. (e.g., .156 inches in height at 30 inches of viewing distance), or 14 raster lines for words, and 21 minutes (.187 in. at 30 in.), or 18 raster lines, per digit.

In print, line length (i.e., the length of the string of letters on the page) has a significant effect, independent of character size (174). This fact, taken together with Gidding's findings we have just cited, and the fact that at any given time we are watching a fixed raster, suggests that there is some optimal size for TV text: It is not simply a matter of making the text as large as possible.

(One thing about which we can find no information is the effect of "rolling" text up the screen, or across the screen, as a way of increasing the textual information that a display can hold. Pacing will obviously always be a problem with such procedures, as it has been in motion picture usage of this technique, but the problem is aggravated in video because the much smaller resolution available means that fewer words can actually be present at one time, and that the viewer's reading rate must therefore be closer to the rate at which the material is presented.)

As far as measuring the legibility of text is concerned, average perception time per line reflects the difficulty of the material being read (237). This suggests that a self-adjusting procedure, in which the subject himself regulates the rate of presentation, could be used to test legibility "online." (A payoff matrix would be needed to keep his errors at some fixed level: say, 95% accuracy.) This method could be used, in combination with pictorial material to measure the comprehensibility of the picture itself by measuring effects on the legibility of the text that accompanies it. That is, by measuring the degree to which the presence of a particular set of pictorial displays increases the speed and/or accuracy with which the text is read, we will have measured the extent to which the pictures have contributed to the viewer's correct expectations about the text. This is a badly needed line of inquiry, since measures of comprehensibility are going to be badly needed -- a point to which we return later.

(3.2.2) "Subliminal" messages and flash frames

To be illegible does not necessarily mean to be ineffective. There was a great flurry of speculation and research, in the early 1950's, about the possibility of presenting messages (usually words and sentences, but sometimes pictures) which would be too fast (or too dim, etc.) for the viewer to be aware of consciously, but which would presumably be recognized unconsciously, and therefore affect the viewer at an emotional and uncritical level (cf. 197). This was exciting, theoretically, because it promised to bring psychoanalytic inquiry into the laboratory; practically, it seemed to offer a means of heightening the impact of entertainment (and of selling products and people) that was particularly suited to TV, because it could be flashed in a single unnoticed frame; that seemed potentially more effective than any normal presentation could be, because the presentation is unnoticed; and potentially more dangerous, because the viewer would not and could not bring his critical faculties to bear on the message.

Research on which this speculative structure was built was inadequate in two ways: (1) Some of the reported effects were due to <u>response biases</u> (i.e., were due to subjects' readiness to report seeing one word rather than another). (2) The conception of a subthreshold "unconscious" message depends on our assumption that there is a clearcut threshold, above which the stimulus is consciously recognizable and below which it is not -- and that assumption is false. Because of these methodological and conceptual defects, this line of inquiry has been pretty well abandoned, although desultory research continues, usually with additional negative results (29, 198).

But baby may have gone with bathwater: The fact is that a very brief exposre (e.g., a flash frame) can provide information that will affect the viewer, and in particular will affect the way in which he looks at subsequent displays, even if the brief presentation is gone before he can fully grasp what it contained and reexamine it. The shock effects of such interpolations; the uncertainty about their contents; and the fact that the viewer must reconstruct their meaning <u>while</u> he is looking at other things, make such flashes of text (or of picture) a unique component of motion pictures and TV (even if they are not truly "subliminal" nor "unconscious"), and a reich field for research.

Formal titles have been abandoned in motion pictures, but Godard and the underground filmmakers remind us that there are still occasions in which one word is worth many pictures. With the growth of experimental video techniques, flash-frame substitutes of words for pictures may turn out to be acceptable and effective. It would seem worthwhile to undertake research to determine whether flash-frame interpolation of very brief messages or scenes can, after the viewer has learned to expect them, act as mise en scene, and to provide anticipation of future transitions, regardless of the unfortunate history of research on subliminal perception.

