

Oct. 19, 1943.

I. M. TERWILLIGER

2,331,941

METHOD OF PRODUCING RELIEF EFFECTS IN OPTICAL IMAGES

Filed Sept. 27, 1939

4 Sheets-Sheet 1

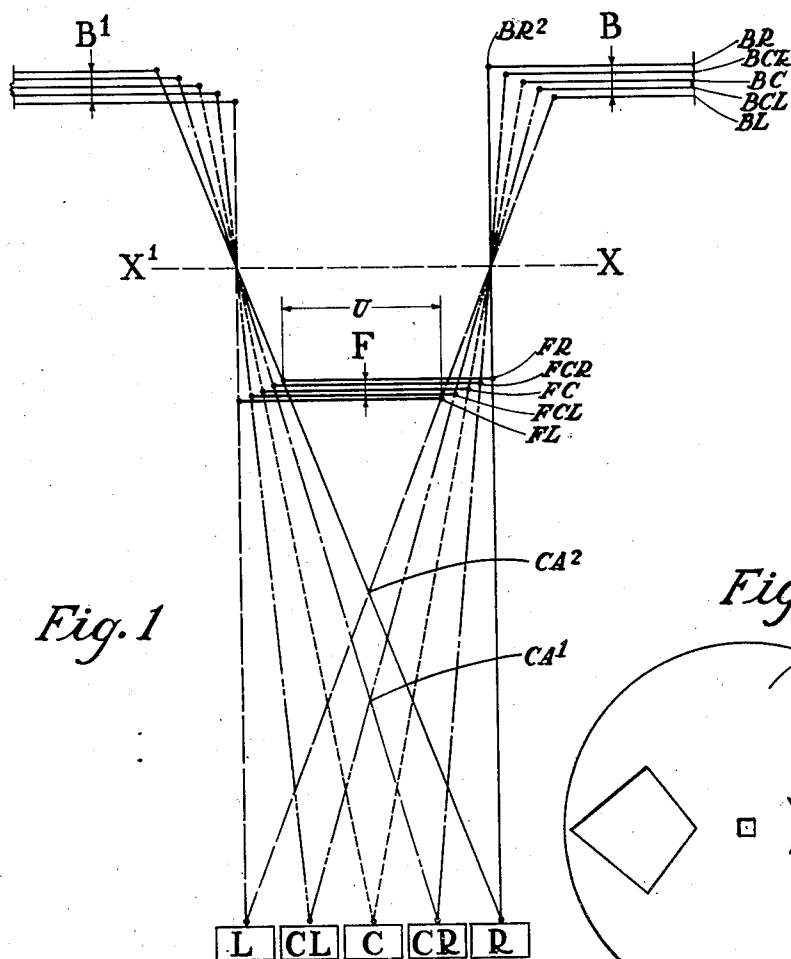


Fig. 1

Fig. 7

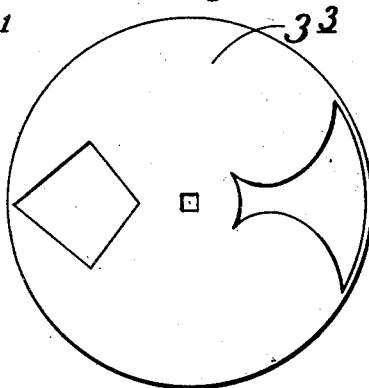
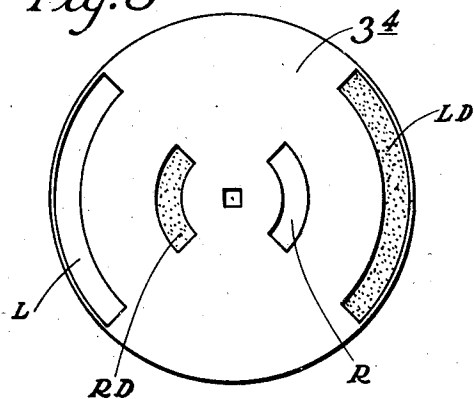


Fig. 8



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Oct. 19, 1943.

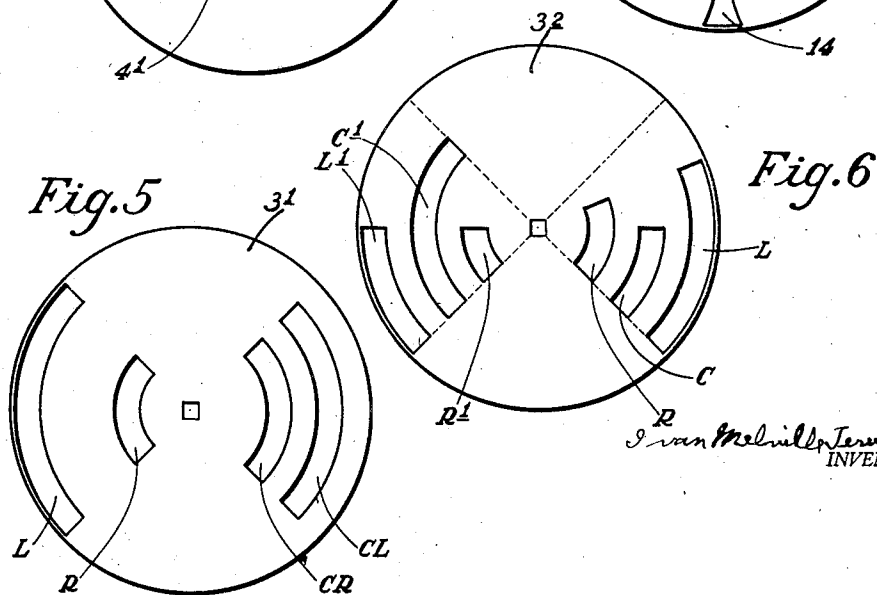
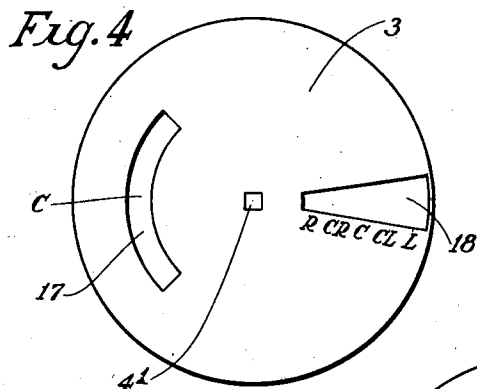
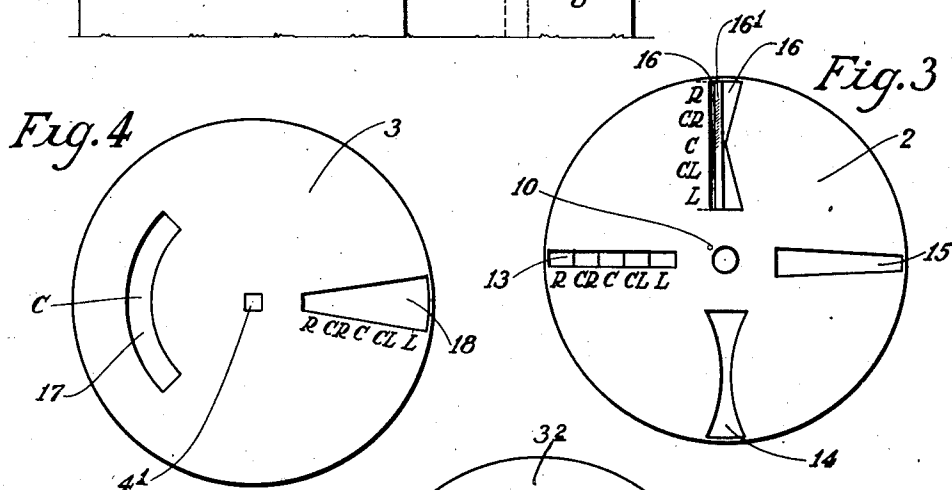
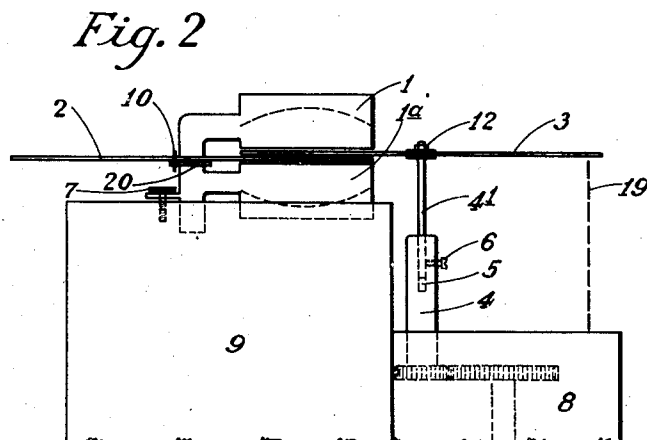
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4 Sheets-Sheet 2



