A RASTER-BASED MAP INFORMATION MEASUREMENT FOR QOS

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ABSTRACT:

With the changing status of GIS from desktop to distributed environment, geographic information is more often required to transmit over networks. As geospatial data is in essence of huge volume and complicated but the bandwidth of a network is limited, it is of great importance for map-QoS to transfer data as less as possible. This paper discusses this problem from the view of information theory and proposes a novel approach of information measurement for minimizing of geospatial data size while delivering map information constantly.

This paper starts from a discussion of map-QoS concerning map as a media carrying geographic information. Either on various display mechanisms or on paper-alike media, geographic information is transformed to map, an image to stimulate visual sentience of human being. However, visual sentience of human being has only limited spatial and frequency resolutions. Map with resolution approaching or higher than this limit increases little or even decreases the amount of information contained. Display mechanisms and paper-alike media also have their maximum spatial and frequency resolutions. It is impossible for a map to display more data than its capacity. For map-QoS, the size of geospatial needed is the minimum to reach this capacity.

Based upon above understanding, this paper proposed a raster-based measurement of geographic information contained in a map. A study of the relationship between data size and map information by this measurement reveals that this is usually a mono-modal curve with a single peak.

1. INTRODUCTION

Web-Based Applications have gained predominant advantages over other ways of information dissemination during the past few decades, and with the changing status of GIS from desktop to distributed computing environment, geographic information is more often required to transmit over networks. Yet, information interchanged nowadays on the WWW is mostly in the forms of hypertexts, highly compressed images (such as GIF and JPEG), and short movie clips that are small in size. Large Objects, such as audio and video can only be transmitted via a special suite of protocols and must rely on broader bandwidth due to their big size, so it is not very popular. This situation will not change in the near future and unfortunately is what the Web-based spatial information service is faced with. While the demand for spatial information through a limited bandwidth (i.e. a 56.6 kbps modem) is emerging and geospatial data is in essence of huge volume and complicated, it is of great importance to transfer map data with acceptable QoS (Quality of Service) which makes users get what they expect within a relatively small delay, even when they connect to Internet via a limited bandwidth. But situations in the spatial information service are not satisfactory. When a user sends a request for an geo-information concerned service, both the user and the server cannot know in advance how much bytes of data must and will be transferred over the network, there is no way to determine the most suitable data amount that must be transferred which not only can fulfil the demand of variable kind of user but also is the minimum data amount that is needed. To meet this dilemma, some principles must be utilized to direct the transmission of geospatial data. We present a raster-based approach in this paper to minimize geospatial data size while delivering sufficient map information in a smooth manner.

This paper discusses map-QoS concerning map as a media carrying geographical information. Either on various display mechanisms or on paper-alike media, geographic information is transformed to map, an image to stimulate visual sentience of human being. However, visual sentience of human being has only limited spatial and frequency resolutions. Map with resolution approaching or higher than this limit increases little or even decreases the amount of information contained. Display mechanisms and paper-alike media also have their maximum spatial and frequency resolutions. It is impossible for a map to display more data than its capacity. For map-Qos, the size of geospatial data needed is the minimum to reach this capacity. It is based on this consideration that our new approach is proposed.

The remaining part of this paper is organized as follows. Section 2 gives a brief introduction and an overall evaluation of current methods of map information measure; Section 3 discuss our approach of raster-based map information measurement concerning relations between data and information; Section 4 is an experimental research and some conclusions are drawn in Section 5.

2. A BRIEF DESCRIPTION OF AVAILABLE METHODS OF MAP INFORMATION MEASUREMENT

Quantitative measure of information had appeared when Shannon (1948) put forward his famous information theory in a thesis named “A Mathematical Method of Communication”, in which he presented a method to measure information based on probability. In this thesis Shannon defined entropy, a concept originated from classical stochastic physics to represent the chaos of physical system, as the measurement of uncertainty and it is calculated as follows:

Let X be a random variable with a set of possible choices $\{A_1, A_2 \cdots A_n\}$ with probability $\{P_1, P_2, \cdots P_n\}$, then the entropy of X is

$$H(X) = H(P_1, P_2, \cdots P_n) = -\sum_{i=1}^{n} P_i \ln P_i \tag{1}$$

When this approach of information measure is introduced into quantitative map information measure, a natural thought is that to give every kind of symbol on the map a probability, and then the information content of the map can be calculated corresponding to the probability. Sukhov (1967,1970) did the initial work. He utilized a statistical model in which each kind of symbol’s probability is calculated based on its frequency of appearance in the map. His method is described as follows.