(3.3) Consequences of texture-information limits and distortions

Regardless of how good the reception may be, the scanning raster must result in a degraded image, in all viewing conditions in which the line width is 1 min. of visual angle or more (see p. 39). This degradation imposes limits that have not been well explored and that may be more interesting than mere "noise" degradation would be; most fascinating is the fact that those limits can apparently be overcome to some extent:

(3.3.1) The advantages of defocusing

A picture that is degraded by breaking it up into homogeneous patches (which of course is what happens along one dimension within the width of a raster line) is rendered more interpretable under the following conditions: if it is viewed at a greater distance; if it is thrown out of focus as a stimulus; if it is viewed with somewhat defocused eyes; if it is viewed through a diffusing screen, etc. This effect demands investigation by anyone interested in video displays. Whether it is due to the elimination of the high-frequency components that are offered by the sharp edges of the raster of whether, as Julesz and Harmon (143) propose, the improvement is due to the elimination of most or all of the visual frequencies that fall within a range, two octaves in width, that contains the frequencies that comprise the essential pictorial elements -- in either case, some defocusing of the viewer's accommodation would help him see the picture, and would be reinforced. It is very important to determine whether in fact the perceptuomotor system maintains a particularly defocused posture when viewing of video displays, and what the consequences of a defocused posture are if it does so (see p. 32). It would also be important to determine whether there are ways of achieving the same goal by some other (electronic or optical) method of intervention.

(3.3.2) Effects of raster on textured displays

One point at which the characteristic fidelity limits of video must be particularly important is in the representation of texture, and in the representation of gradients (rates of change) of texture density. This is so because of resolution limits, and because the scanning raster must interact with any regular, repetitive pattern (p. 27). In theory, this should make TV a low-fidelity medium indeed, as we shall see, but there has been study of the practical consequences of these visual limitations. Two possible consequences are considered here:

(3.3.2.1) Effects on surface quality and on spatial information

Objects' surface qualities are heavily determined by their textures (96); these qualities must be poorly conveyed, therefore, in static presentation via video display. The same must be true of the surfaces' slants and tri-dimensional orientations, to the extent that these attributes are conveyed to the observer by the means of texture-density gradients (95), but the actual efficacy of such static texture-density gradients is questionable, in any case (51, 89). With moving surfaces (or a moving camera), however, the situation may be quite different: the visual system may be able to extract the surface's texture from the "overlaid" scanning raster, subtracting the latter as a constant screen through which the surface texture can be discerned as its elements systematically perturb the raster. The perceptibility of represented objects' surface texture, their tri-dimensional orientations and their motions in space (which are normally revealed by the ways in which the textures undergo transformations due to motion perspective -- cf. 94) may therefore be restorable, at least in principle, by relative motion (i.e., by pans, dollies, etc.). But this will not automatically be true: some combinations of texture, motion and spatial orientation should interact with the raster to produce moire patterns that themselves act as dynamic texture-density gradients. These false texture-gradients would be either uninformative, at best, or actively misleading (being, say, opposite in the slant or direction of motion they imply to the motion and slant of the object that is being represented). There is little that can be done to avoid such misleading patterns when we are photographing real scenes and people, other than to avoid textures as much as possible. The advent of computer graphics, however, makes the use of tailor-make textures and of texture-manipulation practical, and research in this area seems very worthwhile to undertake.

(3.3.2.2) Conflict of two- and three-dimensional "depth cues"

The failure of textural information, the omnipresent high-contrast border that is produced bytthe frame of the picture tube, the strong frontal textrue that is provided by the raster and by any visual noise that may be present (inasmuch as the latter is probably statistically a uniform texture-density gradient of 0.0) -- all of these are indications (or "depth cues") to the viewer that the surface is flat. There are normally features in the scene being represented on the surface of the tube that contain strong depth cues (particularly, motion parallax) which signal the fact that different parts of the scene are at different distances from the viewer. There is thus a perceptual conflict between the features of the display that lead the viewer to perceive tri-dimensional space, on the one hand, and the particularly strong flatness cues of video displays, on the other. Such conflict has been variously held to provide and maintain visual interest (137); to decrease the strength of the geometrical illusions and decrease the degree of portrayed depth (103); and to increase the importance (and noticeability) of the "ground shapes" -- the shapes between the objects. This last factor, if it is true, should presumably make the esthetic consequences of pictorial composition and graphic design more important in TV than they are in motion pictures -- a point that seems somewhat implausible on the face of it. None of these features have, to our knowledge, been tested at all, although it would be important to have information about them, and although techniques for research are probably not too difficult to design.

