

# PROGRESSIVE TRANSMISSION AND VISUALIZATION OF VECTOR DATA OVER WEB

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## ABSTRACT

The progressive transmission of map data over World Wide Web provides the user with a self-adaptive strategy to access remote data. It not only speeds up the web transfer but also offers an efficient navigation guide in information acquisition. The key technology in this transmission is the efficient multiple representation of spatial data and pre-organization on server site. This paper aims at progressive transmission investigating some constraints from three aspects : data organization in server site, data control in the transmission process and data restore after reached to the client. Two strategies, namely on-line map generalization and off-line map generalization, are examined respectively for this kind of progressive transmission.

**Keywords :** progressive transmission, map generalization, spatial resolution

## INTRODUCTION

The appearance of Internet presents two challenges for cartography discipline. One is that we get a new space to be mapped, namely cyberspace or virtual world (Taylor, 1997; Jiang & Ormeling, 1997). Another is pushing mapping technology into web environment, including the delivery of map data through web, the remote access of map data, the on-line making map with data from different web sides, and so on. The previous challenge resulted from new visualization content leads to the cartography re-building basic map concepts which is quite different from those in a conventional map about real space. The latter challenge resulted from mapping technology, on the one hand, provides new opportunities and methods to represent spatial phenomena, on the other hand, results in new challenges to live with web.

Once the map data can be downloaded from web side, the user will demand a high efficiency. There are two questions to be settled: (1) quickly finding the location of map data he needs with a search engine, and (2) quickly downloading data under an interactive control. The first question depends on the special map search engine to efficiently process metadata. For the latter question, the improvement of hardware and web infrastructure, such as broadband extending, is just partly a solution. The data organization on server and transmission approach across web play important roles. In this domain, the progressive transmission of map data from coarse to fine becomes a welcome transmission method. In the sequence of significance, the map data is transferred and visualized on the client step by step with increasing details. Once the user finds the accumulated data meets his requirements, he can interrupt the transmission at any time. It is a self-adaptive transmission procedure in which the user and system can communicate interactively. As the complete data on server usually covers much details over the requirements of users, the interruption can save much time for some users. The progressive transmission not only speeds up the web transfer but also respects the principle from coarse to fine details in the cognition of spatial information. From the point of view of information acquisition, the progressive process behaves as an efficient navigation guide.

Recently the progressive transmission of vector data becomes an active issue. Bertolotto & Egenhofer (2001,1999) first presented the concept of progressive transmission of vector map data and provided a formalism model based on distributed architecture. Battenfield (2001) investigated the requirements of progressive transmission and based on the modified strip tree (Ballad, 1981) developed a model for line transmission. From the point of technology view, Han and Tao (2003) designed a server-client scheme for progressive transmission.

The progressive transmission of raster data and DEM / TIN has been successfully implemented in web transfer (Srinivas, Ladner etc. 1999; Rauschenbach, and Schumann, 1999). But for vector map data, it still remains a challenge. The reason exists in that the multi-scale representation of vector data is much more difficult than that of raster or DEM data. It is hard to find a proper strategy to hierarchically compress vector data, like the quad tree to approximate raster data in different resolution.

The progressive transmission is the application of multiple representation of spatial data in web transfer environment, associated with map generalization. It can be regarded as the inverse process of map generalization at a low interval scale change. The key solution is to pre-organize generalized data on server site in a lineal order with details increment. In this study we present a model to represent multi-details based on changes accumulation. The model considers the spatial representation from one scale to another scale as an accumulation of set of changes.

The progressive transmission has to consider the impacts from both servers and clients. On server side the works involve the pre-organization of spatial data, the off-line generalization of coarse data, the generation of special spatial index and others associated with multiple representation (Bertolotto & Egenhofer, 2001). On client side the transmitted result should be restored or visualized as original complete geographic entity based on sets of details arriving at client in different time. The integrity of spatial entity and relationships among entities may be destroyed after they arrive at the client, due to the decomposition of data into details for the purpose of progressive transmission. To design an efficient server/client scheme to finish the progressive transmission of vector data, a lot of constraints have to be investigated. This study tries to examine these questions from the point of view of data handling.

