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Grid Technology and Digital Signal Processing: facilitating Demanding Media Applications

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Abstract: - Digital Signal Processing (DSP) is becoming a core function for organisations that produce, manage and distribute digital content. Promising applications of DSP include coding, rendering, copyright protection, that is highly demanding application in terms of CPU load. In this communication, some specific cases are presented where GRID computing could be used as an enabling/assisting technology for two demanding DSP techniques: watermarking and encoding. Specific cases of heavy load mathematical transformations for large media objects are discussed. A proposal for incorporating the watermarking procedure in the Grid architecture is also briefly presented.

Key-Words: - Digital Signal Processing, Grid, security, watermarking, coding.

1 Introduction

E-commerce is moving from the age of mass media to the age of knowledge media leading to the creation of new types of enterprises and business models. Current systems include elements such as online sharing communities and collaboration software delivering large amounts of on-line/off-line multimedia content. As content delivery services are gaining importance, new challenges for content management and distribution services arise [1].

Digital Signal Processing (DSP) lies the heart of many techniques that manage digital media. Applications such as digital watermarking used in Intellectual Property Rights (IPR) Protection, rendering, coding of images and video are among the most popular. As media size and number increases, DSP techniques are becoming more and more CPU demanding. The development of specialized processors only partially addresses this problem.

A valid solution to the ever-increasing CPU demands of DSP applications is either parallelism or use of distributed resources. The Grid has long been proposed as cost-effective solution for running long and demanding batch jobs using highly distributed and heterogeneous resources [2].

This paper proposes the use of Grid technology for effective delivery of demanding DSP applications such as watermarking and coding of large digital objects (video sequences, high resolution & multi-spectral images). Extremely demanding processing may become both feasible and operational within the Grid technology framework. Section 2 describes current trends and requirements for DSP in on-line applications and introduces basic Grid technology concepts. Section 3 presents an overview of media watermarking techniques and a series of watermarking cases in which the Grid could be used. Section 4 discusses the possibility of embedding a watermarking module in the fabric layer of the Grid. Section 5 discusses possibilities of using the Grid in image coding and especially in the JPEG2000 pipeline. Finally, section 6 presents future research directions and potentials.

2 DSP and CPU demanding applications

In this work we consider the use of DSP in on-line applications that embrace activities of processing, searching, retrieving and delivering digital media. Such examples are multimedia search engines, e-commerce applications, mobile commerce and digital libraries just to mention a few. In such applications we consider two types of processes that use DSP techniques: protection of Intellectual Property Rights (IPR) and coding of information.

The use of wide distribution channels such as the Internet has forced organisations to set the protection of IPR as a strategic goal. In practice, IPR most often refers to ownership of rights of individuals, including copyrights, patents and trademarks. Attribution, that is the right to be recognized as an author or contributor, also falls in this category.

The ease, with which perfect digital copies are produced, creates great concern to media providers. Copyright violation represents a considerable source of financial loss. Achieving IPR is currently considered a strategic goal for many vendors. The two strategies proposed for achieving IPR for digital media include a priori protection (copy prevention) and posteriori protection (copy detection). Initially, IPR focused on security and encryption as a means of solving the issue of unauthorized copying. The shortcomings of CD/DVD copy prevention systems have shown the lack of effectiveness of the a priori protection [3]. A posteriori protection mechanisms are based on DSP methods, such as digital watermarking, are regarded as a valid solution for multimedia data in a networked environment [4].

A digital watermark is an invisible mark inserted in digital media such as digital images, video and audio so that it can be detected at a later stage as evidence of copyright or it can generally be used against any illegal attempt to either reproduce or manipulate the media. The delivery of large digital objects through media distribution channels and the ever increasing use of streaming media is making the need for efficient watermarking methods more demanding.

IPR for digital content, including multimedia, has received a lot of attention from the scientific community in recent years. IPR standardization is now occurring in a number of organizations: the OpenEBook Forum [5] and the MPEG group are researching solutions in the e-book and multimedia sectors. The Internet Engineering Task Force (IETF) and the World Wide Web Consortium (W3C) have also investigated current trends in IPR and Digital Rights Management [6].

Coding also plays a key role to digital media production. Image and video coding of thousands of files requires enormous resources. New standards such as MPEG, JPEG2000 and MPEG Layer 3 (MP3) are quite efficient in quality and reproduction but quite costly to produce when in large numbers. Future networked business models will arise from the participation of enterprises in highly dynamic partnerships established by the use of Grid networks. Maturing digital-rights-management, digital-signature, and watermarking technologies are linking with Grid and peer to peer (P2P) applications to enable legal and secure distributed networks and peer exchanges. For example large-scale availability of multimedia data over the net may also make necessary watermarking to keep track of source and owner.

