ON FRACTAL COMPRESSION OF IMAGES FOR NARROWBAND CHANNELS AND STORAGE

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Abstract

Fast transmission of digital images and fast video over packet radio can only be possible by compression of the original uncompressed source material that contains many bits. This paper provides several comments on a new class of compression techniques based on fractals. This approach may exceed by far the compression limit of the JPEG technique.

1. INTRODUCTION

Living with ASCII text on packet is no longer satisfactory for me. I would like not only to see a photograph of a radio pal, as well as colour weatherfax, aerial photographs, scientific and technical visual representations, and even fast video, but also to *hear* speech and various sounds, including music. This applies equally well to the fast universal network of networks, the Internet, because its traffic is increasing exponentially. It will also apply to the future information superhighway. Thus, there is an increasing fundamental need for transmission and storage of still and moving images through the available communications channels. If the transmission occurs over radio, the bandwidth of the channels is always narrow because the spectrum is finite. Consequently, the number of bits in the source material (i.e., uncompressed pictures) must be reduced in order to reduce the transmission time of the picture, or send more pictures over the same channel within the same time.

There are numerous lossless and lossy methods and techniques capable of compressing images, as shown in Fig. 1 [Kins91a], [Kins9 1 b]. *The lossless compression* approach is concerned with the removal of *redundancy* from the source (i.e., bits that carry no additional information). The approach is called lossless because no information is lost in the compression and reconstruction process, although fewer bits are transmitted. Examples of such compression implementations are the Huffman [Huff52] and Lempel-Ziv-type [Welc84] and arithmetic coding [WaFK93], [WiNC87] techniques [DuKi91], as found in the PKZIP and other compression computer programs used for archiving and packet transmission.

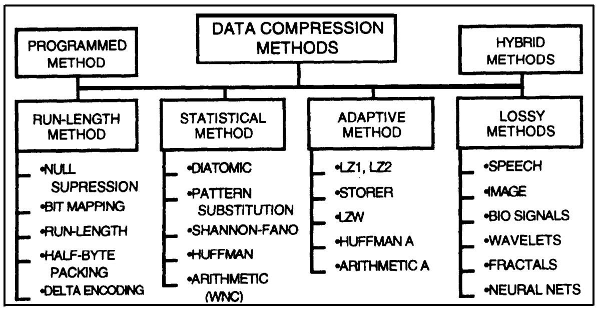


Fig. 1. Compression methods and techniques.

In contrast, the lossy compression approach removes *irrelevancy* from the source (i.e., the features that are not important in human perception). This approach leads to some losses, though imperceptible, in the reconstructed image. Examples of such techniques are the JPEG (Joint Photographic Experts Group) [PeMi93] and wavelet compression [LaKi94]. The wavelet compression reference describes our work on the very promising class of techniques that are ideally suited for perceptually-driven compression. The JPEG reference provides the most accurate description of the international standard for **digital** compression of continuous-tone still images. It **defines a** toolkit of processes for lossy and lossless encoding and decoding of images. It also describes image-coding techniques, with emphasis on Huffman coding, arithmetic coding, predictive coding, QM coding and the discrete cosine transform (DCT) [ChSF77], as well as the JPEG - modes of operation, signalling conventions, and structure of compressed data. A brief overview is also provided of both the JBIG (Joint Bi-Level Image Experts Group), and MPEG (Moving Picture Experts Group).

Barnsley [Barn88] and Jacquin [Jacq90] introduced compression techniques based on fractals [PeJS92] that far exceed the limit of the JPEG scheme, and can reach compression ratios of hundreds or even thousands to one. We have introduced a reduced-search fractal block coding technique, with smaller compression ratios at this time, but much shorter computing times and a systematic analysis of images [WaKi93a].

The lossy techniques can be combined with the lossless techniques in order to remove any redundancy left in the compressed code. Such concatenated codes are very compact, as demonstrated by combining a fractal code with the arithmetic code [WaKi93b]. Furthermore, forward error correction may also bc introduced to protect the code against errors during transmission, as described by this author [Kins90].

Is compression the only problem for data and signal transmission and storage? The answer is yes, if we consider the number of bits delivered to the end-user as the only objective of the solution. However, if we deliver more and more bits, how will the user navigate through them? In fact, if there are more bits to chose from for transmission, how will the user know which bits should be transmitted? In his keynote address at a recent conference in Halifax, NS, the director of the Media Lab at the Massachusetts Institute of Technology (MIT) stated that "people don't want *more* bits, they want the *right* bits". So, the additional problem is how to select (filter) the right bits. Searchability is associated with such filtering of information.

While text can be searched for keywords easily, searching of mathematical expressions, tabular data, and musical scores is much more difficult. Even more difficult is searching of images and sound. This problem will have to be resolved, if we want to have the multimedia form of transmitted information.

(a)

(b)

Fig. 2. Fractal block coding (FBC) compression. (a) The original image of Lena with 256x256 pixels and 8 bpp. (b) Reconstructed image from FBC with compression of 14.3: 1 at 0.56 bpp and 29.1 dB.

3. FRACTAL COMPRESSION

Fractal data compression is an alternative to JPEG and vector quantization, with a much higher compression potential. It has attracted a great deal of interest since Barnsley's introduction of *iterated functions systems* (IFS), a scheme for compactly representing intricate image structures [Barn88], [BaHu93]. Although the applicability of IFSs to the compression of complicated color or gray-scale images is hotly debated, other researchers have applied the concept of self-similarity (fundamental to fractals) to image compression with promising results.

