The Lens

The earliest of cameras, the camera obscura, consisted of a light-tight box with a pinhole in one side. Contemporary cameras, both still and motion picture, operate on the same principle: the box is more precisely machined; photosensitive, flexible film has replaced the drawing paper as the "screen" upon which the image falls; but the greatest changes have taken place in the pinhole. That crude optical device has evolved into a complex system of great technical sophistication. So much depends upon the glass eye of the lens through which we all eventually view a photograph or a film that it must be regarded as the heart of photographic art.
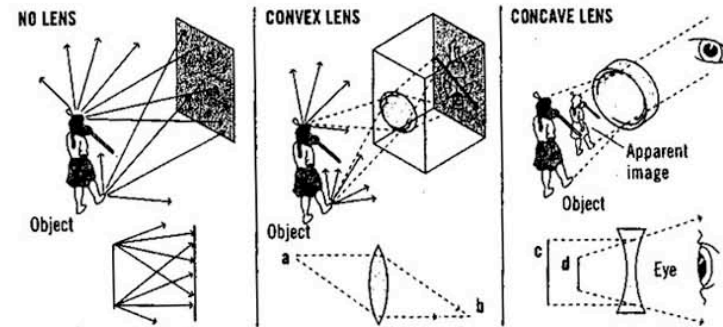
Figure 2-9. LENSES. If there is no lens to focus the rays of light coming from the subject, no image will be produced (left): all rays from all points will strike all parts of the photosensitive plate or film. The convex lens (center) bends the rays from each single point so that they converge on the "focus plane" a certain distance behind it. The image created is reversed right to left and top to bottom. (A transparent negative can then be turned to create the proper left-right orientation in the print.) A pinhole, if it is small enough, will act like a convex lens to give a rough focus. This is the elementary principle which led to the invention of the Camera Obscura (see Figure 2-3). The concave lens (right) causes the rays to diverge in such a way that an observer perceives an "apparent," or "virtual," image which seems smaller than the actual object. The diagrams below the drawings schematically indicate the principles.

Here is the basic idea of the technology of optics: Because light travels at different speeds in different mediums, light rays bend when they pass from one medium to another. Lenses made out of glass or other transparent materials can then focus those rays. While the lens of the human eye is continuously variable, changing in shape each time we unconsciously refocus from one object to another, photographic lenses can only perform the specific tasks for which they are painstakingly designed.

A photographer has three basic types of lenses available to him. These three general categories of lenses are usually classified according to their focal length: the distance from the plane of the film to the surface of the lens. Although a lens is usually chosen specifically for the subject it must photograph, there are various ancillary characteristics to each lens that have become valuable esthetic tools for the photographer. For cameras that use 35 mm film, the "normal" lens has a focal length roughly between 35 and 50 mm. This lens is the most common choice for the photographer because it distorts least and therefore most closely mimics the way the human eye perceives reality.

The wide-angle lens, as its name indicates, photographs a wide angle of view. A photographer finding himself in a cramped location would naturally use this

lens in order to photograph as much of the subject as possible. However, the wide-angle lens has the added effect of greatly emphasizing our perception of depth and often distorting linear perception. The fish-eye lens, an extremely wide-angle lens, photographs an angle of view approaching 180°, with corresponding distortion of both linear and depth perception. Generally, for 35 mm photography, any lens shorter than 35 mm in focal length is considered a wide-angle lens.

The telephoto or long lens acts like a telescope to magnify distant objects, and this, of course, is its most obvious use. Although the long lens does not distort linear perception, it does have the sometimes useful effect of suppressing depth perception. It has a relatively narrow angle of view. Normally, any lens longer than 60 mm is considered a telephoto lens, the effective upper limit being about 1200 mm. If greater magnification were desired, the camera would simply be attached to a standard telescope or microscope.

It should be noted that these lenses are not simply solid pieces of glass, as they were in the eighteenth century, but rather mathematically sophisticated combinations of elements designed to admit the most amount of light to the camera with the least amount of distortion.

Since the 1960s, when they came into general use, zoom lenses, in which these elements and groups of elements are adjustable, have gained considerable popularity. The zoom lens has a variable focal length, ranging from wide-angle to telephoto, which allows a photographer to change focal lengths quickly between shots and, more important cinematographically, also to change focal lengths during a shot. This device has added a whole new set of effects to the vocabulary of the shot. Normal zoom lenses (which can have a focal length range from 10 to 100 mm) naturally affect the size of the field photographed as focal length is shifted (since longer lenses have a narrower angle of view than do shorter lenses), and this effect permits the zoom shot to compete with the tracking shot (see Figure 3-59).

Thanks to computer-aided design and manufacturing techniques and advances in the chemistry of optics, the photographic lens is now an instrument of considerable flexibility; we have reached a point where it has become possible to control individually most of the formerly interrelated effects of a lens. In 1975, for example, optics specialists at the Canon company developed their "Macro zoom lens" in which elements of the Macro lens (which allows closeup photography at extreme short ranges), combined with a zoom configuration, allow zooms that range in focus from 1 mm to infinity.

Only one major problem in lens technology remains to be solved. Wide-angle and telephoto lenses differ not only in angle of view (and therefore magnification) but also in their effect on depth perception. No one has yet been able to construct a lens in which these two variables can be controlled separately.
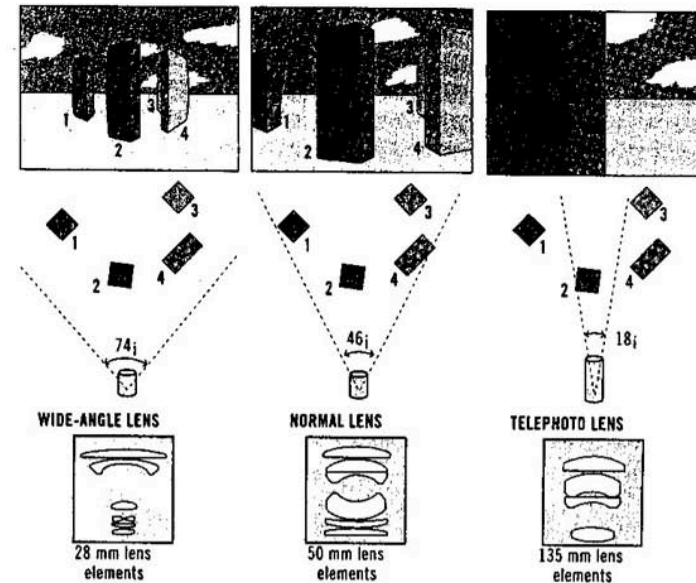

Figure 2-10. WIDE-ANGLE, "NORMAL," AND TELEPHOTO LENSES. Nearly all modern photographic lenses are more complicated than the simple lenses shown in Figure 2-9. Most are composed of sets of elements, such as those which are schematized at the bottom of this diagram. The 28 mm, 50 mm, and 135 mm lenses are common wide-angle, "normal," and "telephoto" lenses in 35 mm photography, whether motion picture or still. Each of the three lenses is seeing the same arrangement of four columns from the same distance and perspective. The frames at the top are exact visualizations of the various images of the scene each lens produces. The wide-angle lens image appears to be taken from a greater distance; the telephoto image is greatly magnified. Notice the slight linear distortion in the wide-angle image and the "flat" quality of the telephoto image. In 35 mm photography, the 50 mm lens is considered "normal" because it best approximates the way the naked eye perceives a scene. (Compare Figure 3-59.)

Alfred Hitchcock spent decades working on this problem before he finally solved it in the famous tower shot from *Vertigo* (1958) by using a carefully controlled zoom combined with a track and models. Hitchcock laid the model stairwell on its side. The camera with zoom lens was mounted on a track looking "down" the stairwell. The shot began with the camera at the far end of the track and the zoom lens set at a moderate telephoto focal length. As the camera tracked in toward the stairwell, the zoom was adjusted backwards, eventually winding up at a wide-angle setting. The track and zoom were carefully coordinated so that the size of the image appeared not to change. (As the track moved in on the center of

Figure 2-11. Providing an ultimate emblem for Hitchcock's life and work, the tower scene from *Vertigo* forged a union of technology and psychology. The camera tracks in and zooms out to distort our perception of depth without changing the range of the frame. (*Frame enlargements.*)

the image, the zoom moved out to correct for the narrowing field.) The effect relayed on the screen was that the shot began with normal depth perception which then became quickly exaggerated, mimicking the psychological feeling of vertigo. Hitchcock's shot cost $19,000 for a few seconds of film time.

Steven Spielberg used a similar combined track-and-zoom in *Jaws* (1975) to add to the sense of apprehension. Perhaps the most interesting application of this unusual technique was in the diner scene from *Goodfellas* (1990). Director Martin Scorsese used it through the tense scene between Robert De Niro and Ray Liotta to heighten the audience's sense of dread.

To summarize: the shorter the lens, the wider the angle of view (the larger the field of view), the more exaggerated the perception of depth, the greater the linear distortion; the longer the lens, the narrower the angle of view, the shallower the depth perception.

Standard lenses are variable in two ways: the photographer adjusts the focus of the lens (by varying the relationship between its elements), and he controls the amount of light entering the lens.

There are three ways to vary the amount of light that enters the camera and strikes the film:

- ❑ the photographer can interpose light-absorbing material in the path of the light rays (filters do this and are generally attached in front of the lens),
- ❑ he can change exposure time (the shutter controls this),
- ❑ or he can change the aperture, the size of the hole through which the light passes (the diaphragm controls this aspect).

Figure 2-12. WIDE-ANGLE DISTORTION. Anna Karina in Jean-Luc Godard's *Pierrot le fou* (1965). (*l'Avant-Scène. Frame enlargement.*)

Filters are generally used to alter the quality of the light entering the camera, not its quantity, and are therefore a minor factor in this equation. Aperture and exposure time are the main factors, closely related to each other and to focus.

