

[54] **THREE DIMENSIONAL DISPLAY**

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Related U.S. Application Data

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[51] Int. Cl. **G03b 21/00**

[58] Field of Search 353/30, 35, 125, 121;
 40/106.1, 96; 35/28

[56] **References Cited**

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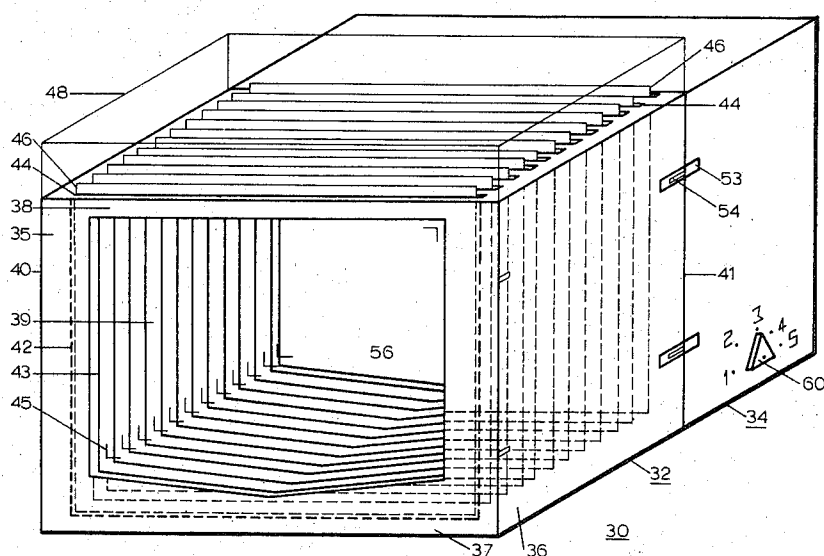
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[57] **ABSTRACT**

A process generates and displays representations of various entities—solid objects, scenes, graphs, lines, and points—in true three dimensional space (3D) space. A series of segments of thin transparent film are marked with respect to reference elements of the film segments to correspond to a series of sections of an entity. The segments are assembled spaced apart in corresponding sequence in an apparatus for display, aligned therein by their reference elements, and illuminated by a diffuse substantially uniform light source at one end of the sequence. The assembly of marks on the film segments can be seen from the other end of the sequence by transmitted light as a three dimensional representation of said entity. Apparatus and film segments have unique features accomodating the process of this invention.

11 Claims, 21 Drawing Figures



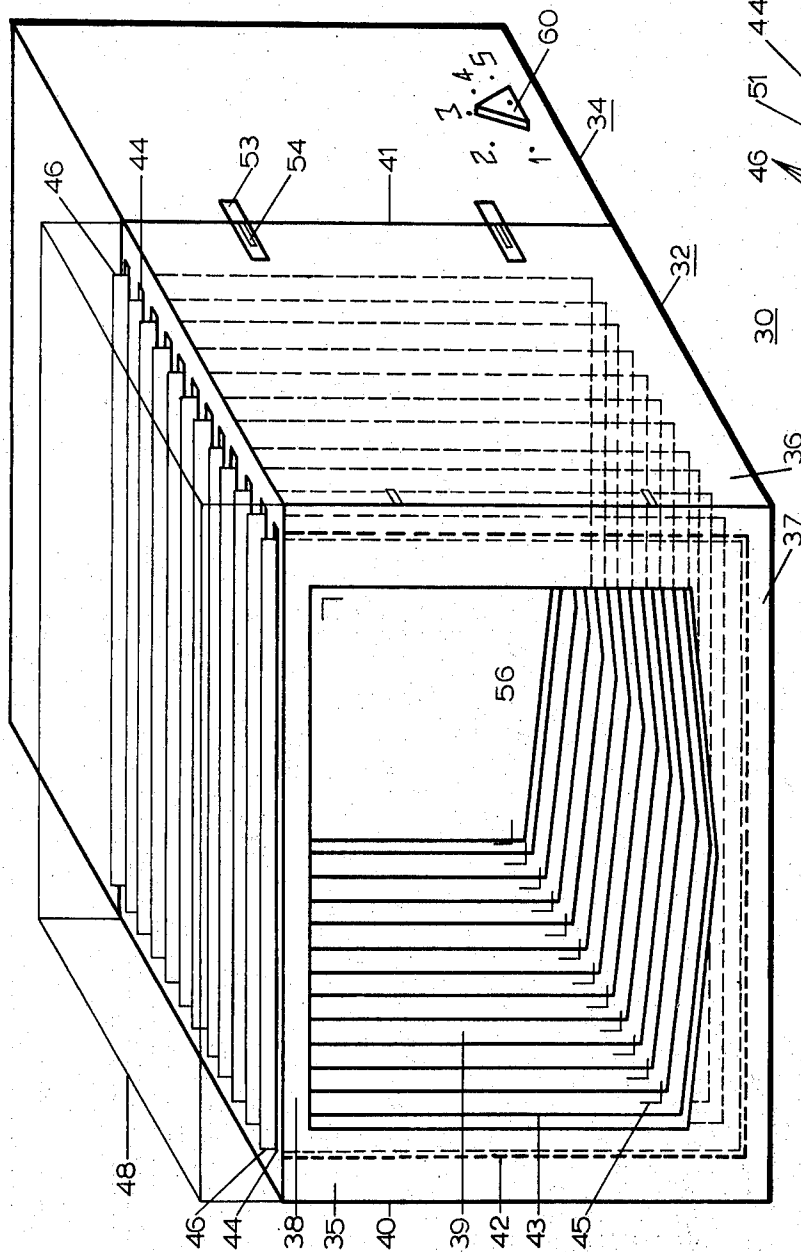


FIG. 1

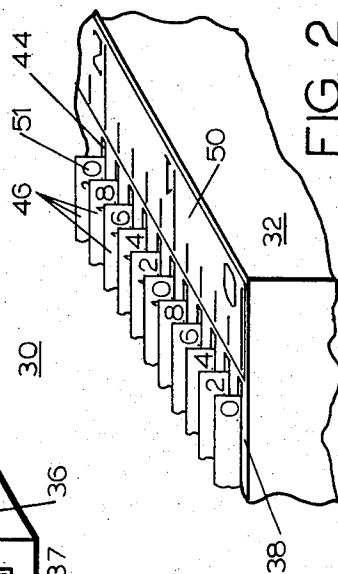


FIG. 2

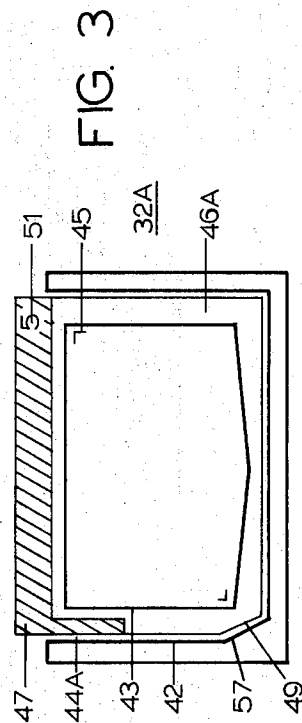
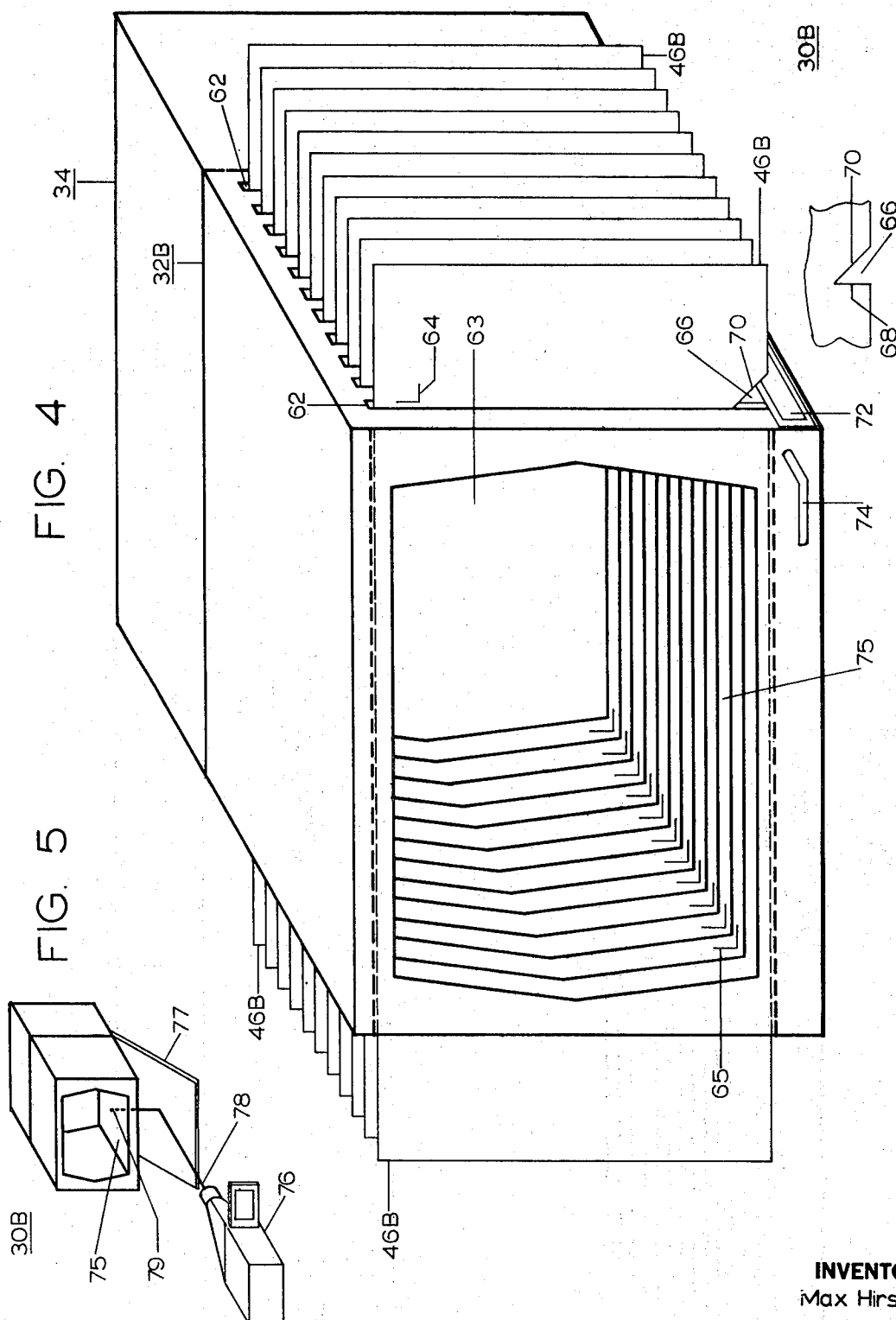


