

COMMONWEALTH OF AUSTRALIA
PATENTS ACT 1952-1969

Declaration In Support Of Convention Or
Non-Convention Application For A
Patent Or Patent Of Addition

(This declaration shall be made by the applicant, or, if the applicant is a body corporate, by a person authorized by the body corporate to make the declaration on its behalf).

In support of the Application made for a patent for an invention entitled METHOD OF AND SYSTEM FOR GENERATING IMAGES OF OBJECT TRANSFORMS.

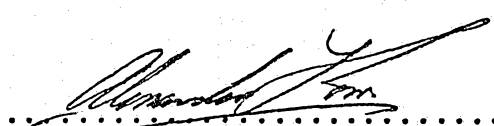
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do solemnly and sincerely declare as follows:

1. I am authorized by International Business Machines Corporation, the applicant for the patent to make this declaration on its behalf.
2. The basic application as defined by Section 141 of the Act was made in the United Kingdom on September 3, 1986 by International Business Machines Corporation.
3. (1) Peter Quarendon of Worsley Lodge, Braishfield, Romsey, Hampshire, S-51 0QF, United Kingdom and (2) Stephen James Paul Todd of 10 Christchurch Road, Winchester, Hampshire, S023 9SR, United Kingdom are the actual inventors of the invention and the facts upon which the applicant is entitled to make the application are as follows:

The said applicant is the assignee of the actual inventor, in respect of the invention.
4. The basic application referred to in paragraph 2 of this Declaration was the first application made in a Convention country in respect of the invention the subject of this application.

Declared at Markham, this 24th day of August, 1987.


.....
Alexander Kerr

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(19) AUSTRALIAN PATENT OFFICE (10) Acceptance No. 602002

(54) Title
GENERATING IMAGES OF OBJECT TRANSFORMS

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(56) Prior Art Documents
AU 600515 77796/87 G06K 9/46, G06F 15/72

(57) Claim

1. A method of generating, in a graphics processing system comprising storage means and processing means, a two-dimensional image of a three-dimensional solid object as viewed in a viewing direction from a viewing point, said image being made up of an array of image pixels, said method comprising:

storing a functional definition of said object in said storage means;

storing a functional definition of a three-dimensional box defining a viewing space in said storage means;

storing an inverse transform operator in said storage means, said operator being an inverse of a transform operator which would be used on said object in world space in order to present a transform of said object with respect to said viewing point and direction within said box in said viewing space;

then:

creating sub-boxes by subdividing said three-dimensional box;

(11) AU-B-77797/87
(10) 602002

-2-

performing inverse transform operations on said sub-boxes using said inverse transform operator and said stored functional definition of a three-dimensional box to generate test-cells in object space;

and comparing each test-cell so generated with the functional definition of the object in said object space to determine whether said test-cell intersects said object,

the steps of creating sub-boxes, performing inverse transform operations and comparing tests cells to the functional definition of the object continuing until rows of sub-boxes are generated having a frontal area corresponding to a desired resolution;

determining for each row of sub-boxes in said viewing direction having said desired resolution, the sub-box nearest to said viewing point for which the corresponding test cell intersects the object;

storing a setting of colour and intensity for each said row in dependence upon the determination of said nearest sub-box for that row;

whereby a two-dimensional image of said solid object is generated without transforming said object.

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COMMONWEALTH OF AUSTRALIA

PATENT ACT 1952

COMPLETE SPECIFICATION

(ORIGINAL)

FOR OFFICE USE

CLASS

INT. CLASS

Application Number:
Lodged:

Complete Specification Lodged:
Accepted:
Published:

Priority:

Related Art:

This document contains the
amendments made under
Section 49 and is correct for
printing.

NAME OF APPLICANT: INTERNATIONAL BUSINESS MACHINES CORPORATION

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COMPLETE SPECIFICATION FOR THE INVENTION ENTITLED:

"METHOD OF AND SYSTEM FOR GENERATING IMAGES OF OBJECT TRANSFORMS"

The following statement is a full description of this invention,
including the best method of performing it known to us :-

METHOD OF AND SYSTEM FOR GENERATING IMAGES OF OBJECT TRANSFORMS

The present invention relates to a method of generating two-dimensional images of three-dimensional solid objects in a graphics processing system and to a graphics processing system for performing such a method.

5 Objects may be represented in a graphics processing systems using various techniques. One which is particularly suitable for representing solid objects is "Constructive Solid Geometry" (CSG). In accordance with this technique a three-dimensional (3-D) solid object is represented by a functional definition identifying the set of points
10 which lie within the object. Typically, the object is defined by a Boolean function which returns a "true" if applied to a point within the object and returns a "false" otherwise. This technique contrasts with, for example, line drawing techniques where the edges and surfaces of an object are defined rather than its volume.

15 The functional definition or representation of an object effectively defines the set of points which make up the object. The functional definition of a sphere, for example, defines the set of points lying within a given radius of a centre point. Composite objects are defined by combining the functional definitions of constituent basic objects, or
20 "primitives", eg spheres, infinite planes, infinite cylinders. The functional definition of a dumb-bell, for example, comprises the functional definition of each of two spheres at different positions, the functional definition of an infinite cylinder whose axis passes through the centres of the spheres, and the functional definition of two planar
25 half-spaces which truncate the cylinder at the spheres. The functional definitions of the spheres, the cylinder and the half-spaces are combined using combinational operators such as the set union and intersection operators (ie using set theory principles). Primitives can also be combined using set subtracting operators to define, for example,
30 a composite object with a cut-out or hole. In this way hollow composite objects can be defined by subtracting a smaller object from a larger one. Such composite objects are still "solid" within the meaning of this application because the individual object definitions which make up the composite object are solid.