The rest of paper is organized as follows. Section 2 investigates the granularity concept in the progressive transmission. How to reduce the data volume when multiple versions of transferred data generate? Section 3 will settle this question offering several strategies. Section 4 discusses the transmission sequence and its impacts on data visualization. Section 5 explores the data restore and maintenance of transferred result in client site. Section 6 provides the conclusion with the future works.

## **THE GRANULARITY OF PROGRESSIVE TRANSMISSION**

On server site the transmitted data is bound to some packets containing different data contents at different resolutions. The granularity of progressive transmission refers to the minimum data unit in one step of transmission. From the viewpoint of visual cognition, only when the change between two transmitted data is small enough can manual eyes acquire the effects of continue or gradual animation. The steep change or suddenly jump of a discontinue scene on screen is hard to find progressive images for our eyes. For the purpose of progressive transmission, on server site the degree that one decomposes the vector data into details has to meet the granularity requirement.

The component of a vector map can be represented as a hierarchical structure with three levels: layer feature, object and geometric detail. The layer feature refers to the object set with the similar theme, such as the hydrological feature. The object is the independent entity with complete geographic meaning under one layer feature, such as the line river, the polygon lake. The geometric detail is the component parts to compose one object, such as the bend contained in the river curve. In web transmission, the data element that each step transmits can correspond to different levels in vector map component structure. We define the transmitted data in one step the transmission granularity. Then there are three kinds of transmission granularities. From layer feature, object to geometric detail, the transmission granularity decreases and the changes between two adjacency transmission also reduce correspondently.

The transmission granularity at layer feature level obviously is too coarse. In Steven's theory of scale measurement(Steven,1946), the concept theme belongs to the nominal variable which is not comparable in significance grade. On server side the pre-organization of data can not predict the later demands from client users according to feature importance. The organization sequence of feature layers usually is not what users want. To download map data, generally the users on client not only have requirements in theme selection but also in representation scale. It implies that the transmission granularity should reach to level of object or geometric detail.

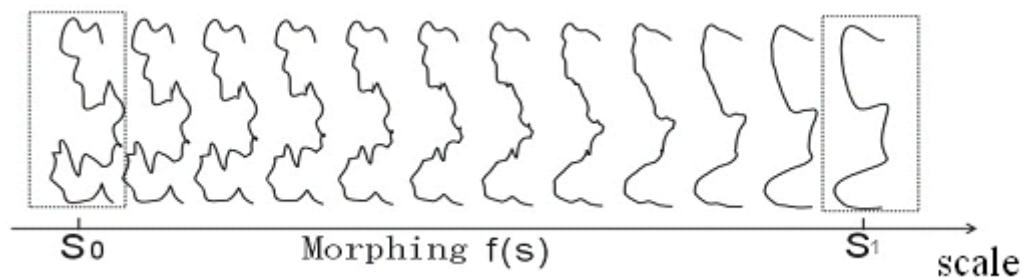
Under a feature layer, the object elements can be sorted on significance grade in spatial representation. For example, in catchment representation the river branches can be organized to a lineal sequence based on Horton code and river length. The transmission of river branches in this order will result in the catchment representation with increasing details. The GAP-tree structure with the lineal sequence of polygon organization is able to support the progressive transmission of categorical area features (Oosterom, 1995; Ai and Oosterom, 2002). Unfortunately not all objects can be structured in such a lineal order, especially for those objects across different themes. However, the object sequence in progressive transmission is not strict, usually behaving as the order among object groups. Objects within group A have to be transmitted before those within group B. But the transmission sequence of objects within same group, i.e. A or B is not of importance. The transmission granularity in object level is enough for the applications whose users only care the representation resolution in object level. The progressive transmission model proposed by Bertolotto & Egenhofer (2001) belongs to this level that each step transmits one object not involving

the geometric details. On client screen, the transmission with the granularity of object level reflects as either appearance or disappearance of one complete object. Once an object appears it remains the same scene without details add. It is still a coarse transmission as far as the granularity is concerned.