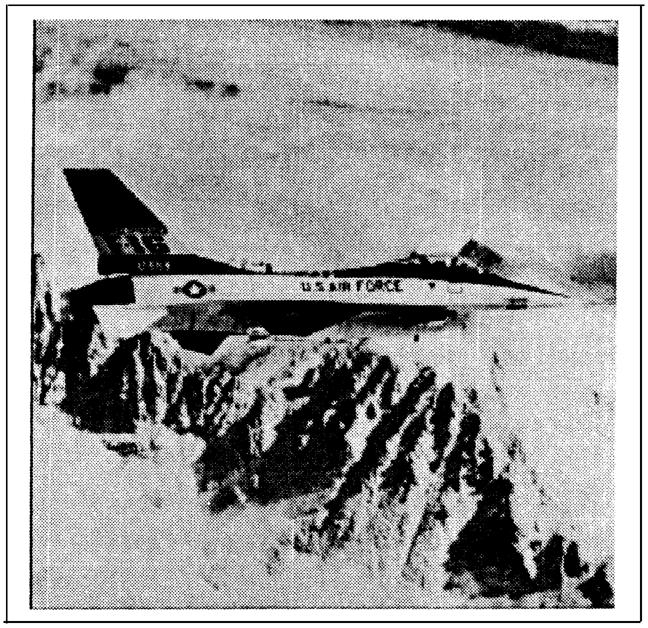
We have developed a block-oriented fractal coding technique for still images [WaKi93], [Wall93] based on the work of Arnaud Jacquin [Jacq90]. Jacquin's technique has a high order of computational complexity, $O(n^4)$. We have used a neural network paradigm known as *frequency sensitive competitive learning* (FSCL) [AKCM90] to assist the encoder in locating fractal self-similarity within a source image. The approach identifies all the affine transformations within the image without the assistance from a human operator.

A judicious development of the proper neural network size for optimal time performance has been provided. Such an optimally-chosen network has the effect of reducing the time complexity of Jacquin's original encoding algorithm from $O(n^4)$ to $O(n^3)$. In addition, an efficient distance measure for comparing two image segments independent of mean pixel brightness and variance is developed. This measure, not provided by Jacquin is essential for determining the fractal block transformations prescribed by Jacquin's technique.

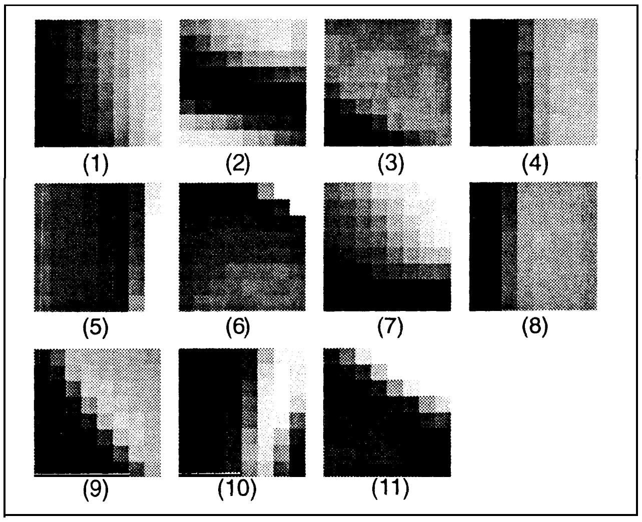
Figure 2 shows the results from our fractal technique. Figure 2a is the original image of Lena represented by 256x256x8 bits. Figure 2b shows Lena reconstructed from the compressed form (14.3: 1 or 0.56 bits per pixel) by the FBC. The peak signal to noise ratio (PSNR) is 29.1 dB. The image quality is quite high, with some details segmented into slightly visible blocks. The block nature of the image is much reduced if we take a higher resolution image (e.g., 512x5 12x8). An added unique feature of FBC is its ability to zoom on details (not shown here).

4. FEATURE EXTRACTIONFOR SEARCHABILITY

The fractal compression techniques just described, together with a learned vector quantization [FeLK93], lends itself to searching in that it provides codebooks of characteristic features.



(a)



(b)

Fig. 3. Finding characteristic features in the form of a codebook for searchability. (a) The original image of AIRPLANE with 256x256 pixels and 8 bpp. (b) Optimal codebook for the image.

The codebooks are extracted in an adaptive fashion, without a "teacher" showing what is and what is not significant in the image or a temporal signal, It is then proposed to search for characteristic features in such objects using the codebooks rather than the direct digital representation of the objects.

Figure 3 shows an example of an optimal codebook (Fig. 3b) for the scene containing an airplane (Fig. 3a). The codebook has been obtained using our fractal compression. To achieve searchability, the codebook must be correlated to and associated with the objects in the image. Work on the association scheme continues.

5. DISCUSSION

As any users of the Internet and the future information superhighway, the users of packet radio will require diverse material ranging from simple text, formatted text, mathematical expressions, tabular data, line drawings, maps, gray-scale or colour still images and photographs, phonetic transcription of speech, music scores, and other symbolic representations, to hypertext, animation and video, actual recordings of sounds such as electrocardiograms or other biomedical signals, telephone and broadcast-quality speech, and wideband audio. Such representations lead to large files.

Consequently, efficient storage and transmission requires data and signal compression. Since the lossless arithmetic coding is better than other statistical techniques, it can be used for critical data where no bit can be lost.

In contrast, lossy compression techniques based on wavelets, neural networks, and particularly fractals have good prospects of becoming important in such a delivery of information. These techniques also provide tools for the development of universal feature codebooks that can be used for searching of nontextual material.

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