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4 Sheets-Sheet 3

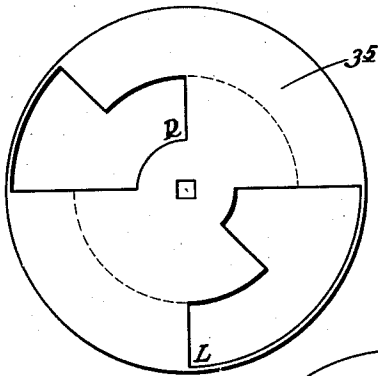


Fig. 9

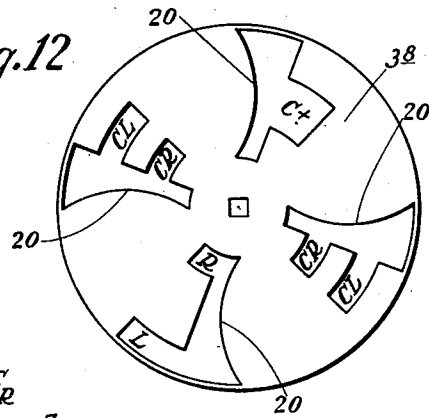


Fig. 12

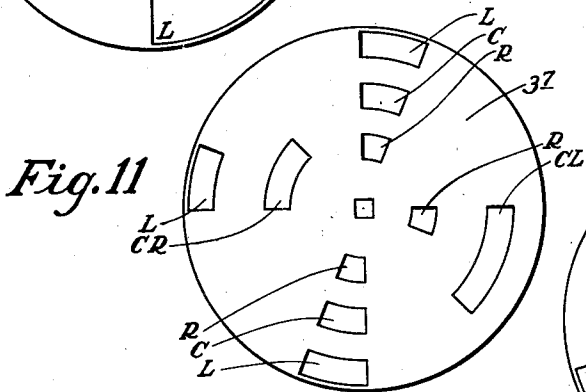


Fig. 11

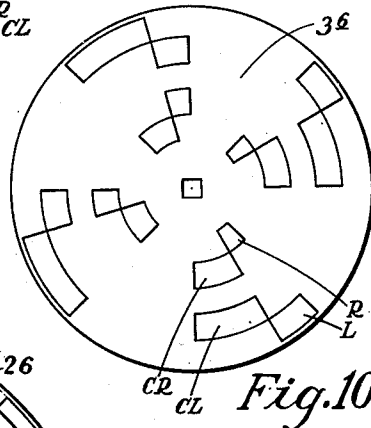


Fig. 10

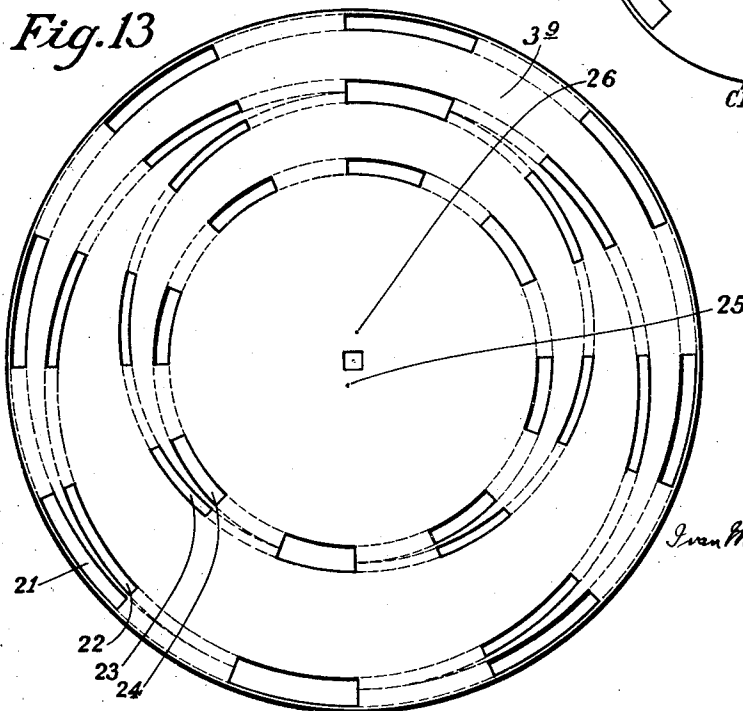


Fig. 13

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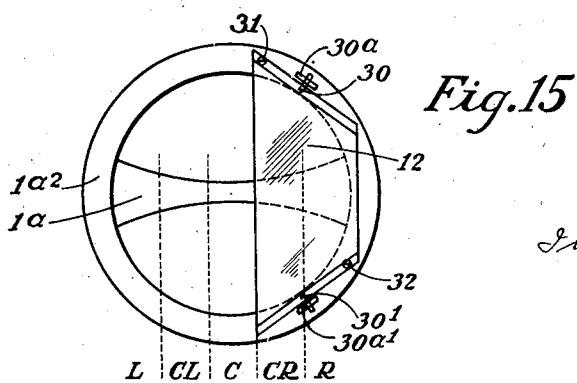
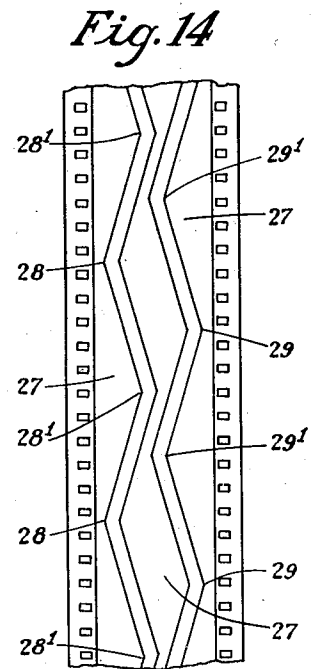
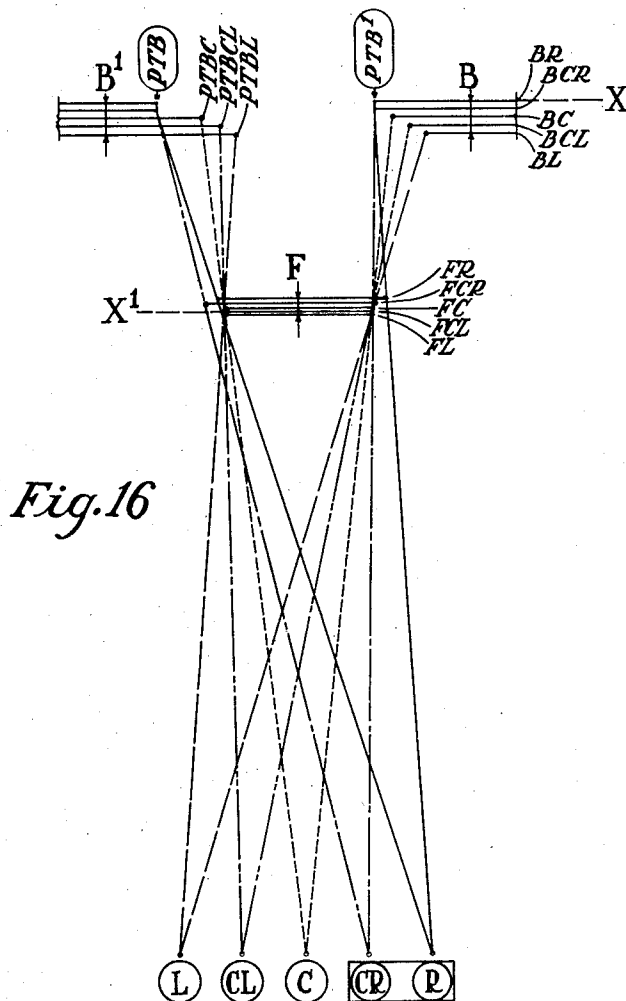
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METHOD OF PRODUCING RELIEF EFFECTS IN OPTICAL IMAGES

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4 Sheets-Sheet 4



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UNITED STATES PATENT OFFICE

2,331,941

METHOD OF PRODUCING RELIEF EFFECTS
IN OPTICAL IMAGES

Ivan M. Terwilliger, Pasadena, Calif.

Application September 27, 1939, Serial No. 296,831

17 Claims. (Cl. 88—16.6)

My invention relates to a method of producing a series of images for viewing in succession to produce relief effects and has particular reference to a method of producing optical images and arranging a plurality of such images in combinations for successive viewing to provide an illusion of relief and depth in the observed overall images and finding particular utility when practiced in connection with the production of motion pictures.

This application is a continuation in part of my copending application Serial No. 194,296, filed March 7, 1938, for Art producing optical image modulations for relief effects in pictures.

Many attempts have been made in the past to devise a method of preparing and projecting motion pictures so as to provide a three dimensional illusion when viewed. These attempts have been, for the most part, based on purely stereoscopic principles and the majority have been directed to provide a means for causing one eye to see only one of a pair of stereoscopic pictures while the other eye is limited to perceive the other picture. Many of such devices have the common disadvantage of requiring some viewing means, such as revolving shutters or spectacles, associated with each spectator who views the projected picture.

In my Patent No. 2,104,779, issued January 11, 1938, and entitled "Method of cinematography to produce stereoscopic solid effects," I suggested the fact that stereoscopic vision is not necessarily binocular, but may be achieved in cinematography through the production of a properly timed and coordinated succession of mental impressions corresponding to a set of stereoscopic aspects of a scene in which dominant and recessive aspects are recurrently intermingled. In my copending application, Serial No. 194,296 previously referred to as a direct parent of the present application, I have disclosed a novel means and a new method for producing a succession of image combinations in further development of this suggestion and in my Patent No. 2,173,866, issued September 26, 1939, I have disclosed a printing method of preparing a motion picture positive bearing such a sequence of related image combinations, and in yet another copending application, Serial No. 289,877, filed August 12, 1939, entitled "Motion picture film and method of producing same," I have disclosed a method of preparing an original negative bearing a sequence of related images in recurrently variable depths of field therealong.

This present application, being directed to a

method for producing a series of images for viewing in succession to produce an illusion of relief or depth irrespective of whether such images are to be recorded on a photographic negative, positive, viewed directly, projected from a film, or transmitted electrically to a remote point as by wire or radio, is a continuation in part of all of the aforementioned copending applications for the reason that there is disclosed herein certain features which are also disclosed in the aforementioned copending applications as well as new and improved features which are not disclosed therein.

In view of the aforementioned disadvantages attendant upon the employment of pure stereoscopic principles in the prior devices for creating a three dimensional illusion in the projected picture, other attempts have been made to combine the images corresponding to differing stereoscopic aspects of a particular scene completely within each frame of the picture as photographed. None of these latter attempts to solve the problem of providing depth in motion pictures has been adequate.

It is accordingly an object of my invention to provide a method for preparing a succession of related optical images, recurrently variable, and arranged along the succession in such manner as to produce an illusion of relief and depth when rapidly viewed in succession.

It is an additional object of my invention to provide a method for producing such a related series of optical images which does not require the employment of auxiliary viewing devices associated with each spectator who desires to view the images.

It is also an object of my invention to provide a method for producing a series of images each of which comprises a compound image formed of a plurality of superimposed elemental images each in different aspects of a given scene, one of said aspects predominating throughout the succession and the relative intensities of the other aspects varying along the strip in a recurring sequence.

It is a further object of my invention to provide a method of producing a succession of images of the character set forth in the preceding paragraph in which the overall intensities of each of the images in the succession is substantially uniform.