Traditionally, Grid computing has addressed the needs of long-running scientific computations submitted as batch jobs [2,7]. Long-running batch jobs were distributed across several nodes in a Grid and executed in parallel, resulting in shorter execution times. A number of experiments with first generation Grids showed that this new technology could be efficiently used for virtualization of extremely heterogeneous and geographically dispersed resources. This led to the second generation of Grids along with the development of the first tools and utilities for its support (e.g. Globus Toolkit and Avaki) [8].

3 Media Watermarking Techniques

Continuing our discussion about DSP applications we focus in this section in digital watermarking. Watermarking stands for the embedding of perceptually invisible information into digital data that identify the rightful creator/owner. Watermarks can be used to prevent illegal use, copy or manipulation of the digital content, as proof of ownership or tampering and others. The problem that these techniques have to encounter is the robustness of the watermark against common processing tasks. Any attempt to remove the ownership information from the original image is called an attack. Some common attacks for still images include filtering, JPEG compression, histogram modification, cropping, rotation and downscaling.

Image watermarking techniques can generally be divided in two main groups depending on the processing domain of host image that the watermark is embedded in. One is the spatial domain group of techniques, according to which the intensity values of a selected group of pixels are modified. The other is the frequency domain group, where a group of the transform coefficients of the image are altered. Up to date, frequency domain approaches have been proved more successful for image watermarking. The transforms usually employed are the discrete versions of the Fourier, Cosine and Wavelet transform (DCT, DFT and DWT) [9]. In these schemes, the image is being transformed via one of the aforementioned frequency transforms and watermarking is performed by altering the resulting transform coefficients of the image.

The complexity of the Discrete Fourier and the Cosine transform is O(N log N) while for the Wavelet transform it is O(N). For large values of N, these transformations are becoming extremely demanding in terms of CPU cycles; however respective algorithms are suitable for distributed processing, as demonstrated hereinafter. Figure 1 depicts how the DCT transformation can be parallelised.

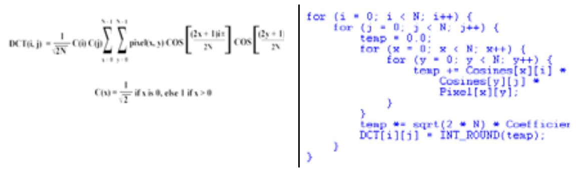

Fig. 1. DCT transformation for a NxN pixels image and corresponding C code.

Another question that occurs in such approaches is the number and the position of the altered coefficients set in the frequency representation of the image. Many different ideas have been proposed, however methods that process the image as a whole are popular. In such cases the number of coefficients altered is in the order of a few thousands (e.g. 3-15 for the case of a 512x512 image).

Where Subband DCT has been used [9], a combination of both wavelets (Haar) and the Discrete Cosine Transform (DCT) has been employed. The original image is filtered and subsampled by means of a set of highpass and lowpass filters in order to produce a first level of decomposition. For each of the resulting four bands, DCT follows. After a zig-zag formulation to produce a one dimensional vector for each band, the standard multiplicative watermarking rule is applied to these coefficients:

$$t_i' = t_i + a\, t_i\, x_i \quad \text{with } i \in [L, L+M-1]$$

where ti are the transformed coefficients, ti' are the watermarked coefficients and xi is a random sequence of Gaussian distribution, used as the watermark. The seed of the random sequence is the watermarking key of the system. The a-parameter has to do with the strength of the casting. The i index ranges from L to L+M-1. L corresponds to the starting position in the coefficients set while M represents the number of those selected. For typical values of L=5000 and M=20000 (512x512 sized image), that means that a number of 80000 coefficients will be altered (20000 coefficients in each band). The whole scheme is graphically presented in Figure 2.

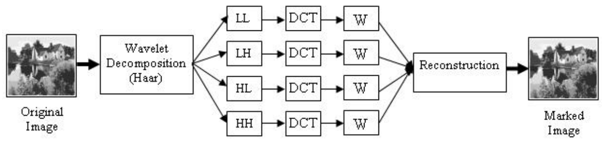

Fig. 2. Subband DCT watermarking process

The question that almost naturally arises is how a Grid could assist this process. It is apparent from the above figure that four processes can be running at the same time. So, right after the wavelet decomposition, each of the four bands can be fed by the initial node (the one that did the decomposition) to one of four other nodes for individual processing (DCT and marking). One may also notice that four bands correspond to each colour channel. In RGB colour images, 12 nodes can be fed simultaneously, while for multispectral images, 4xN nodes can be used (let N be the number of bands). Additional decomposition levels can also be used allowing for more subbands per colour band and additional nodes. Even the decomposition/reconstruction stages may be parallelized since these stages, just like the transforms, can be performed with a row-column strategy. Thus, by loading the Grid nodes with different rows and columns, further parallelization is achievable.