5 A composite object formed from primitives can be structured in a number of ways. However it is usual to use a tree structure with the composite object defined at the root of the tree, the primitives defined at the leaves and operators defining the combinational operations to be performed to construct the object from the primitives stored at nodes in the tree.

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Their method of producing a 2-D perspective view of a 3-D solid object, which employs spatial sub-division, can be summarised as follows:

5 The object in question is transformed into perspective space. This perspective representation of the object is then enclosed in a three-dimensional rectangular box. A test is made to find whether the box intersects this object. If it does the box is subdivided into eight equal sub-boxes, dividing each square face into four smaller rectangles. These smaller rectangular boxes are then tested in turn and any of which are empty are discarded. Those which contain part of the object are kept and subdivided again and the process is repeated until the
10 rectangular boxes are sufficiently small to correspond with single screen pixels. These pixels are then coloured appropriately on the screen.

This prior method works well in principle, as long as the object can be easily transformed into perspective space - if the object has, for example, flat surfaces. In the case of objects such as conical, spherical or cylindrical surfaces, the functional definitions of the object in perspective space rapidly become so complex as to be impractical to manage using the prior approach, especially in the
20 case of composite objects (eg complex molecules) which are made up of many such shapes.

The present invention overcomes the disadvantages of prior approaches to generating two-dimensional images of transforms of three-dimensional solid objects in a graphics processing system by avoiding the need to
30 transform the object per se.



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2 In accordance with the present invention there is provided a
3 method of generating, in a graphics processing system
4 comprising storage means and processing means, a two-
5 dimensional image of a three-dimensional solid object as
6 viewed in a viewing direction from a viewing point, said
7 image being made up of an array of image pixels, said method
8 comprising:

9 storing a functional definition of said object in said
10 storage means;

11 storing a functional definition of a three-dimensional
12 box defining a viewing space in said storage means;

13 storing an inverse transform operator in said storage
14 means, said operator being an inverse of a transform
15 operator which would be used on said object in world space
16 in order to present a transform of said object with respect
17 to said viewing point and direction within said box in
18 viewing space;

19 then:

20 creating sub-boxes by subdividing said three-
21 dimensional box;

22 performing inverse transform operations on said sub-
23 boxes using said inverse transform operator and said stored
24 functional definition of a three-dimensional box to generate
25 test-cells in object space;

26 and comparing each test-cell so generated with the
27 functional definition of the object in said object space to
28 determine whether said test-cell intersects said object,

29 the steps of creating sub-boxes, performing inverse
30 transforms operations and comparing tests cells to the
31 functional definition of the object continuing until rows of
32 sub-boxes are generated having a frontal area corresponding
33 to a desired resolution;

34 determining for each row of sub-boxes in said viewing
35 direction having said desired resolution, the sub-box
36 nearest to said viewing point for which the corresponding
37 test cell intersects the object;



1 storing a setting of colour and intensity for each said
2 row in dependence upon the determination of said nearest
3 sub-box for that row;

4 whereby a two-dimensional image of said solid object is
5 generated without transforming said object.

6
7 The present invention also provides a method of
8 generating image signals representative of a two-dimensional
9 image of a three-dimensional solid object as viewed in a
10 viewing direction from a viewing point, said image signals
11 corresponding to an array of image pixels, said method
12 comprising:

13 accessing object signals, representative of a
14 functional definition of said object, stored in storage
15 means of a graphics processing system;

16 accessing box signals, representative of a functional
17 definition of a three-dimensional box defining a viewing
18 space, stored in said storage means;

19 accessing inverse operator signals, representative of
20 an inverse transform operator, stored in said storage means,
21 said operator being an inverse of a transform operator which
22 would be used on said object in world space in order to
23 present a transform of said object with respect to said
24 viewing point and direction within said box in said viewing
25 space;

26 generating sub-box signals representative of sub-boxes
27 by performing a subdividing operation on said box signals so
28 said sub-boxes are subdivisions of said three-dimensional
29 box;

30 executing inverse transform operations on said sub-box
31 signals based on said inverse operator signals and said box
32 signals to generate test-cell signals representative of
33 respective test-cells in object space;

34 and comparing said test-cell signals with said object
35 signals to determine whether the respective test-cell
intersect said object,

the steps of generating sub-box signals, executing said



1 inverse transform operations and comparing said tests cell
2 signals with said object signals continuing until said sub-
3 box signals represents rows of sub-boxes having a frontal
4 area corresponding to a desired resolution;

5 determining, on the basis of said sub-box, test-cell
6 and object signals, for each row of sub-boxes in said
7 viewing direction having said desired resolution, the sub-
8 box nearest to said viewing point for which the
9 corresponding test-cells intersect the object;

10 generating and storing image signals representative of
11 a setting of colour and intensity for each said row
12 depending upon the determination of said nearest sub-box for
13 that row;

14 whereby said image signals represent said two-
15 dimensional image of said solid object and are generated
16 without transforming said object signals.

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The present invention, therefore, avoids the need to transform the object by performing an inverse transform on space instead.

5 Australian Application No 77796/87, co-pending, of even date, relates to a method of generating a spatial representation of a three-dimensional solid object and a system for performing such a method. The spatial representation referred to could be an image of the object, but could also relate to the
 10 spatial distribution of the object per se. Moreover, the co-pending application is concerned with the generation of such representations of objects which cannot be defined directly in terms of simple object primitives. In contradistinction thereto, the
 15 present invention is solely concerned with generating two-dimensional representations of the transforms of objects.

The present invention will be particularly described with reference to the attached drawings of which:

20 Figures 1A, 1B and 1C are illustrations of a dumb-bell, a tree structure for defining the dumb-bell, and a spatial sub-division method for evaluating the object respectively;

25 Figures 2A and 2B are schematic diagrams illustrating the prior art approach to generating a perspective view of a solid object;

Figures 3A and 3B are schematic diagrams illustrating the approach adopted by the present invention to generate a perspective view; and



Figure 4 is a schematic block diagram showing the interrelationship between logical and storage units of part of a graphics processing system.