FIG. 3

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FIG. 6

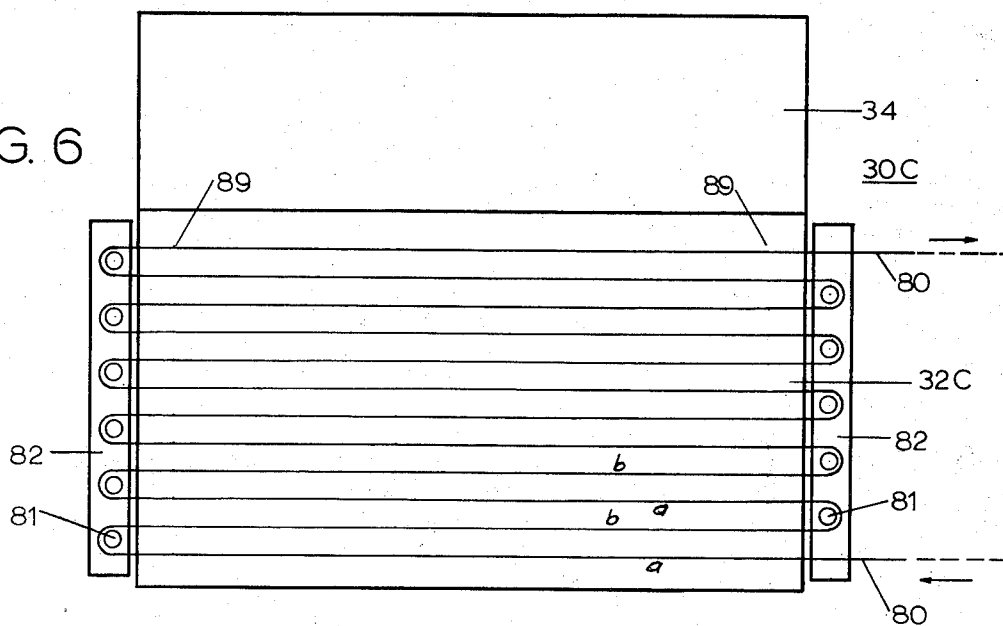


FIG. 7

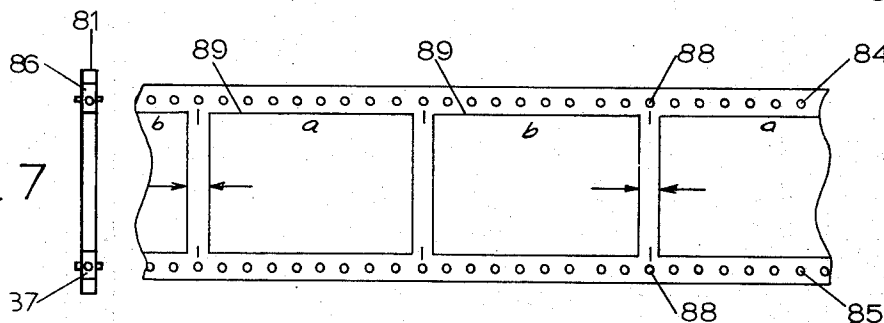


FIG. 16

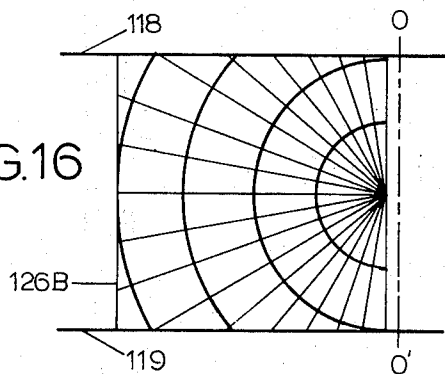


FIG. 17

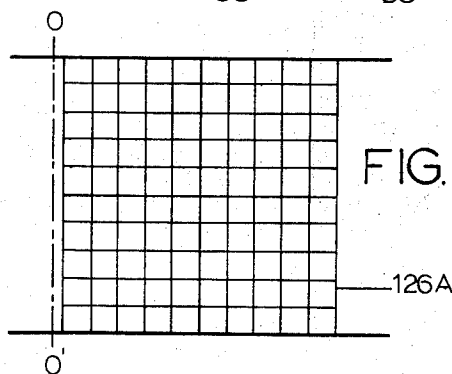
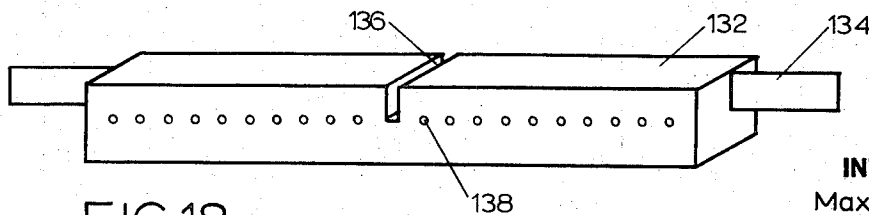
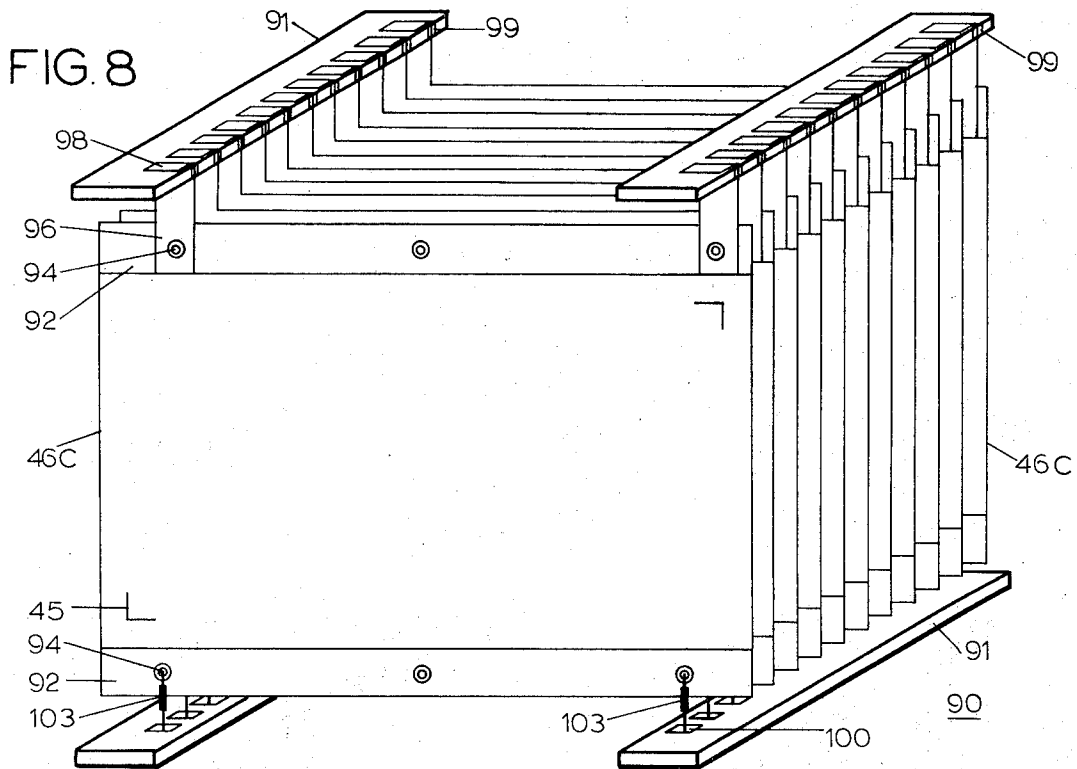
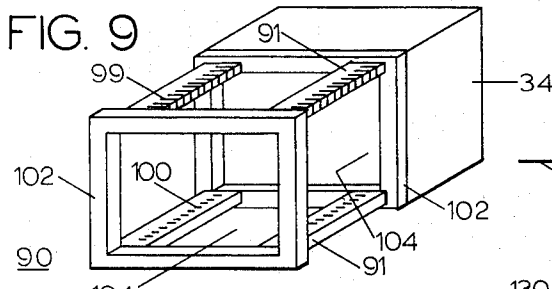
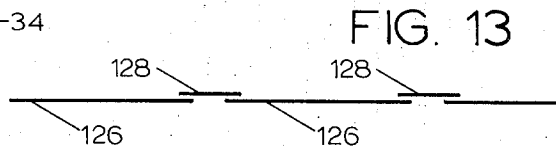
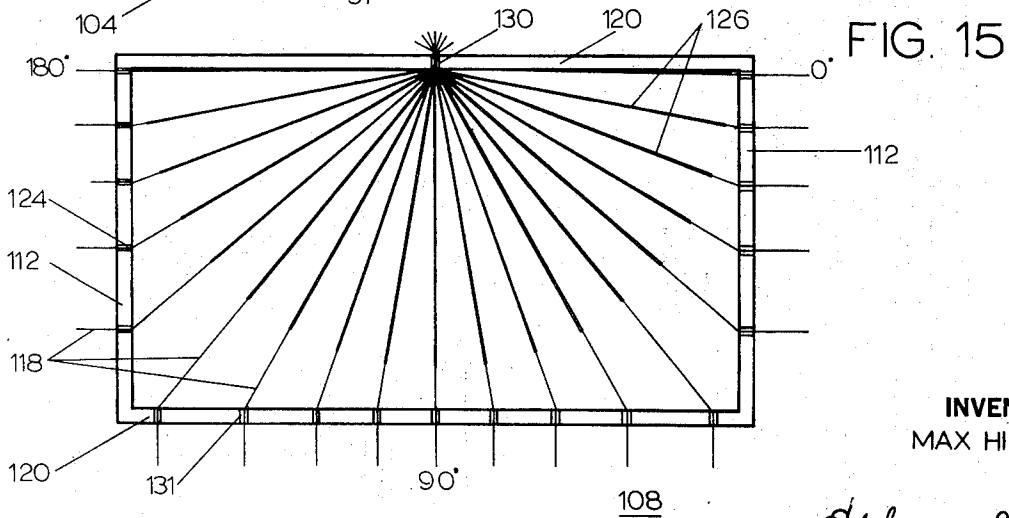


