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MOVING PICTURE FRACTAL COMPRESSION USING I.F.S. - A REVIEW (II) -

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I. Introduction

The aim of this report is to set up state-of-the-art methods in the field of moving picture fractal coding using I.F.S. This topic is recent, that is why, this review may often be updated. Using I.F.S. for moving pictures is a natural extension of studies conducted in still image compression (see section II). The growing number of articles in this field since 1991 indicates the interest for this technique in the compression community (see section III). In this section, the two main approaches, already defined for moving picture fractal coding using I.F.S., are introduced. Available commercial and public softwares are presented in section IV. In section V, readers can find several summaries of relevant papers. In section VI, open questions, put forth by the previously described methods, are introduced. An extensive (but certainly not complete)* list of relevant references is given in section VII.

II. Still Image Coding

The reference algorithm, from which different projects in still image coding using I.F.S. are based, has been proposed by A. Jacquin in his Ph.D. supervised by M. Barnsley:

"Image Coding Based on a Fractal Theory of Iterated Contractive Image Transformations"
A. E. Jacquin
IEEE Trans. on Image Processing Vol. 1 No. 1 January 1992.

Readers can find a complete review in still image coding using I.F.S. in:

A guided Tour of the Fractal Image Compression Literature
D. Saupe, R. Hamzaoui
ftp: ftp.informatik.uni-freiburg.de/papers/fractal/Guide.ps.gz

There also exists a recent book on Fractal Coding, edited by Yuval Fisher,

Fractal Image Compression: Theory and Application
Spinger-Verlag publisher
New-York, 1995

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* if you have any information, news, or request, to update this paper, please feel free to contact us by e-mail: {dugelay,ifs}@eurecom.fr

Current works on image coding/processing using I.F.S. can be classified into **5** categories,

1) Some authors work on **basic aspects** of this technique, i.e.: iterative process, contractivity constraint,...

2) One can notice that majority of studies focus on some problems of **implementation** and optimization,... More precisely, the more frequent addressed topics are segmentation, domain blocks classification, reduction of computational complexity,...

3) More recently, some papers deal with image processing using I.F.S., in addition to coding. The aim is to introduce some **functionalities** such as hierarchical/progressive decoding, zoom, indexing, watermarking,...

4) Another category includes works done for designing an **extension** of Jacquin's algorithm, defined for still, gray-level images, to moving/color/multispectrum images. The main problem is either to take into account an additional dimension (i.e. temporal one) or to deal with vectorial data (i.e. color values) instead of scalar ones (i.e. grey-level ones).

5) A last category can be defined from a limited set of recent papers in which I.F.S. is compared or combined with some **other techniques** such as VQ, Wavelets, ...

Most of papers of each category are available via one of the following sites:

Monro's site @ *http://dmsun4.bath.ac.uk/papers.html*
Hamzaoui's site @ *ftp://ftp.informatik.uni-freiburg.de/papers/fractal/Readme.html/*
Fisher's site @ *http://inls.ucsd.edu/y/Fractals/*
Kominek's site @ *http://links.uwaterloo.ca/fractals.papers.html/*

The following sections deal only with the extension of the coding algorithm from still images to moving pictures.

III. Moving Picture Coding

Studies on moving picture coding using I.F.S. are more recent (1991) and are generally based on previous works intended for still image compression. The majority of the following references were published in 1994 (see table 1, below),

Year	1990	1991	1992	1993	1994	1995	1996	1997
publications	0	1	2	5	14	6	7	?

- table 1 -from our bibliography, section VI.

Currently, two approaches are proposed in the literature for a possible extension of Jacquin's algorithm for moving picture coding:

A. Block coding schemes

i) realised picture by picture (see section II), eventually using motion information in order to limit the search for the matching between range and domain blocks.

ii) an "intra" coding mode using I.F.S. associated with an "inter" coding mode using block-matching. This method is close to MPEG standard using D.C.T. (Discrete Cosinus Transform) and the block-matching technique (***see figure***).

