Spatial Presentation and Aggregation of Georeferenced Data

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Abstract

In this paper, we will introduce a method of spatial presentation of georeferenced data in a three-dimensional space. Photographs, Quicktime VR's, videos, and computer graphic renderings provide realistic presentations rich in visual information. We believe, however, there is an issue of visualizing georeferenced data such as attribute data for spatial objects as well as showing the objects themselves. We will introduce orientation-based visualization model for visualizing georeferenced data, and we will discuss abstraction of the georeferenced data through their spatial aggregation in the space specified by a user.

1 Introduction

Aspen Movie Map[1] produced by the Architecture Machine Group, Media Lab, MIT in 1979 is known as a system for generating a virtual tour of the town from the video data previously recorded. NTT developed the Video Hyper Media[2] composed of a structural support tool, a multimedia database management facility, and an interactive player which is used to construct a multimedia guide system. Such systems enables the user to experiece a virtual tour of a town or various sites with visual information retrieved and modelled from video databases. There are also virtual cities expressed in VRML (Virtual Reality Modeling Language)[3] such as Virtual Tokyo [4] where you find the town of Shinjuku represented in three-dimensional modelling data with texture mappings and sounds. In the project "Terrapresent - Terrapast"[5], Art+Com integrates video data with the computer graphic modelling data of Berlin in the form of "film objects".

Such applications provide intuitive presentations rich in visual information, but we think that there is an issue of visualizing georeferenced data such as attribute data for spatial objects. For example, one can view buildings from different directions in videos, photographs, Quicktime VR's, and also in computer graphic renderings. In videos and photographs, one can view the objects more in detail if the camera moves closer to them, and they look different as the camera changes its position capturing the objects from different angles. In computer graphics, there is a function called LOD or "Level of Detail"[3] which controls the rendering quality of objects so they look as though they were real objects existing in the real world. One cannot see, however, their attribute data such as the name, structure, etc., of the buildings one is watching based on the spatial relationship between the viewer and the object.

In this paper, we will introduce a method of visualizing georeferenced data in the three-dimensional space, and a method of spatial aggregation of those data in the space specified by a user.

2 Basic Concepts

One of the characteristics of watching objects in a three-dimensional space is that you can view them from locations and directions you choose. As you move, the spatial relation between the object and the viewpoint changes, and its view changes as a result. This is what happens when you go out and watch the landscapes. This is also true when you watch photographs, etc, and computer graphic renderings.

The first part of our study is to devise a model for visualizing georeferenced data in the three-dimensional space. We think that visualizing georeferenced data such as the attribute information for spatial objects is also important in three-dimensional presentations. By visualizing the georeferenced data, one can find out what object one is looking at as illustrated in Figure 1 based on orientation of view and the distance between the user and the object with the appropriate level of detail. We introduce "orientation-based visualization model"[6] which controls three-dimensional visualization of georeferenced data based on orientation of view.

Orientation-based visualization model is a model for controlling the visualization of georeferenced data using the weighted values calculated from the spatial relationship between the object and the viewer. In this model, a spatial object is to be contained in a minimum bounding box. Surrounding the minimum bounding box are the adjacent 26 boxes on all the faces and apexes representing the approximated viewpoints. Depending on which of the surrounding boxes you are in, the visualization of the georeferenced data on the faces of the minimum bounding box in the center changes so that the data visualized on the face which faces towards the viewer has the maximum priority in visualization. In addition, the "LOD" control function provides the visualization of attribute data in an appropriate level of detail based on the distance between the viewer and the object. We called this algorithm of determining visualization priority and level of detail of the attribute information "InfoLOD".

The second part of our study is the abstraction of georeferenced data in the space specified by the user through spatial aggregation. When browsing the three-dimensional space generated based on our orientation-based visualization model, you would notice different geo-referential data visualized on the faces of the objects. The priority of visualization differs according to the spatial relationships, and since there are more than one object in the space, the characteristics of that particular space would be determined by the objects present in the space. By specifying your location, and the space by specifying the size, the objects of interest and their spatial relations are fixed. Then it becomes possible to aggregate the georeferenced data visualized according to our orientation-based visualization model of objects visible from that particular location.

