ITERATED FUNCTION SYSTEMS FOR STILL IMAGE PROCESSING

J.-L. Dugelay, E. Polidori and S. Roche
Institut EURECOM, MultiMedia Communications dept.
2229, route des Crêtes, B.P. 193, F-06904 Sophia Antipolis Cedex
E-mail: {dugelay,polidori,roche}@eurecom.fr
URL: http://www.eurecom.fr/~image

Abstract

Iterated function systems have been recently applied to the field of image coding. This paper exploits the fractal properties included in the coding and decoding schemes, in order to add useful tools for image processing. The first contribution consists of an improvement of the classical fractal zoom which allows, with a unique code, to increase the image resolution without loss in sharpness. The second one, in addition to compression, aims at enhanced security of still images thanks to the protection of few code parameter bits.

1 Introduction

The publication of Arnaud Jacquin's article on still image coding using Iterated Function Systems (IFS) [2], stimulated much research on IFS for image processing and coding [7]. Current work on this topic can be classified into four main categories, depending on the problem considered : basic theory, implementation, extension and functionality.
The category "basic theory" mainly covers work linked to contractivity constraint notions, general formulation and basic aspects of the algorithm. Although some theoretical problems in using IFS for image compression remain [3], the majority of studies currently available in the literature deals with implementation aspects such as segmentation, domain blocks classification, reduction of computation complexity, and combination of IFS with some other techniques such as DCT. Several relevant papers have proposed improvements on Jacquin's algorithm [3]. By extending the basic algorithm adapted for still grey-level images, some authors also work on a possible design of the method for video, color, and multispectral images. After a brief review of Jaquin's algorithm in section 2, we focus on the last category of studies. In particular, this paper deals with a possible implementation of some tools such as zoom [4], described in the section 3, and some security functionalities such as access control [6], described in section 4, as part of a coding scheme based on the IFS technique.

2 Brief review of image compression by IFS

Given an original image μ, the goal is to build a lossy representation of this image *via* a transform τ. The reconstructed image μ_a is obtained by the iterative process of recursively applying the transformation τ [1]:

$$\mu_a = \lim_{n\to\infty} \mu_n = \tau(\mu_a) \text{ and } \mu_n = \tau(\mu_{n-1})$$

from an arbitrary initial image μ_0. Note that μ_a is called the attractor of the transformation τ.
In order to obtain $\mu_a \approx \mu$, the encoding stage consists of selecting τ that minimizes the collage error $\varepsilon_c = d(\mu,\tau(\mu))$, where d is the distance measure. By the collage theorem [1], the reconstruction error $\varepsilon_r = d(\mu,\mu_a)$ is upper bounded by:

$$\varepsilon_r \le \frac{\varepsilon_c}{1-s} \qquad (1)$$

where s is the contractivity factor of the transform τ.
In order to reduce the coding complexity, the image μ is divided into N non-overlapping blocks [2], called the range blocks. Each range block R_i, for $i \in \{1,...,N\}$, is coded independently by matching it with a bigger block D_i in the image μ, called a domain block. This match defines a transformation τ_i , and the global fractal code is then given by the union $\tau = \cup\tau_i$ of local transforms. Moreover, each local code τ_i is restricted to consist of a reduction, a discrete isometry and an affine transformation on the luminance. Hence, τ_i can be modeled by:

$$\tau_i \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} a_i & b_i & 0 \\ c_i & d_i & 0 \\ 0 & 0 & s_i \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} t_{i,1} \\ t_{i,2} \\ o_i \end{pmatrix} \qquad (2)$$

where a_i, b_i, c_i, d_i, $t_{i,1}$, $t_{i,2}$ represent the geometric transforms and s_i, o_i the grey-levels transform ; x, y are the pixel coordinates and z the corresponding luminance value.

3 Zooming using IFS

By virtue of the iterative decoding process which uses a "fractal" transform τ, the corresponding attractor μ_a is a fractal object. Although the original image μ has a fixed size defined by its number of pixels, the code τ, built by taking advantage of image self-similarities, has no intrinsic size and is theoretically scale-independent. Thus, by applying the transformation τ on an initial image μ_0, we may obtain a reconstruction μ_a of the original image with the same resolution as μ_0 (see Fig. 1). Hence, thanks to this coding scheme, we eliminate the fixed resolution aspect of digitized images.