B. Cube coding scheme

- The sequence to be coded is partionned into several G.O.P. (Group Of Picture). Instead of segmenting an image into a set of square blocks, each G.O.P. is segmented into a set of cubes. The third dimension is associated to the temporal dimension (***see figure***).

IV. Sofware

There is a company which offers fractal video compression, and also, a site which contains some public domain C sources:

- Iterated Systems (company created by M.F. Barnsley) **-**

Iterated Systems, Inc.
5550-A Peachtree Parkway
Norcross, GA 30092
http://www.iterated.com

This company offers a commercial service in fractal compression of colour video sequences for multimedia products planned to be released on CD-ROM. These sequences are coded and returned to the customer on CD-ROM, with a software which allows to display audio-video sequences under numerous platforms. The algorithm used includes an intra-frame coding using I.F.S. in cooperation with an inter-frame coding realised using block-matching. Results obtained with a fractal approach are better, in terms of visual quality for a given compression rate. With a bit-rate from 6 to 9 Moctets/min with the sound (that is to say, compression around 25 to 30), this package yields an audio-video sequence with an acceptable quality, without specialised hardware and with a simple double speed reader (a quadruple speed reader is not absolutely necessary in this case). The audio is not compressed but interlaced with the video, in order to preserve the audio-video synchronisation during decoding.

- Limbo -

Limbo is a program developed by students from Aalborg University (Denmark) and distributed on the InterNet. The coding scheme is similar to Jacquin's one, with some improvements. The domain and range blocks are first classified into 'Edge' (blocks with a significative gradient) and 'Shade' (uniform blocks) depending upon the variance. Then, the blocks 'Edge' are classified using different criteria in a 'Feature Space'. A range block is matched with neighbouring domain blocks in the 'Feature Space'. More precisely, a domain block is in the neighbourhood of a range block if its criteria are close to those of the range block. A simple Quadtree partitioning is used (a block is divided into four sub-blocks if the matching error exceeds a given threshold). The program also allows color images and sequence coding. Colour images are divided into their RGB components, and every component is coded separately. The sequence coding uses a cubic approach, while keeping the bi-dimensional coding described previously. A range cube is NxNxN, while a domain cube is 2Nx2Nx2N. The subsampling is three-dimensional (from 2x2x2 voxel to 1 pixel). The isometries are the bidimensional ones applied to each block of the cube. The program has several options, so that the user can adjust parameters like the range block size, the scale bounds, an error threshold for possible post-processing with more exhaustive searching in the domain pool, others thresholds for the Quadtree partitioning and the Shade-Edge classification, the Quadtree depth, and the decoded image size, ... The encoding is quite fast. The C source files are available from ftp site 'danablue.vision.auc.dk' in 'pub/Limbo/'.

V. Some summaries

In this section, several summaries of revelant papers are given. Those articles examine the current state-of-the-art in fractal moving picture coding using I.F.S. (according to the fractal compression definition of Jaquin's article).

In consideration of the previous section, Table 2 below classifies those summaries into several parts:

the approach used is a coding scheme:

{Ai} - realised picture by picture, with a possible use of some motion information,
{Aii}- relying on a joint approach motion/ifs,
{B} - based on an extension of the primitive "block" used in the context of still image compression to the primitive "cube";

If {2D} appears, those papers are extensions of previous work (of the same laboratory) in still image compression.

Main author	**n° of ref.**	**{2D}**	**{Ai}**	**{Aii}**	**{B}**
Beaumont	[1]	**x**		**x**	**x**
Novak	[5]	**x**			**x**
Reusens	[6]	**x**	**x**		**x**
Hürtgen	[10]			**x**	
Monro	[15]	**x**	**x**	**x**	
Fisher	[17]		**x**	**x**	
Naemura	[21]				**x**
Lazar	[22]				**x**
Barthel	[24]	**x**			**x**
Kim	[27]			**x**	
Dugelay	[34]				**x**
Dugelay	[35]			**x**	

- table 2 -

ref. [1] J. Mark BEAUMONT
"Image Data Compression using Fractal Techniques" (1991)