We will describe our orientation-based visualization model in detail, demonstrate our prototype implemented based on our concept, and discuss spatial aggregation of georeferenced data in the following sections.

Figure 1. InfoLOD

3 Presentation of Georeferenced Data Based on "InfoLOD"

3.1 Basic Ideas

We use orientation of view and distance between the user and the object in order to control visualization of georeferenced data. Firstly, we describe our orientation-based visualization model.

In visualizing georeferenced data of spatial objects in the three-dimensional space, the visualization has to be controlled so they may be viewed from any direction the user may choose. In our orientation-based visualization model, we surrounded the spatial object in a minimum bounding box(MBB) and devised an algorithm for controlling the visualizations on all six faces of the box by computing the weight value for each face which determines its visualization priority.

In order to approximate the orientation of view, we prepared 26 subdivided boxes adjacent to the surfaces of the MBB so we can determine the one's orientation of view by finding out which "boxes" one is in as shown in Figure2.

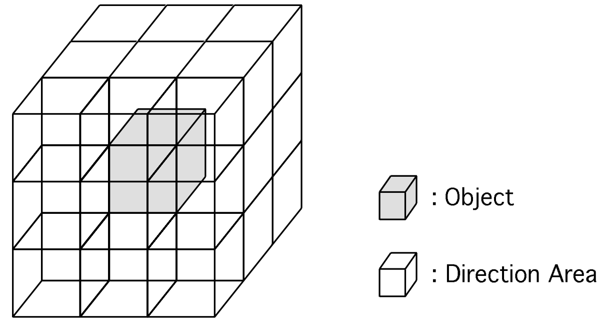

Figure 2. Orientation-Based Visualization Model Using MBB

3.2 Determination of Visualization Priority Based On Orientation

In order to control visualization, we propose to determine the visualization priority of the georeferenced data for each face of the MBB based on orientation. Since we made approximations by using the MBB and the adjacent 26 boxes, the following three cases should be considered when viewing an object in the three-dimensional space.

1. Viewpoint is directed at a face of MBB
2. Viewpoint is directed at a side of MBB
3. Viewpoint is directed at an apex of MBB

The number of faces visible in the cases stated above are one, two, and three, respectively.

We let the viewpoint located inside one of the twenty six subdivided boxes in Figure 2 be $d_i (i = 1, 2, \cdots, 26)$ and the set of faces visible from the viewpoint d_i be $face(d_i)$. We express the georeferenced data to be authored from viewpoint d_i as $G(d_i)$.

The georeferenced data $G(o_j)$ visualized when viewed from viewpoint d_i is expressed as $V(o_i)$ in the following equation. The georeferenced data could take the form of a set of keywords describing a spatial object or a feature vector derived from the keywords or a text describing the object.

$$V(o_i) = \{w_{ij} \cdot G(o_j) \mid j = 1, 2, \cdots, 26\}. \quad (1)$$

Here, we define each weight w_{ij} as,

$$w_{ij} = \frac{\mid face(d_i) \wedge face(d_j) \mid}{\mid face(d_i) \mid} \cdot \frac{\mid face(d_j) \wedge face(d_i) \mid}{\mid face(d_j) \mid} \quad (2)$$

The former part of this equation expresses how many of the MBB faces visible from the current viewpoint is visible from the direction of the face where we want to visualize georeferenced data. The latter part expresses how many of the MBB faces visible from the MBB face where we want to visualize georeferenced data is visible from the current viewpoint.

When $i = j$, or when the direction of viewpoint equals the direction of visualization, the priority of visualization equals the maximum value one. When no faces visible from the current viewpoint are visible from the direction of visualization, the priority of visualization equals the minimum value zero.

3.3 Calculating Visualization Priority

We will explain our method of calculating the visualization priority in the following examples. We name the faces of the MBB containing the spatial object A, B, C, D, E, and F as shown in Figure 3. We calculate the weight factor w_{ij} in order to determine the visualization priority for the georeferenced data $V(d_i)$ to be visualized for the viewpoint d_j for the following three cases: 1)viewing towards the apex, 2)viewing towards a side, 3)viewing towards a face.