(4) Principles of TV cutting

In discussing how special video factors effect the viewer's comprehension of any change in scene, we first present a brief outline of what appear to be the perceptual principles that underlie cinematic representation as a general cognitive task, and then consider the two variables of cutting rate and comprehension tone as they are specifically affected by factors characteristic of TV: i.e., by display size, resolution and viewing distance.

Esthetic considerations aside, this is an important area, and one in which reliable and quantitative knowledge is to be gained. Aside from a very few studies that are only indirectly relevant to cutting and editing (101, 99, 127), there is at present practically no research base for the speculations that have been offered. We can review what speculation there is briefly enough. There are two main areas in which formulations specific enough for research purposes have been made: (1) Cutting rate; (2) Comprehension.

(4.1) Cutting rate

There is considerable tradition and some actual research to the point that viewers prefer stimuli that are novel (and stimuli at some optimal level of complexity) than those to which they have been long exposed, that they look longer at such stimuli and that they show more physiological indices of arousal and/or of "cognitive load" in response to novel and/or optimally complex stimuli. "Visual fatigue" sets in rapidly (224). Motion pictures and TV can change the stimulus, via cutting to maintain visual arousal and interest at the desired level. The fact that cutting can have beneficial effects is doubly fortunate, because TV, with its small and low-resolution display, must change its views often for two reasons: It must use montages of many views (usually closeups) to assemble larger scenes; and it must also change often because the low resolution of the screen probably also makes for displays having low information (low complexity), which in turn makes for rapidly accruing boredom with a given view. These two reasons interact in their effects on cutting rate, which itself has at least two determinants: (i) The purely sensory components of change per se, and (ii) The change in comprehended content. Spottiswoode (224) has offered a speculative model of optimal cutting rate which incorporates both determinants. Although Spottiswoode's theory is based solely on his introspective observations, it does seem to fit the parameters that have been obtained in much more recent and objective research in visual perception (125, 223). And althouth Spottiswoode's prescriptions have been formulated for motion pictures, it should not be difficult to apply them to video (to which they should, in fact, be even more important than they are to film).

(4.1.1) Sensory determinants of cutting rate

Spottiswoode asserts that the pure fact of sensory change per se, regardless of the content of the change, maintains visual interest or arousal (which he calls affective tone). When a change occurs, it takes 200 msec to register that the eye has received a new view. Arousal then arises rapidly, and falls somewhat more slowly than it rises. If the next change is made just when the increment that was produced by the previous change has dissipated completely and the viewer's arousal returns to zero, no overall increase in arousal, from one cut to another, will occur. With a shorter delay between changes, there will be a net increase in arousal. A progressively accelerated cutting rate will be required to maintain that level, however, because the viewer comes to expect the changes, and they therefore produce smaller increments of "surprise" or arousal. The greater the sensory changes, the greater the increment, and what we mean by sensory "change" here is probably the abrupt occurrence of gross differences in the distributions of light and shade. Therefore, changes from one equal-flux display to another; between displays that have homogeneous distributions of lightness; and between displays whose masses of light and shade are very similar -- all of these transitions will be low in arousal value, even though the successive views may change greatly in meaning (e.g., from a scene in a forest to a scene in a factory).

Marked sensory changes are therefore changes of view which do not depend on the viewer's perception that the meaning or content has changed in order for him to detect that changes have occurred. Films or video sequences that are designed to maintain and manipulate the arousal effect of such sensory changes should be effective with any audience, regardless of the viewer's culture and knowledge (cf. p. 15). But substantive content interacts with these sensory determinants, and must, in general, be taken into account.

(4.1.2) Substantive determinants of cutting rate (comprehension time)

Because of its simplicity, its general familiarity, or its expectedness, a view may need (and should receive) only a very brief exposure (say 500 msec). A more informative, unexpected or complex shot will take more time to comprehend, and should therefore be able to sustain a slower cutting rate without loss of interest: each shot can last longer on the screen before the viewer "gets bored." According to these assumptions, then, there is a trade-off between several factors whenever a view changes: To the degree that the two views are dissimilar in sensory distribution and similar in content, the time needed to understand the transition between them will be short, and the filmmaker or video director can switch from one view to the next without confusing the viewer. If a sequence of such easy transitions is presented, the changes can therefore occur with a relatively high frequency (e.g., 500 msec per shot or 0.5 Hz). But because the viewer will eventually expect each change to occur, the rate will have to be speeded up, or the transitions will have to be changed in some other way, in order to obtain from them the same increments in arousal, and to maintain the same degree of visual interest or momentum. By making the content less easy to comprehend within a single glance, we can thus increase the time that can elapse before the subject tires of each view, and the same degree of visual interest can presumably be maintained at a slower cutting rate.