Only the transmission with granularity at the level of geometric details is a real progressive transmission. The granularity geometric detail usually reflects as the segment of line, bend of curve, concave/convex parts of polygon and so on ( Ai, Guo etc. 2000; Muller,1992 ). The gradual add of geometric details refines the object representation and let user get the image of dynamic evolution. Compared with the pixel to compose image, the vector data is more complicated in both element structures and component methods. The decomposition of object into series of details is a difficult question when considering scale impacts. Thus the transmission of vector data under the granularity of geometric detail becomes a bottleneck (Under the other two levels is relatively easy.) The LOD technology in the field of computer graphics can be introduced to resolve vector data decomposition. But most algorithms on LOD are based on grid or mesh structure and aim at three dimensional object.

How to determinate the transmission granularity among three levels? The objective of progressive transmission is to provide users with a spatial representation over a broad scale range to get the information cognition in multiple details. So the determination of transmission granularity depends on what spatial concept that users interest and how broad the cognition ranges in scale space. If the user is interested in the catchment representation, the transmission granularity at river branch is suitable. The further separation curve into bends is not necessary. But if users are interested in the representation of line river, the transmission granularity has to reach to the level of curve bends. So there is the principle that the transmission granularity is down one level compared with the level of spatial concept that users interest in vector map data component structure.

Once the transmission granularity is determined, we need to apply certain operations to decompose the representation into details adaptive to this granularity. From the point of view of map generalization, it is the scale transformation that separates the transmission granularity. The progressive transmission can be regarded as the mapping from the representation over spatial scale to the representation over temporal scale. Each time transmits (or displays) one representation suitable for a certain spatial scale. Every generalization operation must yield representation changes but the change degree is different. In generalization operation, there are three hierarchical strategies, namely operators, algorithms and parameters (Shea and McMaster, 1991). We can design a generalization method with different hierarchical strategies to get the transmission granularity we want according to the change degree.



**Figure1.** The Morphing transformation to interpolate middle representations between a direct line and a curve.

The operators selection/elimination and typification result in the appearance or disappearance of one object completely (change at object level). The operators simplification, collapse, aggregation, amalgamation generate changes in geometric details of one or many objects. To tune the tolerant parameters in generalization algorithm can further adjust the changes in different granularity levels. Figure 1 shows the morphing transformation from a line with two end-points to a complex curve. The transformation steps and speed will determine the detail changes and the transmission granularity when the series data is sent over web. Not all existing generalization algorithms are adaptive to decompose transmission granularity. If one generalization algorithm is sensitive in scale, which means the algorithm can output a new representation state once the scale occurs little change, this generalization algorithm is suitable for the progressive transmission.

## DATA VOLUME

Reducing the data volume as much as possible is another requirement for data transmission over web (Buttenfield, 2002). Generally the data volume that aims at the progressive transmission is much larger than that of complete representation with full details due to the add of middle gradual representations. If the user wants to download the whole data, he will suffer from the progressive transmission taking more time than that of direct transmission. However its advantages in other aspects show it a valuable process. The solution of the contradict between progressive transmission and large data volume exists in the compression of vector data. We may settle this question by three strategies: (1) only recording change parts rather than complete representation states, (2) distinguishing key representation and removing unimportant ones, and (3) deriving new representation state through the transformation function.

In the compression of multimedia data, such as audio data and video data, we try to detect change parts and record it in the file. In vector representations over spatial scale two consecutive states must have much overlap parts. We can also extract the change parts to express the vector representation. Based on this idea and for the purpose of data volume decrement, we will present our method, the changes accumulation model in section 3 to record details in different levels. Unfortunately, many generalization algorithms can just output independent representations corresponding to one scale without providing connections among the series of representations over scale range. A post-process is required to extract changes through the comparison between two consecutive output results.

