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ANALYSIS AND COMPARISON OF CONNECTIVITY AND GEOMETRY MESH COMPRESSION IN 3D OBJECTS

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АНАЛІЗ І ПОРІВНЯННЯ СІТКОВОГО СТИСНЕННЯ ЗВ'ЯЗНОСТІ І ГЕОМЕТРІЇ 3D ОБ'ЄКТІВ

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АНАЛИЗ И СРАВНЕНИЕ СЕТОЧНОГО СЖАТИЯ СВЯЗНОСТИ И ГЕОМЕТРИИ 3D ОБЬЕКТОВ

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Abstract. In this article the different connectivity and geometry compression algorithms of 3D objects were analyzed and compared. Mesh connectivity is completely unknown to the encoder before the compression. Face Fixer, Edgebreaker and Valence-based approach as well as a Huffman code and an arithmetic code was applied to encode connectivity information and compare experimental results. In geometry, compression typical and non-typical methods of encoding meshes, images, and video were applied. Elias gamma code, Even-Rodeh code, Rice code, Gray code (or RBC), and Fibonacci sequence were among them. Furthermore, the stage of pre-processing coding geometry of mesh models was suggested. Additionally, the use of a Residue numeral system in pre-processing stage was offered.
Key words: 3D image, mesh compression, connectivity encoding, geometry encoding.

Анотація. У цій статті проаналізовано і порівняно різні алгоритми стиснення зв'язності і геометрії 3D об'єктів. Зв'язність сітки повністю невідома кодеру перед стисненням. Для кодування даних зв'язності і порівняння експериментальних результатів використовувалися алгоритми Face Fixer, Edgebreaker і Valence-based approach у поєднанні з кодом Хаффмана й арифметичним кодом. При стисненні геометрії застосовувалися типові і не типові для кодування сіток, зображень і відео методи, серед яких гамма-код Еліаса, код Івен-Роде, код Райса, ряд Фібоначчі. Крім цього, був запропонований етап попереднього оброблення кодування геометрії сіткових моделей. На доповнення пропонується використовувати систему залишкових класів на етапі попереднього оброблення.
Ключові слова: 3D зображення, сіткове стиснення, кодування зв'язності, кодування геометрії.

Аннотация. В этой статье проанализированы и сравнены различные алгоритмы сжатия связности и геометрии 3D объектов. Связность сетки полностью неизвестна кодеру перед сжатием. Для кодирования данных связности и сравнения экспериментальных результатов были применены подходы Face Fixer, Edgebreaker и Valence-based approach в сочетании с кодом Хаффмана и арифметическим кодом. При сжатии геометрии применялись типичные и нетипичные методы кодирования сеток, изображений и видео, среди которых гамма-код Элиаса, код Ивэн-Роде, код Райса, ряд Фибоначчи. Кроме того, был предложен этап предварительной обработки кодирования геометрии сеточных моделей. В дополнение предложено использовать систему остаточных классов на этапе предварительной обработки.

Ключевые слова: 3D изображение, сеточное сжатие, кодирование связности, кодирование геометрии.

Introduction. Television (TV) has come a long way since its first demonstration in 1925 and the first television station WRGB in 1928 based on mechanical scanning. Television has gone from monochrome to color, analog to digital, CRT to LCD, from passive broadcast to interactive Video on Demand (VoD) services. Presently, it has been moving to the stage of development of ultra-high definition TV (UHDTV) and three-dimensional TV (3DTV). TV aims to give users feel that they are watching real objects and involved in current events, i.e. the effect of presence. The factors, which should be considered to progress a successful 3DTV services, include the ease of 3D data capture, coding and transmission efficiency of the 3D data over channels.

3D mesh representation is one of the standard methods to describe 3D objects, where surfaces of 3D objects are covered with so many polygons [1]. A mesh can be defined as the hierarchical assembly of different elements, among which are vertices, edges, and faces. The information contained in any mesh can generally be divided into three categories:

– the connectivity data (structure of the mesh elements);

– the geometry data (position of each vertex);

– the optional attribute data (colors, normal, etc.).

This article deals only with the compression of the connectivity and geometry information.

Most mesh compression algorithms are focused on triangular meshes and a special triangulation operation is performed for the processing of polygonal meshes. Although now there are some proposed methods for encoding polygon meshes directly without additional triangulation, in this article we consider only triangular meshes.

Experimental results in connectivity compression. Compressing meshes differs from compressing other types of multimedia data such as sound, images and videos. Its connectivity is completely unknown to the encoder before the compression. Besides having to code the geometry (vertex position), as the pixel colors would be coded for an image, a mesh encoder must encode the structure, which is connectivity [2].