Let N be the total number of symbols on the map, M the number of symbol types and F_i the number of *i*th type, then $N = F_1 + F_2 + \cdots + F_M$, the probability of each type of symbol can be decided by

$$P_i = \frac{F_i}{N} \tag{2}$$

Where P_i is the probability of the *i*th type.

Then the entropy can be calculated through the probabilities defined above.

$$H(X) = H(P_1, P_2, \cdots, P_M) = -\sum_{i=1}^{M} P_i \ln P_i \tag{3}$$

This method firstly introduced information theory into map information measurement, yet its fault is obvious. It completely did not consider any position and topological information in the map, which are very important components of spatial information that we can get from a map. If symbols on the map scatter in different manner (i.e. Fig.1), undoubtedly we can get different amount of information from these two maps, yet this statistical method mentioned above fails in this situation for it can only obtain equal amount of information.

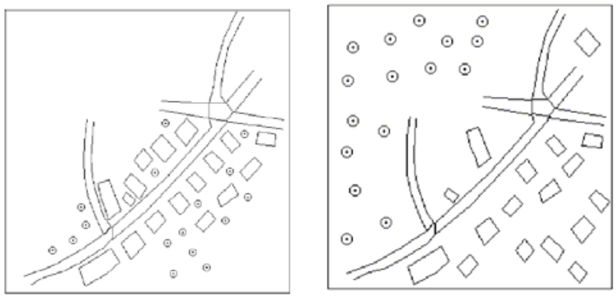

Figure 1. Two maps with same amount of symbols but different distribution

For consideration of topological information more methods are developed by researchers, some of them deserve being mentioned here. Neumann (1994) proposed a method to estimate the topological information of a map. In this method vertices are classified according to their topological information, such as how many neighbors they have. After the classification entropy can be computed the same way by formula (2) and (3). Yet in this method the classification of vertices is hard when a map is relatively complex and the significance of the classification is not so consistent with the real map.

Bjørke (1996) was not satisfied with such ways to define topological information then he provided another definition of topological information by considering the topological arrangement of map symbols. He introduced some other concepts, including positional entropy and metrical entropy. ‘The metrical entropy of a map considers the variation of the distance between map entities. The distance is measured according to some metric’ (Bjørke 1996). He also suggests to ‘simply calculate the Euclidean distance between neighboring map symbols and apply the distance differences rather than the distance values themselves’. The positional entropy of a map considers all the occurrences of the map entities as unique events. In the special case that all the map events are equally probable, the entropy is defined as H (X)=ln (N), where N is the number of entities.

Li and Huang (2002) proposed their consideration of topological information on the map. In their paper they took into consideration both the spaces occupied by map symbols and the spatial distribution of these symbols. They divide information about the features in the map into three types:

- (Geo) metric information related to position, size and shape.
- Thematic information related to the types and importance of features.
- Spatial relations between neighboring features implied by distribution.

Based on this division they introduced Voronoi diagram to deal with (Geo) metric information and spatial relations. A Voronoi diagram is essentially a partition of the 2-D plane into N polygonal regions, each of which is associated with a given feature. The region associated with a feature is the locus of points closer to that feature than to any other given feature as shown in Fig.3. As this region is determined by both the feature’s size and the feature’s relative space, in some sense it can represent the (geo) metric information and spatial relations.

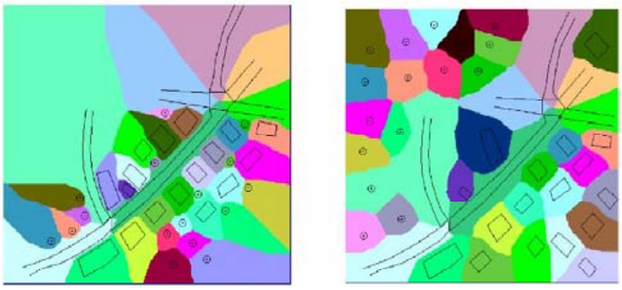

Figure 3. Voronoi diagrams of the maps shown in figure 1.

After a Voronoi diagram is formulated, the total area of the map is tessellated. Let S be the whole area and the tessellation is defined by $S_i, i = 1,2,\cdots n$. Then probability of a feature can be determined by the area it holds as follows:

$$P_i = \frac{S_i}{S} \quad (4)$$

The entropy of the metric information, $H(M)$, can be defined as follows:

$$H(M) = H(P_1, P_2, \cdots P_n) = -\sum_{i=1}^{n} P_i \ln P_i = -\sum_{i=1}^{n} \frac{S_i}{S}(\ln S_i - \ln S) \quad (5)$$

As to thematic information, they proposed a similar way that classify a symbol’s neighbours according to their thematic type and calculate the information according to the classification.