5 Before describing the present invention in detail it is perhaps useful to discuss the principles of evaluating a functional definition of an object using CSG.

10 In general terms, the evaluation of a solid model is the process of determining the inside and outside and thus the boundaries of the solid. The most common use of the evaluation process is to draw a 2-D picture of the object. In general, it is also possible to compute the mass properties such as volume or centre of gravity, to determine the surface area of the object, and so on, but the present invention is not concerned with such other applications.

15 Conventionally an object is defined in accordance with the principles of constructive solid geometry in terms of a tree structure such as that shown in Figure 1B.

20 Figure 1A is an illustration of a dumb-bell 10 such as that mentioned earlier. Figure 1B illustrates a tree structure 20 for defining the dumb-bell. A practical implementation of this could be a linked-list storage structure. Different element types could be included in the linked-list to identify combination of operators, functional definitions etc. Mathematically, the definition of
 25 the dumb-bell could be expressed as
 30

$$\text{Dumb-bell} = A+B+C*D*E$$



Where "*" is the mathematical union operator shown as "AND" in Fig. 1B, "+" is the mathematical intersection operator shown as "OR" in Fig. 1B and A, B, C, D and E are the mathematical expressions for the sphere A, the sphere B, the infinite cylinder C, the half space D to the right of the line 12 and the half-space E to the left of the line 14. The corresponding functional definitions for the primitives A, B, C, D and E are located at the leaves 22a, 22b, 22c, 22d and 22e respectively in the tree structure 20.

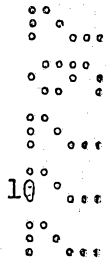
In order to perform calculations based on such a definition it is usual to employ a spatial sub-division technique, as illustrated below with reference to Figure 1C.



The basic method of spatial sub-division is as follows:

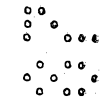
A region of space 30 is considered containing the object to be evaluated. The constructive solid geometry expression 20, or functional definition, which defines the object is inspected and simplified within this region of space. The simplification is not valid everywhere, but is equivalent to the original object within the region under consideration. The simplification procedure is:

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1. For primitive objects, determine whether the object is completely outside the cube of space. If it is, replace the object by an EMPTY object, one which has no inside. Also determine whether the object completely encompasses the region of space. If this is so, replace the object by a FULL object - one which has no outside.

10



2. For compound objects made by applying set operators, recursively apply (essentially three-valued) Boolean logic to the simplified operands. For example:

15

EMPTY	UNION expression2	->	expression2
expression1	UNION EMPTY	->	expression1
FULL	UNION expression2	->	FULL
expression1	UNION FULL	->	FULL

20

and

EMPTY	INTERSECT expression 2	->	EMPTY
expression1	INTERSECT empty	->	EMPTY
FULL	INTERSECT expression2	->	expression2
expression1	INTERSECT FULL	->	expression1

25

If the result of this simplification is EMPTY, the object has no inside within the region under consideration. If a picture is being drawn, this region will make no contribution to the screen image. (NB: If mass properties note being computed, the region would make no contribution to the volume or moment.)

If the result of the simplification is FULL, the region is completely occupied by the object. When constructing a picture from one view, this region will not contribute to the image as it does not contain a surface facing the viewer, and the inside of an object is hidden by its surfaces. (NB: For mass properties, the entire region would contribute to the volume or moment being computed.)

Normally, the expression will contain at least one term. In some circumstances, the expression will be sufficiently simple to be treated directly. For instance it may be a single planar half-space. The contribution to the picture or mass property of the total object can be computed directly. In order to proceed in other cases, the region of space is divided into smaller regions. Most simply, it could be divided in half perpendicular to its longest dimension. However, in Figure 1C the space 30 is shown divided into 8 smaller regions 31, 32, 33, 34, 35, 36, 37, 38. The simplification process is then repeated on these new regions until expressions such as FULL, EMPTY or other simple cases are obtained.

Eventually, some lower limit on the size of regions is reached and still some regions contain non-simple expressions. When drawing a picture, the convenient stopping point is when regions are smaller than a single pixel. At this stage, regions which contain a single object will contain a pixel-sized surface of the object. Regions containing two objects will contain an edge where the two surfaces meet and regions containing three objects will normally contain a vertex.

When drawing a picture, the surface or edge is drawn. For a surface, the normal to the surface is computed at the centre of the region of space and this is used, in conjunction with the known positions of light sources to compute the amount of light reflected from that point toward the viewer. For a more complex edge or vertex region, a ray-tracing method can be used to isolate one visible surface to be treated in this way. (NB: When computing mass properties, the cell could simply be assumed to be half-full.)

5 When generating a 2-D image of the solid object, it is sometimes necessary to produce an image based on some transform of an object. Most commonly it is desired to produce an image of the object in true perspective. In this case the transform concerned is a perspective transform.

The following description of the invention is concerned with the generation of a 2-D perspective image. It should however be understood that the invention applies equally to generating images based on other transforms, eg to simulate distortions of an object.

10 Figures 2A and 2B illustrate how such a perspective image would be produced using the teaching of the prior art.

15 Figure 2A represents the cylinder 46 within a region of space 44 shaped as a truncated pyramid, which illustrates the extent of space seen by a viewer looking through a window 40 located coextensive with the front surface 42 of the truncated pyramid. Conventionally, in order to produce a 2-D perspective image, the object is transformed into perspective viewing (transform) space such that the region of space within the truncated pyramid 44 is contained within a rectangular box 48 as shown in Figure 2B. The distorted object 50 is then evaluated by applying the spatial sub-division method discussed earlier.