An arbitrary section of the mesh model was chosen to obtain experimental data. To encode connectivity information and compare ~~of~~ experimental results the following encoding methods were applied:

1. Edge-based approach (by example Face Fixer, Martin Isenburg, Jack Snoeyink), Fig.1,a.
   The Face Fixer algorithm compresses the connectivity of manifold polygon meshes with arbitrary face degrees using a face traversal of the mesh. The encoder generates one symbol per edge. Experimental results yield connectivity compression rates ranging from 1.7 to 2.9 bpv [2].
2. Face-based approach (by example Edgebreaker, Jarek Rossignac), Fig.1,b.
   The Edgebreaker algorithm encodes the connectivity of triangular meshes by iteratively nibbling its faces. Each time a new face is traversed, the configuration of its patch among the five is encoded. The face is then removed and an adjacent face is processed. In practice, after entropy coding, a mesh is encoded with about 1.8 and 2.4 bpv [2].
3. Vertex-based approach (by example Valence-based approach, Touma, Gotsman), Fig.1,c.
   The Valence-driven approach principle is to consider the edge boundary formed by an initial triangle and expand this boundary by iteratively adding adjacent vertices. The connectivity is encoded by the valence of the inserted vertices typically concentrated around six. Therefore, the generated list of verte valences can be efficiently compressed by an entropy coder (2.3 bpv) [2].

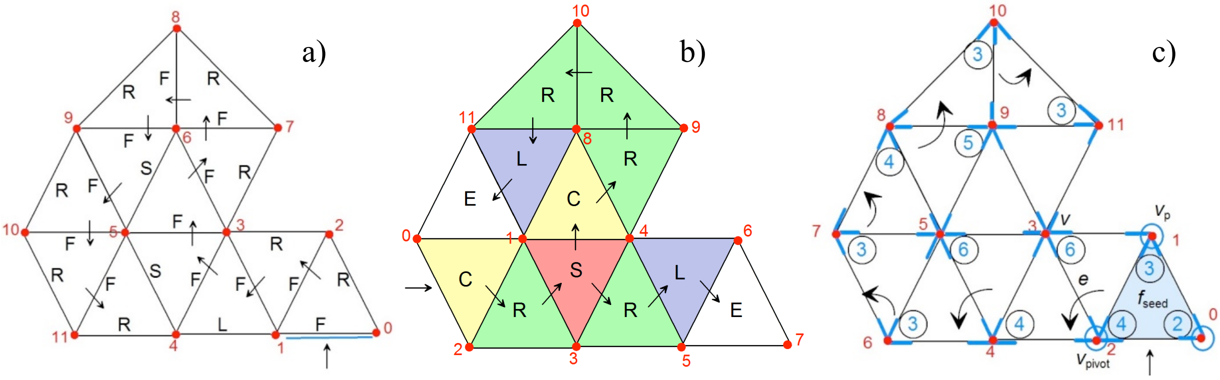

Figure 1 – Connectivity compression using different methods:
a) Face Fixer; b) Edgebreaker; c) Valence-based approach

In all these algorithms, the generated symbols are then entropy-coded using, for example, a Huffman coder or an arithmetic coder. The results were formalized in the Table 1.

Table 1 – Code and bitrate of connectivity compression using different methods

Connectivity compression method	Huffman coder		Arithmetic coder	
	Obtained code	Bitrate, bpv	Obtained code	Bitrate, bpv
Face Fixer	1 011 1 011 1 010 1 1 1 011 1 011 1 011 1 001 1 011 1 011 1 011 001	3,75	10101100111110001 01011101011101111 101001100000	3,83
Edgebreaker	0 101 100 101 110 11 1 0 101 101 101 110 111	2,67	10000001111110010 0101001011001111	2,75
Valence-based approach	0001 1 01 001 01 001 1 1 01 0000 1 1	2,08	1111011101111110 11000111	2,08

As a result, experimental data showed that the most effective method was Valence-based approach with 2,08 bpv.

Experimental results in geometry compression. Mesh geometry compression (the compression of the vertex coordinates) is very important as, in most cases, it is bigger than the connectivity information [2].

Firstly, for convenient work with vertices, they were normalized and reduced to integers (described in detail in [3]).

In this article some entropy coding methods were considered and compared, among them Elias gamma code, Even-Rodeh code, Rice code, Gray code (or RBC), Fibonacci sequence. ~~In~~ At [4] the stage of pre-processing coding geometry of mesh models was proposed. This intermediate stage allows the reduction of values, which are necessary for coding vertices, but simultaneously not the reduction of accuracy. Using the Residue number system (RNS) at this stage allows to apply parallel processing and to reduce the necessary numbers of bits per vertex (bpv) for encoding. Also ~~in~~ for [4] the efficiency of the selection a Residue number system for pre-processing was analyzed.