There are a number of interesting relationships that one can elaborate from the simple functions that Spottiswoode proposes (including the implication that <u>one could presumably measure on-line comprehension rate by determining the cutting rate that maintains a steady level of visual interest</u> -- surely a very important tool, if true, because obtaining a measure of comprehension time must be given a high priority for a number of theoretical and practical reasons). And research tests of those relationships seem relatively easy to perform, if suitable measures of visual interest can be found. (E.g., does the time required to comprehend each individual view determine the rate at which the views can be presented in succession? Does visual interest require an accelerating cutting rate, or can a relatively simple -- or random -- sequence of rate-cutting maintain visual interest?)

At present, there is no research base for answering such questions: we have only intuition and speculation on these matters, so further spelling out of the inplications of Spottiswoode's proposals is premature.

But note that this is an important line of research to initiate for video purposes. Also note that cutting rate cannot be prescribed without knowledge of transition-comprehensibility Comprehensibility is itself not merely an empiral question, to be determined by testing the comprehensibility of a particular set of views: there are some perceptual determinants of transition-comprehensibility that we can identify <u>in principle</u>

that appear in both views (i.e., identifiable areas appear with some displacement before and after the disjunctive transition); and as long as the displacement between those masses of dark and light, from one view to the next, is not too great. These assertions are made on the assumption that something like Johansson's vector-extraction explanation of "optical proprioception" is correct and is applicable to discontinuous as well as to continuous transitions (140, 141). Research is needed to determine whether in fact that assumption is correct. But even if the assumption is correct, it does not mean that comprehension of Type II transitions is always achieved rapidly (or that it is achieved at all). If the overlap between views is small; if the scene lacks readily-identifiable masses that appear in both views (which is frequently the case in video, because of size considerations -- cf. p. 57); if the displacement of those masses from one view to the next is too great (e.g., in "stop action," there may be some separation between the places in which an object appears in successive views that cannot be exceeded without destroying the intelligibility of the movement being depicted) -- in these cases, comprehension should be impaired. More important, although in real life the succession of views that the eye receives will usually have a great deal of overlap between views of the same object, the artificial juxtaposition of views that is possible in motion pictures in general, and that is particularly likely in experimental video, may bring Type I and Type II transitions into conflict with each other, to the detriment of the Type II transition; we consider this question in 4.2.2, below. In any case, the study of these factors seems straightforward and fruitful.

<u>Type III</u> transitions are changes of view which could not be produced by any action that the observer couls take in real time or real space, and which are not possible within a single scene (or "long shot"). Motion pictures would be very different if only Type I and Type II transitions were used, and the fact that video displays must rely heavily on closeups, and that they contain little peripheral information (and hence little overlap from view to view) means that in video sequences even Type II transitions act very much like Type III transitions. We have proposed above that Type II transitions (i.e., abrupt changes of view from a single standpoint or camera angle) may <u>simulate</u> the effects of rapid attentional saccades, and may draw on the same cognitive processes that are used to make sense out of saccadic glances. To the degree that this is true, the systematic study of Type II transitions is not only useful in achieving more precise rules for visual communication -- it is also an important tool for the study of perceptual attention.

It is important, therefore, to identify the processes that are responsible for the effectiveness of the filmmaker's various techniques, and not to succumb too readily to the temptation to consider those techniques to be merely arbitrary conventions, invested by (and at the disposal of) the filmmaker. But there remains one type of transition in common use that *is* arbitrary: Films regularly contain transitions that have no internal stimulus information to connect them to each other: e.g., successions of views taken from different scenes (and/or at different times). The classic *montage* then becomes the temporal equivalent of a *collage*: A scene of the Golden Gate Bridge, of the Empire State Building, of the Eiffel Tower, in a sequence of three disjunctive shots, contains within the sequence no intrinsic information that can reveal the spatial or temporal relationship between the three views. Here is where the viewer's knowledge, culture, and some body of arbitrary filmic convention are needed to achieve comprehension: In this example, the first thing that is needed is, of course, the viewer's knowledge that the film has been constructed according to some deliberate purpose of the filmmaker, however obscure or ill-conceived, and that therefore some connection between the views is to be searched for; second, the viewer must have some knowledge of what these landmarks are, and of their relative geography; third, he must understand any arbitrary signals that may be used, (such as street signs, directional arrows, calendar leafs, etc.) which were either established by the filmmaker in the film itself, or by other filmmakers in the history of the medium. We don't know anything about these "literary" components of film making, in any scientific sense, and it is not clear that there are meaningful research questions to be asked about them until we learn a great deal more about the more perceptual components, and about the relationships between the Type I, II and III cuts. We consider this last point below.