The diaphragm works exactly like the iris of the human eye. Since film, more so than the retina of the eye, has a limited range of sensitivity, it is crucial to be able to control the amount of light striking the film. The size of the aperture is measured in f-stops, numbers derived by dividing the focal length of a particular lens by its effective aperture (the ratio of the length of a lens to its width, in other words). The result of this mechanical formula is a series of standard numbers whose relationship, at first, seems arbitrary:

f1	f1.4	f2	f2.8	f4	f5.6	f8	f11	f16	f22

Diagram F1

These numbers were chosen because each successive f-stop in this series will admit half the amount of light of its predecessor; that is, an f1 aperture is twice as "large" as an f1.4 aperture, and f2.8 admits four times as much light as f5.6. The numbers have been rounded off to a single decimal place; the multiplication factor is approximately 1.4, the square root of 2.

The speed of a lens is rated by its widest effective aperture. A lens 50 mm long that was also 50 mm wide would, then, be rated as an f1 lens; that is, a very "fast" lens that at its widest opening would admit twice as much light as an f1.4 lens and four times as much light as an f2 lens. When Stanley Kubrick decided that he wanted to shoot much of *Barry Lyndon* (1975) by the light of a few eighteenth-century candles, it was necessary that he adapt to movie use a special lens the

Figure 2-13. TELEPHOTO DISTORTION. A shot from Robert Altman's *Buffalo Bill and the Indians* (1976). Bill's posse is at least a half mile from the camera.
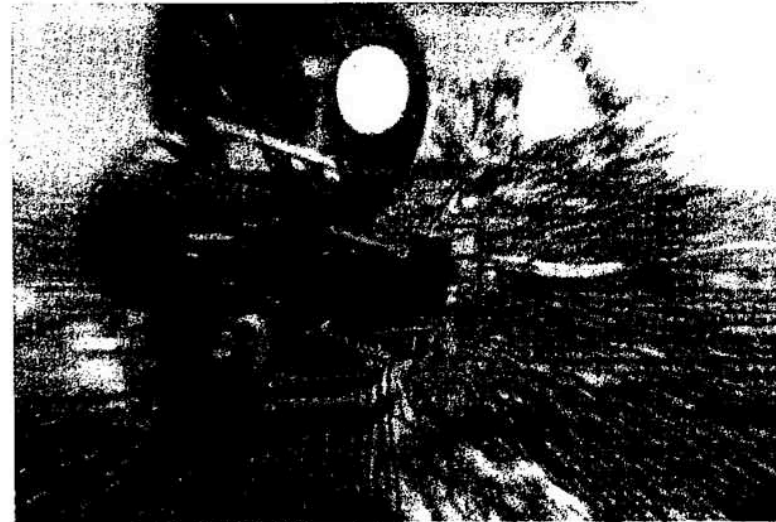

Figure 2-14. This frame enlargement from Godard's "Camera-Eye" (1967) clearly shows the effect of rapid zooming during the shot. The blurred lines aim toward the center of the image. Most zooms do not occur quickly enough to blur individual frames like this. (*l'Avant-Scène. Frame enlargement.*)

Zeiss company had developed for NASA for space photography. The lens was rated at f0.9, while the fastest lenses then in general use in cinematography were f1.2s. The small difference between the two numbers (0.3) is deceiving for, in fact, Kubrick's NASA lens admitted nearly twice as much light as the standard f1.2 lens.

Since the development of these ultrafast lenses filmmakers have had powerful new tools at their command, although only knowledgeable filmgoers might notice the new effects that are possible. Fast lenses are also important economically, since lighting is one of the most time-consuming and therefore expensive parts of filmmaking. Modern amateur cinematographers expect their Camcorders to record a decent image no matter what the light, and most do; only the professionals know how remarkable a technical feat this is. A contemporary CCD ("charge-coupled device") Camcorder is so effective at amplifying the light the lens transmits that it can serve as a night-vision scope, more efficient than the human eye.

The concept of the f-number is misleading, not only because the series of numbers that results doesn't vividly indicate the differences among various apertures, but also because, being a ratio of physical sizes, the f-number is not necessarily an accurate index of the actual amount of light entering the camera. The surfaces of

lens elements reflect small amounts of light, the elements themselves absorb small quantities; in complex multi-element lenses (especially zoom lenses) these differences can add up to a considerable amount. To correct for this, the concept of "T-number" was developed. The T-number is a precise electronic measurement of the amount of light actually striking the film.

Changing the size of the diaphragm—"stopping down"—because it effectively changes the diameter of the lens also changes the depth of field: the smaller the diameter of the lens opening, the greater the precision of focus. The result is that the more light there is available, the greater the depth of field. The phrase "depth of field" is used to indicate the range of distances in front of the lens that will appear satisfactorily in focus. If we were to measure depth of field with scientific accuracy, a lens would only truly be in focus for one single plane in front of the camera, the focus plane. But a photographer is interested not in scientific reality but in psychological reality, and there is always a range of distances both in front of and behind the focus plane that will appear to be in focus.

We should also note at this point that various types of lenses have various depth-of-field characteristics: a wide-angle lens has a very deep depth of field, while a telephoto lens has a rather shallow depth of field. Remember, too, that as
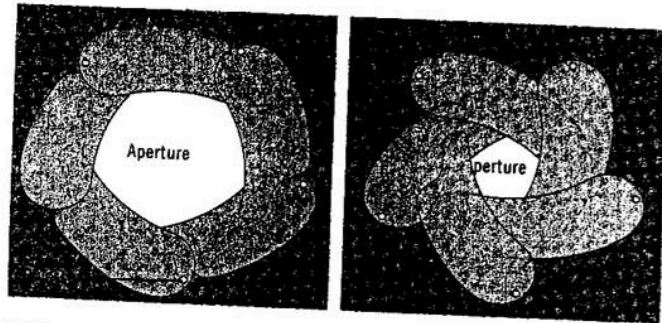
Figure 2-15. THE DIAPHRAGM. One of the simplest elements of the photographic system, as well as one of the most important, the diaphragm is constructed of wafer-thin, spring-loaded metal leaves—usually five or six in number—which overlap each other so that the size of the aperture can be accurately adjusted.

each particular lens is stopped down, as the aperture is narrowed, the effective depth of field increases.

Filmmakers and photographers are thus presented with a complex set of choices regarding lenses. The style of photography that strives for sharp focus over the whole range of action is called deep focus photography. While there are a number of exceptions, deep focus is generally closely associated with theories of realism in film while shallow focus photography, which welcomes the limitations of depth of field as a useful artistic tool, is more often utilized by expressionist filmmakers, since it offers still another technique that can be used to direct the viewer's attention. A director can change focus during a shot either to maintain focus on a subject moving away from or toward the camera (in which case the term is follow focus) or to direct the viewer to shift attention from one subject to another (which is called rack focus).

The Camera

The camera provides a mechanical environment for the lens, which accepts and controls light, and the film, which records light. The heart of this mechanical device is the shutter, which provides the second means available to the photographer for controlling the amount of light that strikes the film. Here, for the first time, we find a significant difference between still and movie photography. For still photographers, shutter speed is invariably closely linked with aperture size. If
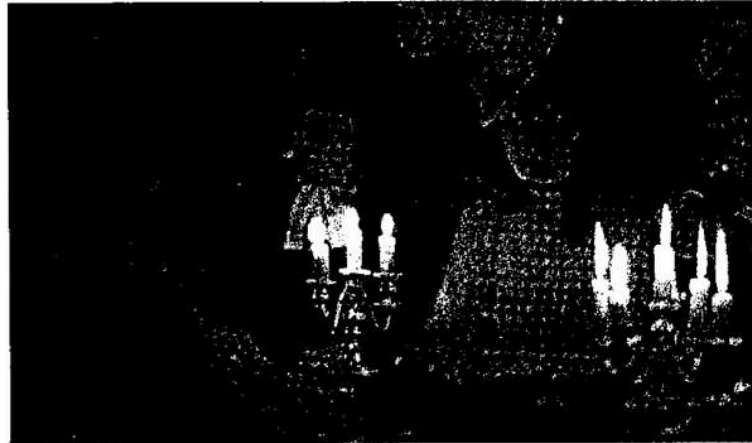

Figure 2-16. Ten candles provided all the light for this scene from Kubrick's *Barry Lyndon* (1975). Murray Melvin and Marisa Berenson. (*Frame enlargement.*)

they want to photograph fast action, still photographers will probably decide first to use a fast shutter speed to "freeze" the action, and will compensate for the short exposure time by opening up the aperture to a lower f-stop (which will have the effect of narrowing the depth of field). If, however, they desire the effect of deep focus, still photographers will narrow the aperture ("stop down"), which will then require a relatively long exposure time (which will in turn mean that any rapid action within the frame might be blurred). Shutter speeds are measured in fractions of a second and in still photography are closely linked with corresponding apertures. For instance, the following linked pairs of shutter speeds and apertures will allow the same amount of light to enter the camera:

F-STOP:	f1	f1.4	f2	f2.8	f4	f5.6	f8	f11	f16
SHUTTER SPEED	$\frac{1}{1000}$	$\frac{1}{500}$	$\frac{1}{250}$	$\frac{1}{125}$	$\frac{1}{60}$	$\frac{1}{30}$	$\frac{1}{15}$	$\frac{1}{8}$	$\frac{1}{4}$

Diagram F2 (* approximately)