20 However, as has already been mentioned, although this approach works in theory, it is impractical for a large set of objects and/or transformations because of the complexity of the transformed functional definitions. The present invention avoids the need for transforming the objects themselves by transforming space instead, and therefore allows a much greater range of objects and transformations to be evaluated.

25 Although for ease of representation and understanding, only the generation of the 2-D perspective image of a cylinder is illustrated, it should be understood that the object would normally be of a high degree of complexity, much higher, even, than that of the dumb-bell shown in Figure 1A.

5 The or each component primitive of the object is in fact retained in its own coordinate system, and is tested against regions of space in that coordinate system. The functional definition of box 48, eg a rectangular box, is established which defines the perspective viewing space into which the object would conventionally have been transformed. However, rather than transforming the object as taught by the prior art, the rectangular box is instead transformed through the inverse of the transformation which would conventionally have been performed to provide, in the case of the perspective transformation, a truncated pyramid 44. If then, the rectangular box in perspective viewing space is subjected to the sub-division algorithm discussed above, but with the inverse transforms of the sub-boxes created being tested for intersection with the primitive(s) making up the object, the need to transform the object itself is eliminated.

15 The sub-division algorithm is not affected in any material way if the region of space considered is larger by some factor than it should be. All that will happen is that the expression resulting from the simplification will sometimes contain terms which, strictly speaking, could be eliminated. Provided the error is reduced as the regions under consideration get smaller, these redundant terms will be eliminated later in the evaluation. Efficiency will be reduced and it may be necessary to continue evaluation to a smaller minimum region-size but the sub-division algorithm continues to operate correctly.

20 The method of generating a two dimensional perspective image of a cylinder using the teaching of the present invention will now be illustrated with reference to Figures 3A, 3B and 4.

25 Figure 4 shows the functional elements of a graphics processing system which are relevant to the explanation of this method.

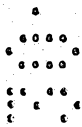
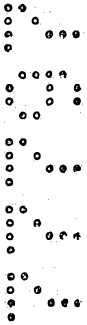
These functional elements could be implemented by suitably programming a conventional programmable graphics processing system. Alternatively, the functional units shown in the figure could be provided as separate hardwired circuits in a graphics processing system. Conventionally a graphics processing system will comprise storage and processing means and means for the input of data (eg a keyboard) and for the output of data (eg a cathode ray tube display device).

Firstly, a functional definition of the object to be transformed - in this case a cylinder 46 - is stored in object definition storage 72. In the case of a composite object a tree structure of the type described with reference to Figure 1B would be stored in the object definition storage.

A functional definition of a box 48 is stored in viewing space definition storage 54. In this case the box is rectangular. It could however take any other suitable form, eg that of a cylinder. The functional definition could also take any suitable form. One possibility would be a tree structure in the form of a linked list. The definition of a rectangular box could then take the form of the intersection of six planar half-spaces. Another possibility for a cube would be to identify the centre and to define the vector from that centre to one corner of the cube. The box 48 is defined in perspective transform space with respect to the intended viewing point and viewing direction. Conveniently, one of the axes of the box can be aligned parallel to the intended viewing direction so that the front surface 52 of the box is normal to the viewing direction.



5 An inverse transform operator is stored in inverse transform operator storage 56. In this case the operator is an inverse perspective transform operator, that is the inverse of the perspective transform operator which would be needed to transform the object stored in definition storage into the rectangular box 48 in perspective viewing space so as to create the intended functional representation of the object.



5 Then the control logic 58 causes the box/sub-box definition logic 60 to select the rectangular box for comparison against the object. The inverse transform logic 62 performs an inverse transform operation on the rectangular box using the inverse transform operator. The resulting truncated pyramid 44 (in the case of the inverse of the transform shown in Figure 2) can then either be passed by the test-cell generation logic 64 directly to the comparison logic 66, or, as will be described later, a simplified test-cell can be generated from the inverse transform of the rectangular box (or sub-box) by the logic 64 and this passed to the comparison logic 66.

10 The object and the test-cell functional definitions are tested for intersection by being compared in the comparison logic 66 and an essentially three-valued Boolean comparison output generated as described earlier - ie FULL, EMPTY or partly filled. The output of the comparison logic is passed to the control logic 58 and to the object simplification logic 68.

15 The control logic reacts in one of a number of ways dependent on the result of the comparison

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- 20 i) In the case where an intersection is detected and the box or sub-box under consideration has a frontal area which is larger than a desired resolution, then the control logic causes the box/sub-box subdivision logic to divide the box or sub-box under consideration into a number, for example, eight smaller sub-boxes for evaluation in order in the next stage.
- 25 ii) In the case where an intersection is detected and the size of the box or sub-box under consideration has a frontal area which corresponds to the desired resolution, then this fact is stored in the result storage 70.

iii) If there is no intersection, then examination of the box or sub-box under consideration is terminated and this fact is recorded.

5 A pixel map of the image can thereby be built up in the results storage
70 by the control logic 58. Conveniently, a rectangular box is arranged
with respect to the intended viewing point such that one of its axes is
parallel to the viewing direction, and the sub-division process is
arranged to examine rows of sub-boxes parallel to that viewing direction
in making up the image. Each pixel on the image can then be arranged to
10 correspond to a row of sub-boxes having a frontal area corresponding to
the size of a pixel parallel to the viewing direction. This arrangement
is not, however, essential, and other shapes and orientations of the box
are possible, particularly if it is desired to generate unusual views
(distortions, stereo views etc) of the object. The control logic will
15 be arranged to cause sub-boxes which are nearer to the front of the
object, as seen in the intended image, to be processed before those
further away, so that the front surfaces of the object may be
determined. Where a pixel-sized sub-box in a row (ie a sub-box whose
frontal area approximates the size of a pixel) is found whose
20 corresponding test-cell intersects the object, sub-boxes in that row
further from the front of the object need not then be considered. The
control logic maintains a record of the progress of the sub-division
process. This record could be in the form of a tree-structured record,
a bit-map, or any other suitable form.

