Data Compression for Network GIS

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SYNONYMS

None

DEFINITION

Data compression of Network GIS refers to compression of geospatial data within a network GIS so that volume of data transmitted across the network can be reduced. Typically, a properly chosen compression algorithm can reduce data size to 5~10% of original for images [1-2], and 10~20% for vector [3] and textual data [4]. Such compression ratios result in significant performance improvement.

Data compression algorithms can be categorized into lossless and lossy. Bit streams generated by lossless compression algorithm can be faithfully recovered to the original data. If loss of one single bit may cause serious and unpredictable consequences in original data (for example, text and medical image compression) lossless compression algorithm should be applied. If data consumers can tolerate distortion of original data to a certain degree, lossy compression algorithms are usually better because they can achieve much higher compression ratios than lossless ones. Some commonly used lossless and lossy data compression algorithms are listed in Table I.

Table I Lossless and lossy data compression algorithms

Lossless	Lossy
Huffman Coding	Differential Pulse Coded Modulation (DPCM)
Arithmetic Coding	Transform Coding
Lempel-Ziv Coding (LZC)	Subband Coding
Burrows-Wheeler Transform (BWT)	Vector Quantization
…	…

Practical data compression applications do not have to be restricted to a single type. For example, the JPEG (Joint Photographic Expert Group) image compression [5] first uses DCT (Discrete Cosine Transform) to decompose images into transform coefficients. These transform coefficients are lossy quantized and the quantized coefficients are losslessly compressed with Huffman or arithmetic coding.

HISTORICAL BACKGROUND

Data compression of network GIS is similar to other data compression algorithms on distributed computing platforms. Image compression algorithms such as JPEG had been applied since the first Web-based GIS emerged in 1993 [12]. However, the compression of vector data is introduced much later, such as the Douglas-Peuker algorithm [13] and the work done in 2001 by Bertolotto and Egenhofer [9].

SCIENTIFIC FUNDAMENTALS

Data compression originates from information theory [14], which concentrates on systematic research on problems arising when analog signals are converted to and from digital signals and digital signals are coded and transmitted via digital channels. One of the most significant theoretical results in information theory is the so-called source coding theorem [14], which asserts that there exists a compression ratio limit that can only be approached but never be exceeded by any compression algorithms. For most practical signals it is even very difficult to obtain compression algorithms whose performance is near this limit. However, compression ratio is by no means the unique principal in the development of compression algorithm. Other important principals include fast compression speed, low resource consumption, simple implementation, error resilience, adaptability to different signals, etc. Further study about information theory and data compression can be found in texts [2] [15] and journals (e.g. *IEEE Transactions on Information Theory*).

Progressive transmission algorithms are mostly based on wavelet decomposition, especially in digital images. In wavelet decomposition, signals are represented as a weighted sum of a group of wavelet bases. These bases are fast-decaying in both spatial and frequency domain, which makes analysis of local properties of signal effective. An example of image wavelet decomposition is illustrated in Figure 1. Since wavelet decomposition is recursive, a progressive transmission algorithm can be constructed immediately by transmitting frequency bands successively from low to high. Other more efficient progressive transmission schemas may utilize the similarity between frequency bands [6-7] or add more truncation points optimally [8].

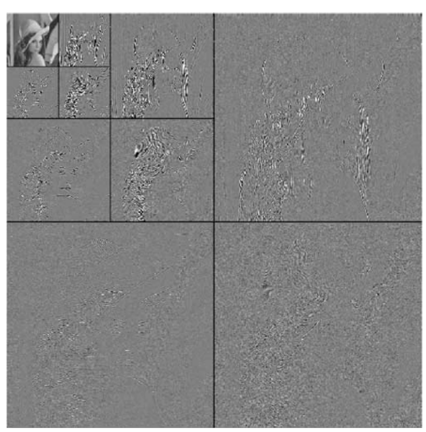
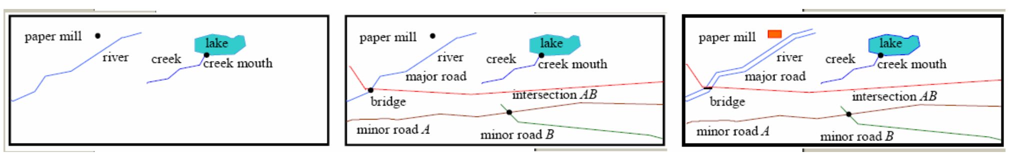