In motion picture photography, however, the speed of the shutter is determined by the agreed-upon standard twenty-four frames per second necessary to synchronize camera and projector speed. Cinematographers, therefore, are strictly limited in their choice of shutter speeds, although they can control exposure time
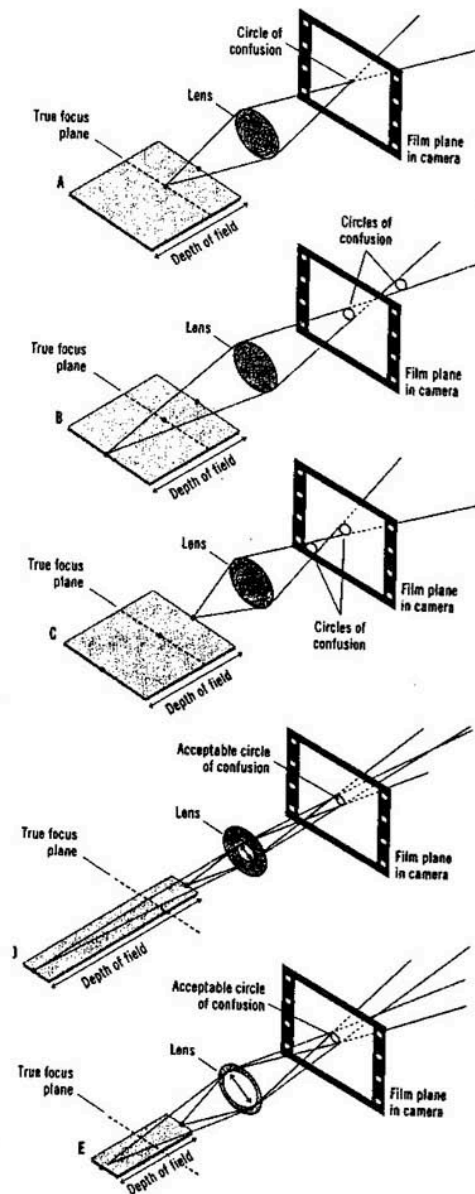
Figure 2-17. FOCUS AND DEPTH OF FIELD. Lenses bend light rays in such a way that only one plane in front of the lens is truly and accurately in focus. The dotted line in these five drawings represents that true focus plane. However, psychologically, a certain range of distances in front and in back of the focus plane will appear satisfactorily in focus. This "depth of field" is represented here by the shaded areas.

In A, an object point on the precise focus plane produces the narrowest "circle of confusion" on the film plane behind the lens. In B, an object point at the far end of the range of depth of field produces the largest acceptable circle of confusion. For objects beyond this point, the circle of confusion is such that the eye and brain read the image as being "out of focus." In C, an object point at the near boundary of depth of field produces a similarly acceptable circle of confusion. Objects nearer to the lens than this will produce an out-of-focus circle of confusion.

D and E illustrate the effect of aperture size (or diaphragm setting) on depth of field. The narrower aperture in D yields a greater depth of field, while the larger aperture in E limits the depth of field. In both illustrations, points at the near and far end of the depth of field range produce equal, acceptable circles of confusion.

In all five drawings depth of field has been slightly reduced for illustrative purposes. The calculation of the depth of field of a particular lens and aperture is a simple matter of geometry. Generally, depth of field extends toward infinity. It is much more critical in the near range than the far.

Figure 2-18. SHALLOW FOCUS. Characters are sharply in focus, background is blurred in this shot from Kubrick's *Paths of Glory* (1957). (*MOMA/FSA.*)

within narrow limits by using a variable shutter, which controls not the time the shutter is open, but rather the size of the opening. Clearly, the effective upper limit in cinematography is 1/24 second. Since the film must travel through the projector at that speed, there is no way in normal cinematography of increasing exposure time beyond that limit. This means that cinematographers are effectively deprived of one of the most useful tools of still photography: there are no "time exposures" in normal movies.

Focal length, linear distortion, distortion of depth perspective, angle of view, focus, aperture, depth of field, and exposure time: these are the basic factors of photography, both movie and still.

A large number of variables are linked together, and each of them has more than one effect. The result is, for example, that when a photographer wants deep focus he decreases the size of the aperture, but that means that less light will enter the camera so that he must add artificial light to illuminate the subject sufficiently, but that might produce undesirable side effects, so, to compensate, he will increase exposure time, but this means that it will be more difficult to obtain a clear, sharp image if either the camera or the subject is moving, so he may decide

Figure 2-19. DEEP FOCUS. One of the more extraordinary deep-focus shots photographed by Gregg Toland for Orson Welles's *Citizen Kane* (1941). The focus reaches from the ice sculptures in the near foreground to the furniture piled up behind the table at the rear. (*MOMA/FSA.*)
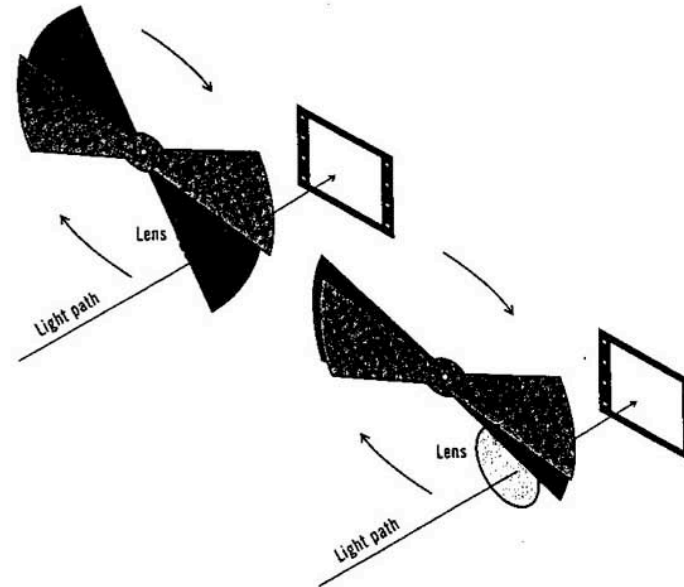

Figure 2-20. THE VARIABLE SHUTTER. In still photography, the shutter is simply a spring-loaded metal plate or fabric screen. In motion-picture photography, however, the time of exposure is limited by the 24-frame-per-second standard speed. The variable shutter allows some leeway in exposure time. Although it revolves always at the same 24 fps speed, the size of the "hole" and therefore the time of the exposure can be varied by adjusting the overlapping plates.

to switch to a wider-angle lens in order to include more area in the frame, but this might mean that he will lose the composition he was trying to achieve in the first place. In photography, many decisions have to be made consciously that the human eye and brain make instantly and unconsciously.

In movies, the camera becomes involved in two variables that do not exist in still photography: it moves the film, and it itself moves. The transport of the film might seem to be a simple matter, yet this was the last of the multiple problems to be solved before motion pictures became feasible. The mechanism that moves the film properly through the camera is known as the "pull-down mechanism" or "intermittent motion mechanism." The problem is that film, unlike audiotape or videotape, cannot run continuously through the camera at a constant speed. Films are series of still pictures, twenty-four per second, and the intermittent motion mechanism must move the film into position for the exposure of a frame, hold it in position rock steady for almost 1/24 second, then move the next frame into position. It must do this twenty-four times each second, and it must accomplish this mechanical task in strict synchronization with the revolving shutter that actually exposes the film.

In the U.S., Thomas Armat is usually credited with inventing the first workable pull-down mechanism in 1895. In Europe, other inventors—notably the Lumière brothers—developed similar devices. The pull-down mechanism is literally the heart of cinema, since it pumps film through the camera or projector. The key to the success of this system of recording and projecting a series of still images that give the appearance of continuous movement lies in what Ingmar Bergman calls a certain "defect" in human sight: "persistence of vision." The brain holds an image for a short period of time after it has disappeared, so it is possible to construct a machine that can project a series of still images quickly enough so that they merge psychologically and the illusion of motion is maintained. Al Hazen had investigated this phenomenon in his book *Optical Elements*, as early as the tenth century. Nineteenth-century scientists such as Peter Mark Roget and Michael Faraday did valuable work on the theory as early as the 1820s. During
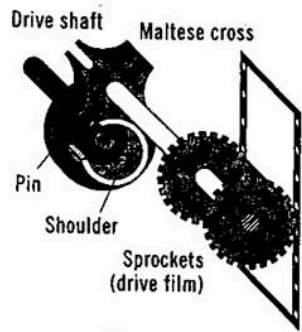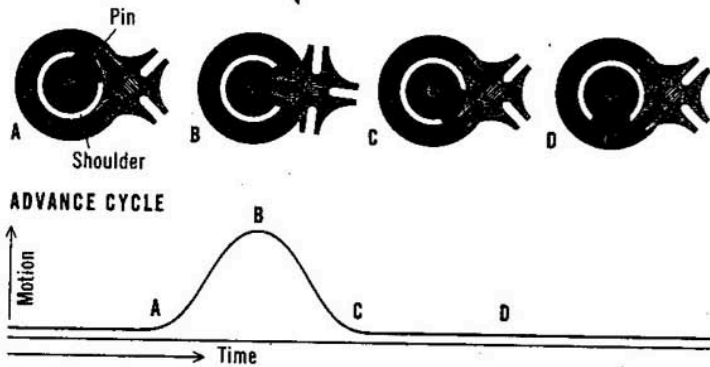
Figure 2-21:
THE MALTESE CROSS MECHANISM.
The drive shaft rotates at constant speed. At the beginning of the cycle (A), the pin engages the Maltese cross gear which is connected by a shaft to the sprockets which drive the film. So long as the pin is engaged in the Maltese Cross (A,B,C), the film is moving. Through most of the cycle, the pin is not engaged and the shoulder holds the cross (and the film) steady (D). The graph describes cross and film movement throughout the full cycle.
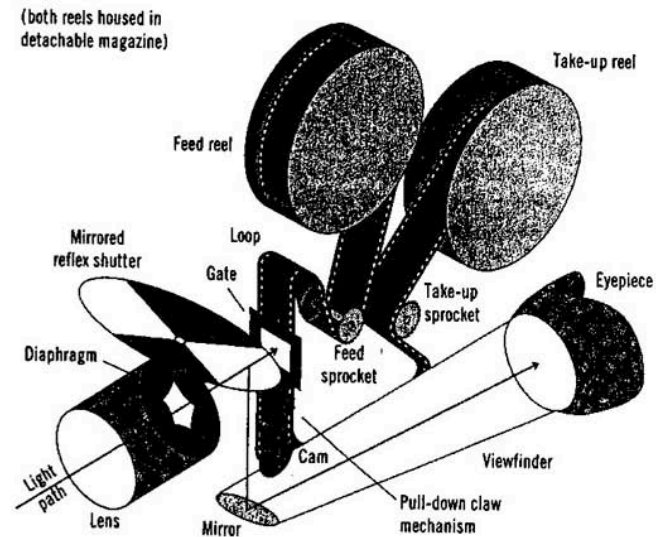

Figure 2-22. THE REFLEX CAMERA. The feed and take-up reels are housed in a separate magazine which can be changed easily and quickly. The feed and take-up sprockets run continuously. Intermittent motion in this machine is provided by a cam-mounted claw mechanism rather than the more complicated Maltese cross system illustrated in Figure 2-21. The heart of the reflex camera is the mirrored shutter. Tilted at a 45° angle to the light path, this ingenious device permits the camera operator to see precisely the same scene through the viewfinder that the film "sees." When the shutter is open, all light strikes the film. When the shutter is closed, all light is redirected into the viewfinder. The reflex camera has almost entirely replaced earlier systems with separate viewfinders, both in still and motion picture photography.

the early years of this century Gestalt psychologists further refined this concept, giving it the name "Phi-phenomenon."