From coarse state to fine state, among the series of representations the contribution of each state in gradual evolution is not equal to each other. When we put the representations in a line layout, we may find some of them are key stages but others not. The removal of unimportant stages will not affect the progressive transmission, but the miss of important stages will destroy the refining process. So distinguishing and removing some of unimportant representations is an useful step to reduce data volume. In map representation space, every spatial entity has a limited range of representation scale (Cecconi, 2002). For instance, the building can be represented as polygon under large scale (1:5,000), a rectangle under middle scale (down to 1:20,000), and a point under small scale (down to 1:50,000). When further down scale such as 1:50,000, the building will disappear if just considered the impacts from spatial scale without special purpose from semantics. We define the scale range for one object representation the "generalization lifecycle". Over the generalization lifecycle, one object faces different operations to abstract the representation and we can distinguish two change stages: the key stages and non-key stages. The key stages are those associated with steep change in geometric or semantic aspects, such as the disappearance of one object (elimination), the decrement of spatial dimension from three to two or from three to one (collapse), the amalgamation of various objects within a region to get a new concept object, and so on. The non-key stages are those related to smooth change in quantity with the basic properties preserved in quality, such as the simplification of curve or polygon, local displacement, exaggeration, rectification of building. The key stage happens at one point while non-key stage occurs within a duration over scale range. The key stage and non-key stage happens in turn, which means a key-stage is followed by a non-key stage and vice versa.



**Figure 2.** The generalization lifecycle of river feature, including polygon simplification, collapse, line simplification, and elimination.

Figure 2 shows the generalization lifecycle of the river representation from detailed to simplified states, the inverse of refining transmission, in the order: polygon simplification (non-key stage), collapse (key stage), line simplification (non-key stage), elimination (key stage). The generalization related to key stage is usually more difficult than that to non-key stages due to the consideration of more constraints and more complexities to maintain the relationships after steep change. The key stage transformation is usually finished in off-line generalization requiring complicate algorithms and much running time while the non-key stage is finished in on-line generalization. To reduce the data volume for progressive transmission, we can examine the generalization lifecycle to distinguish the key stage and non-key stages and remove part of non-key stages.

If we can find a suitable transformation function, say morphing (Cecconi, 2002), to automatically change the representation from one key stage to the next key stage and also can output middle representation stags, we can just

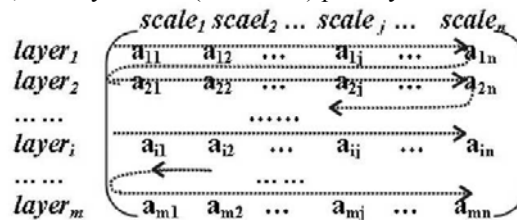
store the key stage representation and let the function later to derive the non-key stages. Apparently the data volume is greatly reduced. Under the control of two terminal key stages, the morphing transformation reflects as the interpolation of representation. This on-line transformation is able to output generalized results in real time. Maintaining the spatial relationships, such as the handling of conflicts when too many objects simultaneously appear, can be accomplished by the mathematic transformations of translate, rotation and scale of some object. For instance, we can record an offset variable with object A and in later transmission if neighbor B appears let A move the offset distance through translate operation. The data volume is smaller compared with the storage of two states. Another kind of transformation is the combination of details based on “change parts” which have been decomposed in pre-organization process. The combination operation acts as the simple addition and subtraction of changed details.