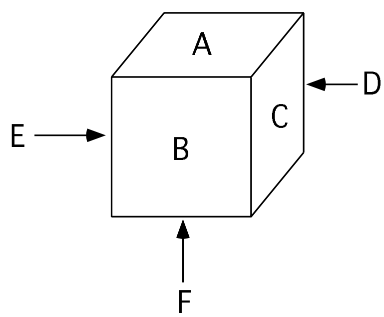

Figure 3. Faces of the Visualization Model

1. **Viewing towards an apex**

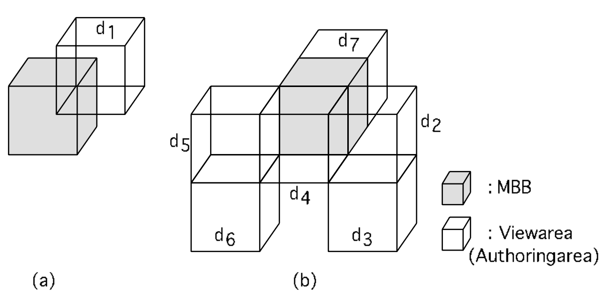

Figure 4. View Towards an Apex

As shown in Figure 4, we calculate the weight w_{1n} $(n = 1, 2, ..., 26)$ in order to obtain the georeferenced data presentation $V(d_1) = \{w_{11} \cdot G(d_1), w_{12} \cdot G(d_2), \cdots, w_{126} \cdot G(d_{26})\}$ when viewed from d_1.

When $face(d_1) = \{A, B, C\}$ for d_1, one can view the faces A, B, and C from d_1, and the orientation of visualization exactly matches. Thus, the weight of the georeferenced data equals the maximum value one as expressed in the following equation.

$$w_{11} = \frac{|\{A,B,C\}|}{|\{A,B,C\}|} \cdot \frac{|\{A,B,C\}|}{|\{A,B,C\}|} = \frac{3}{3} \times \frac{3}{3} = 1$$

for $face(d_1) \wedge face(d_1) = \{A, B, C\}$.

When $face(d_2) = \{B, C\}$ for d_2, one can view the faces B and C but one cannot view the face A. Thus the weight of the geo-referential data is decreased from the maximum value as expressed in the next equation.

$$w_{12} = \frac{|\{B,C\}|}{|\{A,B,C\}|} \cdot \frac{|\{B,C\}|}{|\{B,C\}|} = \frac{2}{3} \times \frac{2}{2} = \frac{2}{3} = 0.66$$

for $face(d_1) \wedge face(d_2) = \{B, C\}$.

When $face(d_3) = \{B, C, F\}$ for d_3, one can view the faces B and C just like d_2. However, $face(d_3)$ concerns the faces B,C, and F instead of just B and C. Thus, the weight of the geo-referential data is further decreased as expressed in the following equation.

$$w_{13} = \frac{|\{B,C\}|}{|\{A,B,C\}|} \cdot \frac{|\{B,C\}|}{|\{B,C,F\}|} = \frac{2}{3} \times \frac{2}{3} = \frac{4}{9} = 0.44$$

for $face(d_1) \wedge face(d_3) = \{B, C\}$.

When $face(d_4) = \{B\}$ for d_4, B is the only face one can view from d_1, thus the weight of the geo-referential data is expressed as the following equation.

$$w_{14} = \frac{|\{B\}|}{|\{A,B,C\}|} \cdot \frac{|\{B\}|}{|\{B\}|} = \frac{1}{3} \times \frac{1}{1} = \frac{1}{3} = 0.33$$

for $face(d_1) \wedge face(d_4) = \{B\}$.

When $face(d_5) = \{B, E\}$ for d_5, B is the only face visible and $face(d_5)$ concerns B and E, thus, the weight of the geo-referential data is further decreased as expressed in the following equation.

$$w_{15} = \frac{|\{B\}|}{|\{A,B,C\}|} \cdot \frac{|\{B\}|}{|\{B,E\}|} = \frac{1}{3} \times \frac{1}{2} = \frac{1}{6} = 0.16$$

for $face(d_1) \wedge face(d_5) = \{B\}$.