It is a further object of my invention to provide a method of producing a sequence of optical images of the character set forth in the preceding paragraphs, together with a method for control-

ling the relative intensities of each of the elemental images.

It is a further object of my invention to provide a method of producing a succession of images of the character set forth in the preceding paragraphs, together with a method for controlling the sharpness and definition of each of the elemental images irrespective of whether they are derived from a foreground or background object.

It is also an object of my invention to provide a method of producing a succession of images of the character set forth in the preceding paragraphs in which elemental images corresponding to different foci aspects of a scene are combined in fractional intensities which vary along the sequence.

Other objects and advantages of my invention will be apparent from a study of the following specifications, read in connection with the accompanying drawings, wherein:

Fig. 1 is a diagrammatic representation of an optical system which may be used in the practice of the method of my invention and showing how the various elemental images employed to form each of the images in the aforementioned sequence of images is formed;

Fig. 2 is a schematic representation of one form of mechanism which may be employed in the practice of the method of my invention to produce the desired succession of images;

Fig. 3 illustrates one form of aperture disk which may be employed with the apparatus of Fig. 2 and further illustrates a number of types of apertures which may be used at the nodal point of an objective system associated with this apparatus;

Fig. 4 illustrates one form of rotary shutter which may be used with the apparatus of Fig. 2 in the practice of the method of my invention to produce a particular sequence of optical images;

Figs. 5 through 13, inclusive, illustrate modified forms of the shutter disk illustrated in Fig. 4, each of these shutter disks being especially adapted for the production of differing types of image successions according to the method of my invention;

Fig. 14 is a diagrammatic representation of another type of shutter mechanism which may be employed with the apparatus illustrated in Fig. 2;

Fig. 15 is a schematic representation of an optical system which may be employed in the practice of the method of my invention to produce a succession of compound images each of which comprises a plurality of elemental images having a foci separation one from the other; and

Fig. 16 is a diagrammatic representation of an optical image system employing the plural focal objective illustrated in Fig. 15 and showing how the various elemental images which are compounded to form the compound images in the succession are produced.

The method of my invention of producing a series of images which, when viewed in succession, will give an illusion of relief and depth may perhaps be best described in general terms by having reference to the preparation of a motion picture film. In this case, generally speaking, the method comprises the following steps:

(a) exposing each frame of the motion picture film strip to compound images which are

built up of one or more elemental images superimposed upon each other, each of the elemental images being in different viewpoint aspects of the scene or objects being photographed;

(b) producing a variation or modulation between compound images along the length of the film through variations in the elemental images, which elemental image variations may be produced by either or both:

(1) varying the brightness or the length of exposure, or both, of at least some of the elemental images to produce silver images on the film which vary in density among the frames, such variation of image density being so arranged as to maintain the average density of the compound image substantially uniform, or

(2) varying the appearance of at least some of the elemental images by varying the viewpoint aspect of the image or the sharpness of the image independently of image density and arranging such variations in such manner as to maintain the average density of the compound image substantially uniform; and

(c) adjusting the relative densities of the elemental images in each frame and from frame to frame so as to place the overall predominating density of the picture when projected in one viewpoint aspect or a selected portion of the viewpoint aspects.

The prior attempts to provide such a succession of images have failed either because of failure to maintain a uniform average image density or through failure to produce an overall predominating viewpoint aspect or through failure to cause the images to vary in nature among the frames. Success in this undertaking requires not alone that each of the parts of the viewed images represent the complete field of the scene and completely cover the viewing area, but that the majority of the elemental images be substantially registered with each other in each compound image, and that at the time of viewing a substantially recessive periodic variance in relationship between a portion of a foreground image and an adjacent portion of a background image be produced. In the method of my invention these requirements are met and the predominance of one aspect or group of aspects is either actually maintained or the stabilizing result of such predominance is achieved by careful compensatory combining of opposed shifts between selected viewpoint aspects. The manner in which these results are achieved will be apparent from the following detailed description. As used herein, the term "aspect" is taken to mean an appearance of the natural scene to the eye and may represent such aspects as viewpoint aspects by which the scene or group of objects may be recognized. The term "aspect" as used herein does not refer to that appearance of a scene or group of objects which depends solely upon the point in time at which the aspect is recorded, thus excluding from the definition of the term those characteristic appearances which result solely from the changing positions of moving objects within the scene.

Referring to the drawings I have represented diagrammatically in Figs. 2 and 3 one form of apparatus which may advantageously be used in the practice of my method. This apparatus may include an objective system comprising spaced sets of objective lenses 1 and 1^a carried in any suitable mounting 20 upon a light-tight housing portion 9 of a conventional motion picture camera. The housing 9 is provided ordinarily with

means for supporting an image reception area in the form of a motion picture film strip and includes also a means connected through a gear box 8 for intermittently advancing the motion picture film between successive exposures thereon.

I prefer to dispose between the objective lenses 1 and 1^a an aperture disk 2 which, as illustrated in Fig. 3, may be provided with a plurality of apertures such as indicated at 13, 14, 15 and 16. In order that these apertures may individually be brought into an operative position aligned with the optical axis of the objective system, I prefer to mount the aperture disk for rotation about its center upon the supporting arm 20 and to provide a pin 10 which may be employed to lock the disk 2 against rotation whenever any one of the apertures 13—16 is disposed in alignment with the optical axis of the objective system. Each of the apertures preferably has a width substantially equal to the maximum aperture of the objective system while the apertures in the disk 2 are narrowed considerably in a vertical direction. The aperture 13 preferably comprises five adjacent rectangular openings which are indicated in Fig. 3 by the reference characters R, CR, C, CL and L.

I have illustrated in Fig. 1 by diagrammatic means the manner in which the objective 1—1^a operates in connection with the aperture 13 to provide a compound image comprising superimposed elemental images in different viewpoint aspects. In Fig. 1 the rectangles bearing the reference characters L, CL, C, CR and R represent, respectively, the corresponding rectangular openings forming the aperture 13. The elements forming the objective system are not shown in this drawing, it being understood that the above noted five rectangles indicate not only the zonal apertures but the objective elements associated therewith. It is assumed that an image reception area such as a photographic film will be disposed at substantially the focal length of the objective system to the rear of such objective system and will occupy a position such as that indicated by the line X¹—X in Fig. 1.

For the purpose of simplification it is assumed that the objective system is directed toward a scene comprising a foreground object and a background object. Accordingly each of the objective elements L, CL, C, CR and R will each cast an image on the image reception area of the background object and the foreground object.

I have illustrated the elemental foreground images by the reference characters FR, FCR, FC, FCL, FL and the corresponding background images by the reference characters BR, BCR, BC, BCL and BL. While I have indicated on Fig. 1 these images as being disposed before and after the plane of the image reception area X¹—X, it is to be understood that this separation on the drawing is for the purpose of clarity only and while the points of critical focus of these images will lie on one side or the other of the plane of the image reception area X¹—X, it will be understood that the images which will cast on this plane will be in reasonably sharp focus. In the same manner the five lines representing the five elemental foreground images are illustrated as being spaced from each other, whereas, in actual fact they are all superimposed in the same plane.

The same spacing of images is illustrated for the purpose of clarity with respect to the background images. The various dashed lines ema-

nating from the various sight viewpoints are representative of the light rays which cause the formation of the aforementioned images.

It will be observed that each of the foreground images which are produced from sight viewpoints disposed to the left of the viewpoint R are also disposed correspondingly to the left of the foreground image FR. In a converse manner the background images which are created by the lens elements associated with viewpoints disposed to the left of the viewpoint R are in a converse fashion disposed to the right of the background image BR.

By comparing one set of foreground and background images with another set of foreground and background images the relief effect which may be obtained by this optical system will be readily perceived. For example, by comparing the images projected from the right viewpoint R with images projected from the left viewpoint L, it will be observed that the right foreground image FR is displaced to the right of the left foreground image FL while the right background image BR is displaced to the left of the left background image BL so that when the foreground and background images in each set are superimposed the compound image viewed from the right viewpoint permits more of the background image to pass around the right end of the foreground image than is the case when the viewpoint is situated at L. In a similar manner when the images from viewpoint L are superimposed more of the background is visible from behind the left side of the foreground image and less is visible from behind the right side of the foreground image. It will be apparent that if these two sets of images are viewed alternately, the composite effect will be that of having seen the entire foreground image and that of having seen around the ends of the foreground object to establish a background image having greater scope than if such background image were established from but one viewpoint.

It will be perceived by an inspection of Fig. 1 that all of the lines which represent the lines of sight controlling the location of the limits of the elemental foreground and background images cross at the plane X¹—X. This plane corresponds to the horopter of the five viewpoint locations illustrated and is one of the conjugate focal planes of the objective system. The location of the plane X¹—X is so chosen as to place the horopter between the foreground and background objects. It is well known that the horopter may be considered as the locus of a series of points which I shall term "sight pivots," such points representing the crossing of the axes of spaced viewpoints so that the relation displacement between images of objects nearer than the horopter is in a direction opposite to that of images of objects farther away than the horopter.

It will be understood from the foregoing that the various aspects referred to are analytically related aspects. For example, it will be understood that the viewpoint aspects must be related to each other as by being separated from each other a distance such that lines extended from each viewpoint to a common point in the scene are not identical but are inclined relative to each other at a small angle. Where I have used the term "different aspects" hereinafter, it is to be understood that such different aspects are related to each other as in the example above, or otherwise.

Before discussing the manner in which these

various images are combined along the length of the motion picture film strip or spaced in time when employed with other means of viewing, such as television and the like, it is desired to call attention to the fact that a certain portion of the foreground image F and indicated by the dimension line U in Fig. 1 is common to all of the elemental foreground images. For the purpose of simplification, I will refer to this portion of the foreground image as "umbra" image while those parts of the compound foreground image lying outside of this "umbra" portion will be referred to as "penumbra" portions. In this same way it will be appreciated that the background images combine to form a compound background image having "umbra" and "penumbra" portions. It should also be noted that the area of the "penumbra" portion of the image relative to the area of the "umbra" portion of the images is dependent almost entirely upon the space separation between the viewpoints from which these images are projected. Furthermore, the density of the "penumbra" portions of the compound images may be controlled independently of their relative areas by controlling the relative densities of the elemental images which go to make up the compound image.