As it happens, a speed of at least twelve or fifteen pictures per second is necessary, and a rate of about forty pictures per second is much more effective. Early experimenters—W. K. L. Dickson for one—shot at speeds approaching forty-eight frames per second to eliminate the "flicker" effect common at slower speeds. It quickly became evident, however, that the flicker could be avoided by the use of a double-bladed projection shutter, and this has been in common use since the early days of film. The effect is that, while the film is shot at twenty-four frames per second, it is shown in such a way that the projection of each frame is interrupted once, producing a frequency of forty-eight "frames" per second and thus eliminating flicker. Each frame is actually projected twice.

During the silent period—especially during the earliest years when both cameras and projectors were hand-cranked—variable speeds were common: both the cameraman and the projectionist thus had a degree of control over the speed of

the action. The average silent speed was between sixteen and eighteen frames per second, gradually increasing over the years to twenty and twenty-two frames per second. Twenty-four frames per second did not become an immutable standard until 1927 (although even now it is not entirely universal: European television films are shot at twenty-five frames per second in order to synchronize with the European television system, whose frequency is twenty-five frames per second). When silent films are projected at "sound speed," as they often are nowadays, the effect is to make the speeded-up action appear even more comical than it was originally.

The effect of frequency is not to be underestimated. Because we grow up inundated with motion-picture and television images in the 24 fps to 30 fps range (or 48 fps to 60 fps projected), we learn to accept this moving-picture quality as stan-

dard, when it is in fact just adequate. One of the most effective ways to increase image quality is to increase frequency, which you can prove to yourself by visiting a Showscan or Imax installation. Both of these proprietary technologies for museum and theme park shows use higher frequencies. (Imax also uses wider stock.) When the U.S. standard for HDTV (high-definition television) was adopted in 1994, increased frequency was a major element of the prescription.

The genius of the device Armat invented is that it alternately moves the film and holds it steady for exposure in such a way that there is a high ratio between the amount of time the film is held still and the amount of time it is in motion. Obviously, the time during which the frame is in motion is wasted time, photographically. The sequence of operations is described in Figure 2-21. Considering the smallness of the frame, the fragility of the film, and the tremendous forces to which the tiny sprocket holes are subjected, the motion picture camera and projector are formidable mechanisms indeed. The Maltese Cross gear itself is an eloquent emblem of nineteenth-century mechanical technology.

The speed of the camera introduces another set of variables that can be useful to filmmakers, and it is in this area that cinema finds its most important scientific applications. By varying the speed of the camera (assuming the projector speed remains constant), we can make use of the invaluable techniques of slow motion, fast motion, and time-lapse (extreme fast motion) photography.

Film, then, is a tool that can be applied to time in the same ways that the telescope and the microscope are applied to space, revealing natural phenomena that are invisible to the human eye. Slow motion, fast motion, and time-lapse photography make comprehensible events that happen either too quickly or too slowly for us to perceive them, just as the microscope and the telescope reveal phenomena that are either too small or too far away for us to perceive them. As a scientific tool, cinematography has had great significance, not only because it allows us to analyze a large range of time phenomena but also as an objective record of reality. The sciences of anthropology, ethnography, psychology, sociology, natural studies, zoology—even botany—have been revolutionized by the invention of cinematography. Moreover, filmstocks can be made that are sensitive to areas of the spectrum outside that very limited range of frequencies, known as "colors," that our eyes perceive. Infrared and other similar types of photography reveal "visual" data that have hitherto been beyond our powers of perception.

The terms "slow motion" and "fast motion" are fairly self-explanatory, but it may nevertheless be useful to describe exactly what happens in the camera. If we can adjust the speed of the pull-down mechanism so that, for example, it shoots 240 frames per second instead of the standard 24, then each second of recording time will stretch out over ten seconds of projected time, revealing details of motion that would be imperceptible in real time. Conversely, if the camera takes, say, three frames per second, projected time will "happen" eight times more

Figure 2-23. TIME-LAPSE PHOTOGRAPHY. Because film can compress (and expand) time, as a scientific tool it serves purposes similar to the microscope and telescope. (*Courtesy Archive Films. Frame enlargements.*)

Figure 2-24. Slow motion is occasionally useful in narrative films, as well. This frame from the sequence in extreme slow motion that climaxes Michelangelo Antonioni's *Zabriskie Point* (1969) captures some of the ironic, lyrical freedom of the explosion fantasy. (*Sight and Sound. Frame enlargement.*)

quickly than real time. The term "time lapse" is used simply to refer to extremely fast motion photography in which the camera operates intermittently rather than continuously—at a rate of one frame every minute, for example. Time-lapse photography is especially useful in the natural sciences, revealing details about phenomena like phototropism, for example, that no other laboratory technique could show.

It doesn't take many viewings of slow- and fast-motion films made with primarily scientific purposes in mind before it becomes obvious that the variable speed of the motion picture camera reveals poetic truths as well as scientific ones. If the slow-motion love scene has become one of the hoariest clichés of contemporary cinema while the comedic value of fast-motion early silent movies has become a truism, it is also true that explosions in extreme slow motion (for example, the final sequence of Antonioni's *Zabriskie Point*, 1969) become symphonic

celebrations of the material world, and time-lapse sequences of flowers in which a day's time is compressed into thirty seconds of screen time reveal a natural choreography that is stunning, as the flower stretches and searches for the life-giving rays of the sun.

The camera itself moves, as well as the film, and it is in this area that cinema has discovered some of its most private truths, for the control over the viewer's perspective that a filmmaker enjoys is one of the most salient differences between film and stage.

There are two basic types of camera movement: the camera can revolve around one of the three imaginary axes that intersect in the camera; or it can move itself from one point to another in space. Each of these two types of motion implies an essentially different relationship between camera and subject.

In pans and tilts, the camera follows the subject as the subject moves (or changes); in rolls, the subject doesn't change but its orientation within the frame is altered; in tracks (also known as "dollies") and crane shots, the camera moves along a vertical or horizontal line (or a vector of some sort) and the subject may be either stationary or mobile. Because these assorted movements and their various combinations have such an important effect on the relationship between the subject and the camera (and therefore the viewer), camera movement has great significance as a determinant of the meaning of film.

The mechanical devices that make camera movement possible are all fairly simple in design: the tripod panning/tilting head is a matter of carefully machined plates and ball-bearings; tracking (or traveling) shots are accomplished simply by either laying down tracks (very much like railroad tracks) to control the movement of the camera on its mount, or using a rubber-tired dolly, which allows a bit more freedom; the camera crane that allows a cinematographer to raise and lower the camera smoothly is merely a counterweighted version of the "cherry-pickers" that telephone company linesmen use to reach the tops of poles. (See Figure 3-60.)

As a result, until relatively recently, technical advances in this area were few. Two stand out. First, in the late 1950s, the Arriflex company developed a 35 mm movie camera that was considerably lighter in weight and smaller in dimension than the standard Mitchell behemoths that had become the favored instruments of Hollywood cinematographers. The Arriflex could be hand-held, and this allowed new freedom and fluidity in camera movement. The camera was now free of mechanical supports and consequently a more personal instrument. The French New Wave, in the early sixties, was noted for the creation of a new vocabulary of hand-held camera movements, and the lightweight camera made possible the style of cinéma-vérité Documentary invented during the sixties and still common today. Indeed, one of the cinematographic clichés that most identified
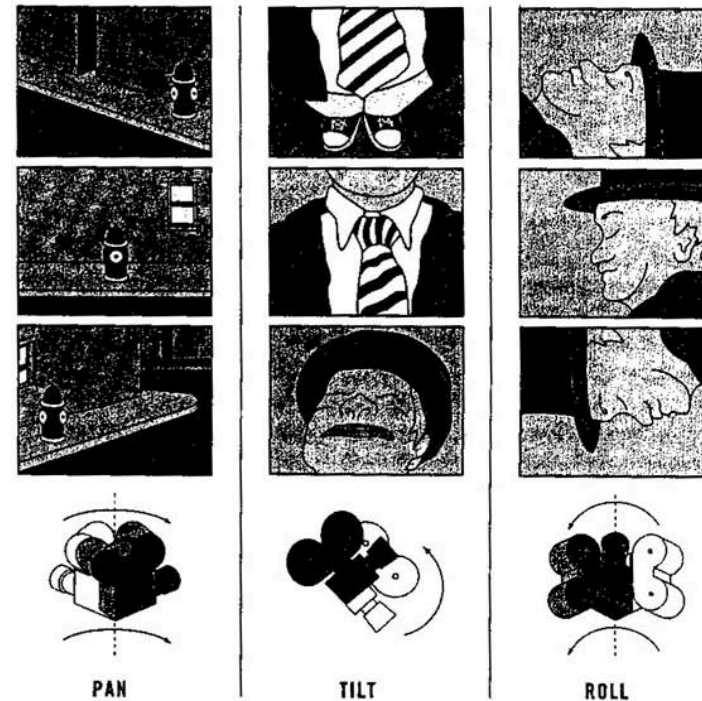
| PAN | TILT | ROLL |

Figure 2-25. PAN, TILT, AND ROLL. The pan is by far the most common of these three elementary movements. The roll, since it disorients and doesn't provide any new information, is least common.

the 1990s was the quick-cut, jittery, hand-held exaggeration exploited in so many television commercials. The more things change, the more they remain the same.

