Simplification Computing for Visual Events Based on Distinct Silhouette and View-Independent Pruning Algorithm

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Abstract. In this paper, a practical and efficient algorithm based on the triangulated polyhedra is proposed to calculate EV (Edge & Vertex) and EEE (Triple Edge) events for 3D viewpoint space partition. At first step a few triangular faces that contain distinct silhouette vertexes and edges are chosen in order to simplify the model, and then some of the EV and EEE events occluded by other faces is pruned by using the view-independent pruning algorithm. After the first step, the rest of EV and EEE events are actual critical events which are then calculated for space partition. Therefore we avoid calculating many EV and EEE events which are not actually existent before space partition so that it reduces computational complexity enormously. In the last section of this paper, we apply this method to two kinds of aircraft models and one kind of car model for experiments. The results show that it can effectively carry out calculation of EV and EEE events and space partition. And the representative viewpoints are placed over the viewpoint space evenly. On this foundation, actual 3D object recognitions could also be implemented.

1 Introduction

Currently some research [1-3] shows that achieving the goal of 3D recognition by matching the projections of certain object to representative pictures in the objects database is promising. A method often used is to represent a 3D object by a group of 2D projection pictures, whose amount should be as few as possible. In this way, we translate the complex recognition between 2D images and 3D object to the recognition between 2D images, which are much simpler.

According to the Catastrophe Theory, we can obtain the collection of representative viewpoints, which are used to reconstruct the 3D models, and 2D aspect graphs related with that viewpoints for setting up the 3D models database. In [1], the author analysis on several approaches to aspect graph space partition. An EV-event occurs when an image vertex intersects an image edge. This happens when the corresponding object vertex and non-adjacent object edge are aligned along an extended sight line from the viewpoint. An EEE-event occurs when three image edges (or, equivalently, an image

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edge and a T-junction formed by two other image edges) intersect at a point. Such an event happens when the three corresponding pairwise non-adjacent object edges are aligned along an extended sight line from the viewpoint (Fig. 1).

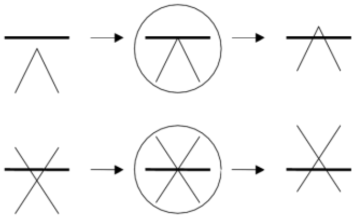


Fig. 1. An EV-event (top row) and an EEE-event (bottom row)

In [2], the author carries out 3D model recognition by using aspect graph. However, it is very difficult to apply these approaches of aspect graph to practical application because of enormous complexities in calculation [3]. Currently, much effort has been devoted to pruning algorithm and approximation of model, these researches are infinite spatial resolution involved with notion of scale, vertex clustering, Triangle Contraction Confined by Envelopes, edge collapse [4-7].

In this paper we propose an efficient representation of model and a view-independent pruning algorithm for EV and EEE events calculation, which is the major computation in obtaining representative viewpoints. At first we choose a certain amount of triangular faces which contain distinct silhouette vertexes and edges. And then by using a pruning algorithm, we select the EV and EEE events related to vertexes and edges chosen in the first step that are not occluded by other faces. This pruning step reduces calculation complexity enormously and it is suitable to space partition later. In the end, we apply this method to three kinds of plane models and two kinds of car models for experiment, the result shows that it can effectively carry out calculation of EV and EEE events and space partition. With this foundation, actual 3D object recognition could also be implemented furthermore.

2 Silhouette Extraction Algorithm

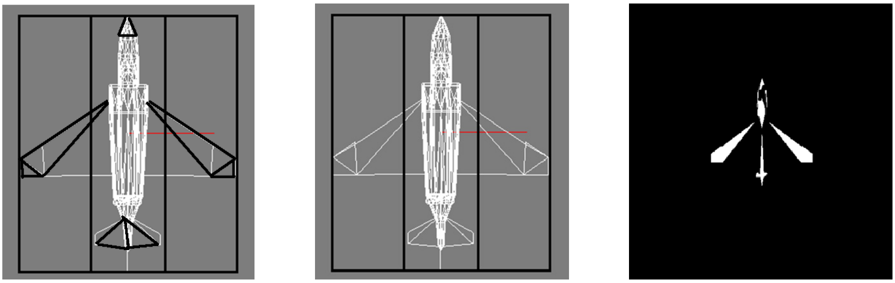
2.1 Model Silhouette Representation by Critical Triangles

3D model of real object is often too complex for direct implementation of viewpoint partition algorithms. Many approximation methods were proposed in order to simplify the model by reducing the amount of triangles of the model, but it is still not feasible to perform EV and EEE events calculation on this simplified model. A new triangle-pruning algorithm that could select some critical triangles which effectively represent the silhouette of the model will be favorable for further calculation. We expect to be able to control the amount of screened triangles, on the other hand, the screened triangles should be placed all over the model, thereby it is more likely to contain most of the features of the model for obtaining a better aspect graph.