(4.2.2) The interaction (and relative strengths) of Type I, II, and III determinants

Smooth or continuous apparent movement that occurs between views in which object's contours have been displaced by a small amount (Type I transition). The determinants of such apparent movement are probably most overlearned, and most effective. We encounter sudden large displacements less frequently as a result of objects' motions, and more frequently the result of our own saccadic eyemovements. In fact, the *discontinuous* displacement of contours in two successive views is probably one of the signals to the perceptual system that a saccade has

has occurred. There is some reason to believe (204) that exploratory eyemovements "freeze" following any abrupt displacement between successive views, suspending further glances until the viewer comprehends the transition that has occurred. And conversely, if major contours (and/or masses of light and dark seen in peripheral vision) fall in essentially the same places at two different moments in time, that fact should be a signal to the oculomotor system that no eyemovement or other change in viewpoint has occurred. Similarly, if there is ongoing motion in one shot, there must be motion in the second shot as well, and the rate of motion in the second shot should be closely matched to that of the first shot or the discrepancies between velocities will act as a signal that a gross view-change has occurred.

Filmmakers often maintain "smoothness" of cutting when showing different objects in successive views, by placing those objects so that their contours fall on the same places on the screen in the two views (i.e., so that no large abrupt displacement of contour occurs). And similarly, if the two successive views show quite different objects in motion, "smoothness" may be achieved by making sure that the velocities of the two different objects match when they are shown in the two discontinuous successive views. Such matching of contours and of velocities should minimize the "change" signals that the visual system will normally receive from discontinuous cut. But while this suppression of change-signals should minimize "freezing" of eyemovements and other low-level results of visual disorientation during the disjunctive transition, it may (at least theoretically) be very misleading as well, and impair comprehension in several ways, precisely because a major transition in views has occurred but the visual system has not been alerted to that fact.

The determinants of Type II transitions (transitions which simulate saccades and other changes of gaze) are also likely to be overlearned, and to act strongly and rapidly. They should easily overcome the determinants of Type III transitions. Type II transitions should be rapidly comprehended (although there appears to be an inherent limitation of about 200 msec for minimum processing time). The comprehensibility of Type II transitions may be impaired by interference from Type I determinants, however. For example, if the displacement between two views is such that one object's contours fall on or next to the place previously occupied by the contours of a different object (Fig. 5), the second object may be interpreted by a low level of the perceptual nervous system as being the object shown in the first view. When this happens, a misleading or inconsistent perception of the relative direction of the two views may occur, and this would retard or impair comprehension of the spatial meaning of the scene that is to be represented by the sequence of views. Moreover, if the scene from which the views are being taken lacks distributed masses of light and dark, so that each view that the observer receives contains no strong contours that are peripherally detectible, and that serve to signal the direction in which each view is displaced in relation to the preceding view (i.e., that serve to indicate which way the camera has moved), then it should theoretically take longer to comprehend a transition (and more errors should be made in comprehending it). Research here seems relatively straightforward to design and execute.

In summary, it is proposed that the following relationship obtains between the different kinds of transition both in terms of strength (when two sets of determinants are put into conflict) and in terms of speed of comprehension:

$$\text{Type I} > \text{Type II} > \text{Type III}$$

This hypothesis can (if it is correct) generate a number of rules that should be followed in making transitions between views. These rules explain, as special cases of the general perceptual and cognitive principles involved, those "cutting rules" that have been stated by filmmakers, in print or in conversation. To the degree that they are objectively and quantitatively stated and established, these rules would permit us to improve (or impair) comprehensibility, at will. And to the degree that comprehension-time is an important factor in determining what cutting rate should be (and what cutting rhythm will be like), these rules should be important to the study of cutting rate as well. They should apply to video as well as to theater motion pictures. There are special features of TV which must be taken into account in any attempt at application, however, and we consider these factors next.

