Fractal Iterated Function System (IFS) Compression for Image and Video

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Abstract

Fractal Image compression, a technique pioneered in the late 80's and 90's, attempts to compress 2D signals via repeated downsampling. After each downsampling stage, an interpolator function f is learned for each image patch and attempts to capture the lost information with 'fractal coefficients', or rather, parameterizations of the interpolator for each patch. Initially discarded in favor of more efficient and effective compression algorithms, such a technique warrants revisiting with the rise of application domains like satellite imagery, computer vision, and video classification. This semester we will implement efficient, more effective encoders for fractal compression and use this system to investigate a number of usage areas across computer vision, image processing and signal compression. We will also explore its uses in the 1D and 3D (audio and video) domains.

1 Research Problem Statement

With the complete proliferation of 1D, 2D, and 3D signal information across most computer systems today, there is a distinct need for intelligent compression algorithms to reduce the size of this data. While traditional approaches like JPEG(DCT)[2] and JPEG2000(DWT)[1] exist, these techniques are traditionally symmetric with respect to compression and decompression time. For non-real-time applications there is a constant need for better compression ratios, and in this domain, long compression times are preferred to larger file sizes.

Additionally, in the fields of image processing and computer vision, feature selection is strongly informed by what transform bases are available. Fourier analysis is universally useful, but non-optimal for certain classification tasks. Specifically with geometric or modulated signal data, we believe that transforming data into new domains such as the "fractal" domain could be illuminating for certain classification tasks.

Finally, computational capabilites have drastically increased since the 90's in even the most basic computer systems, and image algorithms are used across domain areas that have only recently become popular in industry. Due to this, several older techniques likely need to be reevaluated in terms of both their usefulness across research domains and their computational cost.

2 Literature research

Fractal Image Compression (FIC) was first proposed in 1988 by Michael F. Barnsley[7][3]. The algorithm is implemented as an iterated function system (IFS); images are divided into patches, downsampled, and then coefficients for upsampling the patch are found to minimize error. This technique was explored theoretically, but the first fully automated algorithm for fractal image compression was not proposed until 1992 by Jacquin[8] using the "Partial Iterative Function System," or PIFS[6]. This algorithm certainly improved the viability of FIC, but several problems remained, foremost being the disproportionately large compression time. There were several attempts to remedy the computational cost of encoding such as one using classification techniques[10], but the effort was seemingly abandoned in industry after the early 2000's. Further research in 2013[9] improved both speed and image quality of fractal compression, but the topic remains niche.

FIS has historically achieved comparable results to those of it's more standard competitors (JPEG, JPEG2000), and on repetitive images has even proved a superior method. However, more research is needed to speed up the encoding process of fractal image compression, implement it on modern hardware, and prove any added usefulness today.

3 Proposed Solution

3.1 Efficiency

FIC is asymmetric with respect to compression and decompression; the compression stage is computationally expensive, whereas the decompression stage is very fast. As a consequence, performance gains in the compression stage can significantly improve the prospects for usability of these fractal techniques.

We propose the integration of heuristics into the compression stage to facilitate fast identification of near-optimal compression coefficients. To our knowledge, there has only been cursory application of heuristics to this field[12], so there is a diverse range of hitherto untested yet promising methods, such as swarm methods or tabular search, which we will explore.

3.2 Efficacy

One significant limitation of FIC, as it exists today, is that it can only be performed using linear transformations; downsampled images are decompressed using linear transformations into the corresponding upsampled representation. However, images can rarely be effectively represented as a linear transformation of their downsampled representations. We propose the use of a variety of transforms – ranging from the traditionally-used affine transformation to more exotic nonlinear transforms – to better capture complexities in images during the compression stage.

4 Datasets

We plan to use the UC Berkeley Segmentation Dataset and Benchmark(BSDS500)[4]. The dataset consists of 500 natural images, and the data is explicitly separated into disjoint train, validation and test subsets. These images are meant to train image segmentation algorithms, but we believe they represent a truer test of fractal image compression algorithms than the typical texture database[11].

5 Evaluation metrics

For evaluating computational viability, we will use runtime complexity analysis (both serial work and parallel span), as well as benchmarks on common hardware platforms. Peak Signal to Noise Ratio (PSNR) will then be used to quantify image quality after decompression. Additionally, we will evaluate the algorithm based on it's compression ratios for a standard library of 2D signals, and compare the results to those of PNG, JPEG, and JPEG2000.

Qualitatively, we will evaluate whether deriving fractal coefficients for a signal yields additional insight into the structure of the data, or reveals any powerful features for downstream classifiers. We also will compare our algorithm to existing audio and video encoders as we extend to those domains.

6 Timeline

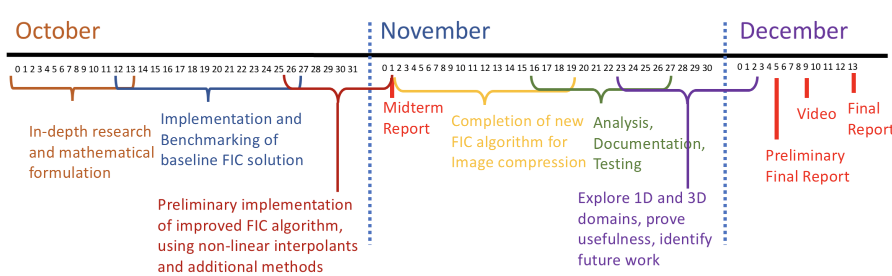

Figure 1: Project Timeline - Baseline is Texas Instruments FIC Algorithm[5]

7 Division of work among team members

Our experience is split between traditional DSP and Machine Learning, and so we expect to collaborate as a group on most of the mathematics for this project. We will each investigate different application areas and techniques during our research in October, and we plan to work together to implement and evaluate the Texas Instruments algorithm. Once a development plan is in place, Scott and Vrishab will focus primarily on signal processing, algorithmic complexity analysis and implementing any low-level parallel algorithms that are needed. Bridget and Weishan will then focus on improving our machine learning models, choosing datasets and verifying that any models have converged. We will help each other as needed and as ambiguities are cleared.

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