It is intended that the mis-registration between each of the elemental images be primarily in a horizontal direction and that the images be substantially registered in a vertical direction since horizontal mis-registration between foreground and background images is the primary and outstanding characteristic of ordinary binocular vision. For this reason I prefer to employ horizontal elongated zonal apertures, such as those indicated at 13, 14, 15 and 16 in Fig. 3. The aperture 13 to which reference has been had hereinbefore is illustrated as comprising five separate rectangular openings in the aperture disk 2. It is to be understood, however, that the number "five" is purely illustrative and that a greater or fewer number of such openings may be employed as desired. Furthermore, the zonal aperture 13 may comprise a single elongated slot rather than a number of closely spaced but separate individual openings.

It is intended that the zonal apertures operate in combination with the objective lenses 1-1^a to distribute the light which is passed through any selected part of the objective over the complete image reception area. I have discovered, however, that a lens of relative short focal length and large diameter passes normally considerably more light onto the image reception area through the center lens portion than through an edge portion of equal area. I have accordingly provided in the aperture disk 2 zonal aperture 14 which has a contour intended to correct this inherent deficiency in fast lenses. This aperture is also elongated in a horizontal direction so as to provide, in effect, a multiplicity of sight viewpoints spaced from each other along a horizontal line while being restricted in a vertical direction. The zonal aperture 14 is, however, made wider at its ends than it is at its center portion so that a relatively greater area is presented for the passage of light at the peripheral portion of the lens than is provided at the center, thus compensating for the inherent weakness of the edge portions of high speed objectives.

Many lenses useable in an old style camera are unsuitable for my process, since I have increased the relative proportions of the amounts of light passed through the sides of the lens. I prefer to

use an optical system which is effectively corrected against defects such as "spherical aberration" and "chromatic aberration." If such a corrected system is not used, the R and L elemental images will not be properly complementary to each other, particularly in the corners of the field of the picture.

I have also provided an alternative form of aperture which I have identified by the reference character 15, this aperture having a greater width at that end disposed nearest the center of the disk than at the end which is disposed near the periphery of the disk. This aperture, it will be noted, is also elongated primarily in a horizontal direction and the differences in width between the ends is intended to compensate for inherent deficiencies found in some shutter mechanisms with which the aperture may be used.

It will be readily appreciated that it is desirable at times to control the amount of light which is passed through the zonal apertures and for controlling this amount of light I have provided the aperture 16 in the aperture disk 2. This aperture is preferably provided with one straight side and with an opposite side having a contour defining a triangular shaped area, the apex of which is extended into the aperture space. This provides for a greater area at the ends of the aperture than at the center so as to compensate for the inherent deficiencies in high speed lenses in the manner pointed out in connection with the zonal aperture 14.

The aperture plate is provided with means mounting a lid 16¹ for slidable movement down over the aperture 16. The lid preferably has a height less than the height of the aperture 16 so that as it is moved downwardly from the straight edge it will operate to uniformly reduce the aperture area throughout its length until it has been moved into abutting relation with the apex of the triangular portion at which time the aperture will be divided into two triangular apertures disposed on opposite sides of the center. Further downward movement of the lid 16¹ does not effect any increased reduction in area of the aperture but instead begins to block out the triangular portions and provide an opening above the lid so that when the lid is finally moved to its lowermost position the triangular portions of the aperture are completely blocked out and a substantially rectangular aperture remains. It will be observed, therefore, that the lid 16¹ performs two functions, namely, that of controlling the amount of light which is passed through the aperture 16 and that of regulating the relative amounts of light which are passed between the center and the sides of the aperture.

The forms of apertures which I have illustrated have been included herein purely for illustrative purposes and it is to be understood that the apertures may be in many forms having irregular or regular contours as desired without departing from the spirit of this invention as long as these apertures are characterized by providing a plurality of sight viewpoints which are spaced from each other along a horizontal line. It is preferred, of course, that the light transmitting ability of each of these sight viewpoints be substantially uniform.

In order that this optical system which I have just described may be used to provide a sequence of compound images in which the relative intensities of the elemental images going to make up the compound image are varied along the length of the film strip, I provide a rotary shutter

3 which may be supported for rotation upon a shutter shaft 4¹. The shutter shaft 4¹ is slidably received within a drive shaft 4 and may be secured in any one location by means of a set screw 6. The drive shaft 4 is extended from a gear box 8 and drivably engaged therein with the same driving mechanism which is employed to intermittently advance the film through the motion picture camera 9. The rotation of the shaft 4 is preferably synchronized with the advancement of the film so that the shaft 4 is rotated one-fourth of a revolution during the time the film strip is being advanced from one frame to the next, rotated another one-fourth of revolution while the film is disposed in a position to receive the images cast by the objective system 1-1^a, rotated a third one-fourth of a revolution while the film is again being advanced and rotated a final one-fourth of a revolution with the film in a stationary position ready to be exposed.

The shaft 4¹ is preferably provided with a squared end adapted to be received in a correspondingly squared hole provided in the shutter disk 3 which may be locked in position on the end of the shaft 4¹ as by means of a nut 12. The objective system 1-1^a is preferably mounted for slidable movement inwardly and outwardly relative to the motion picture camera 9 so that the objectives may be focused on a nearby foreground object or a relatively distant background object. For this purpose I mount the supporting bracket 20 for axial slidable movement on the motion picture camera 9 and provide a focusing screw 7 for effecting this slidable movement of the carrier. Inasmuch as I prefer to dispose the shutter disk 3 between the individual elements 1 and 1^a of the objective system and closely adjacent the aperture plate 2, it will be realized that such focusing operation must also be accompanied by movement of the shutter disk 3 axially with respect to the shaft upon which it is mounted. This axial movement of the shutter disk may be readily accomplished by loosening the set screw 6 to allow the shaft 4¹ to slide inwardly or outwardly within a bore 5 provided in the end of the drive shaft 4 and in which the shaft 4¹ is received.

The shutter disk 3 is provided with a pair of shutter apertures 17 and 18, the aperture 17 constituting an arcuate slot subtending a central angle of 90 degrees so that as the shutter disk is rotated in the manner pointed out hereinbefore the time required for the complete passage of the slot 17 past the optical axis of the objective system is substantially equal to the length of time the motion picture film is held in a stationary position to receive an exposure. This arcuate slot is made with a width substantially equal to one-fifth the width of the zonal aperture and disposed so as to occupy a position previously identified with the center viewpoint C. The other shutter aperture 18 is disposed diametrically opposite the shutter aperture 17 and is also arcuate in shape but has a width substantially five times the width of the aperture 17 so that it embraces all of the sight viewpoints R, CR, C, CL and L. Conversely, the arcuate length of this aperture is made substantially equal to one-fifth the length of the aperture 17 so that while the aperture 18 passes five times as much light at any given instant as does the aperture 17, it will remain disposed athwart the optical axis for only one-fifth the time that the aperture 17 remains to result in the same over all exposure of the motion picture negatives.

In operation, one frame of the negative is exposed to a predetermined density by the shutter aperture 17 and receives a single elemental image in the center viewpoint aspect only. During the time the opaque portions of the disk are between the objective elements 1 and 1^a the motion picture negative is advanced one frame by the intermittent feeding mechanism and held in a stationary position during the time the shutter aperture 18 is passing across the optical axis of the objective system. In passing this optical axis the shutter aperture 18 exposes the motion picture negative to the same predetermined density as the preceding frame was exposed by the shutter aperture 17. However, the image which is recorded on the negative in this latter case comprises a plurality of superimposed elemental images which may, for the sake of convenience, be identified as representing viewpoint aspects projected from each of the sight viewpoints R, CR, C, CL and L. As pointed out in connection with Fig. 1 this compound image comprises an "umbra" portion having a predetermined total density substantially equal to the density of the single image recorded on the preceding frame fringed in a horizontal direction by laterally misregistered "penumbra" portions which vary from a maximum density immediately adjacent the "umbra" portion to a minimum density at the extreme edges of the frames.

This photographing operation is continued so as to provide alternate frame groups or series, one series comprising a single image of a predetermined average density while the other group comprises frames bearing a compound image having the same predetermined average density as those images in the alternate series but with the compound images comprising superimposed elemental images of equal density and representative of a plurality of viewpoint aspects of the scene being recorded.

When such a sequence of images is viewed successively the predominating effect of the "umbra" portions of the images and the predominating effect of the single and sharper image occurring on alternate frames provides for clarity and stability in the finished picture while the "penumbra" portions of the foreground and background images being projected at timed intervals intermittently in interference provides for the mental recognition of double vision at the lateral contours of the foreground figure.

I have discovered that by projecting such a sequence of images upon a screen or by otherwise presenting to both of a viewer's eyes the above described sequence of compound images representative of a plurality of viewpoint aspects that an illusion of depth and third dimension may be readily achieved. The illusion which is thus created closely approaches the illusion of depth which is obtained through normal binocular vision.

I have found that various modifications of this sequence of images may be employed for achieving different special effects and for enhancing or diminishing, as desired, the apparent depth of space or roundness of form which is imparted to the sequence of viewed images. Accordingly, I prefer to mount the shutter disk 3 upon the shaft 4¹ in a removable fashion so that I may substitute therefor a modified form of shutter disk.

All of the shutters which may be employed have certain characteristics common to them all. Among these characteristics is the arrangement of shutter openings such that the transit of dif-

ferent shutter openings or different combinations of shutter openings over the face of the zonal aperture subjects successive frames to substantially equal quantities of light while subjecting such frames to a recessive variance in the compound images. All of the shutters are so constructed that their openings operate with the device to expose successive frames to substantially uniform amounts of light without, however, exposing each of the frames through all of the openings. Those of the shutters which employ a multiplicity of openings are so arranged that exposure through a selected portion of the openings corresponding to various sight viewpoints, passes an amount of light equal to the exposure through a different selected portion of shutter openings.