FIG. 18



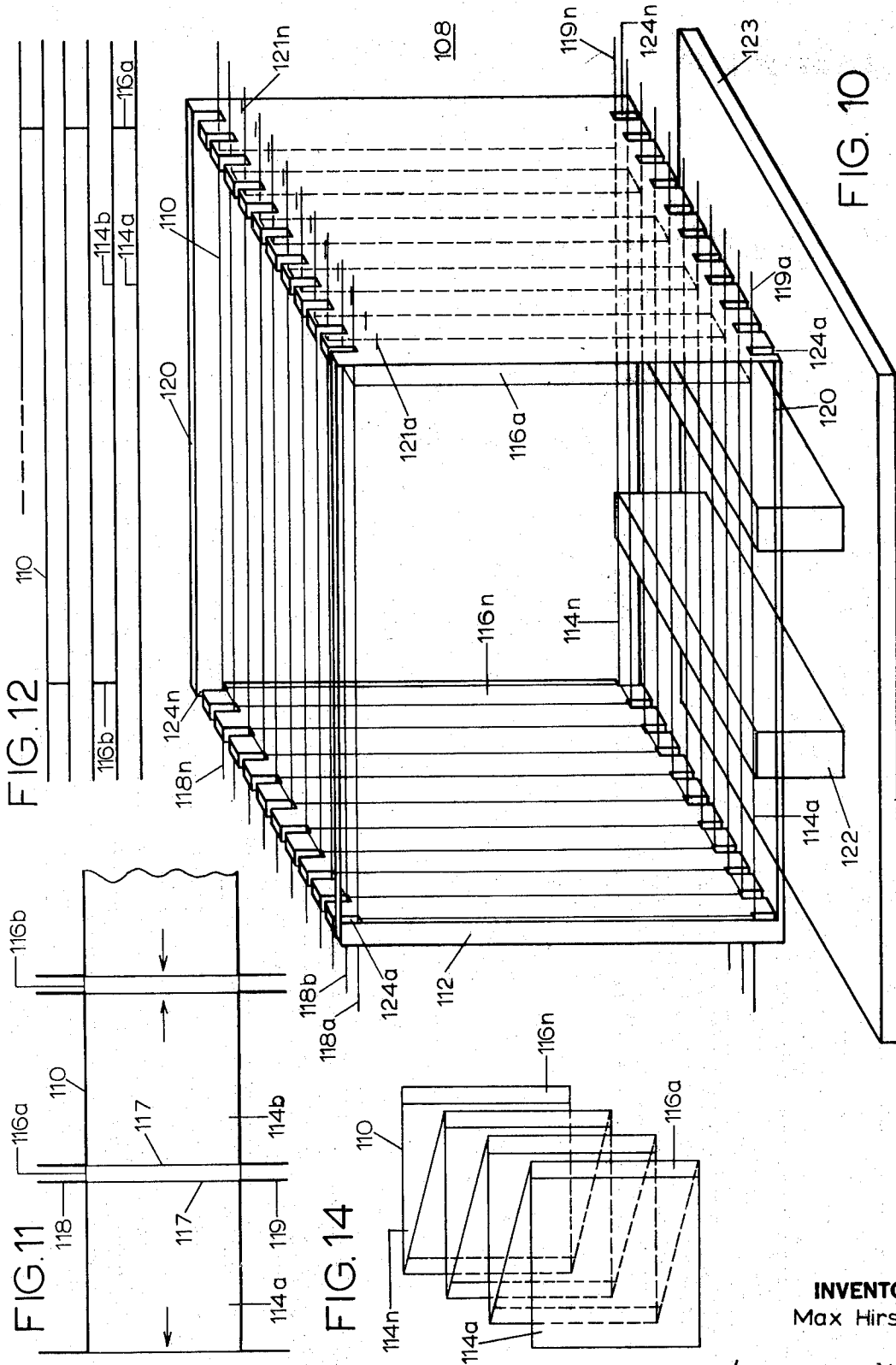
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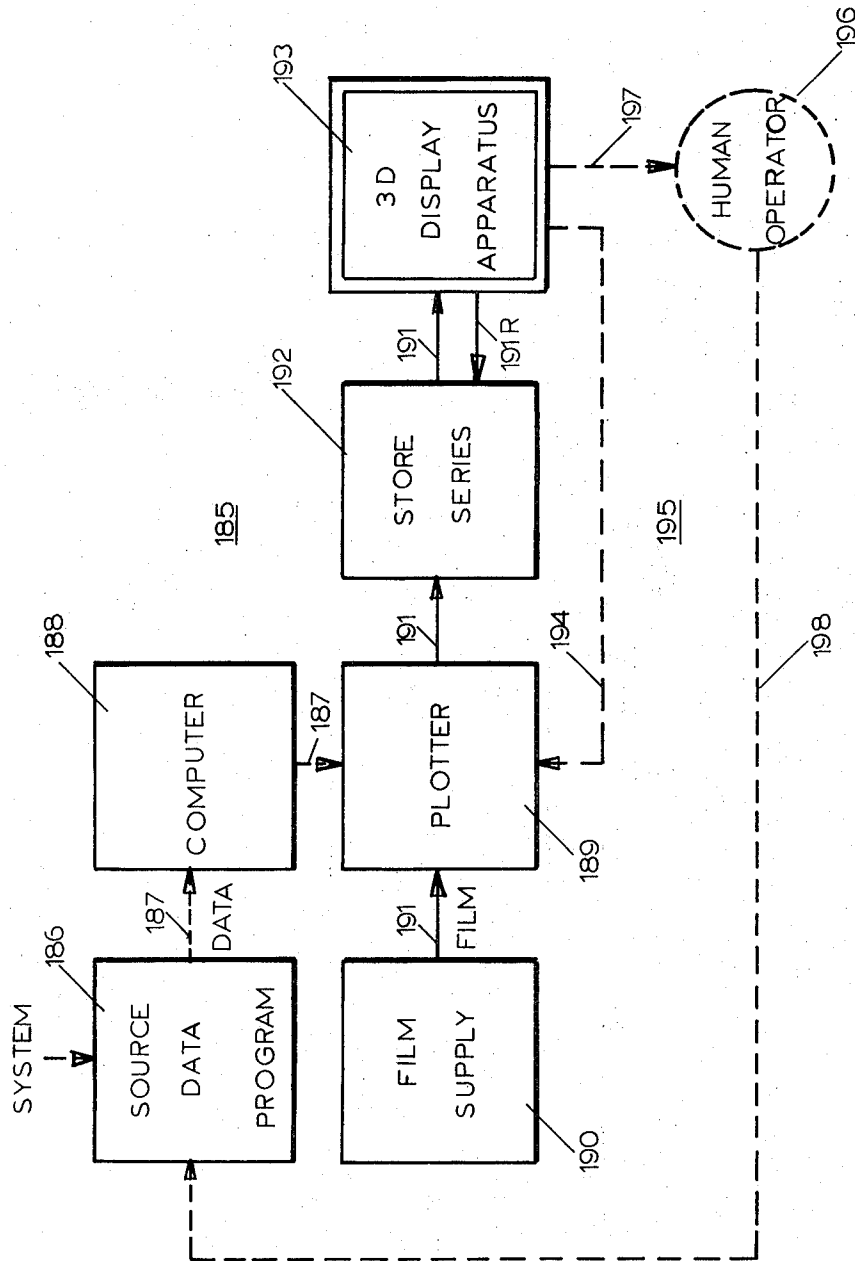


FIG. 21

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THREE DIMENSIONAL DISPLAY

This invention relates generally to a new and improved apparatus, process and materials for generating and representing scenes, solid objects, surfaces, lines and points in true three dimensional space, and is a division of my co-pending U.S. Pat. application Ser. No. 823,392, filed May 9, 1969.

More particularly, this invention concerns facile means for exhibiting on a series of thin transparent sheets of film progressive sections of an object in such spacial array as to reconstitute said object so as to be visible by an observer in its 3D form.

The representation of scenes, solid objects and the like by sculpture has long been known. The arts of sculpturing and model making are tedious and time-consuming, requiring artistic or mechanical skill. The graphic arts are more easily and economically practiced manually and automatically with the aid of extensive developments in reproduction methods, chemical and electronic photography, and XY plotters driven by computer control. The unique features of the present invention make these advanced developments of the graphic arts readily applicable to true 3D representations.

Erwin Raisz, in "Principles of Cartography" (p.262, McGraw-Hill Book Co., N.Y.C., 1962) and U.S. Pat. No. 2,556,798 to Concordet, both describe the encapsulation of a stack of thick transparent plastic plates upon which map contour intervals have been printed. Such solid block models suffer from the objections of considerable bulk, weight and cost, as well as requiring an uneconomical use of time and effort.

Other forms of pertinent prior apparatus are disclosed in the U.S. Pats. No. 2,577,320 to Fenyo, No. 2,727,327 to Colby, and No. 3,079,959 to Johnston, provide for the spacing apart, one behind another, of a series of transparent slides or plates, each one of which bears a portion of a complete scene and together composing a scene enhanced by a 3D effect. As shown, the slides or plates required for the apparatus disclosed in those patents must be of sufficient thickness for them to be self supporting when standing on one of their edges. By contrast, the present invention utilizes very thin film sheets which are incapable of standing on their edges longer than momentarily. More specifically, the thin, transparent sheets of this invention are incapable of supporting their own weight as simple columns or beams since the ratio of one of the broad dimensions of the sheet to the thickness generally is greater than 1,000. While thin and flexible sheets have been depicted by Stark U.S. Pat. No. 2,151,055 and Foley U.S. Pat. No. 2,565,553 for use in multi-layered picture devices, those devices do not contain provisions for alignment, brightness independent of depth, or for obtaining any resolution in depth for object reproduction, graphs and designs in true 3D such as is capable of being achieved in the present invention by a coordinated set of means and methods described below. Moreover, the present invention is also uniquely distinguished over these earlier designs by virtue of its provision for ready insertion and removal of the film segments from the apparatus by random access and serially.

The obtainment of considerable depth and resolution in depth are among the unique features of this invention. The many thin film sheets associated with a 3D

display, having considerable depth and resolution in depth, require a systematic method for their proper alignment. This method includes the steps of marking a series of sheets in relation to reference features embodied in the sheets or fiducial markings on them, assembling the sheets in the apparatus, and positioning the sheets in relation to the same reference features or fiducial markings in conjunction with alignment features of the apparatus. A rear uniform extended and diffuse illumination source is provided in the display apparatus to make similar markings on sheets at different depths have similar brightness. The methods and apparatus are extended from use for a series of sheets to a sequence on a strip of thin transparent film.

Displays in true three dimensions are inherently of considerable volume. The means of quick and easy insertion, and removal of sheets or strips of thin film allows a great variety of 3D displays to be shown with relative economy of space. The sheets and strips can be stored in a much smaller volume approximately equal to their bulk. The insertion of thin flexible film sheets rather than self supporting relatively thick plates or slides makes for great economy in cost of the materials of display. But most important of all thin film can be readily accommodated to virtually all the advanced processes of the graphic arts. This makes high quality reproduction and inscription on the film surfaces for this invention possible at low cost.

The "open slot," "suspended sheet" and other embodiments in the apparatus of this invention illustrate unique means for supporting thin sheets and strips of transparent film in extended and smooth form for display. They are each conjoined with the several unique means of alignment, insertion, removal, illumination, etc., and are coordinated in the process of making and assembling for the production of true 3D displays. This process includes unique means for sketching, upgrading, superimposing, and sequencing 3D display. The sheets and strips of thin transparent film are materials having unique features for handling and alignment, accommodating them to the process and apparatus of the present invention.

The invention will be better explained and understood by reference to the accompanying drawings, wherein:

FIG. 1 is a view in perspective of a rectangular 3D display apparatus in which the slots for support of thin transparent sheets are shown at the top for insertion and removal;

FIG. 2 is a fragmentary, enlarged view showing the upper right corner of the FIG. 1 apparatus additionally provided with an index for identifying the sheets and the corresponding slots in which they are mounted;

FIG. 3 is a sectional view through a slot of an apparatus similar to the illustration of FIG. 1 apparatus, but depicting a diagonally notched sheet and diagonally keyed slot;

FIG. 4 is a view in perspective of a rectangular 3D display apparatus, similar to the apparatus of FIG. 1 but in this embodiment having dual opening slots and roller assemblies enabling transparent sheets of film to be inserted or withdrawn from either side of the apparatus;

FIG. 5 is similar to the FIG. 4 view but additionally provided with means for rear projections of an image on an inner surface of the apparatus;

FIG. 6 is a horizontal, longitudinal, sectional view through the dual opening slot apparatus, somewhat similar to that of FIG. 4 but differing in that is provided with roller assemblies for adapting the apparatus to strip film use;

FIG. 7 is a lateral view of one of the rollers of FIG. 6 apparatus and of a strip of film that passes over the rollers and folds back and forth in a multiple traversing of the apparatus;

FIG. 8 is a view in perspective of an alternate mode of the invention in which transparent sheets are suspended between beams;

FIG. 9 is a view similar to FIG. 8 showing frames for supporting beams;

FIG. 10 is a perspective showing of the invention in which there is supported by suspension a strip of thin transparent film folded into many parallel surfaces;

FIG. 11 is a frontal view of a string-suspended, continuous strip film extended flat;

FIG. 12 is a top plan view of a string-suspended continuous strip film which has been folded in position for viewing many parallel film surfaces;

FIG. 13 is a side view of a continuous strip of film fabricated from discrete sheets;

FIG. 14 is a perspective showing of a continuous strip film partially fan folded for storage;

FIG. 15 is a top plan view of the suspended film apparatus of FIG. 10 adapted to discrete sheets mounted in radial array;

FIG. 16 is a frontal view of a string-suspended discrete sheet for radial arrays marked for a 3D cylindrical coordinate system;

FIG. 17 is a front view of a string-suspended discrete sheet for radial arrays marked for 3D spherical coordinate system;

FIG. 18 is a device for adapting the suspended sheet apparatus of FIG. 10 for radial arrays of 360°;

FIG. 19 is a view in perspective of another embodiment of the invention in which discrete sheets are stacked between discrete variable interval frames;

FIG. 20 illustrates a pointer and an alphanumeric label employed to locate features of interest in a 3D display;

FIG. 21 is a flow diagram of the process for generating and exhibiting 3D displays with computer and plotter.