To reduce the data volume in progressive transmission, the above three strategies have something to do with map generalization but it concerns more transformation procedures. The traditional generalization technology which focuses on state representation at target scale needs to be improved in some degree. In multi-scale spatial database, various versions of data are digitized from paper maps usually related to some points in scale range, say scales 1:10,000, 1:50,000. For the sake of progressive transmission, assessing the generalization lifecycle of every feature to extract the key stages, we may find different features have different partitioning of representation scale. For building feature, scale 1:50,000 drives a steep change from polygon to point representation, but for river feature the change at this scale is smooth. So scale 1:50,000 is not a key scale point for the representation of all features and it is not necessary to store the representation of all features at this scale point when considering key stage representation.

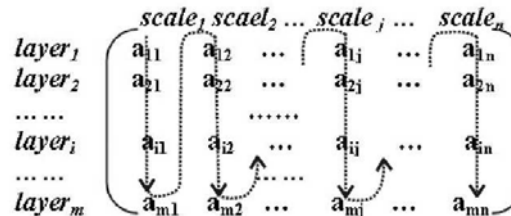
## TRANSMISSION SEQUENCE

Spatial scale and semantics are two independent impacts on progressive transmission. One representation must under certain spatial scale and simultaneously belong to one thematic layer. Considering the priority of transmission sequence, on server side the data organization for progressive transmission has two cases, namely the sequence of scale priority and semantics priority. Correspondingly, there are two transmission sequences. The sequence of scale priority implies that the important (in the sense of scale) and large objects or details will first be transmitted no matter the semantic layers they are. The sequence of semantics priority implies that under one thematic layer the objects or details are transmitted in the order of significance decrement. After the data of one thematic layer are fully transmitted, the transmission point moves to the next thematic layer. The result of previous transmission is similar to the topographic map whose data has common significance to each other in semantics without privilege to some features and in this process the scale determines whether an object or detail represented or not. The result of latter transmission is similar to the thematic map in which some features play main roles standing out from background features. It is the consideration of semantics that makes the spatial multiple representation differs from that similar LOD representation in the community of computer graphics.

A lineal index for the data to be transmitted needs to be built according to the transmission sequence. Construct a matrix with the row representing the thematic layer and the column the spatial scale. Then the lineal index of transmitted data has two methods, namely the row(semantics) priority and the column(scale) priority.



The lineal index of row(semantics) priority



The lineal index of column (scale) priority

The transmission of scale priority aims at the client users without special preference in spatial information acquisition. The transmission of semantics priority aims at the users who are interested in some special features, and we can only execute progressive transmission on the interested foreground features and let background features directly transmit by the normal way.

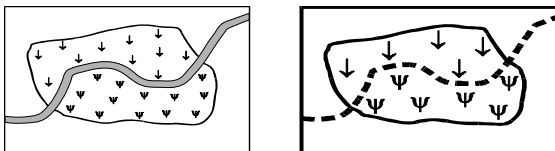
Each snapshot of the progressive transmission is one approximated representation of features. After the end of transmission the representation with full details can be regarded as the truth representation. Then from the point of view of spatial data quality, the progressive transmission is a process to represent spatial data with quality increasing. The progressive transmission should be convergency gradually accessing to truth representation. The following scene  $S_{i+1}$  of scene  $S_i$  has to be more precise in detail representation. To help user knowing the progress level and the distance to the full state, we can design a progress bar to visualize the dynamic process in interface. Furthermore, some measures of spatial data quality, such as the hierarchical attribute grade, area ratio, location precise, etc. can be designed to describe the current transmission state.