Another form of such a shutter may be constructed along the lines illustrated in Fig. 5. It will be observed that the shutter illustrated in Fig. 5 includes two sets of shutter apertures, namely, one set comprising apertures L and R and another set disposed diametrically opposite to the first set comprising apertures CR and CL. Each of the slots forming each of the apertures L, R, CL and CR preferably embraces a central angle of 90 degrees and has a width substantially equal to one-fifth the length of the zonal aperture with which they are to be used so that the negative frames which are exposed to the apertures L and R are exposed to substantially the same density as are those frames which are exposed to the apertures CL and CR. Each of the slots has a width substantially equal to one-fifth the length of the zonal aperture and the slots are so disposed in the shutter disk 3¹ as to identify the first set of apertures L and R with a left sight viewpoint L and a right sight viewpoint R, respectively. In the same fashion the apertures CL and CR are so disposed in the disk 3¹ as to be identified with left and right sight viewpoints disposed somewhat nearer the center than those previously mentioned, namely, sight viewpoints CL and CR.

It will be observed that when the motion picture camera is operated in the manner described with the shutter disk 3¹ mounted on the shutter shaft 4¹ that the finished negative film strip will comprise interspersed frame groups or series, one series comprising frames each bearing a compound image of a predetermined density comprising a pair of superimposed elemental images of equal density, one of the elemental images representing an extreme left viewpoint aspect while the other image represents an extreme right viewpoint aspect. The frames comprising the alternate series also bear compound images formed of a pair of superimposed elemental images of equal density but the elemental images in this latter case while being of left and right viewpoint aspects, respectively, represent those aspects as viewed from positions each slightly closer to a central point than do those in the other frame series.

The manner in which the third dimensional effect is imparted by successive viewing of images of this character may be perceived by analyzing the changes which are imparted to the compound images in going from frame to frame along the strip. For example, one frame may comprise a pair of superimposed images representing viewpoint aspects of relatively wide separation. As the viewing is shifted to the next frame the elemental image representing a left viewpoint aspect

is moved inwardly or shifted to the right relative to the left viewpoint aspect presented on the next preceding frame. This shift to the right of the left viewpoint in going from the first to the second frame is, however, compensated by a corresponding shift of the right viewpoint from an extreme right as presented in the first frame to a position to the left in the second frame so that in going from frame to frame the left viewpoint aspect appears to shift slightly from left to right and then back to left again while the right viewpoint aspect appears to shift slightly from right to left and back again while right and left are maintained in an effective space separation throughout.

It has been found in practice that this particular type of sequence of images may be considered in part as analogous to the operation of a range finder in which the angular relation of one line of sight relative to the other is changed to analyze the third dimension or depth of a scene being viewed through the range finder. It will be observed that the recurrent alternate presentation of widely separated sight viewpoint and relatively closely spaced sight viewpoint operates in this same manner to see greater or lesser distances behind the foreground objects, while the compensatory shifting in slight amounts between selected viewpoint aspects provides an inherently stable image.

Attention is called to a fundamental difference which exists between the type of image sequence which is produced by the shutter disk 3 and that which is produced by the shutter disk 3¹. It will be observed that in the case of the image sequence formed by the shutter disk 3 that the area of the "penumbra" portions of the images relative to the area of the "umbra" portion may be considered as being held constant in going from frame to frame along the strip, while the density thereof is varied from zero in the case of one frame to a certain specified fractional density in the alternate frames. In the case of the sequence which is produced by operation of the shutter disk 3¹ it will be observed that the average density of the "penumbra" portions of the images is maintained constant while the area thereof relative to the area of the "umbra" portion is varied from a relatively large area in the case of those frames receiving images representative of widely spaced sight viewpoints to correspondingly smaller areas on those frames which receive images representative of more closely spaced sight viewpoints.

It is intended that any of the possible image sequences which may be produced by the method of my invention be characterized by the maintenance of each of the compound images in normal coverage of the complete field of view of the scene and of the frame area and at a substantially uniform average density and the variations of the images along the length of the sequence being accomplished through variation of either the relative area occupied by the "penumbra" portions of the image or by varying the density of these "penumbra" portions or by varying both the area and the density.

I have illustrated in Figs. 6 through 13 other types of shutters each employing an arrangement of apertures designed to provide different sequence of images when employed with the optical apparatus of my invention. Each of these sequences, however, employs the same principles and is distinguished by the same characteristic as have been pointed out hereinbefore as being one

common to all of the image sequences by the method of my invention. For example, the shutter disk 3² illustrated in Fig. 6 illustrates another way in which the density of the "penumbra" portions of the images may be varied without varying the area thereof. This form of shutter employs two sets of apertures, each set being arranged to provide a compound image composed of superimposed elemental images in a central, a left and a right viewpoint aspect. The length of exposure which is imparted to the motion picture negative is so controlled by these apertures, however, as to provide a sequence of images comprising groups of images arranged alternately along the sequence. In the first group the compound image comprises one image representative of a central viewpoint aspect of the scene having a density substantially equal to one-half the overall average density of the compound image and having superimposed thereon elemental images in right and left viewpoint aspects each having a density substantially equal to one-fourth the total overall density of the compound image. Those images comprising the second group of images in the sequence are compound images which include an elemental image in a central viewpoint aspect having a density substantially equal to one-fourth the average density of the compound image and having superimposed thereon right and left viewpoint aspect images each of which has a density substantially equal to three-eighths the average density of the compound image.

It will be observed that in analyzing the sequence by viewing successively the images in sequence that the right and left aspect images vary from a density of one-fourth to a density of three-eighths and back again to a density of one-fourth while at the same time the central aspect images vary in density from substantially one-half to one-fourth and back again to one-half. It will be observed that the density of all of the "umbra" portions of the compound images is maintained substantially uniform and that the area of the "penumbra" portions is also maintained substantially uniform while the density of such "penumbra" portions is varied from frame to frame along the length of the sequence.

The modification which is illustrated in Fig. 7 provides substantially the same type of image sequence as that provided by the shutter illustrated in Fig. 6. It is to be noted, however, that each of the sets of shutter apertures illustrated in Fig. 6 have been expanded in Fig. 7 so as to comprise single apertures having a contour substantially equal to that indicated by the relative lengths of the slots forming the apertures in Fig. 6. I have, however, in Fig. 7, indicated expansion of the apertures in arcuate direction as regards those portions which normally pass adjacent the edge portions of the objective system so that the aforementioned correction for the inherent diminution of light through these portions may be accomplished by this shutter mechanism instead of by employing a corrective type of aperture in the aperture disk 2. The sequence which is produced by the operation of the shutter illustrated in Fig. 7 is, however, in all other respects identical with that previously described in connection with the form shown in Fig. 6, that is to say, the sequence is characterized by the maintenance of a uniform average density in each of the images along the sequence while the variations or modulations which are presented are effected by varying the density of the "penumbra" portions of the image.

I have also discovered that the illusion of depth and relief which may be realized through the successive viewing of a sequence of images formed according to the method of my invention may be pleasingly modified by varying the sharpness or definition of one of the elemental images in addition to providing the other characteristics which have been pointed out hereinbefore.

I have illustrated in Fig. 8 a shutter which is designed to provide this modulation or variation of image definition. This shutter includes two sets of shutter apertures disposed diametrically opposite to each other in a shutter disk 3⁴. One set of these apertures includes an arcuate slot L which embraces a 90 degree internal angle and contacts with another slot RD which also embraces a 90 degree internal angle. The width of each of these slots is preferably equal to one-fifth the length of the zonal aperture so that the length of exposure which would be provided by each of these slots would, under ordinary circumstances, be exactly equal. The slot RD, however, is preferably fitted with a diffusing material, such as a screen, or other light scattering element, and due to the fact that the diffusing element employed will ordinarily pass only about 80 percent of the light which impinges thereon, it will be seen that the clear slot L will transmit about 60 percent and the diffusing slot RD will transmit about 40 percent of the total light which is transmitted onto the image reception area.

The other set of apertures indicated in Fig. 8 as comprising apertures R and LD include arcuate slots having exactly the same location and size as the slots L and RD previously described. In this latter set, however, the slot R is clear and the slot LD is fitted with the diffusing material. The slots L and LD are disposed in a position representative of an extreme left viewpoint while the slots R and RD are disposed in a position representative of an extreme right viewpoint. When the shutter is mounted on the optical apparatus and operated in accordance with the manner previously described a sequence of images will be produced which comprises compound images falling into two image series and presented in alternate fashion. One of these series will include compound images comprising a pair of superimposed elemental images, one of these images representing a sharp and well defined image having a density substantially equal to 60 percent of the average compound image density and representative of a left viewpoint aspect and another elemental image of a diffused character and having a density substantially equal to 40 percent of the total average compound image density, this latter elemental image being in a right viewpoint aspect. In the other series of image the compound image includes superimposed elemental images with one of the elemental images in a right viewpoint aspect being sharp and clearly defined and having a density substantially equal to 60 percent of the average compound image density and the other elemental image having a density of 40 percent of the compound image density and being diffused in character.

It will be noted that in this sequence the density of the "umbra" portion of the images are maintained constant, the average overall density of the compound images is maintained constant, the area of the "penumbra" portions is maintained constant, while the density and sharpness of definition of the "penumbra" portions is varied in a sequential order along the length of the image sequence. This recurrent shift of sharpness

in the "penumbra" structure between the right and left viewpoint aspects operates to enhance relief while the aspects are completely blended and fused into one whole.

The shutter which is illustrated in Fig. 9 provides a simpler sequence than those previously described in that the total area of the zonal aperture is considered as being divided in the center and comprising a right portion and a left portion. The shutter aperture areas are so adjusted that while each of the frames includes superimposed elemental images in both right and left viewpoint aspects, the left viewpoint aspect in one frame will have substantially twice the density of the right viewpoint aspect in that frame while in the next frame the left viewpoint aspect will have substantially one-half the density of the right viewpoint aspect in that frame. In this case, the area of the "penumbra" portions of the images is maintained constant along the length of the sequence but the density thereof is varied along the length of the strip so as to shift the accent from a left viewpoint to a right viewpoint recurrently along the length of the sequence. As has been pointed out hereinbefore the observer observing these images in sequence is impressed with a rapid fractional intensity variation in the interference phenomenon existing between foreground and background at the edge of the foreground figure which provides an illusion of plastic relief.