Referring now to the drawings, wherein like reference characters indicate like parts, the "open slot" embodiment of the invention represented by FIG. 1 will be considered first. This 3D display apparatus 30 has a hollow box-like holder 32 to the rear end of which is attached a complementary box-like, electric light source 34. Holder 32 consists of two sidewalls, 35 and 36, which together with a bottom wall 37 and a top wall 38 form a rectangular prism having a front face 40 and a rear face 41. Walls 35, 36, 37 and 38 encompass an aperture 39 extending from front face 40 to rear face 41.

A series of narrow transverse slots 44, positioned one behind each other from the front to the back of holder 32, open to the exterior in holder top 38 and extend downwardly through top 38 and side walls 35-36 and continue down into holder bottom 37. Each of the slots lies in a plane parallel to the others. Outer edges 42 of each slot 44 lie hidden within the walls 35, 36 and 37 and inner edges 43 of each slot 44 lie on the surface of aperture 39. The inner edges 43 of narrow slot 44 are

adapted to fit astride a thin transparent sheet of film 46 placed in the slot through the exterior opening in holder top 38, circumscribe the periphery of the sheet at a definite distance from its edges to hold the sheet extended substantially smooth and flat. While a fairly deep slot is needed, most of the support of the film sheets is provided by the inner edges of the slots so that the supporting walls of a holder may be hollow or may be made of a supported lattice of wire.

The series of outer edges 42 lying in walls 35, 36 and 37 fall in three planes in their respective walls with each plane being perpendicular to the planes of the slots 44. Also, the planes in walls 35 and 36 are each perpendicular to the plane in bottom wall 37. Thus, when a series of thin transparent sheets 46 are placed in the series of slots 44 the bottom and left edges of each of the sheets can be made to butt the bottom and left outer edges 42 in walls 37 and 35, respectively, so that all the sheets are aligned with each other. These outer edges 42 act as stops to limit and define the position of the film sheets 46 in the slots 44 and in the holder 32. As shown, the stops are slot edges that are continuous with the edges of sheets 46. If the holder is made with hollow walls or of a wire lattice, the sheets can be positioned in a slot by a set of stops so that each stop engages a sheet edge for only a portion of its length. Since the sheets can be marked with reference to the sheet edges mentioned, the alignment of the sheets then aligns the marks on them. The length of the slots are somewhat greater than the length of the sheets to facilitate insertion in the slots and removal therefrom, and to accommodate dimensional instabilities in the sheets of thin film, and to allow movement of the sheets 46 when they are being aligned with the aid of fiducial markings 45 on sheets 46.

Thus, the right edge of the first sheet 46 does not engage the right outer edge 42. There is a small gap as shown in FIG. 1. Of course, alignment could be to the right instead of the left. When sheets 46 are aligned by their fiducial markings 45 at the extreme corners of the visible portion of the sheets, the aligned positions can be maintained by friction between sheets 46 and narrow slots 44. The frictional forces can be increased by inserting small thin paper or plastic tabs (not shown) between sheets 46 and the openings of slots 44 in holder top 38. The upper edge of each sheet 46 preferably extends a short distance, about one-fourth inch, above the opening of slot 44. This makes sheets 46 not only convenient to handle for insertion and removal, but also for edge and fiducial alignment.

Each slot 44 holds each sheet of thin transparent plastic film 46 at all four of its borders. A thin flexible sheet of film, by its very nature, cannot support itself on its edge. While the slots could be pressure-loaded, i.e., opened to receive a sheet of film and clamped close to hold the film in place, a thin slot of fixed width will suffice to support the sheet provided the depth of the slot, i.e., from the interior slot edge to the edge of the sheet, is sufficient. This is on the order of ½ inch for 8½ × 11 inch sheets and a somewhat greater amount for larger sheets. While a fairly deep slot is needed, much of the support of the film is provided at the interior edges of the slots so that supporting walls, i.e., walls 35, 36, 37 and 38, may be made hollow or indeed of a lattice of wire.

The slots are accurately made so that their edges are smooth and parallel, their width and other dimensions

maintain tolerances and the law of the interval, the distance between corresponding edges of slots, as described below, is preserved. The apparatus 30 is made of dimensionally stable materials at the somewhat elevated temperatures occasioned by the electric light source 34, steel, aluminum and plastics. Other, cheaper materials such as paperboard, cardboard, etc. may be used when reduced accuracy may be tolerated.

A preferred option is to form the inner edges 43 in the bottom wall 37 so as to present the appearance of a wide and shallow V, as seen in FIG. 1. This arrangement facilitates insertion of the sheets, since with this provision the bottom edge of a sheet being inserted, initially engages the bottom inner edge of the slot at only one point on each side and thus slides in smoothly.

The width of the slots may have considerable tolerance over the thickness of the plastic sheets used. A relatively wide slot facilitates insertion of the sheet film; however, it will not keep the sheet extended or flat. For example, with 5 mil acetate film, 8 to 15 mil wide slots or even 20 mil slots can be used. If a slot width of over 10 mils is used, two sheets can be inserted in the same slot to obtain accurate superimpositioning of two or more 3D displays in a single assembly as described below.

Translucent plastic or glass covers (not shown) may be mounted for enclosing the front face 40 and back face 41. A removable dust cover 48 of a rigid plastic or other suitable material may also be used to complete the enclosure and to shield the upper extremities of the transparent sheets and to keep dust and dirt from falling into the slots from above.

As illustrated in FIG. 2, an index 50 may be provided on the top 38 of holder 32. The one shown is made to identify the level of each of the slots and its distance from a reference level. Each transparent sheet 46 can be labelled with markings 51 which correspond with the symbols on index 50 so as to assure that each sheet is inserted into its own slot. Optionally, in order to facilitate marking and reading markings 51, sheet 46 can be rendered non-transparent at its upper border or on all its borders (as shown in FIGS. 3 and 19). A bordered sheet is also more easily seen and more conveniently handled.

As shown in FIG. 3, a diagonally keyed slot 44A is provided in the alternate form of apparatus 32A. A corner of each slot 44A is provided with a diagonal key 57. Each of the thin transparent sheets of film 46A has a diagonal identification notch 49 that accommodates slot key 57 and allows sheet 46A to fit into slot 44A one and only one way. This aids in maintaining the gross orientation of the several sheets in a display and the consistency of the data exhibited. The diagonal notch 49 on sheet 46A aids in orienting series of marked sheets. It is useful in locating drawings on the sheets by identifying the reference edges of the sheets directly and/or with respect to reference surfaces, as set forth in the process description below. In manual drawing using raised reference edges as guides, diagonal notch 49 facilitates temporary adhesion to a work or reference surface of an inner corner.

The upper border 47 of sheet 46A can be rendered non-transparent as shown in FIG. 3. This border can be opaque or translucent and can be made white or any color desired. Rendering the upper border 47 non-transparent prevents the sheet index numbers 51 from being confused when the sheets are in position as

shown in FIG. 2 or when they are stored one above the other. The border 47 also facilitates seeing, handling and the identification of transparent sheets 46A. This border can be employed with or independently of notch 49. The border can extend around the periphery of the sheet or some portion of it. In FIG. 3 it is shown extending down the left side and thus serves to identify the reference edges of sheet 46A.

In the apparatus of FIG. 1 the slot intervals (i.e., distances or spaces between the slots) are uniform. However, the law of the interval increment can be made as desired, i.e., with logarithmic, hyperbolic, perspective, etc. scales.

Reverting to FIG. 1, the box-like light source 34 is shown secured to holder 32 by means of latches 53 which engages catches 54. Light source 34 contains a combination of fluorescent and incandescent lamps (not shown) to give the brightness and relative spectral intensity to the rear diffuse uniform illumination required for the type of display to be exhibited. A multi-positioned or variable switch 60 is provided to adjust the level of illumination by switching different lamp combinations and voltage levels to the lamps. The front face 56 of the light source is a diffusing translucent sheet and extends over aperture 39 at face 41.

Optionally, holder 32 and light source 34 may be constructed as a single unit (not shown) rather than as separate entities.

Another option is to have another set of catches 54 mounted near the front face 40 to make possible reversal of the positioning of the light source with respect to the front instead of the rear face of the holder. By thus reversing the holder and looking into it from the rear instead of the front it is possible to gain a rear view of the display within quickly and easily.

Another means for supplying rear diffuse illumination is to use as a rear cover for holder 32 a diffusing or opalescent sheet and placing the holder 32 before any convenient light source such as a desk lamp, window, etc.

The holder 32 becomes a self sufficient and passive device, no power is needed. The self sufficient form of holder 32 can also be reversed by making its front cover diffusing and the rear face of aperture 39 clear. A convenient means is to reserve the first and last slots 44 for cover sheets that may be diffusing or clear transparent film.

Rear uniform diffuse illumination of a series of marked thin sheets of transparent film is a unique and important feature of this invention because it makes it possible for similar markings on sheets at different levels to have substantially the same brightness. A ray of light traversing a marking on a rear sheet must then traverse all the remaining sheets. A second ray traversing a marking on a front sheet had previously traversed all the remaining sheets. Since both rays traversed similar paths, although in different sequences, the brightness of both markings is approximately the same.

If there are n sheets, each transmitting T amount of the light incident upon it, i.e. about 0.95, and the intensity of illumination of a beam of light I originating in the diffuse source passes through a given number of sheets m and a marking D on the m -th sheet and continues through the remaining sheets $n-m$ to yield on apparent brightness B , thus, $B = IT^mDT^{n-m} = IT^nD$. Thus, the brightness B of a viewed marking is independent of depth (or sheet number m) on which it is marked. For

a given array and given rear illumination, brightness depends exclusively on the quality of the marking D, i.e., as though all markings were on the same level as far as brightness is concerned. Because there is some frontal illumination this relation is an approximation.

Since there is some diffusion and scattering of light by the transparent sheets, when there are many sheets the markings on the rear sheets are not as well defined as are the markings on the front sheets. The quality of the film, its surface treatment, the absence of dust, etc., can help preserve the definition of the rear levels of these 3D displays.

Since the 3D apparatus of this invention may be used where ambient illumination levels are fairly high, reflections of front ambient light from a front cover (not shown) and the transparent plastic sheets 46 may obscure the 3D display to some extent. This effect can be reduced by use of transparent sheets of material having a low index of refraction (and hence low reflection). A front transparent cover can be dispensed with, or if used, should preferably have high contrast qualities, a high ratio of transmitted to reflected light, similar in quality to the cover plates of television receivers or polarizing sheets, and can be tilted downwards.