When $face(d_6) = \{B, E, F\}$ for d_6, B is the only face visible and $face(d_6)$ concerns B,E, and F, thus the weight of the geo-referential data is expressed as the following equation.

$$w_{16} = \frac{|\{B\}|}{|\{A,B,C\}|} \cdot \frac{|\{B\}|}{|\{B,E,F\}|} = \frac{1}{3} \times \frac{1}{3} = \frac{1}{9} = 0.11$$

for $face(d_1) \wedge face(d_6) = \{B\}$.

When $face(d_7) = \{D\}$ for d_7, no face is visible from d_1, so the weight of the geo-referential data equals the minimum value zero as expressed in the following equation.

$$w_{17} = \frac{|\phi|}{|\{A,B,C\}|} \cdot \frac{|\phi|}{|\{D\}|} = \frac{0}{3} \times \frac{0}{1} = 0$$

for $face(d_1) \wedge face(d_7) = \phi$.

After calculating the weight w for all of the 26 orientations for the georeferenced data $G(o_j)$ in the orientation d_1, we obtain a set of weighted values $(w_{11}, w_{12}, ..., w_{26})$. $G(o_j)$ may contain a number of keywords with weighted value $(k_1, k_2, ..., k_m)$ obtained by $tf \times idf$ method often used in text retrieval. The keyword with the highest value which might be “Office Building”may be chosen to be visualized.

2. **Viewing towards a side**

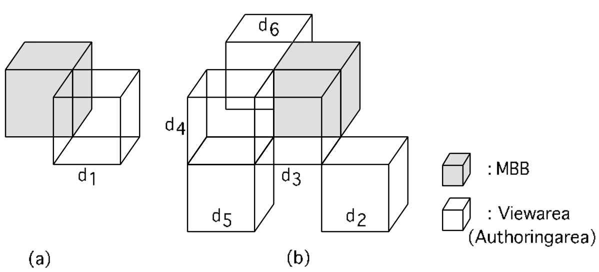

Figure 5. View Towards a Side

When viewing the object from direction d_1 as shown in Figure 5(a), the weight of the georeferenced data to be visualized equals the maximum value one for one can view both B and C from d_1. In this case, two faces instead of three are visible.

$$w_{11} = \frac{2}{2} \cdot \frac{2}{2} = 1$$

The weight of the georeferenced data from d_2 for $face(d_2) = \{B,C,F\}$ can be expressed as the following equation since the faces B and C are visible but $face(d_2)$ concerns B, C, and F.

$$w_{12} = \frac{|\{B,C\}|}{|\{B,C\}|} \cdot \frac{|\{B,C\}|}{|\{B,C,F\}|} = \frac{2}{2} \times \frac{2}{3} = 0.66.$$

The weight of the geo-referential data from $d_4, for face(d_4) = \{B,E\}$:

$$w_{14} = \frac{|\{B\}|}{|\{B,C\}|} \cdot \frac{|\{B\}|}{|\{B,E\}|} = \frac{1}{2} \times \frac{1}{2} = 0.25.$$

The weight of geo-referential data from $d_6, for face(d_6) = \{D,E\}$:

$$w_{16} = \frac{|\phi|}{|\{B,C\}|} \cdot \frac{|\phi|}{|\{D,E\}|} = \frac{0}{2} \times \frac{0}{2} = 0.$$

3. **Viewing towards a face**

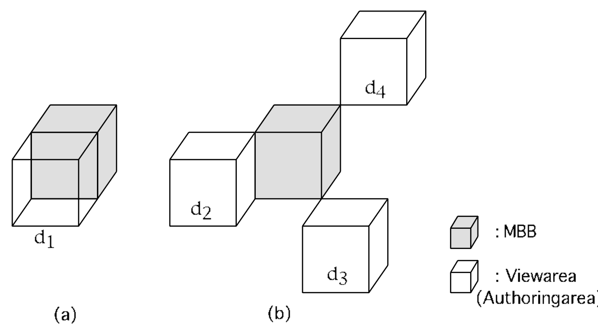

Figure 6. View Towards a Face

In this case, only one face is visible. Thus the weight of the geo- referential data viewed from d_1 equals the maximum value one.

$$w_{11} = 1$$

for $face(d_1) = \{B\}$.