25 When the front surface of the object has been detected, the required
colour and/or intensity of the pixel concerned can be determined using,
for example, a ray-tracing technique. The vector representing the
normal to the surface of the object in any test-cell can be computed
from the functional representation of the object. By comparing the
30 transformed vector against one or more vectors representing
light-sources, the colour and or intensity of the pixel corresponding to
that test-cell can be determined.

5 The object simplification logic 68 is used to generate a simplified functional definition in the case where the object to be transformed is formed from a plurality of primitives. After one or more sub-divisions of the rectangular box, the output of the comparison logic may show that the test-cell does not intersect one or more of the primitives in the object. In this case, on further sub-divisions of that region of the rectangular box, the functional definitions of these primitives need not be compared against the test-cells for that sub-divided region. The object simplification logic selects those parts of the functional definition of the whole object which are relevant at any stage dependent on the results of previous comparison operations. This is achieved by traversing the structure stored in the object definition storage.

10
15 The test-cells can be formed by the functional definitions of the inverse transforms of the sub-boxes. This is not, however, essential. The inverse transform of a sub-box could instead be replaced by a simple 3-D volume centred on and circumscribing that inverse transform. By a "simple 3-D volume" is meant a volume such as a sphere, a rectangular box or an ellipsoid. This is because any part of the object which intersects the inverse transform of the sub-box will also intersect the circumscribing volume centred on that transform. If a simplified test-cell is used, this would be generated by the test-cell generation logic 64 by determining the centre of the transform of the box or sub-box and defining the circumscribing simple 3-D volume around the transform, the only effect on the method might be that a further stage of sub-division may be necessary in order to achieve the same resolution as would be achieved with the inverse transform itself as the test-cell.

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30 In order to minimise the degree of mismatch between the test-cell and the transform of the sub-boxes, the lengths of the sub-boxes in the viewing direction and the test-cells used should be chosen so that the test-cell approximates the shape and size of the transform of the sub-boxes. By degree of match is meant the degree to which the transform and the test-cell are co-extensive. This can be achieved by

choosing the depth of the transform of such sub-box to correspond generally to its width and height. Thus all the transforms of the sub-boxes in any particular row will have the same shape although
5 their size will change.

Although specific features of an embodiment of the invention are described in the foregoing, it should be understood that modifications will be obvious to the skilled person. Also, for ease of illustration only relatively simple objects and transforms have been illustrated. However, it should be understood that the present invention allows objects and transforms of high complexity to be treated.

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2 THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

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4 1. A method of generating, in a graphics processing system
5 comprising storage means and processing means, a two-
6 dimensional image of a three-dimensional solid object as
7 viewed in a viewing direction from a viewing point, said
8 image being made up of an array of image pixels, said method
9 comprising:

10 storing a functional definition of said object in said
11 storage means;

12 storing a functional definition of a three-dimensional
13 box defining a viewing space in said storage means;

14 storing an inverse transform operator in said storage
15 means, said operator being an inverse of a transform
16 operator which would be used on said object in world space
17 in order to present a transform of said object with respect
18 to said viewing point and direction within said box in said
19 viewing space;

20 then:

21 creating sub-boxes by subdividing said three-
22 dimensional box;

23 performing inverse transform operations on said sub-
24 boxes using said inverse transform operator and said stored
25 functional definition of a three-dimensional box to generate
26 test-cells in object space;

27 and comparing each test-cell so generated with the
28 functional definition of the object in said object space to
29 determine whether said test-cell intersects said object,

30 the steps of creating sub-boxes, performing inverse
31 transform operations and comparing tests cells to the
32 functional definition of the object continuing until rows of
33 sub-boxes are generated having a frontal area corresponding
34 to a desired resolution;

35 determining for each row of sub-boxes in said viewing
direction having said desired resolution, the sub-box
nearest to said viewing point for which the corresponding



1 test cell intersects the object;
2 storing a setting of colour and intensity for each said
3 row in dependence upon the determination of said nearest
4 sub-box for that row;

5 whereby a two-dimensional image of said solid object is
6 generated without transforming said object.

7
8 2. A method according to claim 1 wherein said desired
9 resolution corresponds to the pixel resolution of said
10 image.

11
12 3. A method according to either claim 1 or claim 2 wherein
13 said two-dimensional image is a two-dimensional perspective
14 image of said three-dimensional solid object and said three-
15 dimensional box defines a perspective viewing space and said
16 inverse transform operator is an inverse perspective
17 transform operator.

18
19 4. A method according to any one of the preceding claims
20 wherein said steps of creating rows of sub-boxes, performing
21 inverse transform operations and comparing test-cells are
22 performed recursively as a plurality of stages where, at
23 each stage, the test-cell corresponding to the bus-box being
24 considered is tested for intersection with said object and,
25 when an intersection is detected, the creation of sub-boxes
26 by subdividing is terminated where the frontal area of the
27 compared bus-box corresponds to said desired resolution and,
28 if said resolution has not been reached, further subdividing
29 said sub-box and, where an intersection with the object is
30 not found, terminating the creation of any further sub-
31 division of the compared sub-box.

32
33 5. A method according to claim 4 wherein sub-boxes nearer
34 said viewing point are compared before sub-boxes more remote
from said viewing point.

35 A method according to any one of the preceding claims



1 wherein said step of performing inverse transform operations
2 comprises determining a predetermined point of the
3 transformed sub-box under consideration and defining a
4 simple three-dimensional volume in viewing space about said
5 point, said volume fully containing said transformed sub-box
6 to thereby form said test-cell for said sub-box under
7 consideration.