For nearly fifteen years, hand-held shots, while inexpensive and popular, were also obvious. Shaky camera work became a cliché of the sixties. Then, in the early seventies, a cameraman named Garrett Brown developed the system called "Steadicam" working in conjunction with engineers from Cinema Products, Inc. Since then, this method of filming has gained wide popularity and has significantly streamlined the filmmaking process. In terms of economic utility, it ranks right up there with ultrafast lenses, since laying tracks is the second most time-consuming activity in film production (and the Steadicam eliminates them).

In the Steadicam system, a vest is used to redistribute the weight of the camera to the hips of the camera operator. A spring-loaded arm damps the motion of the

Figure 2-26. Ingmar Bergman with bulky Mitchell camera on the set of *Hour of the Wolf* (1966), Liv Ullmann to the left.

Figure 2-27. Stanley Kubrick "hand-holding" a small Arriflex: the rape scene from *A Clockwork Orange* (1971). Malcolm McDowell wears the nose.

camera, providing an image steadiness comparable to much more elaborate (and expensive) tracking and dolly shots. Finally, a video monitor frees the camera operator from the eyepiece, further increasing control of the hand-held walking shot. Steadicam operators are among the unsung artistic heroes of the film profession. Most are trained athletes; the work they do is a prodigious combination of weightlifting and ballet. Ironically, the better they do it, the less you notice.

Even a lightweight camera is a bulky device when placed on a standard crane. In the mid-seventies, French filmmakers Jean-Marie Lavalou and Alain Masseron constructed a device they called a "Louma." Essentially a lightweight crane very much like a microphone boom, it allows full advantage to be taken of lightweight cameras. The Louma, precisely controlled by servo-motors, enables the camera to be moved into positions that were impossible before and frees it from the presence of the camera operator by transmitting a video image of the scene from the viewfinder to the cinematographer's location, which can be simply outside a cramped room, or miles away, if necessary.

Devices such as the Kenworthy snorkel permit even more minute control of the camera. As the Louma frees the camera from the bulk of the operator, so the snorkel frees the lens from the bulk of the camera. There are now a number of devices that follow the Louma and Kenworthy principles—and one that represents a quantum leap for the freedom of the camera. Not satisfied with having liberated the camera from tracks and dollies, Garrett Brown developed his "Skycam" system in the mid-1980s.

With hindsight, the Skycam is an obvious offspring of the Steadicam and the Louma. The system suspends a lightweight camera via wires and pulleys from four posts erected at the four corners of the set or location. The operator sits offset, viewing the action on a monitor and controlling the movement of the camera through controls that communicate with the cable system via computer programs. Like the Steadicam before it, the Skycam is often most effective when it is least obvious. But on occasion, especially covering sports events, the Skycam provides exhilarating images that are otherwise impossible. Peter Pan never had it so good.

With the advent of these devices, most of the constraints imposed on cinematography by the size of the necessary machinery have been eliminated, and the camera approaches the ideal condition of a free-floating, perfectly controllable
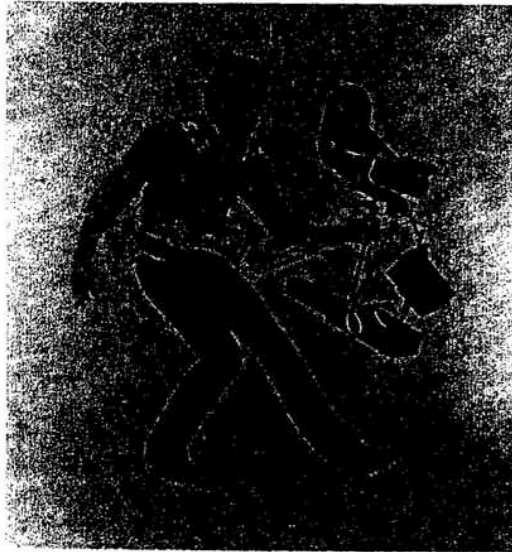
Figure 2-28.
THE STEADICAM.
Springs damp the motion
of the camera. The
harness provides
cantilevered balance.

artificial eye. The perfection of fiber optics technology extended this freedom to the microscopic level; the travels through the various channels of the human body that were science fiction when they were created by means of special effects in 1967 for the film *Fantastic Voyage* could, by the mid-seventies, be filmed "on location" for the documentary *The Incredible Machine*.

The Filmstock

The fundamental principle on which all chemical photography is based is that some substances (mainly silver salts) are photosensitive: that is, they change chemically when exposed to light. If that chemical alteration is visible and can be fixed or frozen, then a reproducible record of visual experience is possible.[*]

Daguerreotypes were made on metal plates and required long periods of exposure, measured in minutes, in order to capture an image. Two developments in the technology of photography were necessary before motion pictures became

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*   The discussion of photochemical filmstock that follows also applies, the necessary changes being made, to all-electronic photography, which we'll discuss in greater detail in Chapter 6.
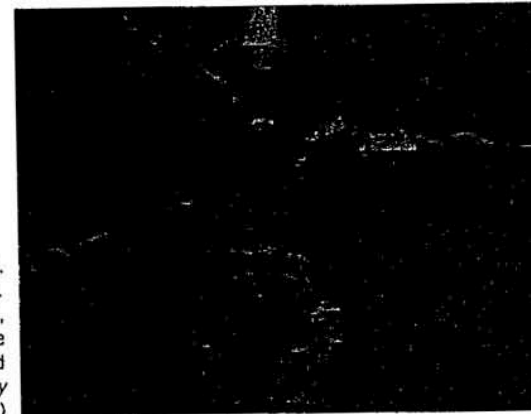
Figure 2-29.
THE SKYCAM.
Suspended by four wires,
the camera and the
winches are controlled
remotely. (*Courtesy
Skyworks, Inc.*)

possible: a flexible base to carry the photographic emulsion, and an emulsion sensitive or "fast" enough so that it could be properly exposed within a time period something like 1/20 second. The speed of standard, popular emulsions is now such that 1/1000 second is more than adequate exposure time under normal conditions.

Not all image-fixing is chemically photographic, however. Television images are electronically produced (although photosensitive and phosphorescent chemicals play a part) and systems used in photocopying (Xerox) machines are also quite different from traditional chemical silver-salt photography. The silver scare of early 1980 when, for a brief period, the price of the metal quintupled, focused renewed attention on non-silver means of photography.

Sony introduced the first all-electronic snapshot camera, the Mavica, in 1989. They were a few years ahead of the market; digital cameras did not find consumer acceptance until the late nineties. In 1992 Kodak (who have the most to lose when photography moves from chemistry to electronics) found a transitional formula: a compromise called Photo CD. The well-established and easy-to-use chemistry-based film is still used to take the picture. Then the commercial photofinisher transfers the image from film to fully digitized files on a version of a CD-ROM, which is returned to the customer just as quickly as his paper prints used to be. The customer inserts the disc in any CD-ROM reader that meets the Photo CD standard and views his snapshots on his monitor or television set.

As color laser and ink-jet printers drop in price and move into the home, the photo buff is able to make his own paper prints, and the darkroom home photo workshop can be replaced by computer software. Already, business software like Adobe Photoshop offers more flexibility than the most advanced photo labs at a

Figure 2-30. Shooting a simple automobile scene can be a time-consuming task. Lights, camera, reflectors, diffusers, and other paraphernalia are all mounted on the car for this scene from *Not a Pretty Picture* (1976). Director Martha Coolidge is at right. (Compare the simple studio rear projection arrangement in Figure 2-57.) (*Photo: Jack Feder.*) Below, the scene as it appeared in the film.
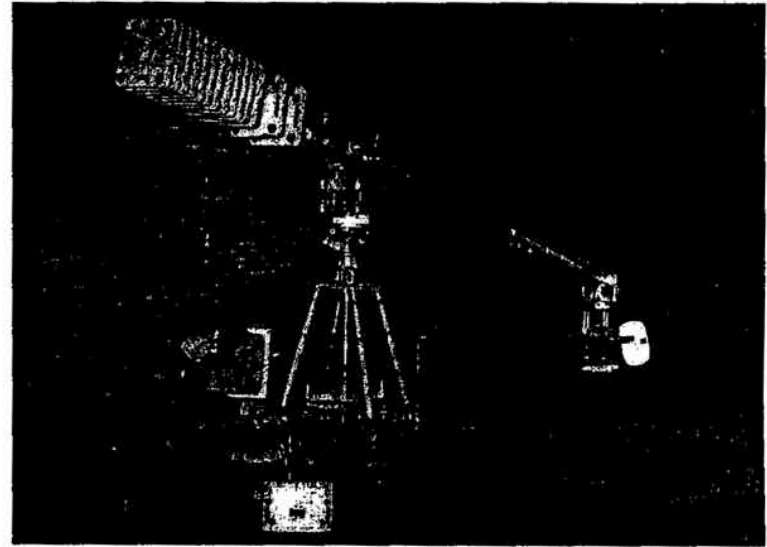

Figure 2-31 THE LOUMA CRANE. The operator controls the movement of crane and camera via servo-mechanisms while observing the image the camera is taking by television monitor. The crane is capable of very precise changes in direction. A zoom motor attached to the camera can also be remote-controlled. (*Photo: P. Brard.*)

cheaper price than any basement darkroom. The camera itself has been the last link in the chain to be digitized; the progression is inexorable. Photo-chemistry, now well into its second century, is about to be replaced. Indeed, as a consumer technology it has enjoyed a record run of more than one hundred years that may be surpassed only by digital computers. The mechanical wax or vinyl record, second in the consumer technology record book, lasted almost as long before it was replaced by CDs in the late 1980s.