## DATA RESTORE

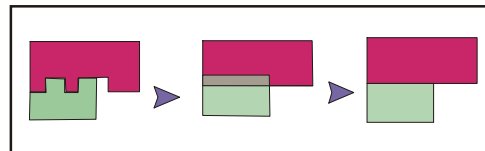
If the transmitted data is just for visualization, the decomposed details arriving at the client need no post-process and the procedure of gradual adding details has reflected the progressive effects. It is just like the raster data transmission and visualization from coarse to fine by LOD technology. However, if the transmitted vector data is downloaded for the purpose of spatial analysis or imported into other application systems, the decomposed details need to be composed and restored as the original form, just like the decoding process in signal processing (Bertolotto and Egenhofer, 2001). In GIS applications, the spatial object has the same representation in logical level among different systems, although the concrete data structures and realization methods may differ. For example, the polygon object is represented as a closed coordinate string with possible one or more inside loops. But for the progressive transmission the resulted data may be quite different from this definition, instead as the integration of a set of basic geometric elements. This data is not convenient to conduct geometric measurement and topologic operation as usual way, such as the measure of area, the distance between two objects, and the detection of neighbors. In order to be compatible with other application systems, the transmitted data requires to be restored in both data content and format. So when we design a strategy to decompose data into details on server side, we have to consider the possibility of data restore later.

For the transmission in object level, the element remains the independent geometry and the component operation is able to simply through the union operation. For that in the level of geometric details, the set operations may be complex depending on the decomposing methods. The details are usually organized in a hierarchical structure. To restore to the original representation, it needs to determine which detail “nodes” in the hierarchical tree should be selected and what relations they have to each other. Some details make the positive contributions in object component, but others make the negative contributions.

In data restore, another question is the maintenance of topological relationship for the final sub-set data when the user interrupts the transmission after the data has enough details to meet his requirements. The retrieved sub-set data is dynamic under the control of user, leading to the difficulties in the maintenance of topological relationship. First detect where the topological relations have been destroyed among the sub-set data through the comparison with original relation based on the neighborhood analysis. Usually the relation destruction results from either the reduction of the number of objects or the change of geometric representation compared with the original representation. Part of relation destructions reflect as the spatial conflicts in map generalization. Then use the consistency operation to restore the original relation. In Figure 3, when the user interrupts the transmission, the middle road is represented as line rather than narrow polygon and then two neighbor land-use parcels will no longer have “touch relation” to each other. Due to the collapse of road object, the gap between two land-use parcels need to fill by polygon extension toward to keep the original “touch relation”. In Figure 4, two buildings with full details representation have “touch relation” to each other. During the progressive transmission, retrieving the approximate



**Figure 3.** The collapse of road leads to the extension of associated parcels to fill the gap



**Figure 4.** The simplified buildings need the displacement to maintain touch relationship.

representation at a coarse detail, such as the bounding rectangle, leads to the overlap conflict, against the original relation. It needs displacement operation to correct the destroyed relation.

Bertolotto & Egenhofer(2001) pointed out the consistency is an essential property for the usability of data. The consistency question is associated with the horizontal contexts and by now few generalization methods have settled the context consistency well. Decomposing the representation at different detail levels and selecting part of objects or details must result in inconsistency. For progressive transmission, on server site we can not forecast what objects will appear together and in what detailed representation. It is nearly impossible to find a way to decompose details to guarantee all possible consistencies among different components of later transmitted data. So the post-process on client side becomes an inevitable step.

## CONCLUSION

The progressive transmission provides users with a self-adaptive method to access data over web. Also it plays an important role in the data navigation for users to acquire spatial information from coarse to fine, consistent with the process of information cognition. The image data, raster data and DEM has been realized this transmission method. The progressive transmission of vector map data is still an open question. In this paper we discuss the characteristics of progressive transmission of vector data, investigating the constraints in transmission granularity separation, data volume compression, transmission sequence organization and data restore. The multi-scale representation and hierarchical organization of vector data is a key technology for progressive transmission. Indeed, the progressive transmission can be regarded as a mapping process of data representation from spatial scale to temporal scale. The data details separated on the basis of spatial scale is then transmitted in time range domain. Each snapshot in time domain corresponds to one representation at certain spatial scale. The waiting for a longer time will get the representation at a higher resolution in spatial scale.

In technology the progressive transmission is associated with map generalization. If one generalization can output dynamic data within a wide scale range rather than at one scale point, the series of data is well suitable for progressive transmission. Unfortunately, most of existing generalization algorithms can just derive new data at some scale point.

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