Fig. 1 Wavelet decomposition of image

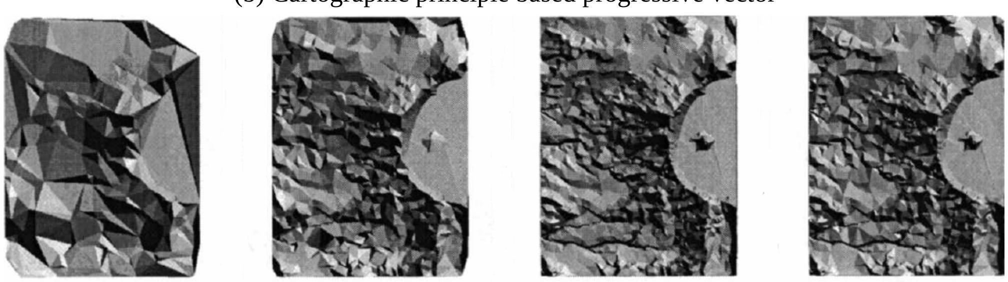
Web-based platform has new challenges for data compression algorithms because web users are pretty diversified in terms of number, objective, and performance tolerance. Within such a context, data compression algorithms should be robust and fast while consuming server resource as less as possible. Progressive transmission (PT) was proposed for such requirements [6-8]. A PT-enabled bitstream acts as a finite decimal number (e.g. 3.23897401), which, if decimated from beginning to certain place (e.g. 3.2389), will result in a shorter bitstream that can be reconstructed to a low-precision version of original data. Only one version of PT-enabled bitstream needs to be stored and all lower precision bitstreams can be obtained herein.

PT is based on multiresolution data decomposition [6-8]. For raster data, many effective algorithms can be used to generate such decomposition. For non-raster data, it is quite hard to construct progressive bitstreams effectively because these data are not defined in a regular spatial grid and commonly used multi-resolution decomposition algorithms (e.g., wavelet) are hard to be applied [9-11]. Therefore, other methods (e.g., cartographical-principle based decimation, Figure 2b and Figure 2c) may be adopted.

(a) Image



(b) Cartographic principle based progressive vector



(c) TIN

Fig. 2 Progressive transmission of different types of data in networked GIS

KEY APPLICATIONS

Raster data compression

Raster data compression algorithms are the same as algorithms for compression of other image data. However, geospatial images are usually of much higher resolution, multi-spectral and of significant larger volume than natural images. To effectively compress raster data in networked GIS, emphasis must be put on the following aspects:

- ✓ Statistical properties of imagery in GIS may be quite different from other types of imagery,

- ✓ Correlation among different spectrums,
- ✓ Managing schemas [16] to deal with large volume of geospatial raster data,
- ✓ integration of different other types of datasets (e.g., vector and 3-D data)

WebGIS:

- ✓ TerraServer [24] uses the so-called pyramid technique to assist the SQL Server to manage images. With this technique, a relatively large image is extracted into different levels of detail to construct a pyramid structure. The images are transmitted only when the data of interest are requested by the user.
- ✓ ArcGIS also uses the pyramid technique in handling big images and the pyramid is built on the fly every time when the image is accessed. However, this method is not suitable for managing images on WebGIS because the response time will be too long. Yang, *et al.* [16] developed a method to managing a permanent pyramid so that performance can be improved.
- ✓ Google Earth [25] divides remote sensing images into many slices and organizes each slice into different resolutions using progressive transmission method. Besides, some Web2.0 techniques (e.g., AJAX) is incorporated so that user experience can be improved.

Non-raster data compression

Different methods can be utilized to compress non-raster data, such as 2-D and 3-D vector data (e.g. roads and borders), 3-D mesh models, and TIN.

For vector data, a survey of simplification algorithms can be found in [17]. Simplification aims at extracting a subset of original vector data according to predefined criteria. Resulting vector data is also compressed. Algorithms that derive binary coding for vector data [3] [18] also exist. Compression algorithms for vector data are far less than those for raster data. Researches on progressive vector transmission algorithms concentrate more on topological and semantic aspects than pure binary coding [9-11]. However, due to the complexity of this problem, existing solutions are far from satisfaction.

For 3-D mesh models, usually its structure and attribute information are coded separately. Structure information records how vertexes are connected and must be losslessly compressed. Attribute information records information of each single vertex and can be lossy compressed. Progressive mesh transmission algorithms [19] depends on how to decimate vertex one by one so that a given error criterion can be optimized.

Compression and progressive transmission of TIN is similar to 3-D mesh models [20].

GIS Interoperability

Interoperability gains popularity in sharing geospatial resources. However, the standardization of interoperable interfaces increase the volume of data has to be transmitted. Therefore, the compression methods associated with interoperable encoding language is very important. For example, GML could be several times larger than the original data in binary format [21]. Possible solutions to such problems include:

1. A BLOB (Binary Large Object) object can be embedded in the textual XML document to store the binary compressed stream of geospatial data.
2. Textual XML file can be compressed using common compression tools (e.g. zip and gzip) before transmitting.
3. The BXML (Binary eXtensible Markup Language) proposed by CubeWerx Inc. [22] and OGC (Open GIS Consortium) also provides promising results [23].

FUTURE DIRECTIONS

Future research needed in this area includes 1) principals and algorithms for optimally choosing proper compression schemas and parameters when compressing raster data, 2) semantically and topologically well designed progressive transmission algorithms for non-raster data, and 3) incorporating proper compression algorithms for both raster and non-raster data into different Web infrastructure.

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