Negatives, Prints, and Generations

Since the salts on which chemical photography is based darken when exposed to light, a curious and useful quirk is introduced into the system. Those areas of the photograph that receive most light will appear darkest when the photograph is developed and put through the chemical baths that fix the image permanently. The result is a negative image in which tones are reversed: light is dark and dark is light. A positive print of this negative image can easily be obtained by either contact printing the negative or projecting it on similar filmstock or photographic paper. This makes possible the replication of the image. In addition, when the negative is projected the image can be enlarged, reduced, or otherwise altered—a significant advantage. Reversal processing permits the development of a direct, projectable positive image on the "camera original"—the filmstock in the camera when the shot is made. Negatives (or reversal positives) can also be printed directly from a reversal print.

The camera original is considered to be first generation; a print of it would be second generation; a negative or reversal copy of that, in turn, is third generation. With each successive step, quality is lost. Since the original negative of a film is usually considered too valuable to use in producing as many as two thousand

Figure 2-32. An early example of endoscopic fiber optics cinematography: a human fetus in the womb. From *The Incredible Machine*, 1975 (*PBS*).

prints that might be required for a major release of a feature, the print you see in a theater is often several generations removed from the original:
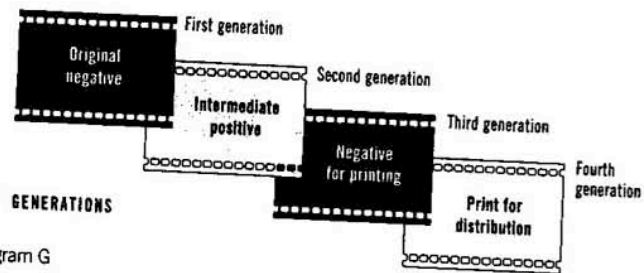

GENERATIONS

Diagram G

If complicated laboratory work is required, then several more generations may be added. "CRI" stock (color reversal intermediate), developed especially to bridge the intermediate positive stage, lessened the number of generations in practice. When large numbers of prints and laboratory work were not needed, reversal stocks provided a very useful alternative. In the 1970s, when film was still the medium of choice for television news, and before the all-electronic newsroom became commonplace, the reversal stock that a television newsman shot at 4 pm, might have been developed at 5 and gone directly into the film chain, still wet, for broadcasting at 6. Amateur cinematographers almost always use reversal films such as Kodachrome or Ektachrome.
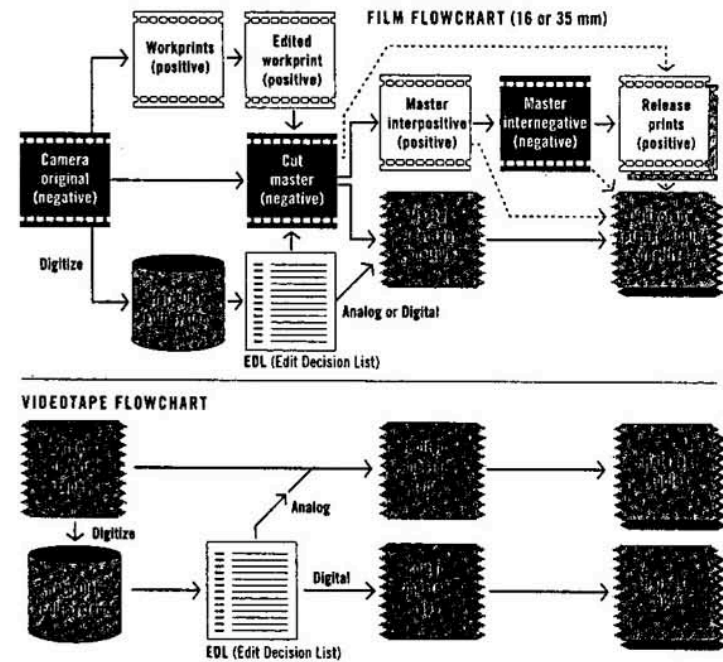

Figure 2-33. STOCK, PROCESSING, GENERATIONS. Most of the production systems commonly in use today are outlined in this flowchart. American theatrical films usually follow the path of the solid line, which means that the print audiences see is fourth generation. European theatrical films often are produced along the path of the dotted line: audiences see a second generation print of better quality. A third system, not shown, interposes a "Reversal Intermediate" between the negative and the print. Although 16 mm film production can follow the same patterns, it is also common to use Reversal originals, which can be screened directly. The addition of tape to the equation allows for an even greater variety of inputs and outputs. When the tape is digital the release copies are equivalent to first generation.

This is a broad outline of the basic choices of filmstock available to the filmmaker. In practice, the variety is much greater. The Eastman Kodak company has very nearly a monopoly position in the professional filmstock market in the U.S. (even if it has some distant challengers in the amateur and still film markets) and is dominant abroad as well. But Kodak enjoys that monopoly partly because it produces a large number of very useful products. And while the professional filmmaker is effectively limited to Eastman Kodak raw materials, there is a variety of processing techniques available (see the discussion of color below). Yet all these

processes reveal basic similarities, since they all must deal with the particular chemistry of the filmstock Kodak supplies.

One of the main reasons the company holds such a strong position in the industry is this close connection between stock and processing. A private laboratory will invest hundreds of thousands of dollars in equipment to process a particular stock. Naturally, such large investments require a degree of financial caution by the labs, especially when the technology is developing rapidly and the useful life of the equipment may be no more than six or eight years. Eastman's 5254 stock, for example, introduced in 1968, was technically superior to color stocks that had existed before then, but it lasted only six years before it was replaced by 5247 in 1974 with an entirely different chemistry. 5247 then was replaced by the EXR stocks (5296, 5293, 5248, 5245).

For these reasons and others, Kodak still enjoys a monopolistic position that is in some ways similar to the situation of IBM in the computer industry before the microcomputer revolution of the early 1980s. It was George Eastman who developed the first flexible, transparent roll filmstock, in 1889. Like IBM in its heyday, Eastman's company has largely defined the languages and systems that must be used by the great majority of their customers. Film is an art, but it is also an industry. Kodak's revenues from filmstock each year are approximately 1.5 times the box-office revenues of the American film industry.

But like IBM, Kodak may be in danger of disappearing from the scene if it cannot make the transition from the chemical technology of the nineteenth century to the digital technology of the twenty-first. Photo CD is a good start, but it merely extends the life of Kodak's chemical franchise. Eventually all photography will be digital, and the company has many more competitors in the disc and tape fields than in filmstock; moreover, there is far less variation among brands in this area than in photochemical film.

While economic and logistical decision still play a large part in the choice of filmstock and process, there are other, more esthetic, decisions that are integrally involved in these choices. The esthetic variables of filmstock include: gauge, grain, contrast, tone, and color. Intimately involved with these variables, especially the first two—although it is not truly a function of the filmstock used—is the aspect ratio, or frame size of the film when projected.

Aspect Ratio

The ratio between the height of the projected image and its width—the aspect ratio—is dependent on the size and shape of the aperture of the camera (and of the projector) and, as we shall see, on the types of lenses used. But it is not solely a function of the aperture. Early in the history of film, an arbitrary aspect ratio of four to three (width to height) became popular and was eventually standardized
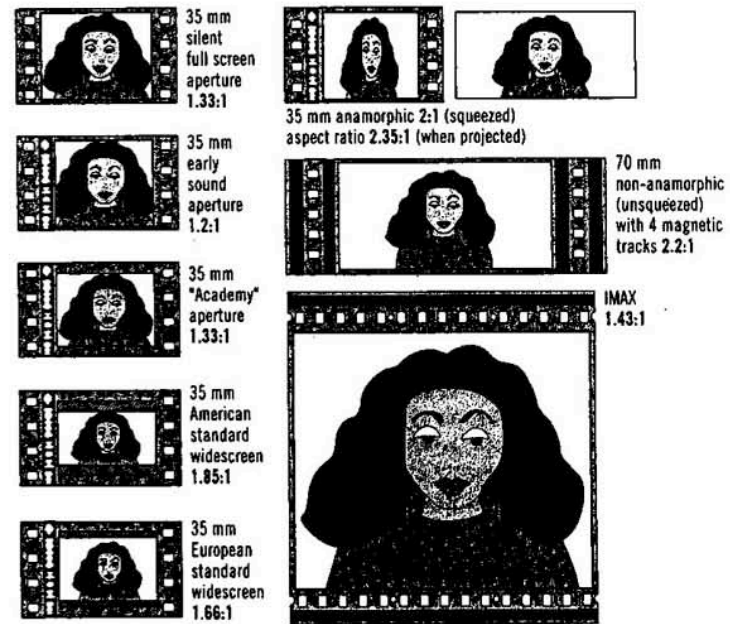

Figure 2-34. ASPECT RATIOS. Standard and widescreen systems.

by the Academy of Motion Picture Arts and Sciences (so that it is now known as the "Academy aperture" or "Academy ratio"). This ratio, more often expressed as 1:1.33 or simply as the 1.33 ratio, while it was undeniably the most common, was never really the sole ratio in use.

Filmmakers—D. W. Griffith is especially noted for this—often masked off part of the frame to change the shape of the image temporarily. When sound was developed and room had to be made on the edge of the filmstock for the soundtrack, the square ratio was common for a while. A few years later the Academy shrank the amount of space within the potential frame that was actually used in order to regain the 1.33 ratio, and this standard gradually developed a mystique, even though it was the result of an arbitrary decision.

Some film textbooks connect the 1.33 ratio with the Golden Section of classical art and architecture, a truly mystical number expressive of a ratio found everywhere in nature, often in the strangest places (in the arrangement of the seeds of a sunflower, for example, or the shape of a snail's shell). The Golden Section is derived from the formula $a/b = b/(a + b)$, where a is the length of the shorter side of the rectangle and b is the length of the longer. While it is an irrational number,

Figure 2-35. The Golden Mean as a sunflower displays it. (*JM*)

this Golden Mean can be closely approximated by expressing the ratio of height to width as 1:1.618. This is very close to the most popular European widescreen ratio in use today, but it is certainly a far cry from the 1.33 ratio of the Academy aperture. While the Academy ratio, arbitrary as it is,[*] really only dominated for twenty years or so (until 1953), it was during this time that the television frame was standardized on its model; and that, in turn, continues to influence film composition. Widescreen HDTV, however, has an aspect ratio of 16:9 (or 1.777:1), much closer to the Golden Mean.