The author studies two approaches for video sequence compression: the first one is a straight extension of the 2D algorithm, and the other one is a mixed solution derived from his 2D algorithm, explained in the same paper. He claims for a rate of 80 Kbits/s for a video sequence 352*288 in 10 Hz. After a brief summary of the I.F.S. theory, the author presents a better coding scheme: the image is divided into two components, one called the low-pass slab (which is the image of the grey-level average for each range block) and one called the high-pass slab (which is the difference between the original image and the low-pass one). The high-pass slab is coded with IFS, and its high-pass characteristic makes the shift information redundant. Therefore, the low-pass slab is sent instead and is used by the decoder as the initial image to achieve a faster decoding process. Then the author studies the "natural" extension from the square block to the cubic block in order to code moving pictures. He finds the result not acceptable, on the base of psychovisual criteria. So he proposes another solution, using the same scheme as his 2D coder: Each picture from the sequence is split in a low-pass slab and in a high-pass one. The low-pass slab is DPCM coded. The high-pass slab is coded using IFS but with a Domain search made in the previous picture.

ref. [5] H. LI, M. NOVAK, R. FORCHHEIMER
"Fractal-Based Image Sequence Compression Scheme" (1993)

The proposed 3-D sequence coding scheme is based on the self-transfomation system (STS). A sequence is subdivided into sets of frames, which are partitioned into 3-D non-overlapping domain blocks. Every 3-D domain block is split into 8 3-D range blocks, and contractive transformations are calculated to map a 3-D domain block into the 3-D range blocks belonging to it. For the massic transformation, using a second-order polynomial function as offset and least-squares method to compute its parameters, are suggested. The authors claim that this scheme permits a better compression ratio while keeping a certain image quality.

ref. [6] E. REUSENS (reusens@ltssun3.epfl.ch)
"Sequence Coding based on the Fractal Theory of Iterated Transformations Systems" (1993)

The Fractal based sequence coding of this paper exploits Spatial Self-Similarities or Temporal Redundancies depending upon the nature of the 3-D range block (uniform and non-moving, intricate and non-moving, containing translational motion).
For a 3-D range blocks coded with Self-Similarities, the 2-D Fractal Block Coding is used in each frame of the blocks. For the others, 3-D domain blocks are mapped into 3-D range blocks with a geometric translation. The translation in the temporal direction is strictly negative.
An adaptative partitioning of the sequence is applied. It consists of a temporal splitting and a spatial splitting

ref. [10] Bernd HÜRTGEN, Peter BÜTTGEN (huertgen@ient.rwth-aachen.de)
Fractal Approach to Low Rate video Coding (1993)

This video coding scheme is a mixed algorithm using D.P.C.M. prediction and I.F.S. coding. The goal is very low bit rate coding: 8-64 kb/s. Each picture of the sequence is predicted with a temporal loop(DPCM). The bad predicted blocks are IFS coded directly (instead of coding the prediction error). A QuadTree segmentation is added to the classic coding algorithm. The search of the Domain Blocks is done in the whole frame, and is accelerated with hierarchic codebook search.

ref. [15] David L. WILSON, J. A. NICHOLLS, D. M. MONRO (D.M.Monro@bath.ac.uk)
"Rate Buffered Fractal Video" (1994)

This coding scheme is a straight application of the Bath Fractal Transform (BFT) for video coding. Using the BFT as the coding scheme allows a symmetrical time for coding and decoding: they achieve a rate of 40 kbits. Each picture is coded with BFT. The code is then quantized and compressed "on the fly" with Huffman coding. The order of transmission of the blocks is based on a prediction error for each block: the blocks with the highest error are transmitted first. The full coding scheme includes color coding.

ref. [17] Yuval FISHER (fisher@inls.ucsd.edu)
"Fractal (self VQ) Encoding of Video Sequences" (1994)

Each picture from the sequence is coded using the previous picture as the Domain block dictionnary, using a classic Jacquin IFS coding scheme optimised with a 'Quadtree' segmentation and a fast search using classification. The author thinks that 20 fps (frame per second) is reachable on the decoding stage. The author writes that looking for the Domain block in the precedent picture is "more or less, a crude form of motion compensation, without any motion". This leads to a decoding process with no iteration needed; but the contractivity condition can still be seen as an error-reduction. The author states the problem of the first image which has no previous frame: it can be coded a different way (i.e. a direct I.F.S. coding) or just ignoring the problem and code the first image with a fictitious previous picture, leaving the first images of the sequence poorly decoded.