2.2 The Algorithm

Based on the analysis above, a pruning algorithm for the purpose of screening a few triangles which representing the silhouette of the model is proposed as follows:

By projecting the model onto YOZ-plane, we obtain a 2D projection image of the model. Then we divide the image into several zones along Y-axis equally. (Fig.2 (a)).



(a) (b) (c)

Fig. 2. Silhouette extraction algorithm. (a) The division of the projected image into several zones along Y-axis equally. (b) Fringe triangles representing the silhouette along Z-axis of projected image (not accurate). (c) Pruning result--3D silhouette of the model.

By comparing Z-value of all the vertexes in each zone, we could obtain the vertex with maximal or minimal Z-value called “fringe vertexes” in each zone. Then, by traversing all the triangles in the model, we could obtain the “fringe triangles” which roughly represent the silhouette along Z-axis of the projected image, see Fig. 2 (b). These “fringe triangles” are more critical in the calculation in EV and EEE events, so we can prune other triangles to reduce the complexity of model effectively without losing much important “fringe information”.

Repeat steps above along Z-axis, we could obtain the “fringe triangles” which roughly represent the silhouette along Y-axis of the projection image.

By combining all the fringe triangles obtained above, we could roughly represent the whole silhouette of the projection image of the model in the first step.

Project the mode onto XOY-plane and XOZ-plane, repeat the same steps above, we could obtain more “fringe triangles”, combining which we could roughly represent the silhouettes of projection images onto XOY-plane and XOZ-plane.

By uniting all the fringe triangles obtained three projections in three directions, we pick up the 3D “silhouette” of the model with a few critical triangles. See Fig. 3 (c).

Our triangle-pruning algorithm could easily control the amount of fringe triangles by changing the number of zones divided. And all the “fringe triangles” are placed evenly all over the model, in that we ensure that almost all the potentially crucial features of the model are included in the simplified model for the calculation of EV and EEE events in the next step.

3 Potential Critical Event Pruning Algorithm

There are three kinds of critical events: the first one is EV event in one triangle, this event is involved with a vertex V and a non-adjacent edge *e* formed by two other vertexes in the same triangle. The set of potential critical regions induced by EV event in one triangle must be the actual critical regions because *e* and *v* are in the same actual triangle. The second one is EV event in different triangles, this kind of event is also involved with a vertex V and a non-adjacent edge *e*, the vertex V and the edge *e* are in different triangles. The last one is EEE event, this event is involved with three pair wise non-adjacent edges, we define the group of these three edges is a curve set.

The current approach for handling occlusion is to compute the entire arrangement of potential critical regions before any pruning is performed. In the orthographic model, this involves finding the intersections of the potential critical curves in the arrangement and determining the curve segments that are bounded by these intersections. [1] In this case, computing all the events will cause enormous complexities in calculation. What is more, pruning after computing is related to the event from all the viewpoints, it is necessary to consider all of them, which is very complex.

To reduce complexity and make sure space partition is accurate and view-independent. We propose a new approach to pruning EV and EEE events which don't actually exist before space partition. Pruning these EV and EEE events, which are not actual, is depended on the structure of object. We consider the relationship between EV or EEE potential events and the structure to judge if these events are actual events.

Actual critical regions induced by EV or EEE events are made up of those accidental viewpoints for which there exists an extended sight line with the following properties [1](Fig. 3):

- The line intersects every feature associated with some critical event.
- The line is tangent to the object(s) at the features associated with the event except, possibly, at the feature that is furthest from the viewpoint (it may be tangent to the object or it may penetrate the object at that feature).
- The line does not intersect any other object feature between the viewpoint and that furthest feature.

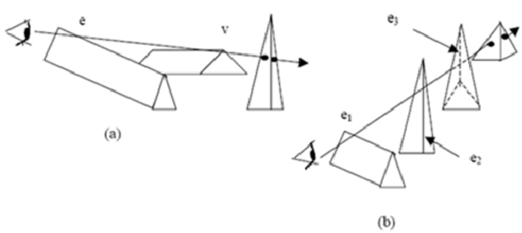


Fig. 3. Accidental viewpoint belonging to actual critical regions. In each case the event shown (an EV-event) in (a) and an EEE-event in (b) is visible in the opaque view.