As in the previous examples, the weight can be calculated.

The weight of the geo-referential data from d_2 in Figure 6(b):

$$w_{12} = \frac{1}{1} \times \frac{1}{2} = 0.5$$

for $face(d_2) = \{B,E\}$.

The weight of the geo-referential data from $d_4, face(d_4) = \{A,C,D\}$:

$$w_{14} = \frac{0}{1} \times \frac{0}{3} = 0.$$

3.4 "LOD" Control Based on Distance

We are also considering the control of the visualization according to the distance between the user and the object which could be defined as the distance between the user viewpoint and the centroid of MBB.

VRML[3] has realized this function of LoD(Level of Detail) for controlling the rendering of the objects themselves. By using LoD, one can prepare a number of models of varying complexity for a single object and decide which model to visualize depending on the distance between the user and the object. Rendering speed can be accelerated by visualizing the coarse model when the user is far from the object and more detailed model when the user is near the object.

As for the attribute information, similar measures can be taken. For example, in our example for orientation-based visualization model, we computed w so it can be multiplied to the georeferenced data G. In addition, the amount of information to visualize can be controlled based on the distance between the viewer and the object. So, when one is far from the object, one may only see the keyword "Office Building" which happened to have the highest value using $tf \times idf$ method. When one moves closer to the object, more than one keyword with relatively high numbers can be visualized so one sees more detailed information about the object.

4 Spatial Aggregation

4.1 Generation of Feature Vectors for Georeferenced Data

In order to abstract the geo-referential data through spatial aggregation, we generate feature vectors from the geo-referential data. Vector space model[7] provides a useful tool for queries in image and textual databases. In the vector space model, the characteristics of the geo-referential data are represented as n-dimensional space vectors. The product of relative frequency of occurence and inverse document frequency or $tf \times idf$ decides the dimension of the space. We assumue that the geo-referential data of the objects o_i has a feature vector $f_i(k_1, k_2, ...k_n)$.

4.2 Spatial Aggregation of Georeferenced Data

In order to aggregate the geo-referential data spatially, one specifies the space $S(c, r)$ defined by the centroid c and the radius r. By defining the space S, the user automatically selects the objects o_s which are contained in S.

The objects o_s have the feature vectors f. Since the viewpoint is defined, its spatial relations to the objects are fixed. We use the equation for obtaining the visualization priority in order to calculate the feature vectors considering the orientation.

$$aggregate(o_s, d_i) = \sum_{j=1}^{26} w_{ij} \cdot f(o_s, d_j) \quad (3)$$

In order to spatially aggregate the feature vectors of the geo-referential data of objects o_s contained in the space $S(c, r)$, we apply the same algorithm for each of them. The orientation d_i from which the objects are viewed may differ, so we define it as $orient(o_s, c)$ determined by the centroids of the space $S(c, r)$ and the MBB of the objects o_s. We let the objects contained in the space S equal $o = \{o_1, \cdots, o_n\}$, and we define the feature vector $F_s(S)$ of the space S as the following equation.

$$F_s(S) = \frac{1}{n} \sum_{s=1}^{n} aggregate(o_s, orient(o_s, c)) \quad (4)$$

The spatially aggregated feature vector $F_s(S)$ of the space $S(c, r)$ represents the abstracted characteristics of the geo-referential data corresponding to the objects in the selected space. The Figure 7 shows our idea of spatial aggregation.

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Figure 7. Spatial Aggregation

5 Implementation

5.1 System Description

Under the assumption that the system would be viewed on the world wide web, we used Netscape 4.08 as the browser. In order to view the spatial objects stored as VRML[3] files, CosmoPlayer2.1 plug-in was required.

In order to allow the Java applets to manipulate the VRML data in the browser, the EAI(External Authoring Interface) was used to access the VRML nodes and fields which include the information about the shapes, locations, etc. of the spatial objects viewed in the browser. The figure 8 shows the configuration of our prototype system.