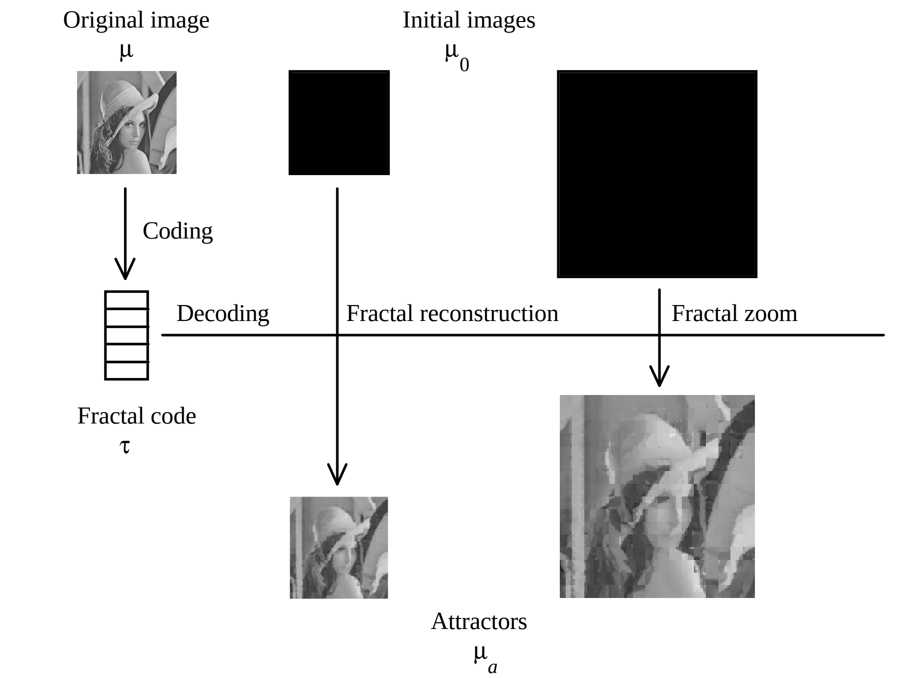
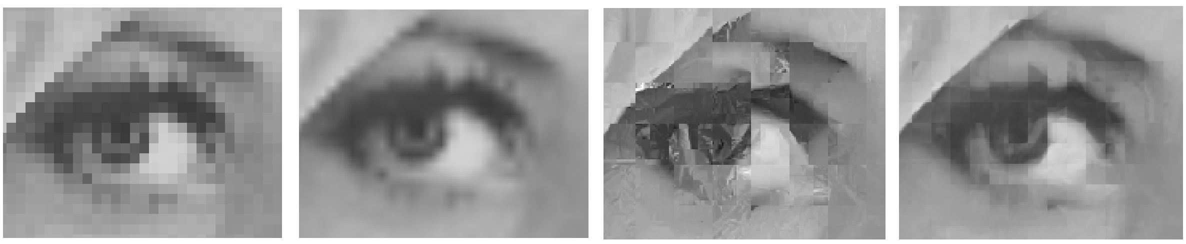


Figure 1: Fractal zoom scheme



(a) (b) (c) (d)

Figure 2: Zoom by a factor 6 on Lenna's left eye using
(a) nearest neighbor interpolation, (b) linear interpolation,
(c) classical fractal technique, and (d) improved fractal technique (without postprocessing)

The fractal zoom is mainly based on this remark. But the result of such a zoom is visually rather poor (see Fig. 2 (c)), although there is no "pixelization" as that due to pixel duplication (see Fig. 2 (a)). Indeed, the fractal zoom causes an important "blocking effect" due to independent and lossy coding of the range blocks. To obtain a good visual quality, some improvements have been made, such as the use of overlapping range blocks [4]. In this case, the coding becomes redundant in overlapping regions of the image μ, and then we average these parts in order to smooth the block effect and to reduce the collage error by chosing among several values for each considered pixel. This yields a zoomed image (see Fig. 2 (d)) with a sharper quality than the classical linearly interpolated image (see Fig. 2 (b)), obtained using a luminance continuity hypothesis. Unfortunately, this improvement is done at the present time at the price of degrading the compression performance. However, this method allows the image to be displayed, from a unique code, at different levels of resolution according to the application requirements.

4 Hierarchical access control using IFS

The advent of multimedia applications has brought new requirements, especially in the security field [5]. Here we propose a hierarchical access control, a system that allows different levels of quality according to the access fee paid. All the receivers of a broadcast channel can display an image, but only at low quality with no commercial value. This message, received through the public channel, remains partially readable in order to attract potential customers who would apply for the commercial service to get the higher quality image. The IFS method is suitable for this because it offers the possibility to control the image quality during the iterated reconstruction process.
More precisely, the contractivity parameter s (see Eq. (1)) is modified throughout the luminance scale-parameters s_i (see Eq. (2)) according to the access level desired. By partially hiding the value of s_i through encryption, several access levels can be obtained. For instance, if s_i is quantized with 8 bits, each of these bits could be let readable (see Fig. 3(a)). In this case the classical reconstructed image with highest resolution is obtained (see Fig. 5(d)). On the other extreme, encrypting all 8 bits of s_i (see Fig. 3(g)) leads to the image of Fig. 5(a) that is unreadable. Between these two configurations, encryption of s_i at intermediate degrees leads to intermediate levels of visualization quality (see Fig. 5(b), 5(c)).

	MSB			s_i bits				LSB
(a)	1	0	0	1	1	1	1	0
(b)	1	0	0	1	1	×	×	×
(c)	1	0	0	1	×	×	×	×
(d)	1	0	0	×	×	×	×	×
(e)	1	0	×	×	×	×	×	×
(f)	1	×	×	×	×	×	×	×
(g)	×	×	×	×	×	×	×	×

Figure 3: s_i parameters masking from (a) no encryption, to (g) full encryption

Nevertheless, we note that any domain block can be viewed as a set of range blocks. Each range block of the decoded image μ_a is thus highly dependent on the block mappings performed on a pyramidal fashion during the previous iterations (see Fig. 4). Hence the s_i values, associated with each of the blocks involved with these mappings, strongly affect the final decoded image. Thus s_i appear to be the key parameter in order to provide access control.