A hood (not shown) may be attached to the front face 40 (or rear face 41) to block undesired ambient light and reduce reflections. The hood can be of shallow construction and easily detachable to make possible wide angle viewing of the 3D display. The effect of undesired reflections can also be reduced by making the rear illumination much brighter than that which is incident at the front of the apparatus.

It should be understood that, although reflections from a front cover or the plastic sheets of the display are not desired, some diffuse illumination through the front aperture is desired, particularly for 3D displays rendered in color. If only rear illumination were provided, color would be seen almost exclusively as a transparency. By means of some frontal illumination there is obtained brighter and more vivid color, also blacks are improved and whites are made visible. Such illumination may also be provided by a diffuse extended light source incorporated in the previously mentioned hood (not shown) on its inner surfaces, so that its light would be masked from a viewer's eyes.

Other sources of ambient illumination that are diffuse and extended may be provided. Optionally, it is desirable to make the inner surfaces of aperture 39 of holder 32 highly reflecting and diffusing (e.g., matte), thereby increasing forward illumination by back scattering of light from a rear source.

The walls 35, 36, bottom 37 and top 38 of holder 32 can suitably be made of any rigid, transparent material such as methyl methacrylate. This increases the solid angle of viewing, although visibility through the walls is to some extent obscured by the slots 44 and the edges of sheets 46. It is possible to take further advantage of the transparent walls by projecting illumination through a wall surface so as to get special effects such as the lighting of a single film sheet 46. In lieu of, or in combination with, illumination by reflected or transmitted light as described above, it is possible to use edge illumination of one or more of the film sheets (not shown).

(In the descriptions that follow, in particular, although the terms "top" and "bottom" will be used in the descriptions of the apparatus of FIGS. 1 and 4 as a

matter of convenience and with reference to the usual mode of use, it should be understood that the apparatus can be used in any physical orientation desired.)

Another version of the "open slot" embodiment 30B of the present invention is represented in FIG. 4. In this form the holder 32B has dual slot openings 62 at both sides of the apparatus. In FIG. 4 the openings 62 on only one side can be seen. The slots in the FIG. 4 apparatus 30B are equivalent construction to those shown in FIG. 1, a difference being that the slots extend entirely through the side walls instead of being confined to the interior, as in FIG. 1. Through these slots a series of thin sheets of transparent film 46B protrude exteriorly to the left and to the right of apparatus 30B. If desired, and in some applications it is preferred, the left and right interior slot edges can be constructed in the form of a shallow V, as described for the interior bottom slot edge in the FIG. 1 embodiment. This accommodates the insertion and removal of the film sheets 46 from either side.

Two alternate methods for aligning the series of thin transparent sheets 46B are provided, one mechanical, the other optical. They may be used either independently or together for the apparatus 32B of FIG. 4. The sheets 46 are aligned mechanically by engaging or butting their bottom edges with the exterior bottom edges of the slot 62 they occupy. On the bottom right edge of each sheet an aligning groove 66 is cut or stamped with a vertical edge 68 and a sloping edge 70. When the sheets are inserted in slots they are adjusted so that their vertical edges 68 are positioned slightly within the exterior edges of their slot openings. An aligning bar 72 is raised by a rotatable lever 74 (through linkage not shown). Each of the sheets is then gently moved so that its vertical edge 68 engages or rests against the aligning bar 72 to produce accurate alignment. To remove or insert other sheets aligning bar 72 is lowered by counter rotation of lever 74. The aligning bar is spring loaded (springs not shown) to press closely to the outer surface of the side wall which is made perpendicular to the exterior bottom edges of the slots. These same edges are also made to lie in a plane perpendicular to the plane of the slots.

Optical alignment requires the adjustment of each sheet 46B. Fiducial marks 64 and 65 are made in the same corresponding positions on all sheets 46B. When the sheets are inserted into apparatus 32B the fiducial markings 65 and 64 are aligned with the interior edges and exterior opening edges of slots 62 respectively. After the marks have been aligned with the edges they can be aligned relative to each other for greater accuracy.

Apparatus 30B is susceptible to virtually all the features of apparatus 30. It can be provided with front and rear covers, dust covers (for the side walls), a light source, latches and catches, and hood with or without front illumination, as well as the operational features such as an index and associated features.

In FIG. 5 apparatus 30B is shown in association with projection apparatus 76 to form a rear projection image 79 on a diffusing ground inner surface 75 of bottom 37 that is made of transparent material. A slide projector 76 optically projects an image by reflection off a plane mirror 77. A central ray 78 of a central beam of light illustratively represents the path of projection. While a convenient arrangement of apparatus is shown in FIG. 5, other folded optical paths can be

employed. Instead of a slide projector a motion picture or other type of projector (not shown) can be used.

The paired openings of apparatus 30B can be used in conjunction with strip of film 80, as shown in FIG. 6. As there shown, two roller assemblies 82 are attached to the sides of the apparatus. The strip of film 80 enters a slot which is positioned closest to the front of the apparatus, as shown, and is folded back and forth through successive slots toward the rear of the apparatus. The entrance of the film at the front and its exit at the rear are designated by arrows in FIG. 6. In each case the film emerging from one slot and then entering the next adjacent slot turns around rollers 81 that are mounted between alternate pairs of slots in roller assemblies 82. Strip 80 can be a continuous strip of thin, transparent film or it may be an assemblage of sheets. In any case each of its segments 89, a portion of transparent material adapted to occupy a level of a 3D display, are connected to a next segment, thereby comprising a sequence of said segments. The film strip 80 is perforated at the top and bottom margins as shown in FIG. 7. The opposed central perforations 88 are marked with identifying strips. Rollers 81 are fitted with toothed wheels 86 and 87 respectively near the top and bottom of each roller as shown in FIG. 7. They mate with the series of perforations 84 and 85, respectively, along the top and bottom margins of film strip 80.

On the original insertion of film 80 in apparatus 30C, and threading it through the roller 81 in assemblies 82, each of the central and marked perforations 88, engages a tooth of the toothed wheels 86-87 oriented away from apparatus 30C. This aligns the side margins of segments 89, as shown in FIG. 6, since the perforations have been spaced accurately to the distance between rollers 81 and the segments 89 have been drawn (or printed, etc.) accurately with relation to said perforations. If graphic content is drawn on all of the segments of strip 80, then alternate segments must be drawn reversed in the longitudinal direction in order for the data which they contain to have a single orientation with the remaining elements in a 3D display. Note the alternation of segment identifications *a* and *b* in FIG. 7. The reversed direction of the arrows on the reversed side of the *b* segments illustrate the data orientation needed, i.e., for the arrows to be in line. This need for reversing alternate segments can be avoided by leaving them blank.

A given 3D presentation can be viewed for some time, then the strip 80 may be driven off at one end (cf. the arrow depicting emergence of strip 80 at the rear of the FIG. 6 apparatus), while at the same time fresh film strip 80 can be introduced at the other end (cf. the arrow showing entrance of strip 80 into the forward end of the FIG. 6 apparatus) to offer a new 3D presentation. Such a continuous strip 3D display means offers a simple and facile means for altering 3D presentations, and is suited for the high rate outputs of computers as well as for advertising where the graphics have been prepared in advance, etc.

Another form of the present invention, referred to as the "suspended sheet" embodiment, employs the principle of supporting thin sheets of transparent film by means of string or stiffening elements attached to opposite edges of sheets of thin film. Such an embodiment is illustrated by the apparatus 90 as shown in FIGS. 8 and 9. It comprises four beams 91, two upper and two lower, each pair spaced apart from one another and

from the opposite pair so as to accommodate transparent film sheets 46C between them. The sheets 46C are held extended in one dimension by means of stiffening elements 92 attached along the top and bottom edges of each sheet, and by the tension of springs 103 in the other dimension.

The stiffening elements 92 can be made of thin sheet aluminum or steel, plastic, or paperboard. Although shown in flat condition, it should be understood that the strips may have hems, bent edges, etc. to make them more rigid and keep them straight, and to keep their weight and cost low. The strips may be attached to one side or both the front and back of each sheet. There is a variety of means for attachment, cementing, self adhering strips, mechanical devices, etc. The advantage of mechanical devices is their reversability and economy. The stiffening elements can be removed and used with other sets of sheets. Also sheets not in use can be stored separately from elements 92 close and flat to save weight and space in storage.

A novel and efficient mechanical means for affixing stiffening elements to sheets of film will be described. Holes are punched along the longitudinal edges of sheets 46C at defined positions. Stiffening elements 92 cut to the lengths of sheets 46C also have similar holes made therethrough at corresponding positions so that when a stiffening element is on the sheet along its upper edge, the holes of element 92 fit on the holes of the sheet 46. The top and bottom holes in the sheets are similar so that the elements can be interchangeable for top and bottom, and for all sheets of a given size. Through the aligned holes of element 92 and sheet 46C are attached snap fasteners 94 similar to those used in the clothing industry. For greater stiffening action and to minimize warping of the sheets two elements 92, one on each side of the sheet so as to sandwich the sheet between them, may be attached. The stiffening elements attached across the tops and bottoms of the sheets, keep the sheets extended longitudinally. They also provide means for suspending the sheets and distribute the forces of weight and tension acting on the suspended sheets so that the forces of weight and tension are not localized so as to tear the thin film composing the sheets.

Extending above the two end holes on the top of each sheet are straps 96. The straps may be made of thin sheet aluminum, steel or plastic. They have a hole through them to accommodate snap fastener 94. The top of strap 96 is bent at a 90° angle so as to form a rest 98. The vertical distance between the edge of rest 98 and the hole is precisely made so that all straps are interchangeable with each other.

The stiffening element 92 and straps 96 have been described above as separate entities. However, the stiffening element and strap could be made as a single continuous member.

The two top beams 91 have a series of slits 99 cut in them for a portion of their width and deep enough to accommodate the full width of straps 96. The nature and size of the intervals between slits 99 are subject to the same factors described above for the intervals between slots 44 in apparatus 30 of FIG. 1. The corresponding slits 99 of the opposed upper beams, lie in a common plane and their inner, left edges lie on two straight lines.

A sheet 46C with bottom and top elements 92 as well as straps 96 attached, is suspended from upper beams

91 by inserting the left and right straps in a pair of corresponding slits 99. The straps 96 are pushed along slits 99 until their leading edges touch the inner left edges of the slits with the rests 98 engaging the top of beams 91 that lie in a plane.

The two bottom beams 91 have a series of holes 100 through them, similarly spaced so that each pair fall in a plane which passes through a corresponding pair of slits 99 in upper beams 91. Springs 103, hooked at both ends, are placed in holes 100 so that the bottoms of the hooks rest on the bottoms (not shown) of the lower beams 91. The top hooks of the springs engage holes in the snap fasteners 94. The tension of the springs, applied through snap fasteners 94 and bottom element 92, are transferred to the thin transparent sheets 46 to which they are connected. This tension keeps the sheets fully extended in their transverse direction. The springs also serve to hold the bottom of the sheets in place. The described suspension keeps the sheets accurately positioned and aligned. The sheets can also be aligned with the aid of fiducial markings 45 by displacing straps 96 from inner left edges of slits 99, and elevating them by narrow tabs (not shown) of paper or plastic above the tops of beams 91.