(4.2.3) Size and acuity limits of video and their effects on transition interactions

It has been argued above (p. 51) that change-of-view is important to interest-maintenance and to affective response. Of the three types of transition, continuous motion (Type I transition) is clearly available to the TV display, and is exploited in the dollies (and quasi-dollies in which two cameras participate in what is essentially one movement) and tracking shots. Type II transitions are more difficult to use in the usual TV display because of the small screen and poor resolution and because little peripheral material can be provided, closeups usually prevail in the views between which transitions are being made, and there cannot be a great deal of overlap between successive closeups. In many cases, and especially in talk shows in which a long shot establishes the spatial locations of a succession of closeups of participants who are not going to move around much for the remainder of the presentation, the knowledge of who is sitting where will maintain the relative direction of shots from one transition to the next. But the "talking heads" arrangement probably works because our perceptual memory for faces is exceptionally good (130), because relative position in not as important to the viewer as who is speaking, and because social convention (e.g., that a speaker faces the one he is addressing) helps maintain spatial comprehensibility. Otherwise, the absence of overlap and the small size of the screen probably make all transitions act the way Type III transitions work in large-screen cinema: i.e., the viewer requires heavy doses of filmic convention and of nonvisual information in order to relate one view to the next. For the same reasons, much lower base rates are probably needed to maintain a given degree of visual interest in TV compared to large screen cinema. Research on the effect of screen size (and of resolution limits) on transition-comprehension and on cutting rate and rhythm would seem to be essential; we know of no research that has been performed to obtain the necessary data.

To some degree, the TV viewer can choose his own "screen size," in the sense that he can increase the visual angle that the screen subtends at his eye by moving closer to the screen. When this is done, the poor detail of the display becomes obtrusive, and peculiar contour effects are probably generated (see p. 28), but in return the viewer obtains a display that is large enough to provide him with peripheral vision, a factor that is probably important to the comprehension of Type I and Type II transitions. There are two inherent limitations, however, on the viewer's ability to increase TV screen contribution to his peripheral vision by decreasing his viewing distance:

(1) The first,is the obvious fact that the resolution of the screen is so poor that reducing the viewer's distance from the screen does not provide him with any additional detailed information. What is worse, it may impair his grasp of detail <u>by increasing the degrading effects of the raster in</u>

foveal vision, which, of course, is the only part of our vision that is capable of using the detail to build up a mental picture, in fine detail, of the scene that is being represented.

(2) The second is the somewhat less obvious fact that a 12 inch screen viewed from a distance of 5 feet probably does not have exactly the same effects on the visual system as does a 24 inch screen at 10 feet. Even if the two screens were viewed in a totally dark room so that there were no visual indications of scale and distance, there are still certain firm corollaries of the actual sizes and distances that are built into the geometry of the head-movements and eyemovements that underlie our perceptions of individual shots and our comprehensions of sequences of shots. For example, with eyes stationary in the head, larger head movements would be needed to scan the near screen than the far one (this situation is one in which the subject changes the direction of his gaze without moving his eyes, an artificial condition but one which illustrates the relationship being described), even though the same eyemovement would scan the two screens if the head is fixed and the eyes were free to move. If one determinant of how large an object looks is the relationship of eyemovements to head movements needed to scan it, the small screen will appear small and the large screen will appear large no matter where the viewer sits. And there are other oculomotor adjustments that will work to maintain this "size constancy independent of viewing distance": E.g., as the lens of the eye adjusts its focus to a nearer distance, the apparent size of an object decreases, even though the visual angle is unchanged.