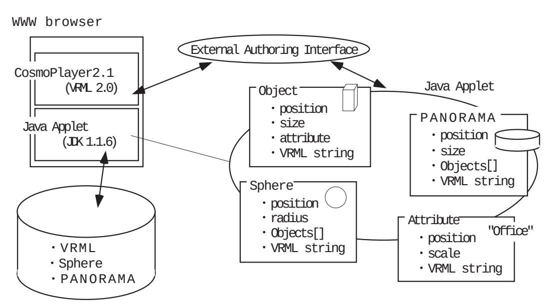

Figure 8. System Description

5.2 "InfoLOD"

We implemented a prototype system based on our concept of "InfoLOD" which is composed of orientation-based visualization model and LOD(Level of Detail) control based on distance. In the Figure 9, one can see that the georeferenced data given for the spatial object which happens to be a building appears in front of the face of the building. In the following Figures 10 and 11, one can see that the letters on the front face of the building getting smaller and those on the sides getting larger instead. This is due to our algorithm which calculates the weighted value to control visualization. Since you see less of the front face of the building, the letters on the front side grows smaller.

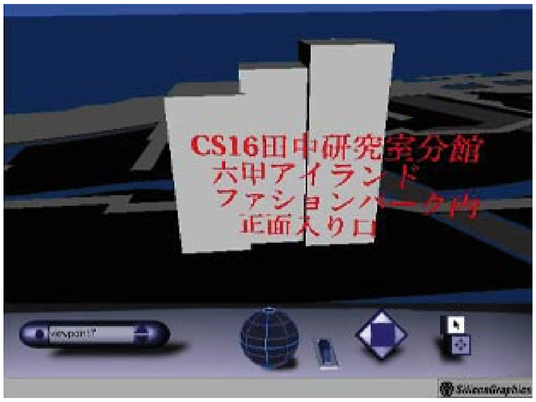

Figure 9. Orientation-Based Visualization(1)

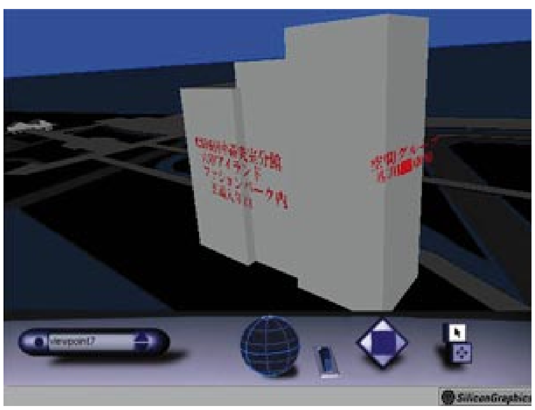

Figure 10. Orientation-Based Visualization(2)

In our implementation, we prepared georeferenced information with varying degree of detail for the spatial objects. The degree of detail is determined by the distance between the user and the object of which the information is being displayed as shown in the Figure 12. One can see that the information displayed for the buildings close to the viewer is more detailed whereas for the ones farther away, only the names are visible.

Figure 11. Orientation-Based Visualization(3)

Figure 12. LOD for attribute information

5.3 ”InfoPANORAMA”

Panoramas can provide intuitive presentations of a place. In our prototype system, one can retrieve panoramic views for navigation. We named it ”InfoPANORAMA” for it can display the attribute information of spatial objects on the panorama. Our “InfoLOD” algorithm is also used in visualizing georeferenced data. On implementation, panoramic image data were mapped to VRML cylinders (Figure 13).It can rotate so one does not need to turn around. When one selects a point on the rotating panorama, the system automatically guide the user to a point where one would have exactly the same view in the VRML space as one would if one were watching the real panorama in the real world(Figure 14).