It is to be appreciated that the sheets 46C are attached to stiffening elements, 92, and the stiffening elements are attached through straps 96 to beams 91 so that sheets 46C are supported through the train of listed elements by beams 91. In a similar way, reference features embodied in sheet 46C, the holes punched along its upper horizontal edge, determine the position of stiffening element 92 with respect to the sheet. Since the straps 96 are accurately positioned with respect to element 92 and slits 99 on beams 91 the sheets 46C are accurately positioned with respect to the beams 91 through the same train of listed elements.

As reference to FIG. 9 will show, beams 91 are rigidly supported by front and rear rectangular frames 102. An extended light source 34 can be attached to the rear frame as shown. A detachable cover (not shown) with a matte reflecting interior surface can be mounted on the sides, top and bottom to enclose apparatus 90, and yet provide ready access to the beams when necessary to suspend or remove sheets therefrom. Technical displays used in engineering, architecture, etc., with which one may view the displays from all angles, top, bottom, sides, front, require extended light sources (not shown), larger than aperture 104. Further, apparatus 90 can be moved and rotated with respect to the light sources and observers, or the light sources and the observers can move so that a given 3D display in apparatus 90 can be seen from different angles.

The "suspended sheet" embodiment of the present invention is well adapted for the economic exhibition of large displays, since thin, relatively inexpensive transparent plastic sheets can be extended for considerable areas, from several square feet to many square yards, on four inexpensive beams. These beams can be a foot or a few feet in length for advertising displays of the kind that would fit in store windows. For large scale 3D layouts, e.g., of prototype structures such as aircraft frames, wings, ships, hulls, etc., the beams can be tens or hundreds of feet long. With the aid of computer-driven plotters such 3D large layouts can be made and exhibited at a fraction of the time and cost of making comparable plywood or other solid models. Such displays are transparent so that all interior elements are

visible, making inconsistencies in design readily apparent, they are also easy to correct and alter.

A second set of beams (not shown) similar to beams 91, but located substantially transverse to them and attached to frames 102, can be provided. Alternatively, the vertical members of frames 102 can provide such a second set of support beams. To this second set of beams a selected number of sheets, perpendicular or oblique to the first set, can be mounted. This second set of sheets can be used to improve the pictorial display with a showing of the ground, the sky, walls, etc. Also, for both first and second sets of sheets, portions of said sheets only may be used for limited areas of interest.

A variation of the apparatus 90 shown in FIG. 8 which employs strings instead of straps, and is adapted to continuous strips of transparent film as well as discrete sheets, and to radial as well as linear arrays, is the string-suspended form 108 shown in FIG. 10. A continuous strip of thin transparent film 110 is folded back and forth between the side walls 112. As shown extended in FIG. 11, strip film 110 is comprised of a series of surface segments 114a, 114b, 114a, etc., on which sectional portions can be recorded. Between each of the surface segments there are incremental portions or "risers," 116a, 116b, 116a, etc.

In FIG. 12 the strip film 110 is shown in isolation and in top view, folded back and forth as if it were situated in apparatus 108. On or close to the upper and lower edges of each surface segment 114 are filaments or strings 118a to 118n and 119a to 119n respectively which have been implanted or affixed firmly to the thin film. At the vertical boundaries of each film segment 114 the strings 118 and 119 are extended free for about an inch or two (see FIGS. 10-11-12).

The apparatus 108 of FIG. 10 essentially consists of the two side walls 112 and transparent front and rear faces 120. Together, these four structural parts comprise a hollow rectangular prism open at the top and bottom. Cross braces 122 are mounted between the bottoms of front and rear faces 120 so that their top edges are just below the bottom level of strip 110, and their bottom edges are a few inches below the bottom edges of side walls 112 and front and rear faces 120. The cross braces hold the bottom edges of the walls, front and rear faces a few inches above a supporting surface 123.

The top and bottom edges of both side walls 112 each has a series (thus, four such series) of slits 124a to 124n, preferably cut one-fourth to one-half inch deep. The distance between the slits equals the incremental portion or riser 116 in the strip film 110 with which it is to be used. As shown in FIGS. 10-11-12, the increments or risers 116 are equal, and hence the distances between each adjacent pair of slits 124a to 124n are equal. Actually, however, the increments and slit spacings can be made to whatever scale desired, i.e., logarithmic, hyperbolic, etc. as well as uniform.

The film strip 110 that is to be exhibited is shown in top view in FIG. 12. Without some constraints on the strip its positioning is imperfect. This folded strip is inserted through the top so that it rests on braces 122. Both ends of strings 118a to 118n and 119a to 119n can be pressed through the four series of corresponding slits 124a to 124n. Each of the strings is then pulled taut separately so that they all rest on the bottoms of their slits, and so that all incremental portions 116 on one side of the strip are pulled against the left wall 112.

The distance between left and right walls 112 is slightly larger than the length of a surface segment 114. Each string can be held taut by fastening a metal or plastic clip to it close to the outer surfaces of the walls (not shown). The strings can also be held by winding their ends around tethering pins 121a to 121n. (The pins 121 below slits 124 on the other three edges of 108 are omitted in FIG. 10 not to obscure the principal features of the apparatus).

By pressing risers 116 against left side wall 112, makes this wall serve as a longitudinal reference. The line formed by the bottoms of the slits serves as a transverse reference so that all surface segments 114a to 114n of the film strip are aligned. When the strings are pulled and held taut their associated surface segments 114 are extended flat and held firmly in place.

In FIG. 10 the strip 110 is shown as fully occupying the apparatus 108; i.e., there are n sets of slits in which are situated n surface segments of film. However, it should be understood that a partial strip (one having less than n surface segments) may be exhibited, or several partial strips, the sum of whose sections are equal or less than n , can be exhibited together. Also, if desired, discrete or separate sheets 126 having dimensions and construction similar to surface segments 114 can be exhibited in apparatus 108. These discrete sheets can be made by eliminating incremental portions 116 from a strip 110, or they can be made anew. Another modification, illustrated in FIG. 13, is to assemble discrete sheets 126 by means of hinges 128 that are strips of transparent plastic with self-adhering (adhesive coated) edges. The non-adhering portion of hinge 128 serves as an incremental portion 116.

Referring to FIG. 14, film strip 110 is shown "fan folded" for flat storage in which each fold contains surface segment 114 and incremental portion 116. Another advantage of fan folding strip 110 is that easy access to any surface segment 114 (see FIG. 12) is provided.

Quite obviously, display apparatus 108 can be adapted with many elements similar to those described previously for apparatus 30 shown in FIG. 1. Apparatus 108 also is susceptible to a wide variety of modifications. For example, as shown by the simplified top view of apparatus 108 in FIG. 15 discrete sheets 126 may be suspended in a radial array. A pair of slits 130, one at the top and one at the bottom (not shown) center of the rear faces 120, together determine a reference axis O-O'. A series of slits 131 on the front face 120 are spaced by the tangent of the angle their associated sheet makes with the central section (marked "90°" in FIG. 15). Slits 130 are made larger than slits 124 since the former must accommodate many strings whereas the latter only holds one in each slit. Slits 124 in side walls 112 also have tangential spacings. However, if they had been made for a linear array with a close spacing, selected slits can give a useful approximation to a tangential spacing. The angular increment of the array shown in FIG. 15 is 10 degrees. Other angular increments can, of course, be used. (It should be understood that although only the top slits are shown in FIG. 15 there is a corresponding set of lower slits each aligned with an upper slit in a vertical plane.)

The radial array of sheets illustrated in FIG. 15, with their peripheral ends inscribing a semi-circle, is useful for the display of characteristics that are a function of angles, i.e. radar antenna patterns. The sheets 126 in

this form of display can be marked to give cylindrical or spherical coordinates. In FIG. 15, for example, a sheet 126A is shown marked with rectangular coordinates that begin at a reference edge that would fall along the O-O' reference line of the radial array, and thus give cylindrical coordinates in three dimension. Sheet 126B in FIG. 17 is similarly marked to give spherical coordinates in a radial array when its reference edge falls on the O-O' reference line.

The radial array of FIG. 15 covers a solid angle equivalent to a hemisphere. For some applications a 3D display with a radial array covering an entire sphere is desirable. One way to achieve this is by assembling two structures 108 so that they are fastened together with their transparent rear faces 120 back to back. Another way of achieving complete spherical coverage with a radial array is through beam 132 shown in FIG. 18. The length of that beam is equal to the interior width of apparatus 108, i.e., to the distance between left and right walls 112. Imbedded in the beam, and extending from both ends of it, are thin flexible steel strips 134. These strips are thin enough to pass through slits 124 of apparatus 108. In the center of the beam is a slit 136 similar to slit 130. Small holes 138 are provided for fastening strings 118.

A beam 132 can be mounted in the upper central slits 124 of apparatus 108, and another such beam can be mounted in the lower central slits 124, while their steel strips 134 rest in slits 124 and their slits 136 face outward. The steel strips 134 can be clamped close at the outer surfaces of walls 112 so that strips 134 are in tension and the two beams are rigidly fastened in apparatus 108. The beams 132 can be made thin, about one-eighth inch wide, but must be wider than the width of slit 124. Discrete sheets 126 can be mounted in a radial array similar to that of FIG. 15 except that the total angle around the array is now 360° instead of 180°, and the beam bisects the array. The depth of apparatus 108 so adapted must at least be as great as its width or the length of sheets 126 must be one-half the lesser dimension (width or depth) of apparatus 108, and radial slits 131 must be made on rear face 120 as well.

An optional choice is to replace strings 118 by plastic threads, thin wires, or any strong filament, for both transparent thin film strip 110 or discrete sheets 126, and used in about the same way as strings in apparatus 108.

The principle of support in the "suspended sheet" embodiments of apparatus 90 (FIG. 8) and 108 (FIG. 10) requires edged support of a segment of thin film in one dimension and extension of that segment in its other dimension by the forces suspending it. The principle of edge support in both dimensions of a sheet of thin film is demonstrated in FIG. 19 with "stack" 150. Frames 152a, 152b, 152c, 152d, etc. made of metal, plastic, paperboard, or cardboard of select thicknesses which are indicated by the letter designations. They are narrow structures circumscribing apertures 153 and can be made hollow or with bent edges to make them light and cheap.

The common surface of a pair of frames 152 forms a level in which a transparent sheet of thin film can be supported. These frames are stacked in a linear array 150. If there are n frames in the stack there are $n - 1$ paired surfaces between which $n - 1$ sheets of thin film can be supported. Any of the discrete sheets 46 described previously may be supported by these frames.

The nature of the sheet employed is adapted to the means of securing the "stack."

To support sheet film so that the sheets are flat and secure in position the frames 152 must press against each other firmly. There are various means for doing this. Strings or wires 156 can be passed around stack 150 and fastened to hold the stack firmly together. Notches 158 cut in the corners of frames 152 and notches 160 cut in the corners of film sheet 46D serve as guides for strings or wires 156, as well as built in reference features for marking and aligning. The width and length of sheet film 46D are the same as frames 152.

Stack 150 can also be held together and assembled in a stack holder 162. Holder 162 has apertures 164 at its front and back which have the same dimensions as the apertures 153 of frames 152. The top 166 is open. The other three walls may be continuous. The width of holder 162 is slightly greater than the width of the frames. Its height is less than that of a frame. Thus, a frame 152 inserted in holder 162 extends above top 166. This facilitates insertion and removal of the frame.