ref. [21] T. NAEMURA, H. HARASHIMA (naemura@harashima.t.u-tokyo.ac.jp)
"Fractal Coding of a Multi-View 3-D Image" (1994)

A 3-D Fractal Coding scheme is used for coding and synthesizing intermediate-viewing-angle images of a Multi-View 3-D Image (The basic idea is to exploit the Fractal Coding property that is scalable to any resolution : the view dimension is oversampled).
In their 3-D Fractal Coding, the authors use overlapped 3-D range blocks (NxNxN, the third dimension is the views one's), a spiral search of 3-D domain blocks (2Nx2Nx2N) and a limited set of 3-D isometries: identiy, a rotation around an axis, an orthogonal reflexion about a plane. They also use an adaptative partitioning of the 3-D range blocks. This partitioning is based on the mean-square-error between the 3-D range block and the matching domain block and it is made in the three directions (i.e. the two spatial and the views one's).

ref. [22] M. S. LAZAR, L. T. BRUTON (lazar@enel.ucalagary.ca)
"Fractal Block Coding of Digital Video" (1994)

After a theoretical introduction of the Fractal Block Coding (FBC) for m-dimensional signals, the authors present a model for 3-D FBC. The video sequence is divided into R-frames and D-frames, for which are respectively defined 3-D range blocks and domain blocks. Each 3-D range or domain block is composed of an ordered set of 2-D blocks. The sub-sampling is a three-dimensional one and is done in each of the three directions (a 4x4x4 voxel gives a pixel by averaging). Two different kinds of isometry operations are proposed. The intra-frame ones, where pixels within frames are shuffled (the Jacquin scheme ones applied to each 2-D block of a 3-D block), and the inter-frame ones, where the order of frames is shuffled (identity and temporal reverse). A Spatio-Temporal Range Block Splitting is also proposed. A 3-D range block is split spatially by 4, or temporally by 2, depending upon the distribution of the matching error within the original block. To decode, they suggest using the final iteration of a given R-frame as the initial iteration of the next R-frame.

ref. [24] K.U. BARTHEL, T. VOYE
"Three-dimensional fractal video coding" (1995)

The authors propose a fractal coding scheme using contraction in all three dimensions. Firstly they motivate their three-dimensional approach. By visualizing 2D and 3D contraction, they show the effects of temporal contraction to the similarities between range and domain blocks. Secondly they describe the 3D FTC and an entropy constrained 3-D fractal coding schema. This paper is an extension of previous work of the same authors in still image compression. For a very simple implementation they use a constant range cube size of 4x4x4 pixels and a first order luminance transformation. Range cubes were coded using either the domain cube surrounding the range cube or using an other domain cube from a search path centered in the range cube. At rates of 80 kbit/s the authors say that the reconstructed QCIF-sequences (25 Hz) are of acceptable quality.

ref. [27] C.-S. KIM, S.-U. LEE
"Fractal coding of video sequence by circular prediction mapping" (1995)

In this paper, the authors proposed a novel algorithm for fractal video sequence coding, based on the Circular Prediction Mapping (CPM). In their approach, each range block was approximated by a domain block in the 4-circularly previous frame, and the size of the domain block was set to be same as that of the range block, in order to exploit the high temporal correlation in real moving images sequences. Also the modified collage theorem, which yields better prediction method for the CPM than the conventional collage theorem, is provided by linear systematic analysis. The computer simulation results on real video-conferencing image sequences demonstrate that the average compression ratios ranging from 60 to 70 can be obtained with good subjective quality.