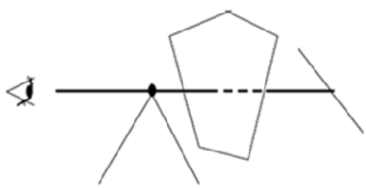


Fig. 4. The occlusion of an edge that would have been involved in an EV-event by an object face

Those EV or EEE potential events which are not actual critical events are not with the third property. In other words, it is possible that there is such an object face causing the occlusion of an edge that would have been involved in and EV or EEE event. (Fig. 4)

According to the third property, we propose an approach to judging if the potential events are actual critical events.

3.1 To Determine the Actuality of EV Event

At first, we define the positive space and negative space related to the *e* edge. In Fig. 5, we assume that the normal vectors of two faces which are adjacent to e edge are n_1 and n_2, both of them point to the external of object.

These two faces separate space into two parts: the positive space and the negative space. The positive space is defined as follows. For any point V in positive space, if these two faces make up of convex corner (Fig. 6 (a)), there is at least one face that the vector from the point on this face to point V has a positive dot product with the normal vector of this face; if these two faces make up a concave corner(Fig. 6 (b)), the vector from the point on any face to point V must have a positive dot product with the normal vector of the certain face.

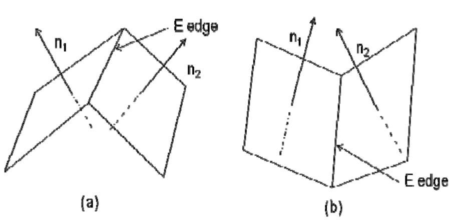


Fig. 5. The location relationship between two adjacent faces which make up of *e* edge. (a) Convex corner (b) Concave corner.

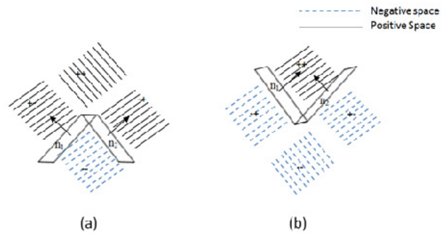


Fig. 6. The arrangement of positive space and negative space. (a) Convex corner (b) Concave corner.

For any point V in the negative space of edge e, the face made up of vertex V and edge e must be in the internal of object. Therefore, no extended sight line (from any viewpoint) intersecting both V and e with the three properties discussed above may exist, and there is no need to compute the potential critical region induced by V and e since there can be no corresponding actual critical region.

3.2 To Determine the Actuality of EEE Event

It is complex to judge the actual critical EEE event depend on the object structure. It is different from EV event that the potential critical region induced by three edges e_1, e_2 *and* e_3 is quadric surface, and its intersection with a portion of the sphere at infinity is yields a potential critical curve.(Fig. 7)

For three edges e_1, e_2, e_3, we assume that their vertex are p_{i1}, p_{i2} (i=1, 2, 3) and there are six vertexes at all. The potential critical region induced by e_1, e_2, e_3 is not the actual critical region unless any point q_i on the edge e_i must be in the positive space corresponding with other two edges e_l, e_m $(l, m \neq i)$ respectively.

The vertexes of e_i are p_{i1} and p_{i2}. We consider whether these two vertexes are located in the positive space of e_m or in the negative space of e_m to judge whether e_i intersects faces which are adjacent to e_m. If p_{i1} and p_{i2} are located in the different sides of the face (Fig. 8 (b)), which is adjacent to e_m, e_i must intersect this face. If p_{i1} and p_{i2} are located in the same side of face (Fig. 8 (a)), which is adjacent to e_m, then all points on the e_i are either in the positive side of face or in the negative side of face.

For the condition that two faces adjacent to e_m make up a convex corner (Fig. 9 (a)), if two vertexes of e_j are both in the positive side of one of these faces, all the points on the e_j must be in the positive space of e_m; if one vertex of e_j is in the positive side of one face n_1 but in the negative side of the other face n_2, the other vertex of e_j is in the negative side of one face n_1 but in the positive side of the other face n_2, we have to consider point of intersection (p_0 in Fig. 9 (a)) of e_j and one face (n_2 in Fig. 9 (a)) corresponding with e_m. In this way, if p_0 is also in the positive side of the other face (n_1 in Fig. 9 (a)), all the points on the e_j are in the positive space of e_m; if it is not, *there must be some* points, which are in negative space of e_m on the e_j .

