Chapter 4
High-Performance Image Reconstruction (HPIR) in Three Dimensions

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ABSTRACT

Commonly used in medical imaging for diagnostic purposes, in luggage scanning, as well as in industrial non-destructive testing applications, Computed Tomography (CT) is an imaging technique that provides cross sections of an object from measurements taken from different angular positions around the object. CT, also referred to as Image Reconstruction (IR), is known to be a very compute-intensive problem. In its simplest form, the computational load is a function of $O(M \times N^3)$, where $M$ represents the number of measurements taken around the object and $N$ is the dimension of the object. Furthermore, research institutes report that the increase in processing power required by CT is consistently above Moore’s Law. On the other hand, the changing work flow in hospital requires obtaining CT images faster with better quality from lower dose. In some cases, real time is needed. High Performance Image Reconstruction (HPIR) has to be used to match the performance requirements involved by the use of modern CT reconstruction algorithms in hospitals. Traditionally, this problem had been solved by the design of specific hardware. Nowadays, the evolution of technology makes it possible to use Components of the Shelf (COTS). Typical HPIR platforms can be built around multicore processors such as the Cell Broadband Engine (CBE), General-Purpose Graphics Processing Units (GPGPU) or Field Programmable Gate Arrays (FPGA). These platforms exhibit different level in the parallelism required to implement CT reconstruction algorithms. They also have different properties in the way the computation can be carried out.

DOI: 10.4018/978-1-60566-280-0.ch004
out, potentially requiring drastic changes in the way an algorithm can be implemented. Furthermore, because of their COTS nature, it is not always easy to take the best advantages of a given platform and compromises have to be made. Finally, a fully fleshed reconstruction platform also includes the data acquisition interface as well as the visualisation of the reconstructed slices. These parts are the area of excellence of FPGAs and GPGPUs. However, more often than not, the processing power available in those units exceeds the requirement of a given pipeline and the remaining real estate and processing power can be used for the core of the reconstruction pipeline. Indeed, several design options can be considered for a given algorithm with yet another set of compromises.

1 INTRODUCTION

1.1 The 3D Image Reconstruction Problem

Also referred to as Computed Tomography (CT), 3D image reconstruction is an imaging technique that provides cross sections of an object from measurements taken from different angular positions around the object (Figure 1). Sound descriptions of the principles and underlying mathematics have been the topic of numerous books and publications (Kak 1988, Herman 1980, Kalender 2005, Natterer 1989). CT is commonly used in medical imaging for diagnostic purposes, in luggage scanning, as well as in industrial non-destructive testing applications. Since Hounsfield (1972) patented the first CT scanner, new X-ray source-detector technologies have made a revolutionary impact on the possibilities of Computed Tomography.

From the pure mathematical point of view, the solution to the inverse problem of image reconstruction had been found for the two dimensional case by Johann Radon in 1917 (Radon 1986). Nevertheless, the use of an ever-improving technology fuels the research community. As a result, there seems to be an endless stream of new reconstruction algorithms.

Image reconstruction is known to be a very compute-intensive problem. In its simplest form, the computational load is a function of $O(M \times N^3)$, where $M$ represents the number of measurements taken around the object and $N$ is the dimension of the object. Both values typically lie in the range between 500 and 1500. Only through the use of High Performance Computing (HPC) platforms the reconstruction can be performed in a delay that is compatible with the requirements of the above-mentioned applications. Moreover, CT scanners have entered the stage of wide deployment, and the requirements for processing power for implementing the new algorithms has steadily been above Moore’s law. As a consequence, one cannot expect to run modern reconstruction algorithms on commonly available computers. Therefore, high-performance computing solutions are commonly used to solve the computational problem of image reconstruction.

Nevertheless, there are significant variations in the size of the reconstruction problem. Even for a given application, e.g. medical imaging, the selected values for $M$ and $N$ can vary depending on several factors, such as the region of interest and the desired image quality. By nature, the reconstruction problem exhibits inherent independence between subsets of input samples and between subparts of the reconstructed volume, making it suitable for parallelization techniques. Indeed the ultimate HPC platforms, as they are required for high-performance image reconstruction (HPIR), must provide powerful processing blocks that allow for parallelization. In addition, HPC platforms also need to remain flexible enough to enable the architecture to scale to address the different problem sizes without undue reduction in the efficiency.

The quality of a given CT implementation is also measured against the quality of the recon-
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