Another desirable variation of the density of the "penumbra" structure of the compound images may be achieved by the employment of a shutter constructed along the lines illustrated in Fig. 10 and arranged to produce a cyclic variation in which each cycle is of longer duration than in the forms previously described. This shutter is provided with four sets of shutter apertures so that when such a shutter is employed upon the apparatus illustrated in Fig. 2 the gear ratios in the gear box 8 should be so adjusted as to rotate the shutter disk once in synchronism with exposure of four successive motion picture negative frames. The shutter disk 3^e illustrated in Fig. 10 is considered as comprising eight equal segments, the alternate ones of which are opaque to provide for the advancement of the film between exposures. The remaining alternate segments include shutter apertures of varying length which are disposed so as to represent the sight viewpoints previously identified by the reference characters R, CR, CL and L, respectively.

The relative lengths of each of these apertures is so adjusted as to cause the production of an image sequence in which the variations in "penumbra" structure vary along the length of the sequence in groups of two, that is to say, that each member of the sequence will include four superimposed elemental images in the viewpoint aspects identified with the sight viewpoints L, CL, CR and R, respectively. It is intended that adjacent pairs of images will be identical and will be alternated with other identical pairs of images which differ in "penumbra" structure. In the first set of pairs of images the left and right aspect images each represent one-third of the total density of the compound image while the CL and CR aspects each represent one-sixth of the total image density. In the other set of pairs the density relationships are reversed so that the L and R aspect images are exposed to a density of one-sixth each while the CL and CR aspect images are exposed to a density of one-third each.

It will be noted that the sequence which is produced by the employment of the shutter illustrated in Fig. 10 is very similar to the sequence which is produced by the shutter illustrated in Fig. 5 and that the illusion which is created by such a sequence is quite similar to the illusion which is produced by the previously described sequence. It should be noted, however, that the variations in the "penumbra" structures which are produced by the shutter of Fig. 10 are variations in density of this structure, whereas, the variations produced by the shutter of Fig. 5 are variations in area.

The shutter 3^e illustrated in Fig. 10 may also be considered as operating on a "subtractive principle" to delete from the images formed all of the elemental image corresponding to the center viewpoint and to suppress or reduce the intensity of the remaining elemental images in a recurring fashion along the length of the sequence. This subtractive principle may be readily extended to provide an entirely different type of image sequence which I have found to provide an excellent illusion of relief and depth when viewed.

Referring to Fig. 4 once more, the shutter 3 may be considered as operating on an "additive principle," alternate images comprising the elemental image in aspect C as formed by the aperture 17 to which is "added" elemental images in aspects R, CR, CL and L. Assume now that the aperture 17, instead of embracing viewpoint C, embraced all the viewpoints except C, namely, R, CR, CL and L. This aperture would then operate to "subtract" from the compound image embracing all of the viewpoints an elemental image in one aspect only. This modification of shutter construction may be likewise made in all of the shutters illustrated, so that the formation of compound images according to the method of my invention may be accomplished not only by the variable "addition" of elemental images, but also by the variable "subtraction" from a comprehensive image of an elemental image in one aspect or group of elemental images in different aspects, or by a partial "subtraction" or suppression to reduce the density of a selected portion of the elemental images. It has been found that whenever the operative width of total sight viewpoints employed is substantially great, best results are obtained by maintaining the subtracted elemental images or the suppressed viewpoints in the minority on each exposure.

Another and distinctly important type of variation in the image combinations which may be produced within the sequence of images is that which may be illustrated through the use of a shutter constructed along the lines illustrated in Fig. 11. This shutter is intended to be substituted for the shutter illustrated in Fig. 10 upon a shutter drive shaft making one revolution for each four frames exposed. The apertures in this shutter disk are so arranged as to permit exposure of the image reception area through all five of the previously identified sight viewpoints L, CL, C, CR and R. A pair of diametrically opposed aperture sets are made identical so that the frames which are exposed by passage of these sets of apertures past the optical axis of the objective system operate to produce a compound image comprising superimposed elemental images in equal intensity of three viewpoint aspects, namely, L, C and R. The remaining alternate aperture sets are different in that one of the sets

is intended to superimpose two elemental images, one in a right viewpoint aspect having a density substantially equal to one-third of the average compound image density and another being in a CL viewpoint aspect and having a density substantially equal to two-thirds of the average image density. The set of apertures which is diametrically opposed to this set is similar except that the one-third density image is in a left viewpoint aspect and the two-thirds density image is in the CR aspect.

Assigning a density of "one" for the sake of convenience to the total average density of each of the compound images, it will be seen that the variation along the length of the sequence of images varies in a recurring cycle, each cycle comprising four images with the first image comprising superimposed elemental images in the L, C and R aspects with a density of one-third each, the next frame comprising superimposed elemental images in the CL and R aspects having a density of two-thirds and one-third, respectively, the next frame being identical with the first frame and having superimposed images in aspect L, C and R of a density of one-third each, and the fourth frame comprising a pair of superimposed elemental images in aspect L and CR and having densities of one-third and two-thirds, respectively. It should be noted that this particular sequence includes variations both in intensity of the "penumbra" structure and in the area of the "penumbra" structure, the changes in area being accomplished by alternate throws to the right and left of the left and right viewpoint images. On each deflection the throw is opposite and equal between the various fractional intensities.

At the time a shift in intensity is made from C onto CR an equal fractional intensity shift is made from R or to CR. A similar equality is maintained pertaining to the image element CL in its relation with the images projected from the viewpoints C and L. It will be observed, however, that some of the compound images will contain elemental images in the viewpoint aspect R unbalanced by opposite elemental images in viewpoint aspect L and that other frames will contain elemental images in viewpoint aspect L unbalanced by opposite elemental images in aspect R. The images, however, when viewed in succession provide a picture which is maintained primarily in balance through the equality of opposite deflections while the roundness of the figures is substantially heightened by the staggered order of the periodic suppressions of the R and L aspects which creates a non-progressive order of modulations.

The shutter openings have been so arranged in this shutter as to produce a variable action primarily within the "penumbra" portions of the image combinations so as to selectively modulate at least a portion of their relative characteristics in a sequence and manner similar to the modulations resulting from a bodily movement of the camera itself along the general path of a figure eight.

Reference has been had hereinbefore to the fact that a relatively fast lens having a short focal length normally passes more light near its center than it does through an equal area disposed near the periphery of the lens. I have illustrated in Fig. 12 a shutter which is provided with shutter apertures of such type as to provide not only an image sequence similar to that produced by the shutter illustrated in Fig. 11 but

which also operates as a corrective means for correcting the deficiencies found in high speed lenses. Each set of apertures which is provided in the shutter of Fig. 12 is made as a single aperture having an irregular contour designed to expose the film according to the requirements of the sequence of images which is produced by the shutter of Fig. 11. Each of these apertures is characterized, however, by having one boundary curved as indicated at 20^a so that the proportional width of the aperture at points associated with the peripheral portions of the objective system are wider than portions normally associated with the central part of the objective. This shutter accordingly functions to give a longer exposure through those sight viewpoints which are disposed near the edges of the objective system and a correspondingly shorter exposure through those viewpoints which are associated with the center of the objective system so as to correct for the above noted discrepancy in light transmitting ability found in high speed lenses.

In the foregoing I have shown how the variations or modulations of the density or area of the "penumbra" portions of the compound image may vary from image to image along the length of the sequence or may vary in pairs of images along the length of the sequence or how such variation may represent a cyclic repetition in which each cycle embraces four consecutive images. It is not to be inferred from this that these are the only types of sequential variations which may be imparted to the "penumbra" structure with respect to the disposition of such portions along the length of the sequence. I have, for example, illustrated in Fig. 13 a shutter disk 3^o which is divided into sixteen segments, the alternate ones of which are opaque and the remaining ones of which are provided with apertures 21, 22, 23 and 24. In view of the fact that a larger diameter disk 3^o is required to accommodate this relatively large number of apertures and segments, I move the shutter drive shaft 4 and 4¹ outwardly to a position such as that indicated in Fig. 2 by the dashed line 19 and in order that this multi-segment shutter may properly cooperate with the intermittent film feed, I adjust the gear ratios in the gear box 8 so as to provide for the rotating of the disk 3^o through one complete revolution in synchronism with the feeding of the film intermittently over a length of eight frames.

Attention is called to the fact that one of the sets of shutter apertures is represented as comprising two arcuate openings through the shutter disk disposed, respectively, in the R and L viewpoints and that the general R viewpoint is formed by the combination of apertures 23 and 24 and that the general L viewpoint aperture is formed by the combination of apertures 21 and 22. It will also be observed that the apertures 21 and 24 corresponding, respectively, to the farthest left and farthest right viewpoints are common to all of the eight sets of apertures provided in the disk 3^o. It will also be observed that as one follows the aperture structure in a clockwise direction about the shutter disk from the position in which but two apertures are provided in the set, that the apertures 22 and 23 gradually move inwardly toward each other so that by the time one has traversed the disk to a point diametrically opposite the starting point the apertures 23 and 24 are disposed in abutting relation so as to provide at that point a set of apertures comprising three arcuate slots disposed in positions repre-

sentative of L, C and R viewpoints, respectively. In continuing the travel of the disk it will be noted that the apertures 22 and 23 again begin to diverge so as to become integral with the apertures 21 and 24 at the time the full circuit of the disk 3⁹ is completed.

By employing the specified gear ratio in the gear box 8 each frame of the motion picture negative is exposed to one set of apertures. It will thus be seen that each frame carries a compound image composed of four superimposed elemental images. It will be further observed that each frame bears an elemental image representative of an L viewpoint and a similar elemental image representative of an R viewpoint.

It is intended that the area of the apertures 21 and 24 shall be so adjusted that the densities of these two elemental images shall be equal and in combination will be substantially 60 percent of the total image density and produce a component constant structure for the image in a predominating intensity. The remaining apertures 23 and 24 operate to produce upon each of the frames another pair of superimposed elemental images of equal intensity and in a combined intensity of substantially 40 percent of the total density of the compound image producing a component variable structure for the image in a recessive intensity.