For the condition that two faces adjacent to e_m make up of concave corner (Fig. 9 (b)), all the points on the e_j are not in the positive unless both vertexes of e_j are in the positive sides of two faces at the same time.

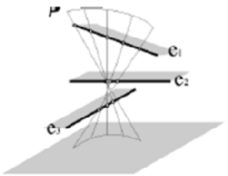


Fig. 7. The potential critical region induced in R^3 by three edges e_1, e_2 and e_3 (excluding the region between the features) and (at the bottom of the diagram) its intersection with a portion of the sphere at infinity (From [5])

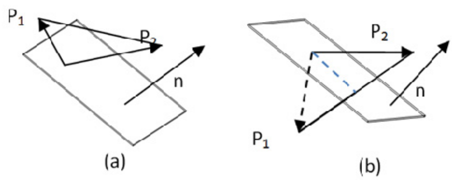


Fig. 8. Two vertexes of edge e_1 and face n. (a) two vertexes are located in the same side of face (positive side). (b) two vertexes are located in the different sides of face.

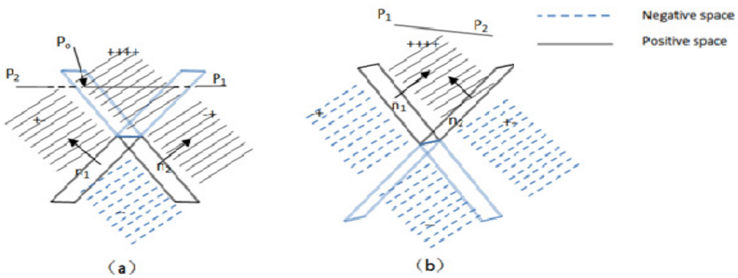


Fig. 9. Two vertexes of e_j and two faces adjacent to $e_{i.}$ (a) Convex corner (b) Concave corner

We define that $I_{mj}=1$ when all the points on the e_j are in the positive space of e_m. EEE event is not actual critical event unless $\forall m \neq j$, $I_{mj}=1$.

4 The Implement of Calculation of EV and EEE Critical Events

The process of implement of EV and EEE events is as follows:

Step 1, a few triangular faces which contain distinct silhouette vertexes and edges are chosen from object model.

Step 2, pick up the combinations of object vertexes and object edges related to the EV and EEE events, which are not occluded by other object faces, and calculate these events.

At first, EV events in different triangles that induce the potential regions, which are occluded by other object faces, are pruned from all the EV events picked in step 1.

Assuming that triangle face *F1* and *F2* are adjacent to edge *e*, they have 4 vertexes in all, and the coordinates of these four points are $\overrightarrow{A_1}, \overrightarrow{A_2}, \overrightarrow{A_3}, \overrightarrow{A_4}$, the terminal vertexes of edge *e* are $\overrightarrow{A_1}, \overrightarrow{A_2}$, the normal vectors of these two faces are $\overrightarrow{n_1}$ *and* $\overrightarrow{n_2}$. The coordinates of vertex V is $\vec{V}$.

If $\overrightarrow{n_{1(2)}} \cdot (\overrightarrow{A_4} - \overrightarrow{A_3})$ is above 0, it is considered that faces *F1* and *F2* make up of a concave corner (Fig. 10 (b)). Otherwise, it is considered that faces *F1* and *F2* make up of a convex corner (Fig. 10 (a)). Then the relative position of vertex V and edge *e* is considered.

For the condition that face *F1* and *F2* make up of a concave corner (Fig. 10 (b)), if $\overrightarrow{n_1} \cdot (\vec{V} - \overrightarrow{A_3})$ and $\overrightarrow{n_2} \cdot (\vec{V} - \overrightarrow{A_4})$ are all above 0, vertex V is placed in the positive space of edge *e* and it is considered that the potential critical regions induced by this kind of EV event in different triangles are the actual critical regions.

For the condition that face *F1* and *F2* make up of a convex corner (Fig. 10 (a)), vertex V is placed in the positive space of edge *e* when $\overrightarrow{n_1} \cdot (\vec{V} - \overrightarrow{A_3})$ or $\overrightarrow{n_2} \cdot (\vec{V} - \overrightarrow{A_4})$ is above 0, and in this case, it is considered that the potential critical regions induced by this kind of EV event in different triangles are the actual critical regions.