8

9 7. A method according to claim 6 wherein each sub-box is
10 of a length which optimizes a match between said inverse
11 transform of said sub-box and said simple three-dimensional
12 volume.

13

14 8. A method according to any one of the preceding claims
15 wherein said storing of said setting comprises comparing a
16 vector representing a normal to a surface of said object
17 within a test-cell with at least one vector representing a
18 light source.

19

20 9. A method according to any one of the preceding claims
21 wherein said steps of comparing test-cells with said
22 functional definition of the object comprises a step of
23 testing for an intersection between the test-cell and a
24 simplified functional representation of said object, said
25 simplified representation being determined from previous
26 intersection test operations.

27

28 10. A method of generating image signals representative of
29 a two-dimensional image of a three-dimensional solid object
30 as viewed in a viewing direction from a viewing point, said
31 image signals corresponding to an array of image pixels,
32 said method comprising:

33 accessing object signals, representative of a
34 functional definition of said object, stored in storage
35 means of a graphics processing system;

36 accessing box signals, representative of a functional
37 definition of a three-dimensional box defining a viewing
38



1 space, stored in said storage means;

2 accessing inverse operator signals, representative of
3 an inverse transform operator, stored in said storage means,
4 said operator being an inverse of a transform operator which
5 would be used on said object in world space in order to
6 present a transform of said object with respect to said
7 viewing point and direction within said box in said viewing
8 space;

9 generating sub-box signals representative of sub-boxes
10 by performing a subdividing operation on said box signals so
11 said sub-boxes are subdivisions of said three-dimensional
12 box;

13 executing inverse transform operations on said sub-box
14 signals based on said inverse operator signals and said box
15 signals to generate test-cell signals representative of
16 respective test-cells in object space;

17 and comparing said test-cell signals with said object
18 signals to determine whether the respective test-cell
19 intersect said object,

20 the steps of generating sub-box signals, executing said
21 inverse transform operations and comparing said tests cell
22 signals with said object signals continuing until said sub-
23 box signals represents rows of sub-boxes having a frontal
24 area corresponding to a desired resolution;

25 determining, on the basis of said sub-box, test-cell
26 and object signals, for each row of sub-boxes in said
27 viewing direction having said desired resolution, the sub-
28 box nearest to said viewing point for which the
29 corresponding test-cells intersect the object;

30 generating and storing image signals representative of
31 a setting of colour and intensity for each said row
32 depending upon the determination of said nearest sub-box for
33 that row;

34 whereby said image signals represent said two-
35 dimensional image of said solid object and are generated
36 without transforming said object signals.



1 11. A method according to claim 10 wherein said desired
2 resolution corresponds to the pixel resolution of said
3 image.

4

5 12. A method according to either claim 10 or claim 11
6 wherein said two-dimensional image is a two-dimensional
7 perspective image of said three-dimensional solid object and
8 said three-dimensional box defines a perspective viewing
9 space and said inverse transform operator is an inverse
10 perspective transform operator.

11

12 13. A method according to any one of the preceding claims
13 wherein said steps of generating said sub-box signals
14 representative of rows of sub-boxes, executing said inverse
15 transform operations and comparing said test-cell signals
16 are performed recursively as a plurality of stages where, at
17 each stage, the test-cell signals corresponding to the sub-
18 box signals considered are tested for intersection of the
19 respective test-cell with said object and, when an
20 intersection is detected, the generation of further sub-box
21 signals by subdividing is terminated where the frontal area
22 of the compared sub-box signals correspond to said desired
23 resolution and, if said resolution has not been reached,
24 further subdividing the compared sub-box signals is
25 performed and, where an intersection with the object is not
26 found, further sub-dividing of the compared sub-box signals
27 is terminated.

28

29 14. A method according to claim 13 wherein the signals of
30 sub-boxes nearer said viewing point are compared before the
31 signals of sub-boxes more remote from said viewing point.

32

33 15. A method according to any one of the preceding claims
34 wherein said step of executing said inverse transform
35 operations comprises determining a predetermined point of
36 the transformed sub-box under consideration and generating
37 signals representative of a simple three-dimensional volume



1 in viewing space about said point, said volume fully
2 containing said transformed sub-box to thereby form said
3 test-cell for said sub-box under consideration.

4

5 16. A method according to claim 15 wherein each sub-box is
6 of a length which optimizes a match between transformed sub-
7 boxes and said simple three-dimensional volume.

8

9 17. A method according to any one of the preceding claims
10 wherein said generating and storing of said image signals
11 comprises comparing a vector representing a normal to a
12 surface of said object within a test-cell with at least one
13 vector representing a light source.

14

15 18. A method according to any one of the preceding claims
16 wherein said step of comparing said test-cell signals with
17 said object signals comprises a step of testing for an
18 intersection between the respective test-cell and a
19 simplified functional representation of said object, said
20 simplified representation being determined from previous
21 intersection test operations.

22

23 19. A method of generating a two-dimensional image of a
24 solid object in a graphics processing system substantially
25 as hereinbefore described with reference to the accompanying
26 drawings.