In inspecting the sequence of images from frame to frame along the length of the strip it will be observed that the variations are imparted to the sequence by the action of the intermediate apertures 22 and 23 so that in the first frame there is superimposed upon the L and R viewpoint aspects a pair of other aspect images representative of left and right viewpoints disposed closely adjacent the L and R viewpoints. It will be observed that the viewpoints from which this secondary set of viewpoint aspect images is projected is caused to move toward each other as the images progress along the sequence so that by the time the fifth frame is reached the viewpoints from which these two images are projected are disposed immediately adjacent each other and at a point corresponding to a central viewpoint. The sequential order is then reversed with the viewpoints from which these secondary elemental images are projected appearing at progressively greater distances from each other until by the time the ninth frame is reached these viewpoints are disposed immediately adjacent the left and right viewpoints L and R, respectively.

This produces images of fixed objects having a static and predominating portion of 60 percent of the total image density and produces a predetermined recurrent variance in the remaining 40 percent of the density whereby normal projection of the image combinations from off the film recreates a plural structure in the composite picture consisting of a picture in normal stability and predominating intensity, in conjunction with a superimposed complementary image which is recurrently identified with a variable multiplicity of elemental viewpoints of the scene.

In analyzing this type of sequence attention is called to the fact that the average compound image density is maintained constant throughout the length of the strip and that the area of the "penumbra" portions of the image structure is maintained constant by virtue of the shutter apertures 21 and 24 being disposed at fixed L and R sight viewpoints. The density of parts of the "penumbra" portion is varied, however, by the shifting of the intermediate sight viewpoints even

though the average density of each elemental image is held constant. It will be observed that the "penumbra" structure disposed to the right of the "umbra" portion of the image comprises the mis-registered portion of the image caused by the moving right and left viewpoints so that while the area of the "penumbra" is maintained constant, the density of particular portions of that "penumbra" structure is varied by the variation in position of sight viewpoints occupied by the shutter apertures 22 and 23.

When I refer hereinafter to variation of the density of the "penumbra" portion of a compound image, it is intended that this term shall include not only the types of density variation previously discussed, but also variations in density occurring within the "penumbra" structure such as that just described as being produced by the type of shutter illustrated in Fig. 13.

I have described the various shutter modifications as comprising rotary types of shutters for use with a camera employing an intermittent feeding mechanism. It is to be understood, however, that the essential principles can be readily followed in connection with a camera or other image recording device which employs a constantly advancing image reception area. For example, if the camera illustrated in Fig. 2 is of the type which moves the negative motion picture film at a constant speed past the film gate, the rotary shutters described hereinbefore may be replaced by an endless band type of shutter.

I have illustrated in Fig. 14 a section out of a typical endless band type of shutter designed to produce in connection with a television or other direct viewing apparatus or on a constantly moving motion picture film a sequence of images embodying the various characteristics laid down hereinbefore. Ways are already known by which successive frames of a motion picture film may be successfully exposed while the film is constantly advanced and an optical image is constantly produced thereon. My endless band type of modulating shutter may, for convenience, be formed of a piece of motion picture film and may include a film body 27 rendered opaque by suitable exposure and development. I prefer to provide two or more transparent paths extending longitudinally along the strip and having an irregular shape so that they tend to move from side to side across the width of the strip and in a sequence which provides an irregular, partially staggered progression, portions of the paths being in relative parallel and other portions in diverse directions. These transparent portions act as do the slots in the rotary shutters previously described to pass light therethrough identified with predetermined and shifting sight viewpoints.

In the example illustrated the transparent portions which I will term "line apertures" are caused to pass over the sight viewpoints in such manner that in perusing the strip downwardly in Fig. 4 the line apertures are caused to move in parallelism with each other and to the left from the point 28' to the point 29' at which time the line aperture 29 reverses in direction and the apertures diverge between the points 28' and 28. At this time the line aperture 28 reverses its direction and travels in a direction parallel to the line aperture 29 until the next point 29 is reached at which time the line aperture 28 undergoes a change of direction and again travels parallel to the line aperture 29. It will be observed that this type of shutter when passed continuously over the aperture of a motion picture film will operate

to produce a recurring sequence of images each of which is composed of superimposed elemental images so arranged with respect to the sight viewpoints from which they are projected that the "umbra" portion of the compound image is maintained in constant density while the area of the "penumbra" portions is varied in a recurrent or cyclic fashion from frame to frame along the length of the film strip produced by this apparatus.

Attention is called to the fact that a problem in photography is presented here as in all photographic processes residing in the difficulty of obtaining pictures in which both background and foreground objects are in accurate and proper focus. I have disclosed and claimed in my copending application Serial No. 227,282, filed August 9, 1938, an optical image system employing refractors for establishing a plural-focal characteristic in an objective lens system. One form of this apparatus is diagrammatically illustrated herein in Fig. 15 as comprising a plane parallel refractor 12 disposed adjacent one of the lens elements 1^a and supported for pivotal movement about a vertical axis by means of pivotal supports 30-30^a and 30^b. It has been clearly shown in the aforementioned copending application how the offset which is produced in the light rays passing at an angle through this refractor 12 operates to cause a shifting of the image formed by those rays laterally relative to the image formed by rays which do not pass through this refractor and how this refractor operates also to alter the apparent effective focal length of that portion of the objective lens area which is encompassed by the refractor.

This apparatus when employed as the objective lens system in combination with any of the various shutters previously described operates to overcome a deficiency which inherently resides in the image sequences produced by the methods described hereinbefore. It will be recalled in connection with Fig. 1 that the focal plane X¹-X was described as corresponding to the horopter of the various sight viewpoints provided, and that this horopter was preferably disposed between the foreground and the background objects so as to also dispose the "sight pivots" therebetween to effect a displacement between the images of the foreground and background objects and create the previously described "penumbra" portions of the image structures.

From that description it will be realized that those objects which exist in the scene at the location of the horopter will consequently provide image figures upon the image reception area which are substantially devoid of any "penumbra" structure. For example, should it be desired to create a sequence of images representative of a relatively long line of columns, trees or similar objects, those of the objects which occupy foreground and background locations would appear upon viewing of the sequence to be rounded and in relief and possessed of a third dimension, while those of the columns, trees or other objects disposed at the location of the horopter, being substantially of "penumbra" structure in the corresponding images, would appear to be flat and lacking roundness.

The plural focal apparatus just described provides for a pair of horopters, one for each of the portions of the objective lens area, one of which may, by proper adjustment of the apparatus, be located at the location of the foreground objects while the other, by a concurrent adjustment, may be disposed at the location of the background ob-

jects. It will appear from this that those images of the foreground objects which are created by that part of the objective having its horopter disposed at the location of the foreground objects will lack "penumbra" structure while the complementary foreground images formed by that portion of the objective having its horopter disposed at the background objects will have the characteristic "penumbra" structure. In a similar manner, a portion of the background elemental images will have a so-called "penumbra" structure while their counterparts will not.

I have illustrated diagrammatically in Fig. 16 the manner in which the laterally directed misregistration of the images and the spaced separation between the horopters of the objective system effects the formation of the image structures. Fig. 16 is a diagrammatic representation similar to Fig. 1 previously discussed. The sight viewpoints R and CR are indicated as being enclosed in a single rectangle to indicate that these viewpoints are the ones which are controlled by the adjustable refractor 12. It is assumed that the focal length of that portion of the objective identified with the viewpoints L, CL and C is so adjusted as to dispose the focal plane corresponding to the horopter of that portion of the objective at the location of the foreground image F. In a similar manner I have indicated that the horopter of the other portion of the objective embracing the viewpoints CR and R is disposed at the approximate location of the background object so as to place the focal plane corresponding thereto at the location of the background image B. It is assumed that the image reception area will in all probability be disposed so as to receive in-focus elemental images from both the background and foreground objects combined with partially out of focus images of these objects. I have indicated in Fig. 16 by means of the dash lines X¹ and X the focal planes which correspond to the two horopters of the objective system. It will be observed that the foreground elemental images FC, FCL and FL which are produced by the portions of the objective identified with the viewpoints C, CL and L are all in accurate registration with each other so that there is substantially no foreground "penumbra" portions of the compound image resulting from this limited group of elemental images. The foreground elemental images FR and FCR are, however, laterally shifted relative to each other and relative to the remainder of the compound foreground image so that these two elemental images do provide a "penumbra" structure in the compound foreground image. In a similar manner the background elemental images BR and BCR which are projected from the viewpoints R and CR are registered so as to provide no "penumbra" structure in the resulting compound image since the horopter of these viewpoints and the sight pivots associated therewith are disposed substantially in the plane of the corresponding background objects. The remaining background elemental images BC, BCL and BL are, however, displaced relative to each other and relative to the other background elemental images so as to also provide a so-called "penumbra" structure in the compound background image. It will be observed that irrespective of the location of an object in the field of view seen by this objective system the compound images which are cast by all of the sight viewpoints of this objective system will be characterized by having a "penumbra" structure.

It will be seen from the foregoing that this

optical system will thus overcome the deficiency existing in the form of optical system previously described so that when the sequence of images is viewed in succession no image or group of images will appear to be devoid of roundness.

Attention is called to the fact that the employment of the various types of shutters described hereinbefore in connection with this form of objective lens system provides not only for the variation in area or density of the various "penumbra" structures but also provides for the complete and accurate registration on certain of the images in the sequence of all of the foreground elemental images or all of the elemental background images so that the predominance of one aspect or group of aspects over the remainder may be readily accomplished by varying the sharpness of definition of the images rather than by varying their relative intensities or area of the "penumbra" structures. It is to be realized, of course, that the complete elimination of "penumbra" structure periodically from an image may be considered as varying either the area of the "penumbra" structure or reducing the density of the "penumbra" structure as to a negligible value.

Attention is called to the fact, however, that a proper modulation of the various elemental images along the length of the sequence to provide for "penumbra" structure in both background and foreground images or images corresponding to objects disposed intermediately between the background and foreground image provides for the illusion of depth and relief as regards all of the images in contra-distinction to the provision of an illusion of depth and relief in the foreground and background images only.