An entire stack 150 of frames 152 and sheets 46 can be inserted in holder 162, and by pressing the individual elements against bottom and left sides the stack can be aligned. The stack can then be pressed together by filling the rest of the holder with space frames (no film) and completing the assembly with a compressing frame (not shown) that has a sandwich construction of soft sponge rubber and two stiff, smooth metal or plastic surfaces. Holder 162 can then be used in any position desired and be provided with the features described above for holder 30.

The select thickness of frames allows a variable increment of any spacing between film sheets desired, and as well as any thickness of film desired. For extremely high resolution within such an array, sheet film can also be stacked continuously to any depth desired.

Indeed, a stack of sheets only, such as sheet 46D in FIG. 19, may be employed. Sheets 46D as shown are provided with notches 160 and are used in a similar manner as previously described for stack 150. Sheets 46E as shown are provided with punched holes 168 that serve as built in reference features for marking or aligning as well as assembly means that are more positive, i.e. for smooth rods closely fitting the punched holes 168 and bolted at the ends. The assembly of stacked sheets of thin film is well suited for the exhibition of displays of high resolution in depth. If 5 or 10 mil sheet film were used there would be a resolution of 200 or 100 lines to the inch, respectively. The borders 47D and 47E may be rendered non-transparent or can be colored to facilitate seeing, handling, and identification of the transparent sheets 46D and 46E respectively. The border can be applied to only one side of sheet and thus serve to identify its sides and to only one edge. A sheet identification number (indicated by reference character 51 in FIG. 19) may be marked on the border. The border can be coded by color and design to identify the nature and thickness of a sheet of film.

FIG. 20 illustrates a 3D pointer 175 for demonstrating features of interest at different levels of a 3d display. The pointer is made of a thin transparent plastic strip on which an arrow 177 has been drawn. The 3D

strip pointer 175 can be inserted in any selected level occupied by a thin transparent sheet 46 or not and manipulated so that the arrow points to any selected position on that level. The pointer can be used with the "open slot" and "suspended sheet" embodiments of this invention. Since the pointer reaches between sheets and to any point on a sheet there is full three dimensional control. Figures or symbols other than an arrow can be used, e.g., circles, squares, aircraft, ships, as well as alphanumeric for labelling, i.e. alphanumeric label 178. The 3D pointer can be clipped to an adjoining sheet, or otherwise fixed in position at a desired point. This frees the hands of a demonstrator and also allows the use of many such pointers in a single 3D display, an example of such use being the marking and identifying of positions of air craft for air traffic control.

A novel process for generating and exhibiting a three dimensional display is demonstrated in the flow diagram of FIG. 21. This process, 185 employing a computer and plotter, is merely illustrative of a wide range of means available for the conduct of a basic method. Program and data are fed from a source 186 over data path 187 to a computer 188. These program and data determine the nature of the markings to be made on a series of segments of thin transparent film. The computer 188 can be digital, analog, or hybrid. If the computer is analog or hybrid, programming constitutes connecting its operational units in a prescribed way. The computer 188 over a continuation of data path 187 controls the marking of film in X-Y plotter 189. The computer is shown directly connected to the plotter. However, it could be buffered by a magnetic tape recorder (not shown) or some other memory device. The plotter 189 is also fed film from a supply 190 over film flow path 191. The film can be in the form of sheets or strips. In either case the film is positioned in the plotter 189 so that the plotter markings are made with respect to reference features embodied in the sheets or strips, i.e., sheet edges or notches, strip perforations, etc. (or fiducial markings). After being marked the film continues on flow path 191 to a series store 192 where it is held available for display. The marked film continues on to insertion in a 3D display apparatus 193 of the kind described above. For exhibition in apparatus 193 the marked film is aligned in cooperation with the same reference features embodied in the film segments (or their fiducial markings) used in marking graphical data. After exhibition in apparatus 193 the marked film can be returned to store 192 by return path 191R, although exhibition in apparatus 193 may be indefinitely long. The part of the process immediately involving the apparatus 193 requires insertion and removal of marked film in interchange with store 192.

FIG. 21 by including another film path 194 illustrates the process 195 of 3D sketching and 3D display upgrading. This process 195 includes the basic process 185. In addition, marked film can be removed from 3D display apparatus 193 and returned by path 194 to the plotter 189. The plotter alters the markings on this returned film and again feeds the film forward by path 191 through store 192 to the apparatus 193. In 3D sketching a human operator 196 observes by visual path 197 the 3D display 193 and inputs through path 198 to source 186 those alterations he decides on. The new data he enters in support of his decision in source 186 will eventually produce new marking through plot-

ter 189. The operator can see the 3D display with substantial continuity. This helps the operator determine what alterations to make.

In 3D display upgrading, for example of a command control system, new information comes from the controlled system (not shown) to the source 186 to alter the 3D display as previously described.

The symbols in process 185 have been described for the most part as specific physical instruments, computer 188, X-Y, plotter 189, while source 186 could be any computer input device, i.e., teletypewriter, card reader, etc. The operations they perform can be assigned to a wide range of means. The operations performed, represented by symbols 186, 188 and 189, can be done by a single person and a drawing board. This could also be performed by a single source (electronic circuit) for 186 connected to an oscilloscope for 188, recorded by a camera for 189, that is supplied by photographic film by 190. They could also be performed by a physiological test animal for 186, being monitored by an instrument for 188, whose data is being received on a strip recorder 189.

The novel process for generating and exhibiting a three dimensional display that represents sections of an entity includes the steps set forth below. An entity is "a thing which has reality and distinctness of being either in fact or for thought." An entity "in fact" may be an object such as a machine part, a mountain, a microorganism, or scenes, such as, a landscape, a group of people, or a stage setting. An entity "for thought" may be graphs, geometrical curves, abstract designs, engineering and architectural designs using symbolic notations etc.

DISCRETE SHEET PROCESS

1A. A series of discrete thin transparent sheets that are marked so that each sheet is a sectional portion of an entity.

2A. The series of sheets marked according to step 1A are assembled by means described previously.

3A. The assembly of sheets formed according to steps 1A and 2A are illuminated for viewing as a 3D display.

4A. All the sheets of an assembly as formed in steps 1A, 2A and 3A can be removed from a given means and another series of sheets can be assembled therein to provide another 3D display.

STRIP PROCESS

1B. A strip of segments of thin transparent film, each connected to a next, is marked so that each segment is a sectional portion of an entity.

2B. The strip of segments marked according to step 1B is assembled in traverse folds back and forth by means described previously.

3B. The assembly of folds as formed according to steps 1B and 2B are illuminated for viewing as a 3D display.

4B. The folded strip as formed in steps 1B, 2B and 3B can be removed from a given means and another strip can be assembled in folds therein to provide another 3D display.

AUXILIARY PROCESSES

5. Any sheet in the assembly of discrete sheets as formed and exhibited in steps 1A to 4A can be removed, altered, and then reinserted in the assembly.

6. To the assembly of sheets or folds (segments) as formed in steps 1, 2 and 3 another sheet or series of sheets is added to alter or to superimpose a second display on the first.

7. To the assembly of sheets or folds (segments) as formed in steps 1, 2, 3 a pointer or alphanumeric tag is inserted into any select level and put to any select position therein for the unique identification of any location in all three dimensions of a 3D display.

8. A series of strips of segments of thin transparent film has corresponding segments marked according to step 1 to comprise a series for a corresponding entity and assembled and illuminated according to steps 2 and 3 in sequence by the movement in unison of the series of strips for a sequence of corresponding 3D displays.

9. To the assemblies of sheets or folds segments formed in steps 1, 2, 3 a surface display can be added so that the surface is perpendicular or oblique to the sheets or folds of the assembly and at their margins.

DETAILED DESCRIPTIONS

The steps and operations listed above in outline fashion are described below in more detail, each one keyed by number and letter to the steps above.

1A1. A series of discrete thin transparent sheets are marked so that each sheet is a sectional portion of an entity.

1A2. The sectional portions marked may be such as to form contours, profiles, or oblique sections, etc. Also these sectional portions can be geometrical sections or they can be sectional intervals. The first produces an assembly of lines that is useful for analysis. The second shows detailed information within an interval, i.e., between section levels. An assembly of sectional intervals can produce a quantized versimilitudinous reproduction of an object, etc., whose definition in depth is determined by the magnitude of the interval.

The correspondence of the marking of a sectional portion to an entity being represented can be a linear scale, 1 to 1 or 150 to 1, etc., or some non-linear mapping function, i.e. logarithmic for either dimension of a sheet. Also correspondence can be complete or selective as to detail. The correspondence of the intervals between sectional portions shown in the 3D displays of this invention and the intervals of the entity being represented can also be some linear scale or some non-linear function.

Further, correspondence of definition in depth, interval magnitude, and entity detail can be selective. This holds not only among 3D displays, but within a given display. The foreground of a scene may be given small intervals while the background may be given large intervals, i.e. by a non-linear perspective function.

1A3. The correspondence or the sequence of sections in an entity and the sequence of a marked series of transparent sheets can be maintained by the physical order of the sheets and by symbolic notation marked on each sheet. The notation can have arbitrary order, alphabetic or numeric. It may also be a measure of separation of the sections of the entity from a base level, and/or made to correspond to the notation of an index (such as index 50 in FIG. 2) on a display apparatus.

1A4. The marking of the transparent plastic sheets is an application of the graphic arts manually, or automatically by the extensive developments in reproduc-

tion methods, chemical and electronic photography, and XY plotters driven by computer control. The markings may be made by inks or paints of any color including black and white and that are opaque or translucent. The marking of the sheets also includes raising of portions of the sheet cameo or intaglio by the application of heat and pressure to those local portions. This can also be done manually or automatically. The depth of raising is limited by the interval being employed. Raising sheets can be displayed by the apparatus of this invention except for the "open slot" form shown in FIGS. 1 and 4.

1A5. The correspondence of the relative position of a series of sectional portions marked on a series of transparent sheets to each other in a display assembly and to the sections of an entity being represented is established in two operations. First, each, marked sectional portion is positioned along two axes of a sheet with respect to reference features embodied in the sheet and/or fiducial markings on the sheet. Second, the sheets are aligned, or held in relative position to each other, by engaging the said reference features embodied in the sheets with aligning means in a display assembly and/or by the fiducial markings.

The reference features embodied in a sheet can be the edges of a corner of an accurately cut rectangular sheet, i.e., in the sheet of FIG. 1 or any two non-parallel edges of, i.e., the bottom edge and leading edge 68 of a notch 70 in the sheet of FIG. 4, or the four notches 160, or the four holes 168 in the sheets of FIG. 19. The aligning means of the display assemblies employed with each of these sheet reference features were described previously. The location of marks on a sheet can be made by direct measurement to reference features embodied in a sheet or fiducial markings.

This method of alignment is general and can be applied to sheets of other shapes, i.e., circular (for disc recorders) or oval, etc. It may also be applied to a series of sheets not of the same size, i.e., changing progressively in size as a function of position in the series, or depth in a display.

Fiducial markings on a series of sheets may be of many forms along with the single form 45 shown in the drawings, i.e., concentric circles, crosses, etc. Also these fiducial marks may be positioned wherever is most convenient on the sheets and remain visible. They may be supplied in connection with the graphical data, i.e. as reference axes with graphs.