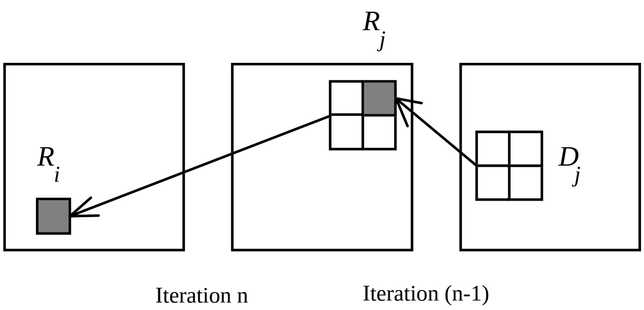
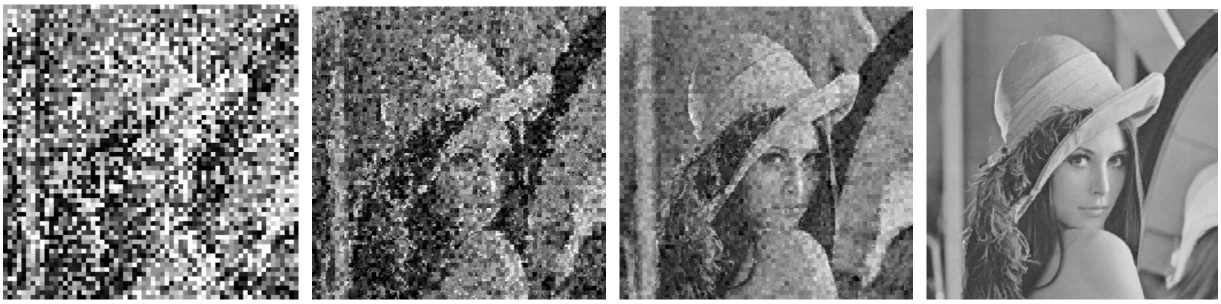


Figure 4: Domain block as a set of 4 range blocks

Then, we propose a hierarchical access control scheme which provides both compression and security functions within a single algorithm. Note that the multi-resolution access can be achieved without any degradation of compression performance. The security evaluation of this scheme is performed in [6].



(a) (b) (c) (d)

Figure 5: Fractal compression of Lenna Face with access control using (a) 8/8 protected bits, (b) 6/8 protected bits, (c) 5/8 protected bits, and with (d) no access control (0/8 protected bits)

5 Concluding remarks

Although IFS is not a fully understood technique, fractal image coding has been used successfully to encode still grey level images. Until now, efforts have mainly focused on the compression aspect of IFS.

Nevertheless, with the growth of multimedia applications and communications, some future coding schemes, such as MPEG-4, are in progress. These schemes consider some functionalities and tools in addition to compression. It is admitted that IFS is a new and interesting technique for image coding. In addition, in this paper, we have tried to demonstrate that IFS may also be a very useful technique for simultaneously performing image coding and processing. Two methods have been described: the first one provides a way to zoom a picture and the second one to control its access. These methods exploit some particular properties inherent in fractal signal processing (scale-independency) and more specifically to the IFS technique. In practice, both zoom and security could be combined for a single framework to control the image resolution.

One future direction for this work could consist in extending the use of these tools and functionalities from still images to video. Moreover, this study may also indirectly contribute to improvements in the general understanding for the use of IFS in the field of image coding.

6 Acknowlegments

This work is supported in part by AEROSPATIALE (service Télédétection & Traitement d'images, établissement de Cannes) and DGA/DRET (groupe Télécommunications & Détection).

References

[1] M. Barnsley & L. Hurd, *Fractal Image Compression*, AK Peters, Wellesley, 1993.

[2] A. E. Jacquin, "Image Coding Based on a Fractal Theory of Iterated Contractive Image Transformations", *IEEE trans. on Image Processing*, Vol. 2, No. 1, pp. 18-30, jan. 1992.

[3] Y. Fisher, *Fractal Image Compression – Theory and Application*, Springer-Verlag, New York, 1994

[4] E. Polidori & J.-L. Dugelay, "Zooming using Iterated Function Systems", *NATO ASI Conf. Fractal Image Encoding and Analysis*, Tromdheim. Norway, July 1995. To appear in a special issue of Fractals.

[5] B. Macq & J.-J. Quisquater, "Digital Images Multiresolution Encryption", *IMA Intellectual Property Project Proceedings*, Vol. 1, jan. 1994.

[6] S. Roche, J.-L. Dugelay & R. Molva, "Multiresolution Access Control Algorithm based on Fractal Coding", *IEEE ICIP'96*, Lausanne, Switzerland, September 16-19, 1996.

[7] D. Saupe & R. Hamzaoui, "A guide Tour of the Fractal Image Compression Literature", *ACM SIGGRAPH'94 Course Notes*, 1994.