27

28

29

30

31

32 DATED this 26th day of June, 1990.

33

34 INTERNATIONAL BUSINESS MACHINES CORPORATION

35 By their Patent Attorneys

36 DAVIES & COLLISON

37

38



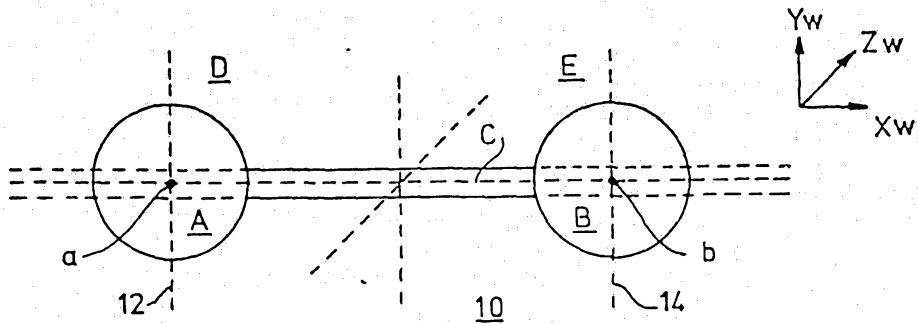


FIG. 1A

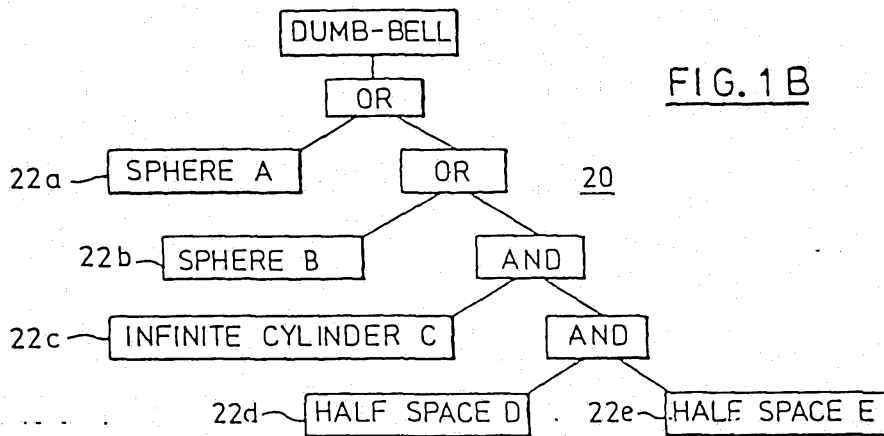


FIG. 1B

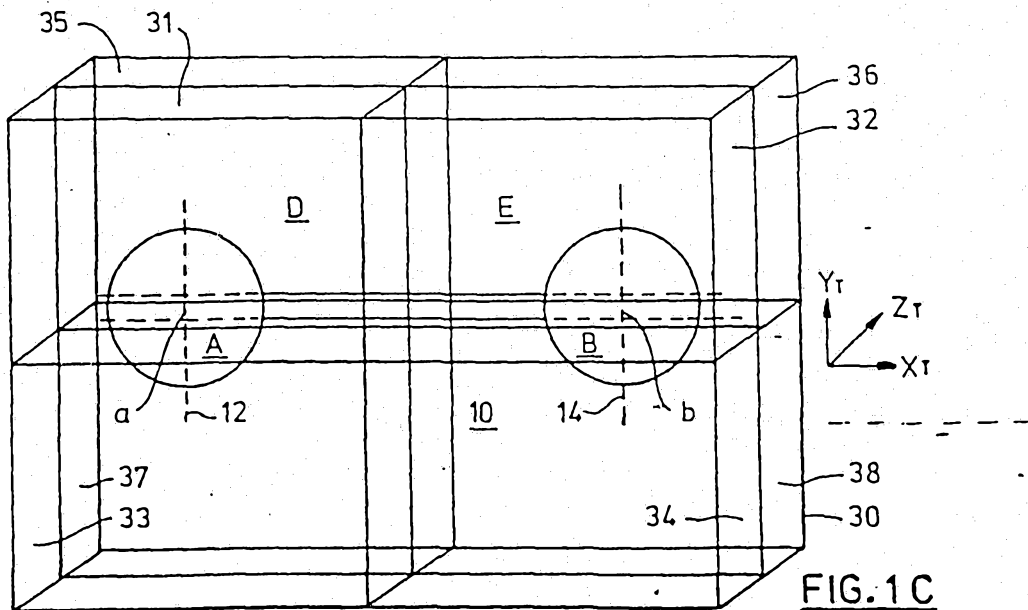


