A New Parallel Approach to Fuzzy Clustering for Medical Image Segmentation

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Abstract. Medical image segmentation plays an important role in medical image analysis and visualization. The Fuzzy c-Means (FCM) is one of the well-known methods in the practical applications of medical image segmentation. FCM, however, demands tremendous computational throughput and memory requirements due to a clustering process in which the pixels are classified into the attributed regions based on the global information of gray level distribution and spatial connectivity. In this paper, we present a parallel implementation of FCM using a representative data parallel architecture to overcome computational requirements as well as to create an intelligent system for medical image segmentation. Experimental results indicate that our parallel approach achieves a speedup of 1000x over the existing faster FCM method and provides reliable and efficient processing on CT and MRI image segmentation.

Keywords: Medical image segmentation, Fuzzy C-Means algorithm, parallel processing, data parallel architectures, MRI images.

1 Introduction

Segmentation is an indispensable step in medical image analysis and visualization. It separates structures of interest from the medical images including organs, bones, different tissue types, and vasculature. Several different segmentation methods and approaches have been applied for different application domains. Some methods including histogram analysis, region growing, edge detection, and pixel classification have been proposed in the past [1]-[3], which use the local information and/or the global information for image segmentation. Some techniques using the neural network approach have also considered the problems inherent in image segmentation [4], [5].

Fuzzy clustering [6]-[8] is a suitable technique for medical imaging due to the limited spatial resolution, poor contrast, noise, and non-uniform intensity variation inherent in the medical images. Fuzzy clustering is a process in which the pixels are classified into the attributed regions based on the global information of gray level

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distribution and spatial connectivity. One of the well-known fuzzy clustering algorithms is the Fuzzy c-Means (FCM) algorithm where c is a priori chosen number of clusters. The FCM algorithm allows overlapping clusters with partial membership of individuals in clusters. However, FCM requires tremendous computational and memory requirements due to the complex clustering process.

Application-specific integrated circuits (ASICs) can meet the needed performance for such algorithms, but they provide limited, if any, programmability or flexibility needed for varied application requirements. General-purpose microprocessors (GPPs) offer the necessary flexibility and inexpensive processing elements. However, they will not be able to meet the much higher levels of performance required by high resolution and high frequency medical image and video data. This is because they lack the ability to exploit the full data parallelism available in these applications.

Among many computational models available for imaging applications, single instruction multiple data (SIMD) processor arrays are promising candidates for application-specific applications including medical imaging since they replicate the data, data memory, and I/O to provide high processing performance with low node cost. Whereas instruction-level or thread-level processors use silicon area for large multi-ported register files, large caches, and deeply pipelined functional units, SIMD processor arrays contain many simple processing elements (PEs) for the same silicon area. As a result, SIMD processor arrays often employ thousands of PEs while possibly distributing and co-locating PEs with the data I/O to minimize storage and data communication requirements.

This paper presents a new parallel implementation of the FCM algorithm to meet the computational requirements using a representative SIMD array architecture. This paper also evaluates the impact of the parallel approach on processing performance. This evaluation shows that our parallel approach achieves a speedup of 1000x over the existing faster FCM method and provides reliable and efficient processing on computerized tomography (CT) and magnetic resonance imaging (MRI) image segmentation.

The rest of the paper is organized as follows. Section 2 presents background information of the FCM algorithm and the SIMD processor array used in this paper. Section 3 describes a parallel implementation of the FCM algorithm. Section 4 analyzes the performance of our parallel approach and compares our approach to other existing methods, and Section 5 concludes this paper.

2 Background Information

2.1 Image Segmentation with Fuzzy C-Means Algorithm

Segmentation is an essential process of image analysis and classification, wherein the image pixels are segmented into subsets by assigning the individual pixels to clusters. Hence, segmentation is a process of portioning an image into some regions such that each region is homogeneous and none of the union of two adjacent regions is homogeneous.

The FCM algorithm has been used with some success in image segmentation in general and also in medical image segmentation. The FCM algorithm [9] is an