1A6. An intermediate reference surface having guides that accommodate the embodied reference features of a transparent sheet and/or its fiducial markings can be used to facilitate measurement, marking, and checking the marks on the said sheet. The guides may be marks or raised members. For guide marks, accommodation allows coincidence with the embodied reference features and/or fiducial markings of a sheet. For raised guide members, accommodation allows engaging said sheet reference features. In either case a sheet is uniquely positioned on said surface and measurements on the sheet can be made with facility from the reference surface.

This reference surface can be marked with axes, scales, grids, and drawings to further facilitate the marking of a sheet. The top layer of the reference surface may be a sheet of paper that may be removed upon the completion of the marking of a series, or a fraction thereof, of transparent sheets for composing a 3D display

and stored with them for checking and altering said sheets.

1B1. A strip of segments, each connected to a next, is marked so that each segment is a sectional portion of an entity. A strip of segments may be continuous strip of thin transparent plastic film with edge perforations (strip 80, FIG. 7) or a folded strip (strip 110, FIGS. 10, 11, 12 and 14). A strip of segments, as previously described, may be separate sheets attached to two long narrow perforated ribbons of metal or plastic to compose a strip similar to strip 80.

The marking of each segment of a strip is similar to marking of discrete or separate sheets as described above. The reference features embodied in the strip may be different, i.e. perforations 84, 85 of strip 80 in FIG. 7, or a bottom edge and a traversing foldable edge of strip 110 of FIG. 11. Also alternate segments of a strip must have its sectional portion drawn reverted with respect to the longitudinal axis of the strip or omitted for all marked sectional portions to have like orientation in display assembly. This operation of the process is described in detail above the strip 80 of FIG. 7. It is applicable to strip 110 and other similar strips. However, where a series of strips are used, each for a different level of a 3D display, as in auxiliary process (8) in list above and described below, reversion or omission of alternate sheets is not needed.

2A. The series of sheets marked according to step (1A) are assembled by means described previously as examples illustrating this step.

2B. The strip of sheets marked according to step (1B) is assembled in traverse folds back and forth by means previously described as examples illustrating this step.

3. The assembly of sheets or folds according to steps 1 and 2 are illuminated for viewing as a 3D display. The several means for illumination and of an assembly are described in connection with the "open slot" embodiment 30 of FIG. 1 and the "suspended sheet" embodiment 90 of FIG. 8. The principles of rear uniform diffuse illumination, passive and active illumination, etc. illustrated are applicable to the other forms of assembly disclosed herein.

4. All the sheets or a folded strip as formed in steps 1, 2, and 3 can be removed from a given means and another series of sheets or strip can be assembled therein to provide another 3D display. The sheets and strips can be conveniently stored in a volume approximately the bulk of the film sheets or strip and displayed again at a later time.

It is important to note that this step can be omitted. A 3D display comprising sheets or strip of this invention can be used indefinitely and on a continuing basis.

5. Any sheet in an assembly of discrete sheets as formed and exhibited in steps 1A to 3A can be removed, altered and then reinserted in the assembly. While a sheet has been removed for alteration the remaining sheets can be viewed. This process is useful for 3D sketching and for 3D control displays upgraded for new information.

This process can be adapted so that all information of a 3D display is subject to virtually continuous exhibition and upgrading. The information pertinent to each level can be recorded on two (or more) sheets or folds (segments).

The procedure is as follows:

- a. One of the sheets or strips is exhibited in a display assembly.
- b. The other sheet or strip is available for recording new information.
- c. After recording new information (and/or removing old data) on the second sheet or strip, the first sheet of a given level or the entire first strip is quickly removed, and the second sheet or strip quickly inserted.
- d. Now the second sheet or strip is similarly upgraded, and held available for further new data.
- e. The cycle is repeated as often as desired.
- f. In order to eliminate disturbance of viewing, the illumination of the 3D display can be extinguished during sheet change. By making this period very short, i.e. less than one-twentieth of a second, the change and extinction will not be perceived. To keep the number of sheet exchanges to a minimum, groups of upgraded sheets can be exchanged concurrently.

This process of upgrading may be performed by human operators, by machine, or a combination of both. While it can be performed with several forms of apparatus of this invention, those of FIG. 4 and FIG. 1 are especially adaptable. The dual openings in the apparatus of FIG. 4 make possible simultaneous insertion and removal during an exchange.

6. To the assembly of sheets or folds as formed in steps 1, 2, and 3 another sheet or series of sheets is added to alter or super impose a second display with the first. The sheet or series added can be inserted in display levels that are between levels occupied by the first series of sheets or folds. They can also be inserted so that they share given levels with the first series. In either case the first and second series are interleaved. The second method, the sharing of levels makes closer comparison, i.e., of intersections and locations possible. A single sheet, with a grid, for example, can be added to demonstrate position at a given level. A series of grid sheets could be added to demonstrate position at a given level. A series of grid sheets could be added to demonstrate position throughout the display space. The intersection of independent surfaces, i.e., a sphere and hyperboloids of revolution, can be demonstrated.

Any apparatus of this invention can be employed with this process. The "open slot" form of FIGS. 1, 4 and 6 make the insertion of a second series expeditious. As previously stated, for level sharing, the slots must be made wide enough to accommodate two or more thicknesses of plastic film. With the "open slot" form of FIG. 6, discrete sheets of a second series can be interleaved with the folds of strip 80. For level sharing in "suspended sheet" forms discrete sheets of a second series can be attached to sheets or folds of a first series.

7. To the assembly of sheets or folds as formed in steps 1, 2, 3 a pointer or alpha numeric tag is inserted into any select level and put to any select position therein for the unique identification of any location in all three dimensions of a 3D display. A pointer and alphanumeric or symbol tag are shown in FIG. 20.

8. A series of strips of segments of thin transparent film has corresponding segments marked according to step 1 to comprise a series for a corresponding entity and assembled and illuminated according to steps 2 and 3 in sequence by the movement in unison of the series

of strips for a sequence of corresponding 3D displays.

The corresponding segments may be all the first elements of the series of strips. They are marked to represent sectional portions of a first object. Their concurrent display exhibits a 3D representation of that first object. The movement of all the strips in unison brings all the second elements of the series of strips to a 3D display of a second object for which they were marked.

This movement of strips can be intermittent with display periods of any desired length of time, or it can be a slow continuous action. The movement of the strips in unison can be repeated (or continued) until all the series of corresponding segments have been displayed. This sequence of displays can be repeated in reverse order by reversing the motion of the strips. The cycle of forward and reverse motion can be repeated as desired. Each strip can have its ends sealed together to make a closed loop. A continued forward motion would then repeat the sequence of displays in the same order.

The several entities displayed can be parts of a single entity and each of the strips can be continuously marked to exhibit in 3D a continuous sequence of parts of that single entity. A panoramic view, for example, may be so displayed.

The apparatus of FIG. 4 is readily adaptable to this process. The series of strips entering the openings of slots 62 at one side can exit at the other. The apparatus of FIG. 10 can be adapted to this process. Cross braces 122 can be removed and apparatus 108 can be supported at side walls 112 so that the opening at bottom as well as the top is clear. A series of strips could then be moved vertically through apparatus 108.

9. To the assemblies of sheets or folds formed in steps 1, 2, 3 surface displays can be added so that the surfaces are perpendicular or oblique to the sheets or folds at their edges. The projection of an image, as shown in FIG. 5, on a flat inside surface 75 illustrates the process of combining such a surface display, the image, with the 3D display of a sequence of surfaces. This process is also illustrated by a previous description given with respect to FIGS. 8 and 9, a selected number of sheets perpendicular or oblique to the first set can be mounted. This can be done on a second set of beams or the members of frame 103. This second set of sheets can be transparent, diffusing translucent, or opaque.

I claim:

1. A process for producing a representation in three dimensional space of an entity which comprises the steps of, marking positively each of a series of segments of thin transparent film to correspond to each of a series of sectional portions of said entity so that similar markings on any segment in said series of segments have similar brightness, assembling said segments in association with display means in a sequence corresponding to the sequence of sectional portions of said entity and holding said segments flat, spaced apart, substantially smooth and parallel to each other in coaction with said display means, illuminating said sequence of segments with light transmitted through said segments from one end of said sequence from a diffuse substantially uniformly bright distributed light source at least coextensive in area with a segment at said one end of sequence, presenting the assembly of marks of said segments to be viewed from the other end of the sequence

by transmitted light from said source as a three dimensional reconstitution of said entity.

2. A process as described in claim 1 wherein said step of assembling said series of segments is reversible, whereby said segments can be removed from said display means and replaced by different series of segments for the display of different entities.

3. A process as described in claim 1 wherein said step of assembling said series of segments is reversible, and further including the steps of, removing select segments from said assembly, altering the markings on said select segments, reinserting said segments in said assembly, whereby alteration for correction of a three dimensional representation of an entity or adjustment to alteration of said entity can be effected.

4. A process for producing a representation in three dimensional space of an entity which comprises the steps of, marking each of a series of segments of thin transparent film with respect to prescribed fiducial markings similarly located on said segments to correspond to each of a series of sectional portions of said entity, assembling said series of segments in association with display means in a sequence corresponding to the sequence of sectional portions of said entity, and holding said segments substantially smooth, parallel to each other and spaced apart in correspondance in depth with said sectional portions and capable of transverse displacement, and the step of aligning each segment systematically and accurately by its fiducial markings with respect to said fiducial markings of other segments by displacement for optical coincidence whereby the assembly of marks on said series of segments can be exhibited as a three dimensional reconstitution of said entity systematically aligned independently of the nature of the subject markings.

5. A process as described in claim 4 wherein said step of assembling said series of segments is reversible, whereby said segments can be removed from said display means and replaced by different series of segments for the display of different entities.

6. A process as described in claim 4 further including the step of illuminating said series of assembled segments with diffuse substantially uniform light transmitted through said segments from one end of said series, whereby a graphical reconstitution in three dimensions of said entity can be systematically effected solely by said markings.

7. A process for producing a representation in three dimensional space of an entity which comprises the

steps of, marking each of a series of segments of thin transparent film with respect to prescribed reference features of said segments similarly located on said segments to correspond to each of a series of sectional portions of said entity, assembling said series of segments in association with display means in a sequence corresponding to the sequence of sectional portions of said entity, and holding said segments substantially smooth, parallel to each other and spaced apart in correspondence in depth with said sectional portions, and the step of aligning each segment systematically and accurately by its reference features with respect to said reference features of other segments by said reference features of the film segments engaging reference means of said display means.

8. A process as described in claim 7 wherein said step of marking said segments includes the step of positioning said segments on a reference surface with said reference features of segments engaging reference features of said surface, whereby drawings, grids, or scales on said reference surface facilitate the marking, checking, and sequential ordering of said segments.

9. A process as described in claim 7 further including the step of illuminating said sequence of parallel segments with light transmitted through said segments from one end of said sequence from a diffuse substantially uniformly bright distributed light source at least coextensive in area with a segment at said same end of said sequence.

10. A process as described in claim 9 wherein said series of segments are sequentially connected in a film strip, wherein said step of marking includes marking each of said segments with respect to said prescribed reference features to correspond to each of a series of sectional portions of said entity and in corresponding sequence with alternate sections marked to correspond to said sectional portions but reversed on the longitudinal axis of said strip, and wherein said assembling step includes folding said segments transversely back and forth into segmental folds, whereby the markings on all segmental folds have a common orientation.

11. A process as described in claim 9 further including the step of displaying graphical data on a surface positioned transversely to said parallel segments and proximate to their margins, whereby said graphical data complements the markings of the segments and provides a setting for the reconstituted entity.

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