Since the 1950s, filmmakers have been presented with a considerable range of screen ratios to choose from. Two separate methods are used to achieve the widescreen ratios in use today. The simplest method is to mask off the top and bottom of the frame, providing the two most common "flat" widescreen ratios: 1.66 (in Europe) and 1.85 (in the U.S.). Masking, however, means that a much smaller portion of the available film frame is used, resulting in diminished quality of the projected image. In the 1.85 ratio, 36 percent of the total frame area is wasted.

The second method of achieving a widescreen ratio, the anamorphic process, became popular in the mid-fifties as "CinemaScope." The first anamorphic process was Henri Chrétien's "Hypergonar" system, which was used by Claude

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[*] Cynics will note that the Academy aperture is an expression of Pythagoras' theorem, but that is an abstract ideal while the Golden Mean is a natural, organic one!
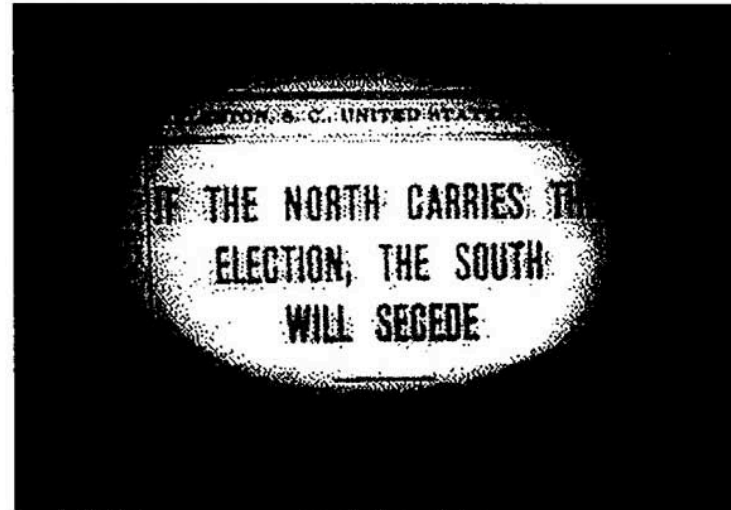
Figure 2-36. D. W. Griffith often masked the image to focus attention, as in this shot from *The Birth of a Nation*. (*Frame enlargement.*)

Autant-Lara in 1927 for his film *Construire un feu*. In the same year, Abel Gance, working with André Debrie, developed a multiscreen system not unlike Cinerama for his epic *Napoléon*. He called this three-projector system Polyvision. A year previously, for their film *Chang*, Merian C. Cooper and Ernest B. Schoedsack had experimented with "Magnascope," which simply enlarged the entire image, much as a magnifying glass would.

An anamorphic lens squeezes a wide image into the normal frame dimensions of the film and then unsqueezes the image during projection to provide a picture with the proper proportions. The standard squeeze ratio for the most common anamorphic systems (first CinemaScope, now Panavision) is 2:1—that is, a subject will appear in the squeezed frame to be half as wide as in reality. The height of the subject is unchanged. Using nearly all the area of the frame available, the earlier anamorphic process obtained a projected image aspect ratio of 2.55; this was later altered to 2.35, which is now standard, to make room for an optical soundtrack.

While the anamorphic system is considerably more efficient than masking, since it utilizes the full frame area available, anamorphic lenses are much more sophisticated optical devices, much more expensive, and more limited in variety than spherical (nonanamorphic) lenses. This results in certain practical limitations
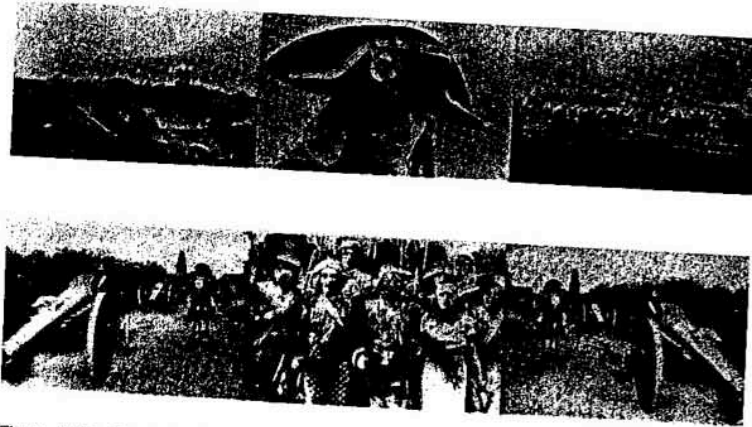
Figure 2-37. Two tripartite screen arrays from the restoration of Abel Gance's *Napoléon* (1927), showing how multiple views can create a single psychological impression. (MOMA/FSA.)

Figure 2-38. *This Is Cinerama*. This is an artist's conception of the view of the giant screen from the audience. It does a good job of evoking the experience. Note the upturned heads.

placed on the cinematographer using an anamorphic system. In addition, although it seems as if an anamorphic negative contains twice as much horizontal information as a standard negative, the unsqueezing process does amplify grain and inconsistencies along with the image. In other words, the anamorphic lens simply stretches a normal amount of information to fill a screen twice as wide.

The age of widescreen began in September 1952 with the release of *This Is Cinerama*, a successful spectacle whose subject was, in fact, the system that was used to shoot it. Employing stereophonic sound, Cinerama, the invention of Fred Waller, used three cameras and three projectors to cover a huge, curved screen. Like many widescreen systems, it had its roots in a World's Fair exhibit. Waller's "Vitarama," which was used at the 1939–40 Fair in New York and later evolved into the Flexible Gunnery Trainer of World War II.

In 1953, the first CinemaScope film, Twentieth Century Fox's *The Robe*, was released. An anamorphic process rather than a multiprojector extravaganza, CinemaScope quickly became the standard widescreen process of the 1950s. Techniscope, developed by the Technicolor company, employed an interesting variation on the anamorphic process. The Techniscope negative was shot with spherical lenses masked to give a widescreen ratio. The camera employed a two-hole pull-down mechanism rather than the standard four-hole, thus halving film-stock costs. The negative was then printed through an anamorphic lens, providing a standard anamorphic four-hole pull-down print for projection purposes.

While filmmakers had experimented with widescreen systems for many years, it was the economic threat that television posed in the early fifties that finally made widescreen ratios common. Having bequeathed the arbitrary 1.33 ratio to the new television industry, film studios quickly discovered that their most powerful weapon against the new art was image size. Because it was so unwieldy, Cinerama quickly fell into disuse. Single camera systems, like CinemaScope and later Panavision, became dominant. Cinerama also engendered the short-lived phenomenon of "3-D" or stereoscopic film. Again the system was too inflexible to be successful and was never more than a novelty attraction, although it made a very brief comeback in the 1980s. What was undoubtedly the best film shot in the two-camera 3-D process, Hitchcock's *Dial M for Murder* (1954), wasn't released in 3-D until 1980.

Ironically, 3-D attempted to exploit an area of film esthetics that was already fairly well expressed by two-dimensional "flat" film. Our sense of the dimensionality of a scene depends, psychologically, upon many factors other than binocular vision: chiaroscuro, movement, focus are all important psychological factors. (See Chapter 3.) Moreover, the three-dimensional technique produced an inherent distortion, which distracted, drawing attention from the subject of the film. These are the twin problems that holography, a much more advanced system of stereoscopic photography, will have to overcome before it can ever be considered a feasible alternative to flat film.

The development of the various trick processes of the 1950s had some useful results, however. One of the systems that competed with CinemaScope in those

Figure 2-39. *The Robe*. Victor Mature and friends set against a large landscape and a larger drama. (*MOMA/FSA.*)

years was Paramount's answer to Fox's process. VistaVision turned the camera on its side to achieve a wide image with an eight-sprocket-hole pull-down (more precisely, a "pull-across"). The frame, then, was twice the size of a normal 35 mm frame and used all the image area available without tricky anamorphic lenses. Release prints were made in normal 35 mm configurations. (Technirama, a later development, combined this technique with an anamorphic taking lens with a 1.5 squeeze ratio).

Today, filmmakers have at their disposal the array of aspect ratios—some for photography, some for distribution prints, some for both—outlined in Figure 2-34. Digital photography, by its very nature, allows all sorts of variations on these themes. When the image is digital any aspect ratio and any vertical and/or horizontal compression scheme can be applied. Similarly, resolutions vary over a wide range. About the only thing that doesn't change in digital photography is the lens: it's still necessary to use curved pieces of glass or plastic to focus the light waves.