Thus, a small screen may be perceived as a small screen, even when the viewer is close to it. On the other hand, if the screen size is doubled, and is viewed from twice the distance, the screen continues to subtend the same visual angles: Small screen at near distance, and large screen at far distance, then produce the same visual angle and the same retinal image. The following complicated situation then confronts the visuomotor system: An object -- say, a man 6 feet in height -- is represented by an eight inch image on a 12 inch screen, viewed from a distance of 5 feet; he is also represented by a 16 inch image on a 24 inch screen, viewed from a distance of 10 feet. The man's image subtends a visual angle of arctan 0.13 or approximately 7°, so an eyemovement of 7° would scan him from head to toe. A real man, 6 feet tall, would also subtend that visual angle and would be scanned by a 7° glance, if he stood about 46 feet away from the viewer. All of this presupposes a stationary head and a moving eye. If the viewer makes head or body movements, the situation changes drastically: With the screen at 5 feet, the viewer would have to move his head 8 inches (if he did not move his eyes at all) in order to scan the 8 inch image of the man; with the screen at 10 feet, he would have to move his head 6 feet! It is clear that the coordination of head and eyemovements cannot be based on the viewer's expectations about men, as objects, or those movements would be inappropriate to the actual size and distance of the screen. But it is also likely that there is some effect of such expectations (cf. 124: pp. 495ff; 510; 544), and that the real size of the man's image (8 inches or 16 inches), the angular size of the image (7%) and the familiar and expected objective size of the man (6 feet) all must interact in determining the eyemovements that the viewer is prepared to make and the speed with which the visuomotor system "decides" how to respond to such conflicting information. If conflicting information about size causes the eye to take longer to "unfreeze" after each transition or cut, then a given cutting rate may not have the same effects on comprehensibility (p. 53), on arousal (p. 13 , 51), and even on conditioned affective or emotional concomitants (p. 12 , 13), as would the same cutting rate without size conflicts.

Viewing distance, subject matter, and screen size all may interact therefore, in a complex but lawful way to determine the ways in which cutting rate effects comprehensibility, interest-maintenance, and affect, in TV viewing. Whether or not full scale research would be fruitful depends not only on the existence of such interactions, but on whether they are large enough and reliable enough to be important. We know of no research on how screen size and viewing distance affect response to video displays. Preliminary research is needed to determine whether strong effects of this kind exist, using comprehensibility, attention, and ratings as dependent variables; if they do, more sophisticated physiological and psychophysical measures (cf. pp. 7 , 12) should certainly be applied to this study: If screen size/viewing distance is an important factor at all, it is probably a very important one indeed.

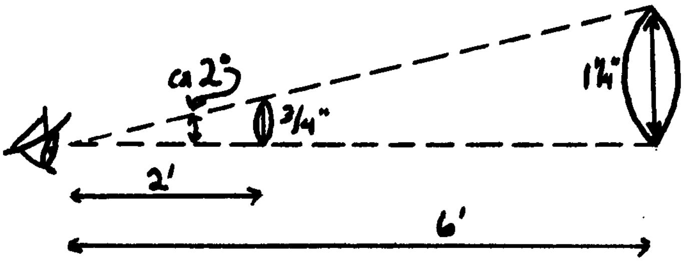


FIGURE 1: Visual angle as a measure of stimulus size: Objects A and B subtend the same angle at the eye although they are of different physical size