The rest of EV events in different triangles which are not those two kinds of EV event in different triangles would be pruned from the set of critical events.

Secondly, potential EEE critical events that induce the potential regions, which are occluded by other object faces, are pruned from all the EEE critical events picked in step 1.

$\forall m \neq j$, to determine whether $I_{jm}=1$, i.e. to determin whether edge e_m is placed in the positive space of e_j, we consider the relative position of two vertexes of e_m and edge e_j respectively. It is the same way we use in EV events by considering the vertexes of e_m as vertex V as in the $\overrightarrow{n_{j1}} \cdot (\vec{V} - \overrightarrow{A_{j3}})$ and $\overrightarrow{n_{j2}} \cdot (\vec{V} - \overrightarrow{A_{j4}})$ respectively. And we adopt the same definition of positive space of an edge as there.

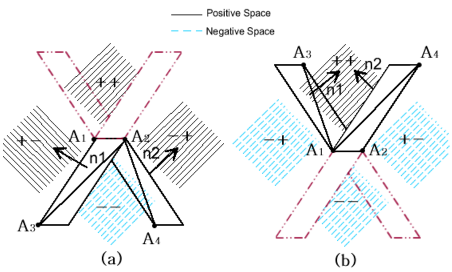


Fig. 10. (a) Face F1 and F2 make up of a convex corner; (b) Face F1 and F2 make up of a concave corner

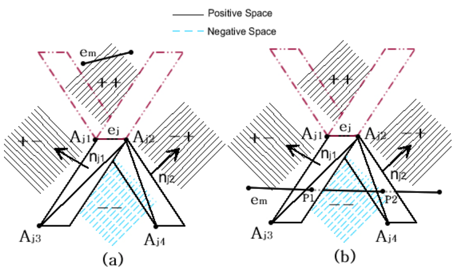


Fig. 11. (a) Case 1. (b) Case 2, when $\overline{n_{j2(1)}} \cdot (\overline{p_{1(2)}} - \overline{A_{j4}}) < 0$

For the condition that face j_1 and j_2 make up of a concave corner, it is considered that all the points of edge e_m are placed in positive space of edge e_j only if the two vertexes of e_m are both placed in the positive space of edge e_j.

For the condition that face j_1 and j_2 make up of a convex corner, first the two vertexes of e_m should both be placed in the positive space of edge e_j, then we discuss whether edge e_m is in the positive space in two cases:

(1) Edge e_m has no intersection with either of the planes that respectively contain the two faces adjacent to edge e_j, and then it's considered that edge e_m is in the positive space of edge e_j. (Fig. 11 (a))

(2) Edge e_m has one intersection with the plane that contains one of the two faces (assuming j_1) adjacent to edge e_j, then the coordinate of the intersection point $\overline{p_{1(2)}}$ is required to determine the relative position of edge e_m and e_j. It depends on the relative position of $\overline{p_{1(2)}}$ and the other face (j_2) being adjacent to e_j. (Fig. 11 (b))

If $\overline{n_{j2(1)}} \cdot (\overline{p_{1(2)}} - \overline{A_{j4}})$ is above 0, e_m is in the positive space of edge e_j, otherwise, e_m is in the negative space of e_j.

Step 3, pre-assigned viewpoints are placed on the Gauss sphere equally, and calculated in the formula of EV and EEE events. For every viewpoint, there is a set of sign for the calculation in the formula of EV and EEE events. Then, pre-assigned viewpoints are classified according to their sets of sign so that the space partition is carried out.

Assuming that the coordinates of vertexes of edge e and vertex V are $\vec{A_1}, \vec{A_2}, \vec{V}$, and the vector of viewpoint is $\vec{P}$, the formula of EV event is as follows:

$$(\vec{A_1} - \vec{A_2}) \times (\vec{A_2} - \vec{V}) \cdot (\vec{P} - \vec{V}) \tag{1}$$

Assuming that edges e_1, e_2, e_3 which are not on the same plane make up of a EEE event, $e_i = A_i B_i$ and vector $\vec{d_i} = \vec{B_i} - \vec{A_i}$, e_i is on the line l_i. P is a viewpoint in view space, so that the normal vector of the plane made up by P and e_i is $(\vec{P} - \vec{A_i}) \times \vec{d_i}$, the formula of EEE event is as follows:

$$((\vec{P} - \vec{A_1}) \times \vec{d_1}) \times ((\vec{P} - \vec{A_2}) \times \vec{d_2}) \cdot ((\vec{P} - \vec{A_3}) \times \vec{d_3}) \tag{2}$$

5 Results

5.1 Results of an Algorithm on Pruning Potential EV and EEE Critical Events

To prove the validity of algorithm on pruning potential critical event, it is required to choose a simple model for experiment. For this reason, we choose a simple cube (Fig. 12) to calculate EV and EEE event and carry out space partition.