Grain, Gauge, and Speed

The development of fast filmstocks (and faster lenses) has given filmmakers welcome freedom to photograph scenes by "available light," at night or indoors. Whereas huge, expensive arc lights were once standard in the industry and greatly restricted the process of filmmaking, fast color and black-and-white filmstocks now give film almost the same sensitivity that our eyes have. The exposure speed of a filmstock is closely linked with its definition or grain, and varies inversely: what is gained in speed is generally lost in definition. Faster films are grainier; slower films give sharper, fine-grain images.
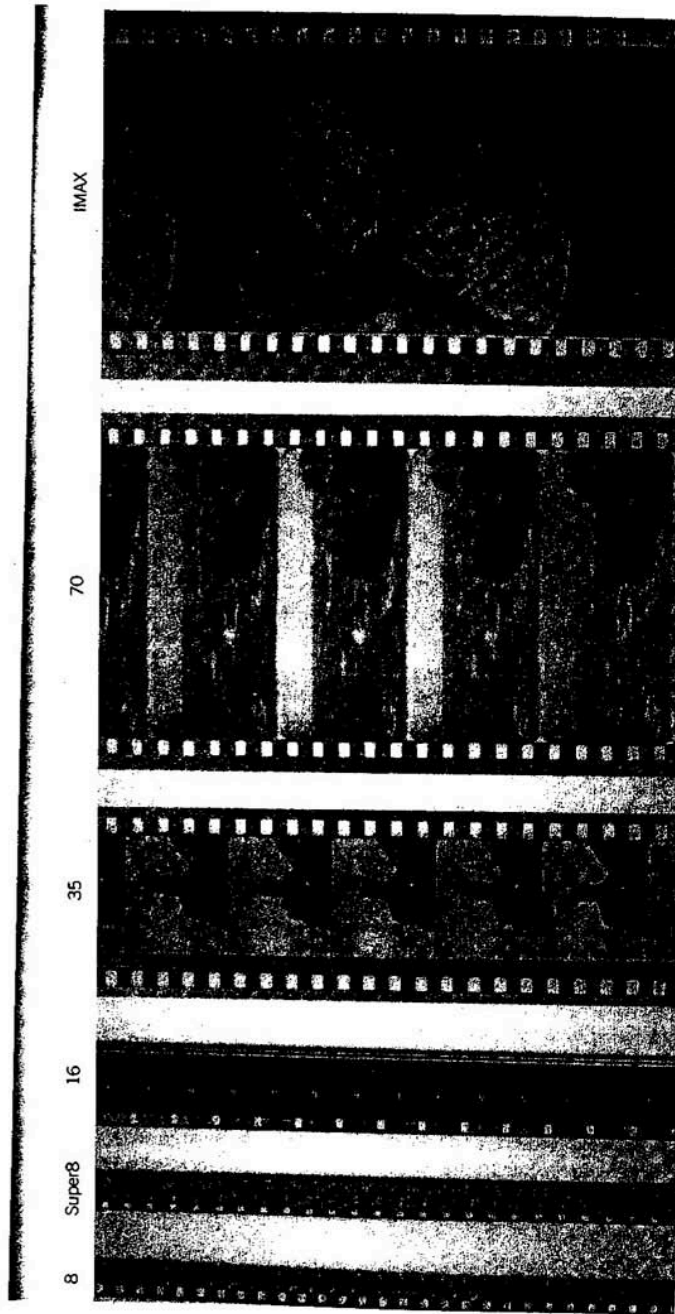

Figure 2-40, GAUGE. These six samples of standard film gauges are reproduced life-size. The 35 mm image is four sprocket holes high. The soundtrack is the thin line to the right of the left-hand sprockets. The 16 mm frames and the 8 mm and Super-8 mm frames are each one sprocket high. In addition, 8 and 16 mm release prints have only one row of sprockets. The 16 mm soundtrack is to the right of the image. (There are no soundtracks on the 8 and Super-8 mm samples.) The smaller sprocket holes of Super-8 mm film provide an image area approximately 35 percent larger than regular 8 mm stock. The 70 mm and IMAX samples offer 10 and 30 times the image area of the standard 35 mm frame, respectively. IMAX runs horizontally through the camera and projector. The frame is 15 sprocket holes wide.
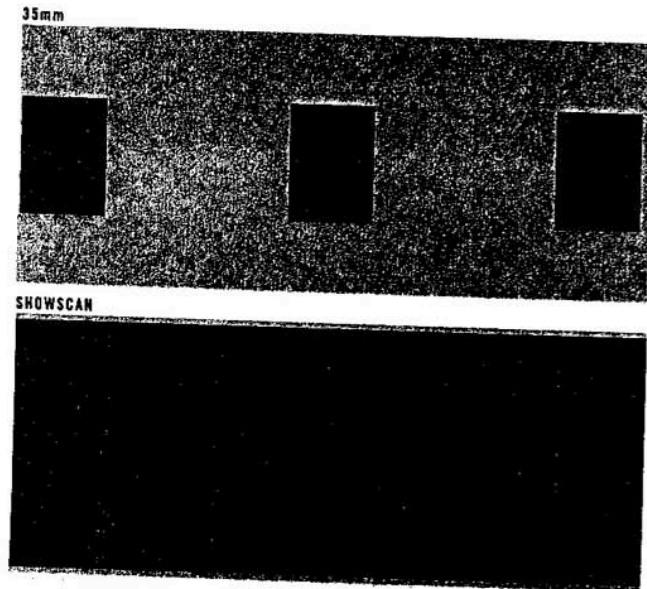
Figure 2-41. VISUAL DENSITY: SHOWSCAN. This telling illustration derived from a Showscan® marketing brochure demonstrates graphically the superior acuity of that process, which delivers about ten times as much visual information (represented by the shaded areas) as conventional 35 mm film. Both strips represent about 1/8 second of viewing. The 70 mm 60 fps Showscan film is photographed at 1/125-second per frame; the 35 mm 24 fps standard film is shot at 1/50-second per frame, so the Showscan image is also sharper. From another point of view, this illustration shows just how little information the standard medium of film communicates. (*Courtesy Showscan.*) Compare Figure 2-42.
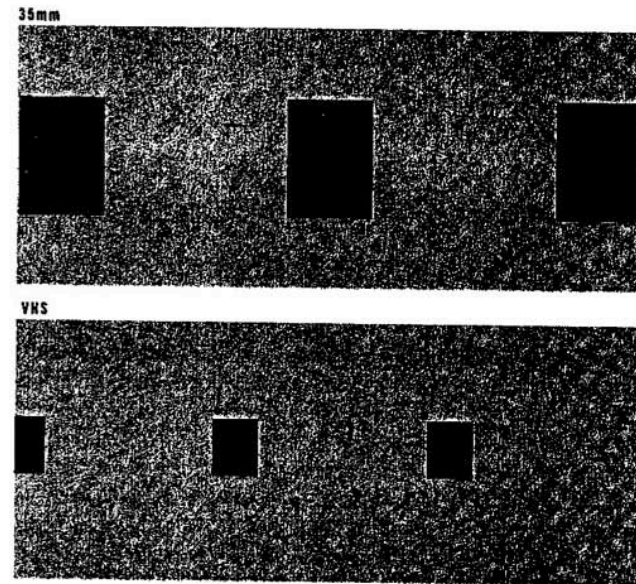

Figure 2-42. VISUAL DENSITY: VIDEO VERSUS FILM. We have extrapolated the Showscan illustration to suggest the difference between 35 mm film running at 24 frames per second and 525-line American/Japanese video running at 30 fps (or 625-line European video running at 25 fps). The dimensions of the video frames have been calculated to illustrate the poorer resolution of standard video. It is remarkable that we can construct a visual experience with so little information!

Grain is also a function of the gauge or size of the filmstock. A standard frame of 35 mm film has an area of slightly more than half a square inch. If it is projected onto a screen that is forty feet wide, it has to fill an area that is 350,000 times larger than itself—a prodigious task; a frame of 16 mm film (since the stock is a little more than half as wide as 35 mm, the area of the frame is four times smaller), if it were to fill the same screen, would have to be magnified 1.4 million times. The graininess of a filmstock, which might never be noticeable if the frame were enlarged to the 8 x 10-inch size that is a standard in still photography, will be thousands of times more noticeable on a motion picture screen.

The distance between the observer and the image is another factor to consider. From the back row of a very large theater with a small screen, the image of a 35 mm movie might appear in the same perspective as an 8 x 10 print held one foot

in front of the observer. In that case, the grain would appear to be more or less equivalent.

The standard width for motion-picture stock has been 35 mm. Introduced many years ago as suitable only for the amateur filmmaker, 16 mm stock became a useful alternative in the 1960s, as filmstock and processing became more sophisticated. It was used in television film work, especially in Europe, and it is still usable for shooting feature films. The "super 16" format, developed in the early seventies, measurably increased the area of the frame and thus the definition of the image. Both regular and super 16 mm formats are still popular in the world of independent filmmaking. Also, 8 mm film, which had been restricted entirely to amateur use until the 1970s, found some applications in commercial filmmaking for a while, especially in television news and industrial filmmaking. Whatever problems of definition and precision exist in 35 mm are multiplied by a

factor of four in 16 mm and by a factor of sixteen in 8 mm, since we are concerned with areas rather than linear dimensions.

By the same arithmetic, a wider filmstock will greatly ameliorate those problems. Hence 70 mm filmstocks are valuable for productions that need a feeling of panoramic detail and power on a large screen. While the possibilities of the wider stocks are intriguing, the increased sophistication of the 16 mm and 8 mm gauges had a greater effect on filmmaking in the 1970s and 1980s because they were so inexpensive: 16 mm stock is two to four times cheaper than 35 mm and therefore opened up filmmaking to a much larger number of potential filmmakers. It not only made it possible for more people to afford to make films, it also meant that more films could be made for the same money, so that professional filmmakers were less reliant on the vagaries of the venture capital market.

Of course, videotape offers still greater economies, but most professional filmmakers are still wedded to chemistry, which continues to maintain its mystical esthetic attraction. Tape has been a viable alternative for filmmakers since the early 1970. And since the videotape revolution of the early 1980s, tape has been the medium via which most viewers experience "films." Yet, the creative personnel in the industry still prefer the physicality and gestalt of old-fashioned film.

Although it didn't survive, the VistaVision of the 1950s suggested two profitable lines of development: first, that the film itself, if it were larger, would permit widescreen photography without loss of clarity. This led to the development of commercial 65 mm and 70 mm stocks.* (Wide stock had been experimented with as early as 1900.) Second, that the system used for photographing the film did not have to be the system used for distribution and projection. Since the 1960s, it has been common to shoot on 35 mm stock while releasing 70 mm prints to those theaters that are equipped to show them. This practice resulted in a slight increase in image quality, but much less than if the film had been shot on wide stock, as well. The main advantage of releasing in 70 mm was the more elaborate stereophonic soundtrack that stock allows. In the 1980s, 70 mm shoots were rare, due to the significant expense (combined with the increased quality of 35 mm stock). Although some films were released in 70 mm in the 1980s, *Far and Away* (1992) was the first U.S. film shot on 70 mm since *Tron* (1982).