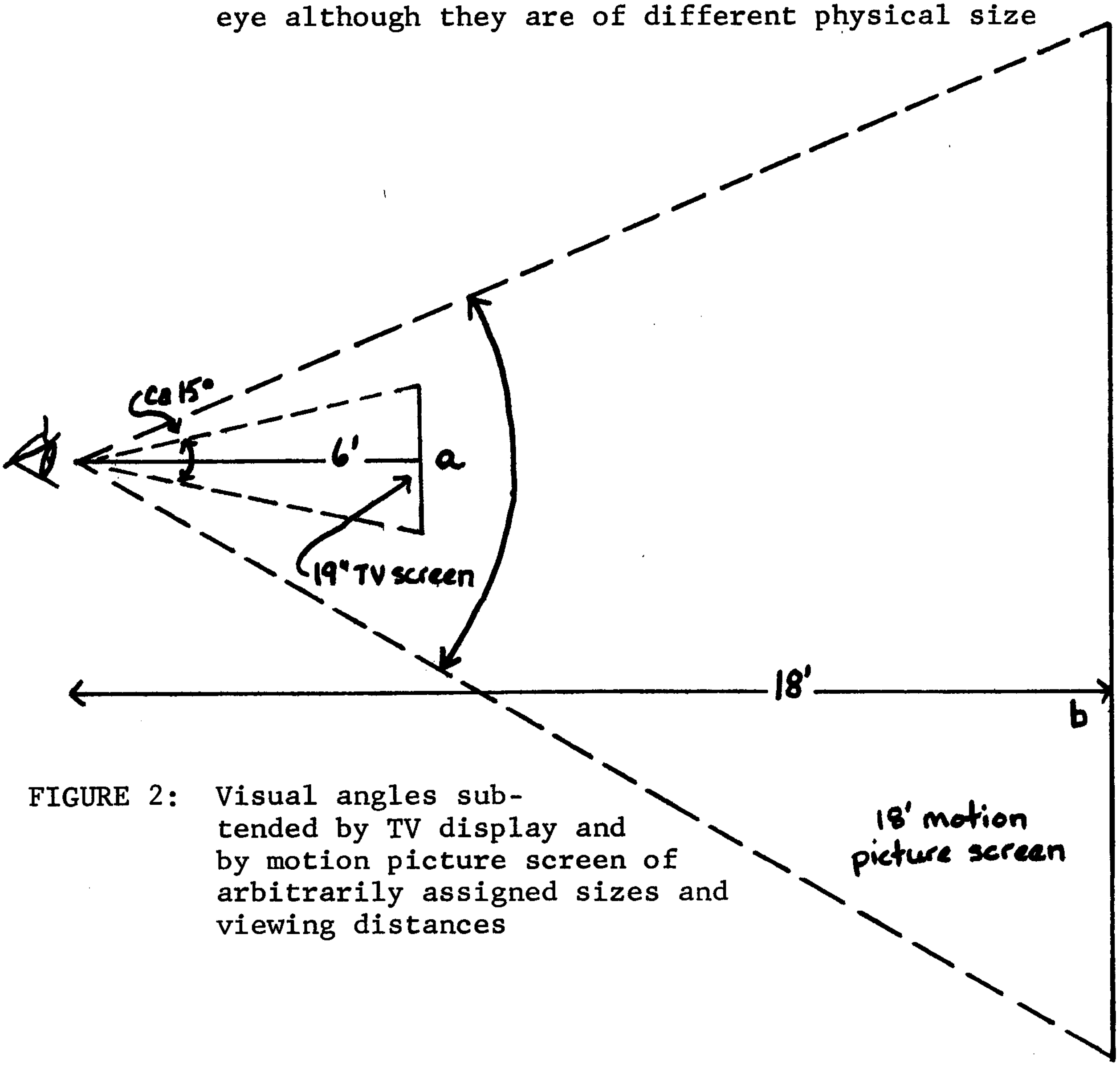


FIGURE 2: Visual angles subtended by TV display and by motion picture screen of arbitrarily assigned sizes and viewing distances

FIGURE 3: By measuring the time course of a response over n repetitions, and obtaining the average measure n at each point in time the accidental perturbations can be removed to reveal the underlying transients.

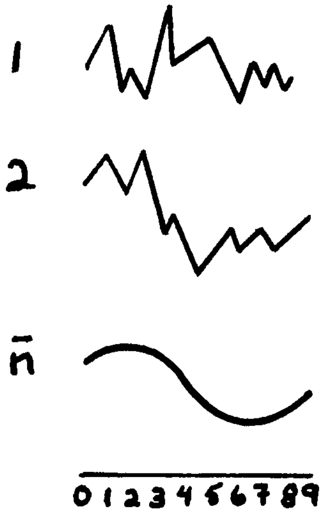
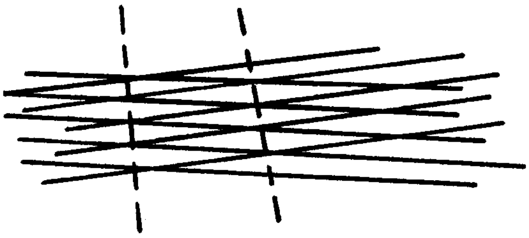


FIGURE 4: Intersecting lines (solid) form a moire pattern (dotted)



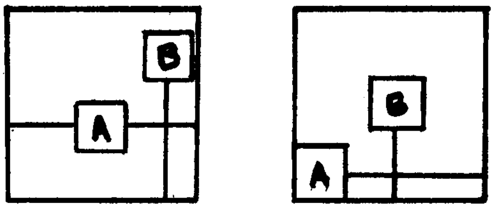


FIGURE 5: Succession involving conflict between Type I and Type II determinants

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