All these methods presented above are based upon Shannon’s information theory, and the major difference between them is the way to calculate probabilities of symbols. When this difference applies, the probabilities are utilized to calculate different kind of information, including statistical information, topological information and (Geo)metric information as mentioned above. Yet on one hand, it is reasonable to place some suspicion on whether this probability model based method can reflect the internal relationship among geographical feature or not and we can find that it is not so suitable to infer the information amount with these method mentioned above. On the other hand, a common drawback of these methods is that they can only deduce a ‘relative’ relation among all symbols of the map, and information amount obtained by these methods only reveals relative relationship among symbols in the same map, thus these methods do not concern any relationship between amount of information and amount of data that contains this information. Suppose the resolution of map is changed, usually we can expect that with more details can be discerned, we can obtain more information from this map. But all methods above can only get the same amount of information after the resolution is enlarged. The other drawback of these methods is that they do not take into account the information actually obtained by users. A symbol may exist in the map but cannot be concerned by the user, if this symbol is not attractive or is too small to be perceived, but the entropy of this symbol is also calculated. From the description above we can see that to apply the information amount to determining the minimum amount of data that we should transfer to a user over network a new approach of calculating information concerning relations between data and information must be presented.

3. RASTER-BASED MEASUREMENT OF MAP INFORMATION

3.1 Relationship between GIS data and information

GIS data is the carrier of spatial information and with the development of remote sensing and other ways of data collection, huge amount of GIS data is produced day by day, thus it provides us a plenty data source for information transmission, share and utilization. As mentioned above, when the environment of information share is transplanted to Internet, the function of GIS data to carry spatial information and even the meaning of information has changed essentially. In the traditional desktop environment, the spatial information is strictly in accord with GIS data that contain it. For instance, a map with lower resolution contains less information than a map with higher resolution and with the increasing of resolution, the data amount of the map increases and the information amount contained by the map increases accordingly. But in a distributed environment, the relationship between data amount and information amount is not such a simple linear one. The resolution of client display device, the bandwidth of the network connection and other factors cast influence upon this data-information relationship and inversely this relationship impacts the principle of data transformation over network, which is what we must take into account when providing spatial information service.

3.2 Raster-based measurement of map information

We start our research of map information amount measurement from a point that concerning map as a media of carrying geographical information, this way we can find some metric of information when GIS data is transferred over networks on purpose of conveying spatial information In computer, or in other paper-alike media the way on which maps carry information is in the form of image that is capable of stimulating visual sentience of human being. There are still other ways of drilling information from maps such as computer-associated analysis, but we cannot depend thoroughly on computer programs even they are powerful. In other words, a sophisticated expert may obtain what he want by some software, but a user of GIS on the Web usually can only rely on his eyes, and Web GIS service providers can not make the assumption that clients have some GIS software. Usually, clients have only browsers, and to those who connect to Internet through wireless or mobile devices, their devices are of limited storage, computing capacity and display resolution. To these clients, the only purpose to transfer data to their machine is to display it and they can then obtain what they want by their eyes.

With the development of remote sensing, communication satellite and image processing, high-resolution images have now become more and more available and popular than before and bring great change to the way people deal with spatial information. Images of these types are often stored in the specially designed image databases and processed by computers. In this way we can get a large amount of information corresponding to their high resolution and large data size. But if it comes to human being things changes. Man’ eyes have a relatively low spatial and frequency resolution, a map with higher resolution may be useful to the computer, but can not give more information to a man with low physical resolution because the resolution added can not be perceived. This resolution-limitation suggests that what a user can get from a map by eyes is not always the same as what the map contains. Maybe this limitation is not so important when we access a local image database and analysis images with corresponding software, but this situation changes dramatically if it is in the distributed environment and Internet.

Suppose there is a user with normal sight and he sends an HTTP request that contains a request for a certain map on the server. If server responds with a map whose resolution is lower than client machine, usually the user can only get part of the information he wants because some details are missed. Through some progressive schema, server can transfer more data to improve the map's resolution. After this stage, usually the user can get more information when he perceives more and more details of the map. But up to some certain resolution if the server transfers more data to improve the resolution and quality of the map, the user cannot get more information even when he is given more data. Obviously, server should stop transfer data on this certain resolution to avoid wasting of bandwidth.

Then our job is to find this resolution. Firstly and obviously, this resolution must be lower than the client machine's resolution, for higher resolution details cannot be displayed on the client's machine. We can find even this simple rule is useful. We can add some header into the request HTTP message to include the information about client machine's resolution, and then server can send data according to this resolution.