FIG. 1C

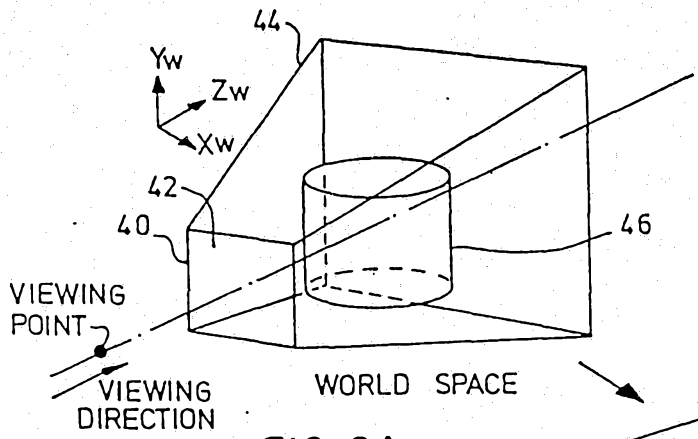


FIG. 2A

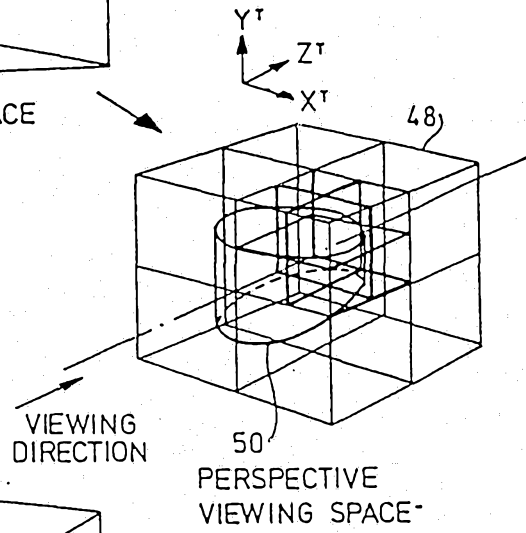


FIG. 2B

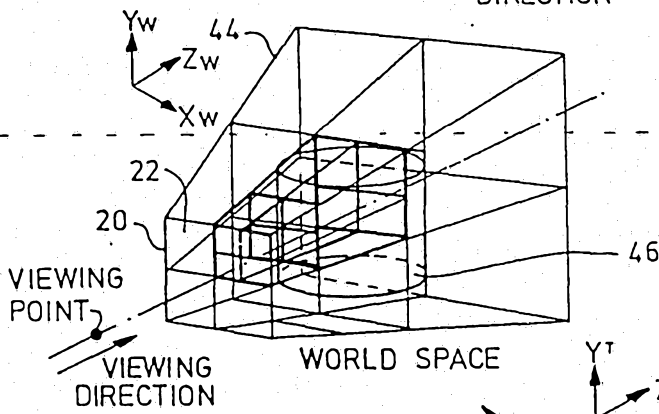


FIG. 3A

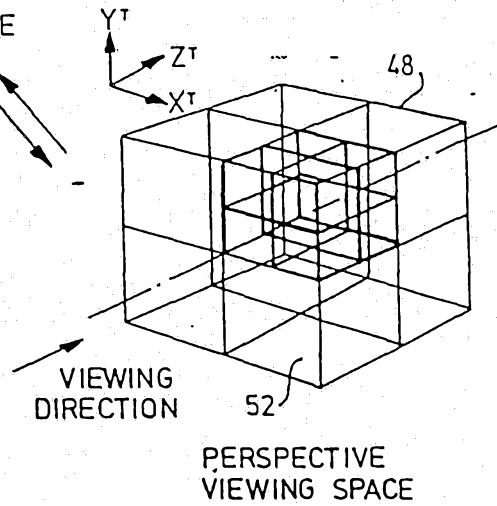


FIG. 3B

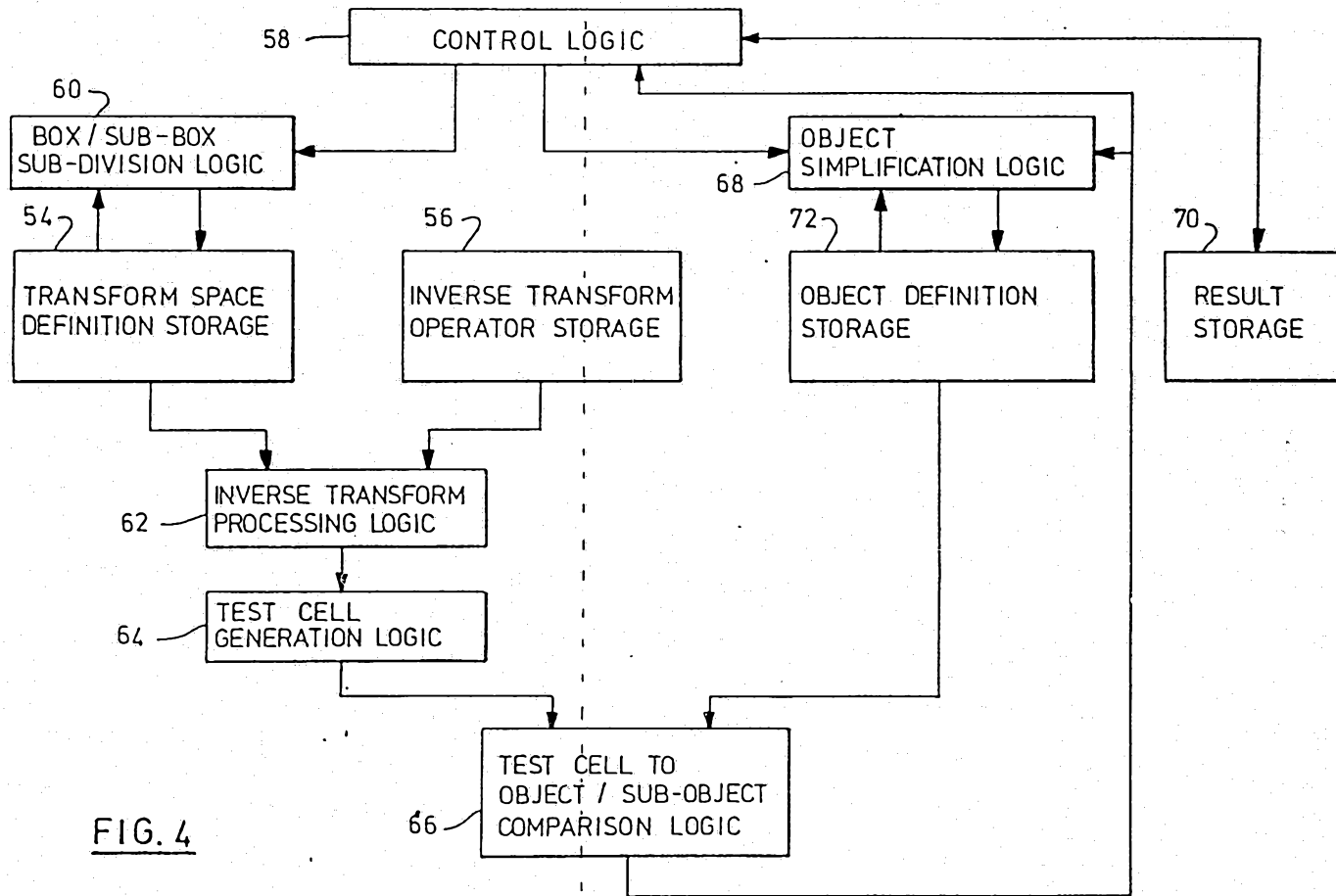


FIG. 4

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