It will also be observed that both the foreground and background images can be so formulated as to include elemental portions thereof which are in critical and absolutely sharp focus, whereas in the apparatus previously described in connection with Fig. 1 one or the other of the compound images could be formed in critical focus but that such critical definition was impossible in both images F and B concurrently. It is accordingly to be understood that when reference is had hereinafter to variations or modulations of the "penumbra" portions of the compound image structures that variations are intended in the "penumbra" structure irrespective of whether that "penumbra" is peculiar to images of background objects, images of foreground objects, common to both images of background and foreground objects, or to images disposed intermediately of the background and foreground objects.

The method of producing a series of images for sequential viewing of my invention has been described in the foregoing as being directed primarily to the production of a motion picture film. It is to be understood, however, that the ultimate result which is achieved by the viewing of such a sequence of images is in the case of a motion picture film only achieved ultimately upon viewing in succession such as when projected upon a motion picture screen. I do not desire to be limited to a motion picture film when I refer hereinafter to a sequence of images, since it will be apparent to those skilled in the art that such a sequential presentation of related images will provide the desired results of lending depth and relief to the observed picture if these images are viewed successively in direct projection upon a view finder or ground glass, or if transmitted electrically to a remote point for direct viewing

as by television or wire. Accordingly the method of my present claimed invention for producing such a sequence of image combinations does not depend upon the physical medium on which such a succession of images may be recorded.

Furthermore, I have restricted the description of my method to a consideration of the results achieved when the various "aspects" in which the elemental images are taken are "viewpoint aspects." I have discovered, however, that an improved degree of color fidelity may be imparted to colored images if my method is employed to produce image sequences in which various elemental images are characterized by being in different "color-aspects" of the scene. Such a modulation of "color-aspects" has also been found to create an illusion of depth by imparting a higher degree of realism to the viewed images. Accordingly, when reference is had hereinafter to "aspects of a given scene," it is to be understood that I intend to define any "aspect" which is a characteristic of the scene, irrespective of whether it is a "color aspect," a "viewpoint aspect," or other characteristic "aspect."

While I have shown and described the preferred embodiment of my invention, I do not desire to be limited to any of the details of construction shown or described herein, except as defined in the appended claims.

I claim:

1. The method of producing a series of images composed solely of compound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene each from a different one of a plurality of stereoscopically related viewpoints of said scene, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; and in at least a part of said compound images changing the relative densities of the individual images from at least two of said viewpoints while maintaining said predetermined average density in each of said compound images, said compound images being so arranged in said series that said changing of relative densities occurs recurrently in said series.

2. The method of producing a series of compound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene each from a different one of a plurality of stereoscopically related viewpoints of said scene, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; in at least a part of said compound images changing the relative densities of the individual images from at least two of said viewpoints while maintaining said predetermined average density in each of said compound images, said compound images being so arranged in said series that said changing of relative densities occurs recurrently in said series; and maintaining the individual image from a selected one of said viewpoints at a relative density in all of said compound images greater than the relative density of each of the other individual images.

3. The method of producing a series of com-

ound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene each from a different one of a plurality of laterally spaced stereoscopically related viewpoints of said scene, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; and in at least a part of said compound images changing the relative spacing of the viewpoints from which two of said individual images are derived, said compound images being so arranged in said series that said changing of viewpoint spacing occurs recurrently in said series.

4. The method of producing a series of images composed solely of compound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene each from a different one of a plurality of stereoscopically related viewpoints of said scene, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images, whereby said compound images include an umbra portion and a penumbra portion; and in at least a part of said compound images changing the density of said penumbra portions while maintaining said predetermined average density in each of said compound images, said compound images being so arranged in said series that said changing of penumbra density occurs recurrently in said series.

5. The method of producing a series of compound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene each from a different one of a plurality of stereoscopically related viewpoints of said scene, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images, whereby said compound images include an umbra portion and a penumbra portion; and in at least a part of said compound images changing the area of said penumbra portions while maintaining said predetermined average density in each of said compound images, said compound images being so arranged in said series that said changing of penumbra area occurs recurrently in said series.

6. The method of producing a series of compound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene each from a different one of a plurality of stereoscopically related viewpoints of said scene, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images, whereby said compound images include an umbra portion and a penumbra portion; and in at least a part of said compound images changing the area and density of said penumbra portions while maintaining said predetermined average density in each of said com-

ound images, said compound images being so arranged in said series that said changing of penumbra area and density occurs recurrently in said series.

7. The method of producing a series of images composed solely of compound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing two complete individual images of said scene each from a different one of two stereoscopically related viewpoints of said scene, and so adjusting the relative densities of said individual images as to provide a predetermined average density in each of said compound images with the individual image from one of said viewpoints predominating in density; and in at least a part of said compound images changing the relative densities of said individual images to cause the individual image from the other of said viewpoints to predominate in density while maintaining said predetermined average density in each of said compound images, said compound images being so arranged in said series that said changing of relative densities occurs recurrently in said series.

8. The method of producing a series of compound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing two complete individual images of said scene each from a different one of two stereoscopically related viewpoints of said scene, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; and in at least a part of said compound images changing the location of the viewpoint from which one of the individual images is derived, said compound images being so arranged in said series that said changing of viewpoint location occurs recurrently in said series.

9. The method of producing a series of compound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing a first compound image by superimposing three complete individual images of said scene, one from a central viewpoint of said scene and two from end viewpoints of said scene disposed on opposite sides of said central viewpoint and stereoscopically related thereto; producing a second compound image by superimposing two complete individual images of said scene, one from one of said end viewpoints and one from a viewpoint of said scene disposed between said central viewpoint and the other of said end viewpoints; producing a third compound image by superimposing two complete individual images of said scene, one from the other of said end viewpoints and one from a viewpoint of said scene disposed between said central viewpoint and said one end viewpoint; adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; and arranging said compound images in a recurring four-image cycle in which said second and third compound images occur alternately with said first compound image interposed between each of said second and third compound images.

10. The method of producing a series of compound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound

images of said series by the steps of superimposing a plurality of complete individual images of said scene each from a different one of a plurality of stereoscopically related viewpoints of said scene, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; in at least a part of said compound images changing the relative densities of the individual images from at least two of said viewpoints while maintaining said predetermined average density in each of said compound images, said compound images being so arranged in said series that said changing of relative densities occurs recurrently in said series, subtracting a minority of the individual images from each of said compound images by elimination of the viewpoints from which they are derived while maintaining said predetermined average density in each of said compound images; and in at least a part of said compound images changing the viewpoints which are eliminated, said compound images being so arranged in said series that said changing of eliminated viewpoints occurs recurrently in said series.

11. The method of producing a series of compound images of a given scene for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene each from a different one of a plurality of stereoscopically related viewpoints of said scene, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; in at least a part of said compound images changing the relative densities of the individual images from at least two of said viewpoints while maintaining said predetermined average density in each of said compound images, said compound images being so arranged in said series that said changing of relative densities occurs recurrently in said series; at least partially subtracting a minority of the individual images from each of said compound images by suppression of the viewpoints from which they are derived while maintaining said predetermined average density in each of said compound images; and in at least a part of said compound images changing the viewpoints which are suppressed, said compound images being so arranged in said series that said changing of suppressed viewpoints occurs recurrently in said series.

12. The method of producing a series of images of a given scene for successive viewing to create an illusion of depth in said scene which consists in casting upon an image reception area an optical image of said scene; interposing between said scene and said image reception area a diaphragm defining a light transmitting aperture; periodically eclipsing said aperture to produce a timed series of said images; changing the shape of said aperture from time to time during eclipses thereof to produce at least a part of said images through said aperture while predominately in one shape and to produce others of said images through said aperture while predominately in a different shape, said changing of the shape of said aperture being performed recurrently in said timed series; and so controlling the light passing through said aperture as to maintain the overall average density of said images at a substantially constant value.

13. The method of producing a series of compound images of a given scene for successive view-

ing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene each from a different one of a plurality of stereoscopically related viewpoints of said scene, diffusing the individual images from a part only of said viewpoints, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; and in at least a part of said compound images changing the diffusion of said individual images to individual images from a different part of said viewpoints, said compound images being so arranged in said series that said changing of diffusion occurs recurrently in said series.

14. The method of producing a series of compound images of a given scene having a plurality of planes of depth for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene each from a different one of a plurality of stereoscopically related viewpoints of said scene, a part of said individual images being critically focused on a plane of depth of said scene different from the planes of depth on which the others of said individual images are critically focused, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; and in at least a part of said compound images changing the relative densities of the individual images from at least two of said viewpoints while maintaining said predetermined average density in each of said compound images, said compound images being so arranged in said series that said changing of relative densities occurs recurrently in said series.

15. The method of producing a series of compound images of a given scene having a plurality of planes of depth for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene each critically focused on a plane of depth of said scene different from the planes of depth on which the others of said individual images are critically focused, and adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; and in at least a part of said compound images changing the relative densities of at least two of said individual images while maintaining said predetermined average density in each of said compound images, said compound images being so arranged in said series that said changing of relative densities occurs recurrently in said series.

16. The method of producing a series of compound images of a given scene having a foreground and a background for successive viewing to create an illusion of depth in said scene which consists in producing each of the compound images of said series by the steps of superimposing a plurality of complete individual images of said scene, at least one of said individual images having in a foreground figure thereof an umbra and a penumbra portion and at least one of said individual images having in a background figure thereof an umbra and a penumbra portion, and

adjusting the relative densities of said individual images to provide a predetermined average density in each of said compound images; and in at least a part of said compound images changing the relative densities of said penumbra portions while maintaining said predetermined average density in each of said compound images, said compound images being so arranged in said series that said changing of relative densities occurs recurrently in said series.

17. The method of producing a sequential variation in a continuously sustained compound image of a given scene to create an illusion of depth upon viewing said image, which consists in producing said compound image by the steps 15

of superimposing a plurality of continuously sustained complete individual images of said scene each from a different one of a plurality of stereoscopically related viewpoints of said scene, and 5 adjusting the relative densities of said individual images to provide a predetermined average density in said compound image, whereby said compound image includes an umbra portion and a penumbra portion; and continuously changing 10 the area of said penumbra portions while maintaining said predetermined average density of said compound image, said changing of the area of said penumbra portion being performed in a recurring time cycle.

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