As already mentioned, processing large digital objects such as large images or video is also CPU demanding. In order to decrease the huge memory requirements and to take advantage of the different nodes available in the Grid, a load distribution strategy can be used. This technique is based on dividing a digital object into smaller entities and processing in parallel on different Grid nodes. Figure 3 illustrates this process for still digital images, while in the video case, instead of image tiles, individual frames are distributed to the watermarking nodes. The distribution process itself depends on the nature of the digital object. For example, in the case of still images, each image component is divided into several tiles, while in the case of video the process is frame wise, meaning that each node can process a bunch of frames. This video object division also depends on the format used i.e. different frames must be used for AVI and MPEG4 video processing. This allows different setups of Grid nodes, depending on the type of the medium being processed.

By generalizing, we will call this distribution strategy, 'tiling' since breaking a video object into frames is similar to dividing the image in smaller tiles. Tiling allows breaking up a single media processing request into multiple requests. This feature has the dual benefit of allowing data to be manipulated more efficiently between input/output operations and in memory and permitting the processing to be distributed to all available nodes. The immediate results are reduced memory overhead and processing time, and maximized application throughput. In short, this approach combines three major advantages: the parallelization of the I/O operation, the parallel processing of tiles and the distribution of computations on different processors. Eventually if the tile size is fixed, memory requirements may stay constant.

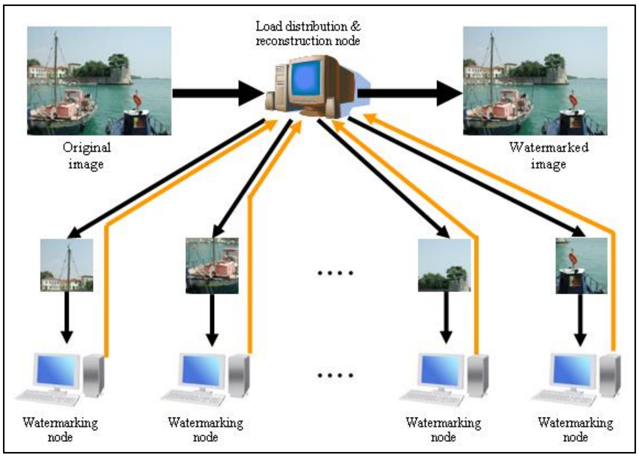

Fig. 3 Parallel watermarking scheme for still images.

Image tiling has already been proposed for supporting image processing applications running on a single parallel machine [10]. For example parallel Processing Watermarking Embedding Schemes have demonstrated to be efficient from a computational and memory usage point of view for very large images. These schemes consist in dividing the image into tiles and watermarking each independently. Nevertheless, widely used single parallel machines usually have a small number of processors and are thus not as efficient in supporting processing of collections of large images or even video. However, research in parallel image processing has stressed the need for using Grid technology especially in demanding, dynamic environments.

4 Embedding watermarking in the GRID infrastructure

Maturing digital-rights-management, digital-signature, and watermarking technologies are linking with Grid and peer to peer (P2P) applications and enabling legal and secure distributed networks and peer exchanges. For example large-scale availability of medical data over the net may also make necessary watermarking of medical images to keep track of medical source and owner. Future Grid-based media applications are viable alternatives and complements to existing networking systems for both corporate and consumer applications.

Watermarking may prove to be a critical tool for broadcasters and providers of digital content. Digital heritage, e-learning [11] and digital television are just some of the applications that could make use of this technology in order to enhance security [12]. Watermarks, combined with digital signature methods, may contain information about proprietary, copyright, the author, the user the number of copies and other important information. Such a watermark system should be strong, not ambiguous, invisible and difficult to remove. It would be useful to consider three different modes in such a procedure. In each mode, different digital objects may be processed: hypertext, image or audio/video objects. A control module identifies object type and the combination of methods to be used.

It must be noted however that at most 2-3 watermarks can be embedded in an image or video object, before the quality of reproduction is significantly altered. In order to maintain a high Quality of Service, a consensus must be found between multiple watermarking and its perceptibility in the digital object. Multiple watermarks can be inserted at the production level, for the identification of the distribution path and/or to identify the end-user path.

Watermarking can also be used for multimedia content identification. Digimarc's MediaBridge

Reader uses the concept of "smart images" wherein the watermarked message includes pointers to some knowledge structure on a local database or on the Internet [13]. The watermark (message) detector extracts the message and hence extracts more information from the database. Such a method is also computationally expensive. Similar multimedia content identification modules can be embedded in the Collective layer of the Grid.