But this simple rule is not enough. We need some rules that are more precise. Suppose there is a map as follows, if we raster it with different resolution, what we get is listed in Fig 4.

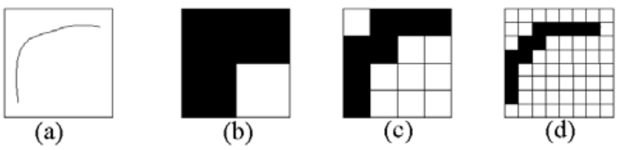

Figure 4. A map rastered with different resolution (only bi-level, grayscale not considered)

In (b), we can only find the line feature passes left-up corner of the map, which is implied by three black pixels. Then we refine the resolution from 2*2 to 4*4, as shown in (c). More details are now displayed and we can get more information about this feature. But if the resolution is refined from 4*4 to 8*8, the information increment that we can get is less than previous step. If the resolution becomes finer and finer, users almost no longer get more information.

From this process we define a new way of raster-based information measurement method. From the point of human sentience, the reason that a pixel can stimulate human eyes is because its color is different with its *context*, which is the collection of pixels adjacent to it as shown in Fig 5., and if the contraction between it and its context is sharper, it can give human eyes more stimulus, thus more information accepted by human eyes. Then we can extract this difference and define the information of a pixel P as follows:

$$Information_P = \sum (Difference\ between\ P\ and\ its\ context) \quad (6)$$

C	C	C
C	P	C
C	C	C

Figure5. A pixel's context

Information obtained by this approach is relevant to the map' resolution, and the data size of the map ultimately. We can utilize the metric of this information to determine how much data should we transfer to a client with certain resolution. A QoS map service can be implemented based on this method.

3.3 Features of raster-based information

Then what is the relationship and difference between this new information measurement and Shannon's concept of entropy? Shannon's entropy is a measurement of 'uncertainty', which is what we want to obtain from the data to be transferred through communication channel. To a certain map, if the purpose of transferring it is just for display, to eliminate this 'uncertainty' completely, the number of pixels we need is related to both the display device's resolution and the map itself. If this map is of high resolution, some part of 'uncertainty' cannot be determined by a low-resolution display device, then it is useless to transfer more details beyond this client resolution to the client. If the map itself is relatively simple (i.e. it contains few features and the shape of features is straightforward) and do not contain many details, a lower resolution (may be lower than the resolution of display device and the original map) can determine all the 'uncertainty' in the map and a higher resolution is unnecessary. From the point of information theory the original map contains a certain amount of information, but what the information theory do not consider is whether all of this information can be received by the user or not. It is not adequate to use only information theory to be guidance on how to deal with data and information, especially on the distributed environment.

We can infer from the discussion above that a quantitative relation between information and data must exist. A brief analysis of this relation is presented as follows. Let us begin by one single pixel. If the whole map is rastered to only one pixel, then the data size is the minimum, and the information amount is 0 due to this pixel has no context. It is obvious for we can know nothing from a single pixel. That is where we begin. Then we improve the resolution, and the map becomes finer and finer as discussed before. In this process, usually information amount is keep arising. But to a certain resolution, the information will not arise with the resolution improved for all the details can be determined with this resolution and the finer version of data is unnecessary. The curve that describes this relation must usually be mono-modal with a single peak and where the peak lies depends on the map itself and resolution of user's display device. We find this relation through experimental research and further we can use this relation as a rule to determine how much data should we transfer through the network, which is what Section 4 does.

4. EXPERIMENTAL EVALUATION

In this section we present a more precise description to our method and make some experimental research to reveal the relation between the information amount and the data amount.

4.1 Calculation of raster-based information

To two adjacent pixels in a gray level image, the difference between them is the absolute value of the subtraction between their gray values. We can apply the same way to a color image (i.e. RGB) by decomposing it into several components and dealing with each component separately. So we only consider gray level images in the following, the method can be applied to color images in the same way.

As mentioned in Part 3, information of a pixel is defined as the difference with its context. To evaluate this difference quantitatively, we proposed a formula to calculate this information as following. Let P be the pixel we want to calculate, the gray value of P is C_P and it has i adjacent pixels C_i. Then the information can be calculated as:

$$\inf ormation_{Pixel} = \frac{1}{n}\sum_{i=1}^{n} k_i \left| C_P - C_i \right| \quad (7)$$

To a certain map, the information amount is the sum of all pixels' information:

$$\inf ormation_{Map} = \sum_{i} \inf ormation_{P_i} \quad (8)$$

Now we make a deeper inspection into the Internet spatial information service. In this type of service, through the so-called three-tiered architecture, Web servers receive and process client request and send responds, application server deal with business logic and communicates with database via some APIs to obtain the data clients want. When users are sending request for a spatial information service, they rarely are interested in the total map, oppositely, there are often some regions or layers that they show their interest in, and these regions or layers keep changing when users are roaming on the map. As for the server, we can think of this activity as opening a small window on the map and sending contents covered by this map to the certain user.