After the pre-processing stage an array of numbers from 0 to 12 is obtained, which is easier to encode with fewer errors. Further for an arbitrary section of the mesh model the bitrates were calculated for using different codes and compared with each other. See Table 2 and Fig. 2.

Table 2 – Encoded sequence of numbers by the selected variable-length codes, which is necessary for encoding mesh geometry

Number	Elias gamma code	Even-Rodeh code	Rice code	4-bites Gray code	Modified Fibonacci sequence
0(1)*	1/1	000/3	000/3	0000/4	11/2
1(2)	01 0/3	001/3	001/3	0001/4	011/3
2(3)	01 1/3	010/3	010/3	0011/4	0011/4
3(4)	001 00/5	011/3	011/3	0010/4	00011/5
4(5)	001 01/5	100 0/4	1000/4	0110/4	01011/5
5(6)	001 10/5	101 0/4	1001/4	0111/4	000011/6
6(7)	001 11/5	110 0/4	1010/4	0101/4	010011/6
7(8)	0001 000/7	111 0/4	1011/4	0100/4	001011/6
8(9)	0001 001/7	100 1000 0/8	11 000/5	1100/4	0000011/7
9(10)	0001 010/7	100 1001 0/8	11 001/5	1101/4	0100011/7
10(11)	0001 011/7	100 1010 0/8	11 010/5	1111/4	0010011/7
11(12)	0001 100/7	100 1011 0/8	11 011/5	1110/4	0001011/7
12(13)	0001 101/7	100 1100 0/8	11 1000/6	1010/4	0101011/7
*in that representation of zero is not possible in the Elias gamma code, its modification (biased Elias) is used					

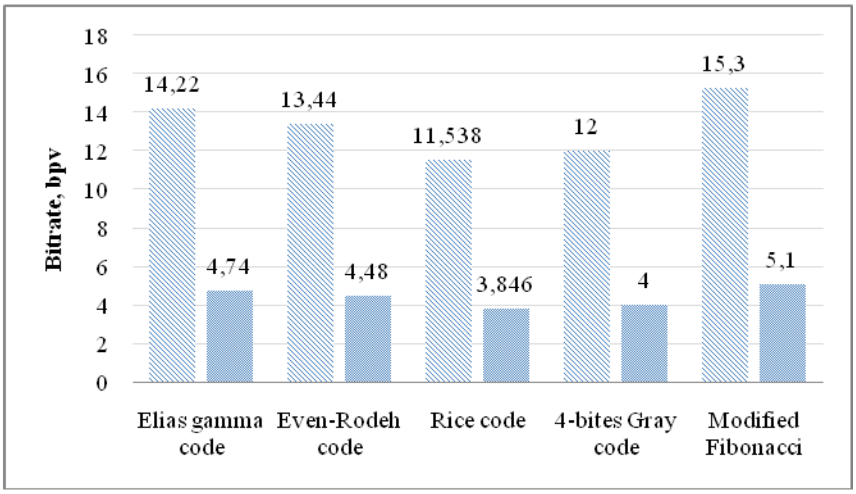

Figure 2 – Comparison bitrates of various methods

Table 2 shows the obtained encoded sequences of a particular coding method for each number and through the slash the number of bits spent on it, respectively. On Fig. 2 data in general calculation are blue marked, green – when using parallel processing of mesh geometry encoding data, as described in [4]. One can see the best bitrate was obtained by a method using Rice code for a mesh geometry encoding after the conversion of the RNS (Residue number system). Its peculiarity is that it is suitable for situations in which the appearance of small values in the input stream predominates.

Conclusion. In this article the different connectivity and geometry compression algorithms were analyzed and compared. Among them were non-typical methods of encoding meshes, images and video. Among them are the Residue numeral system, modified Fibonacci sequence, Elias gamma code, Even-Rodeh code, Rice code, Gray code, and typical methods – Huffman coder and an arithmetic coder. In connectivity compression experimental data showed that the most effective method was Valence-based approach, using both encoders – Huffman and arithmetic. It is still seen as one of the most efficient connectivity compression method since 1998. The proposed stage of pre-processing coding geometry of mesh models helped to substantially reduce the bitrate to 3.85-5.1 bpv. Over and above, it offered the application of a Residue numeral system in pre-processing stage, which made it easier to work with large arrays of vertices coordinates, leading to small integers.

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