5 JPEG2000 Encoding/Decoding

The wealth of information provided by devices and space sensors has grown dramatically as both the spatial and spectral resolutions of image sensors increase. On the other hand, the available communication channels for faithfully transmitting the data to ground are becoming scarce. For example, satellite and aerial images are quite big in size and as such their management is difficult when they are stored using traditional standards (such as JPEG). There is therefore a real need to use advanced data-compression techniques that can support storage and transmission of images of varying resolution and quality. In addition, the compression operations must be fast and require little power for instantaneous processing. The trend is toward more interactive manipulation of imagery and video.

In the image domain, JPEG2000 is the new emerging coding standard providing a decisive optimization in the handling of geo image data including small size, progressive transmission, and multiple levels of resolution, embedded security and regions of interest [14]. All this advantages are provided in a single data stream. The wavelet transform that underlies the JPEG2000 codec for still images and the transform that underlies the MPEG4 standard for video compression share many common properties. With their successful integration in the future, new data-compression techniques should be able to process huge datasets with high fidelity and speed.

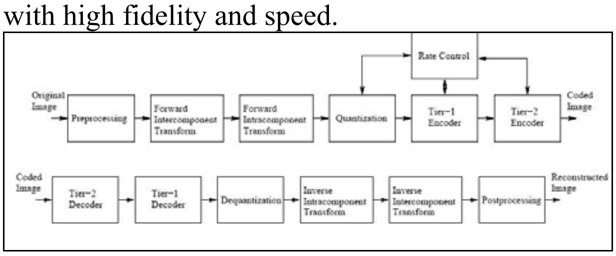

Fig. 4. JPEG2000 encoder and decoder

JPEG2000 is a result of a process initiated in the mid '90s to overcome the limitations of "JPEG" (Joint Photographic Experts Group). The new standard provided a unified coding system for different types of still images (bilevel, gray scale, color, multi-component) with different characteristics (natural, medical, remote sensing etc.) allowing different imaging models (client/server, real time transmission, image library archival etc.). The system performs superior to older standards by achieving great compression ratios while retaining image quality at the same time. Part I of the standard can be used on a royalty and fee-free basis. All these lead to the conclusion that it is only a matter of time before JPEG2000 will become widely accepted.

JPEG2000 coding procedure is based on EBCOT (Embedded Block Coding with Optimal Truncation) [15]. It is commonly acknowledged that the JPEG2000 encoding/decoding process is extremely complicated yet effective (figure 4).

Pre-processing is the first step were the encoder transforms the input sample data to a nominal dynamic range. The second step is an inter-component transform, actually a RGB data to YCbCr data conversion and image tiling to smaller parts (figure 5). Then a Discrete Wavelet Transform (DWT) is applied on each tile to decompose it into a number of wavelet subbands at different levels and resolutions, where transformed coefficients are produced. Quantization is used only in lossy compression: wavelet coefficients in each subband are scalar quantized. Subsequently, each subband is divided into code blocks which are entropy coded independently. Tier-1 includes coefficient bit context modeling and arithmetic coding of the bit-plane data on block samples, and generates embedded block bit-streams. Tier-2 coder operates on the compressed information of every block to arrange their contributions in each quality layer, in a process referred to as packetization. Rate Control is finally used to achieve a given target bit-rate constraint under lossy compression.

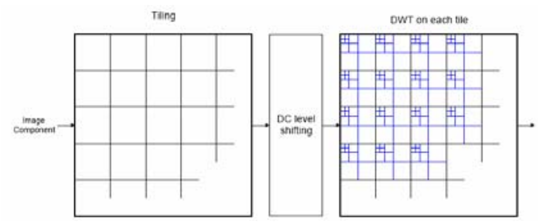

Fig.5 Image Tiling prior to DWT

There are many possibilities for using the Grid in the JPEG2000 encoding/decoding process. Examples of possible parallelism include image tiling, Discrete Wavelet Transform (DWT) computations and some

EBCOT functions (quantization and entropy encoding). The image tiling case was analysed in the previous section. The wavelet functions are comparable to the cosines used in the DCT but their drawback is increased memory and processor requirements.

In recent works, tier-1 of EBCOT was found best suited for parallel or Grid implementation because of its high computation complexity and relatively simple modularity. Especially the Quantization and Entropy Encoding steps are CPU – intensive for specialized processors [16,17].

6 Conclusions

DSP algorithms are demanding in terms of processing power, especially for large digital objects such as large images or video. In this work, the potential of using the Grid for enabling DSP has been exhibited. Future work in this field includes the identification of the different requirements for production and contribution, the requirement for registration authorities and the effective combination of watermarking and signature methods for effective content copyrighting. New media standards such as JPEG2000 and MPEG7 also offer much new potential.

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