Being clear with what the users do when they are requesting for spatial information service, we can utilize the definition of information we proposed before to direct the data transmission of this spatial information service. See, to a certain map, we design our experimental scheme as following. The map stored on the server side is one with high resolution and not being totally requested by the user. A small window, which is on behalf of the scope of map requested by the user, will be used to clip the total map, and what clipped from the total map is the data that may be transferred to the client (but not all of them definitely). This small window may be relatively large, when user want to cover more content on the whole map, even may be the same with the total server map, and it may be relatively small when user is interested with some details of a local part of the server map.

Since the possible data that may be transferred is decided by the small window on the server side through clipping, the next question is how much of this data must be transferred. To solve this question the new information definition proposed by us can be utilized. From the analysis above we know the amount of this information is relevant to the data amount and the resolution, this is the metric we need. Suppose user browse the map with a window with certain size, then the data which is clipped by the server small window will be displayed in this window and we use this window to compute the information amount and the corresponding data amount. The whole process is illustrated in the following Fig.8.

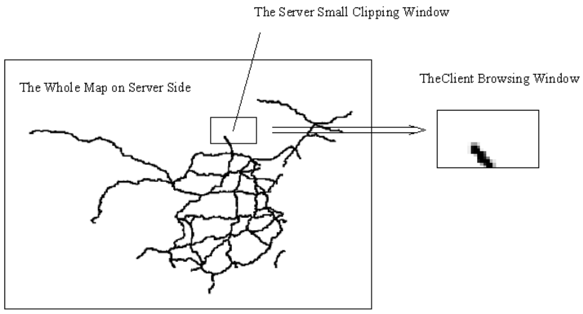

Figure 8. The Process of Spatial Information Service

4.2 Experimental results and evaluation

The Experimental data and results are given as following Figure.9 and Figure.10. To a certain small server small clipping window, an experimental result like Figure.10 can be derived to describe the relationship between data amount and information amount at this certain server small clipping window size.


Figure 9. The Experimental Map

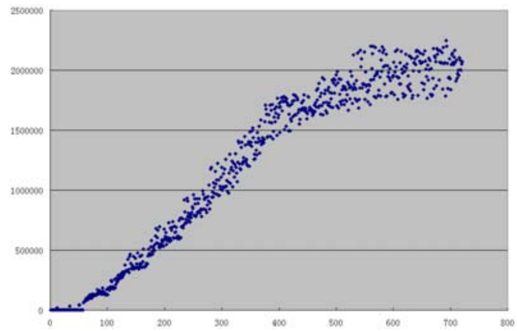

Figure 10. The Experimental Result Corresponding with Figure.9

In Fig.10, we can see obviously the trend of the relation between data amount and information amount in the background of a whole map. When the data amount is little, the information amount is little too, which is obvious because a small bulk of data cannot obtain much information. When the data amount increases, the information amount increases in a common sense, but what we must pay attention to is that a relatively large amount of data does not necessarily contain more information. With a certain amount of data, we can get different amount of information, but the largest amount of information is related to the data amount.

When the data amount increases continually, a turning point is achieved. After this turning point, when the data amount increases, the maximal information amount that contained by the corresponding data amount do not increase. This turning point suggests that to a certain resolution and a window with a given size, there exists an upper limit of information amount. To get this upper limit of the information amount, we need a certain amount of data, if more data is given, we cannot get more information. This conclusion is what we can get from the experimental research and it is accord with what we proposed in Section 3.

5. CONCLUSIONS AND FUTURE WORK

In this paper, the existing quantitative measures for map information are first briefly presented and their common shortage is pointed out. All the existing methods are probability-based and have not reveal the relation between the amount of data and information, which is the major problem that this paper solves. From the viewpoint of QoS in the distributed environment, a new raster-based method of map information measurement is proposed and its rule in the dissemination of spatial information in the Internet is described. Finally an experimental research result is given, and the relation between the so-called raster-based information amount and the data relevant to it is analysed exactly with some statistical method.

What we present in this paper is an initial work about the application of map information measurement in spatial information service and there are more work left to do in the future. We can expect that to certain kinds of map, such as contour lines and road networks there must exist some difference among their data-information amount relationships and it is an interesting region for future research. The quantified comparison between this information measurement and other information measurement can be done more profoundly and more valuable results are expected to be found. More work will be done about this new method of information measurement.

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