There are two triangles on every face of cube; if the algorithm on pruning potential critical event is not applied on calculation, EV event in different triangle and EEE event (they are not actually exist) will be calculate and the result is complex and inaccurate (Shown in Fig. 13 (a)). The accurate result is shown in Fig. 13 (b), it is the result of calculation applying the algorithm on pruning potential critical event.

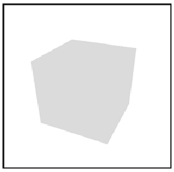
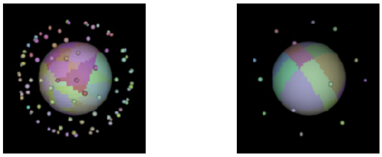


Fig. 12. The model of cube



(a) (b)

Fig. 13. (a) The results of experiment without application of the algorithm on pruning potential critical event and (b) The result of experiment with application of the algorithm on pruning potential critical event

From Fig. 13 (b), it is apparent that 26 representative viewpoint are placed in the viewpoint space evenly. There are 6 representative viewpoints from which only one face can be seen (it is corresponding to six faces of a cube), 8 representative viewpoints from which two faces which are adjacent a edge of cube can be seen at same time (it is corresponding to 8 edges of a cube) and 12 representative viewpoints from which three faces that have a same point of intersection (it is corresponding to 12 points of a cube). (Fig. 14)

Fig. 13 shows the results without application of the algorithm on pruning potential critical event and the result with application of the algorithm on pruning potential critical event.

From this experiment, the result indicates that the algorithm on pruning potential critical event is accurate and efficient, potential EV events and EEE events which are not actually exist can be pruned efficiently before calculation.

5.2 The Result of Using Complex Model for Experiment

The space partition of F4 model, see Fig. 15.

5.3 Discussion of the Results

The results above shows that the models are simplified enormously by using distinct silhouette algorithm and a majority of distinct silhouette vertexes and edges are chosen to represent the model.

Potential EV events and EEE events which are not actually exist can be pruned efficiently before calculation by using view-independent pruning algorithm, so that calculation complexity is reduced.

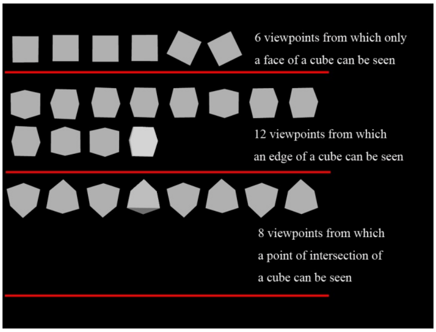


Fig. 14. The projection views seen from 26 representative viewpoints

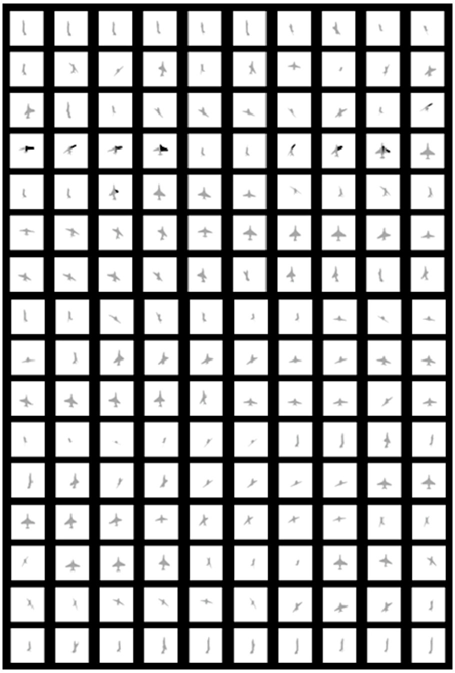


Fig. 15. The projection views seen from 160 representative viewpoints of F4 model

What is more important is that this pruning algorithm ensures that space partition is accurate and view-independent, representative viewpoints are placed all over viewpoints space more evenly. On this foundation, actual 3D object recognition can be also implemented furthermore.

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