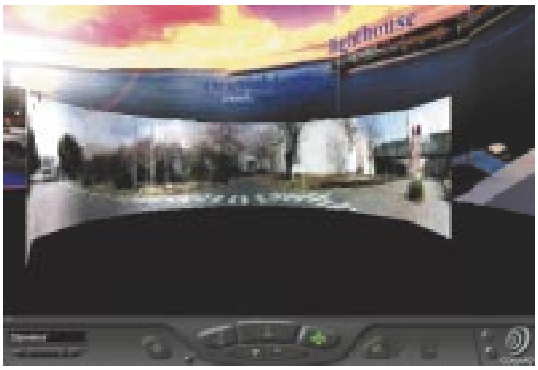

Figure 13. Navigation Using Panoramas

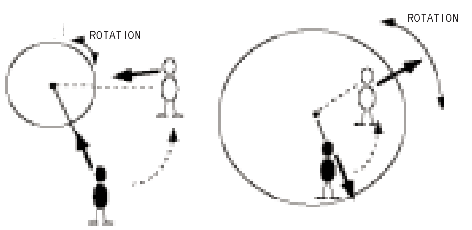

Figure 14. Panorama Rotation

5.4 Spatial Aggregation of Objects

In our prototype system, it is possible to specify a spherical space by selecting the coordinates for a point and a radius. Then the system computes the mean value of the feature vectors of the objects contained in the space(Figure 15). We are thinking of a number of applications for the use of this spatially aggregated feature vector which could also be used as a query vector in vector space search.

1. `DYNAMIC ABSTRACTION`
   One can navigate the spherical space and generate spatially aggregated feature vectors of places one wishes to investigate by dynamic abstraction. It is possible to specify a favorite space, generate the spatially aggregated feature vector, and use it to search for places having similar characteristics. It might also be useful to have sampling vectors of spaces typical of “downtown commercial district”,”suburban residential district”, etc., and make comparisons.

2. `GUIDED SPATIAL TOURS`
   Manual spatial browsing could be tiresome especially if the space is large. It is possible to construct a database of automatic guided tours[8] composed of a series of consecutive spaces each having a spatially aggregated vector. By searching for such tours spatially or submitting a search by specifying the nature of the tour based on the abstracted feature vectors, one can effectively browse the space as if one is on a sight-seeing bus.

One advantage of searching by spatially aggregated vector is that you can search a space containing a group of objects constituting a certain feature. This is especially useful in finding a group of spatial objects forming a cluster such as shopping zones in a city.

Figure 15. Spatial Aggregation of Geo-Referential Data

To our prototype system, we added a function for generating a guided three-dimensional tour. By simply selecting the spaces one specifed and registered, the system connects the centers of the spaces to generate a path for a guided three-dimensional tour which can also be registered for later use. The Figure 16 shows our idea. In addition, the system can set one’s orientation during the tour so that one can face towards the objects contained in each space which compose the tour.

Automation of path generation and setting of view orientation during the tour when there are multiple objects of varying importance is one of our future research issues.

5.5 Further Research Issues on Visualization Control

We are currently involved with developing an algorithm for computing the information which most characterizes the

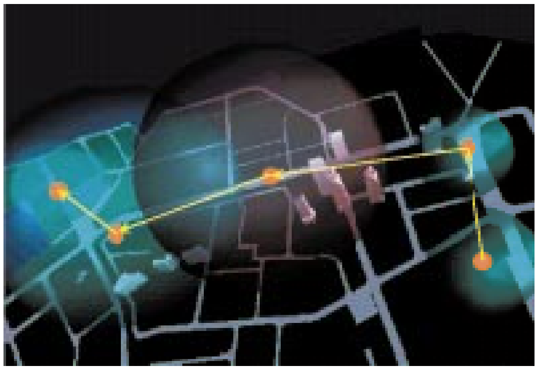

Figure 16. Three-Dimensional Tour

given area. This notion resembles the idea of landmarks used in the field of architecture and geography. Visualizing the information for every single object in view would result in unnecessary calculations and would cause overflooding of information for the user even by using LOD by distance. By using this "landmark extraction"algorithm, it would be possible to view the objects which most characterize or summerize the region one is in selectively. This would help the user get hold of the idea of the area effectively instead of evenly rendering every objects in view at high computing costs,

6 Conclusions

In this paper, we firstly introduced our concept of orientation-based visualization of geo-referential data in order to visualize attribute information of spatial objects in a three-dimensional space. Secondly, we introduced a method of spatial aggregation of geo-referential data in order to abstract the data in a given space. We described a prototype system for geo-referential data visualization based on our orientation-based visualization concept, spatial aggregation concept. We also introduced "InfoPANORAMA"and "Three-Dimensional Tour" as navigational aides. In addition, we discussed some applications using the spatially aggregated feature vectors, and discussed future research issues for "InfoLOD".

7 Acknowledgements

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