Ref. [34] M.BARAKAT, J.-L DUGELAY (dugelay@eurecom.fr)
"Image sequence coding using 3D I.F.S." (1996)

The proposed algorithm is a direct extension of Jacquin's algorithm from still images to moving picture, by replacing blocks by cubes. The authors indicate that range cubes including motion are badly coded. In order to reduce this problem, authors introduce a novel way to construct domain cubes. It consists of offering the possibility to take successive frames constituting a given domain cube with some spatial shifting. Thus, without leaving the 3-D framework, a sort of motion compensation is introduced.

ref. [35] J.-L. DUGELAY, J.-M SADOUL (dugelay@eurecom.fr)
"Moving picture fractal coding using a mixed approach I.F.S. and motion" (1996)

The addressed approach, in this paper, is a mixed approach based on a combination between I.F.S. (inter mode) and motion (intra mode). Authors use a modified block-matching (BM) for inter-frame coding (instead of using D.P.C.M. as described in ref.[12]) and IFS for intra-frame coding. The aim of using a modified BM instead of D.P.C.M consists in offering the same possibilities of transformations in the two modes intra and inter and then to associate the same quantity of information for all blocks whatever the selected coding mode is.

VI. Comments

This summary of state-of-the-art shows that there still exists few works on fractal moving picture coding using I.F.S. (although with a significant increase since 1994). Those works can be divided into three main categories:

{Ai} - picture by picture realised with a possible use of some motion information.
{Aii} - joint ifs/motion approach, based on the MPEG scheme.
{B} - direct extension from the block primitive to the cube primitive.

After having studied the articles mentioned previously (see also the references at the end of this document), several basic questions remain unanswered regarding these three approaches:

♦ Using approach**{Ai}**, images are coded using a still image coding approach: all range blocks are coded from a domain block included in the same picture. Information of motion between images of the sequence is only used in order to reduce the time needed for blocks matching. In pratice, this approach can be difficult to implement for two reasons:
  -The range and domain blocks can both move,
  -The displacements of blocks are generally not in correspondance,
   with the partition of images into range blocks. along time.

♦ The main question brought up by approach **{Aii}** comes from the space search chosen for the Domain Block. With a mixed scheme, a frame can be divided into two parts: the background which has no or little temporal activity is therefore predicted with the Motion Prediction scheme;the foreground, which has moved, is coded using IFS. For this IFS coding process, should we use Domain block for the entire picture, that is to say allow for matching of a block not coded by IFS ? or even restrict the search of the Domain to the previous frame ? It surely insures an exact IFS code, because the matching is done with blocks that are known by the decoder. But, the iterative process is no longer needed, hence it is dubious to talk about convergence to an attractor. No scale constraint is either requested. The problem is thus to decide whether this coding scheme can still be named "fractal" or if it is just an improved block-matching (i.e. using affine transforms). Fisher [17] underlines that such coding keeps its property of scale independance, and that imposing a contractivity constraint limits error propagation. In [10], Hürtgen claims that restricting the search to the background might not ensure an acceptable collage error, due to the small codebook size. A choice of domain blocks on the whole image includes a possible choice of foreground blocks and thus the coding keeps its fractal character.

- In approach **{B}**, the extension strongly using the temporal dimension significantly changes the problem regarding the contractivity constraint, which is still not well understood in still image coding. How to consider the temporal dimension versus the two spatial dimensions (horizontal and vertical) on the one hand, and the luminance information on the other hand? Which extension can be made to generalize the isometries applied to blocks in order to define geometric transformations to apply to cubes? The opinions regarding this approach are different. Beaumont [1] indicates that the extension to sequences of the 2-D Fractal Block Coding produces inadmissible block effects. Nevertheless, it is not the opinion of other authors, as mentioned in [5], [10] et [21], who show encouraging results.

Note that, as for still image coding, almost all authors agree that fractal compression may be suitable for low bit rate applications. It is also interesting to note that several fundamental aspects, linked to fractal compression remain and should be reconsidered for moving pictures (for example, the notions of contractivity and iterative processes) but these problems are rarely addressed in these papers. On the other hand, some improvements suggested in the context of still images are not directly applicable in the context of moving pictures (for example, the way to segment images).

VII. References

The research literature on fractal video compression is experiencing a rapid growth which is hard to keep track of. This bibliography attempts to provide the scientific community with a comprehensive chronological list of references on this topic.

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