SPEECH ANALYSIS FOR MEDICAL PREDICTIONS BASED ON CELL BROADBAND ENGINE

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ABSTRACT

Speech signals analysis can provide useful clinical information that may be used in order to predict certain diseases. Voice analysis can be done quickly and with minimal costs, in comparison with other medical investigations, such as Nuclear Magnetic Resonance. Analysis of speech signals may be used for sorting patients who will be subject to these expensive investigations. In this paper, to perform a preliminary prediction of patients with Parkinson's disease, we propose the usage of FLAME clustering algorithm on the speech signals acquired from the patients. The algorithm has been optimized for CBEA-based processors in order to use intensive computing resources.

Index Terms— Parkinson's disease, FLAME clustering, speech analysis, early prediction

1. INTRODUCTION

Parkinson's disease (PD) is a degenerative disease that occurs due to the slow and progressive destruction of neurons. Depending on the affected area, the disease may have symptoms as tremor, rigidity and bradykinesia[1]. Accurate diagnosis of this disease is expensive and is done by Nuclear Magnetic Resonance investigation or clinical analysis made by a physician. In the most cases, diagnosis is made in the final phase of disease.

Currently, there are more attempts to develop a screening system [2], but there is no a worldwide recognition system. For this reason, the developing of a system for early prediction, based on clinical symptoms, represents a challenge. More research was made for analysis of tremor, voice disorder or posture in order to define a model for PD diagnostic from clinical signs.

Taking into account these clinical signs, it can be developed an integrated software system that acquires signals of tremor [3][4], patient posture [5], speech signals [6][7] etc. The software system can make a prediction of patients suspected of PD based on this data and information stored in different databases. This may be useful in efficient planning of expensive medical investigation by achieving a first screening of patients suspected of PD.

In this paper, we focus on analysis of speech signals in order to determine the patients with Parkinson disease. For this purpose, it is used the Oxford Parkinson's Disease Detection Dataset [8]. On this data set, we applied the Fuzzy clustering by Local Approximation of MEmberships (FLAME) [10] algorithm based on Mahalanobis distance [11]. We developed and optimized the FLAME algorithm for Cell BE processor (from PlayStation 3 game console), based on Cell Broadband Engine Architecture (CBEA) [9]. This architecture consists of nine processors integrated on a single chip.

The algorithm developed for Cell BE processor can be executed only on the core PPE or on all nine cores, by activating the acceleration cores. It analyzed the optimization of FLAME algorithm for CBEA architecture by dividing the computation operation to the acceleration cores, by accessing the main memory through the DMA (Direct Memory Access) transfer and by using specialized mathematical libraries (e.g. SIMD - Single Instruction Multiple Data).

The results obtained by executing the FLAME algorithm on the proposed data set are analyzed in terms of determining patients suspected of Parkinson's disease. Furthermore, a comparison is made between the execution time of those two versions of the FLAME algorithm - with and without activation of accelerating cores.

2. CELL BROADBAND ENGINE ARCHITECTURE

Cell Broadband Engine Architecture was developed by IBM for Cell B.E. processor from PlayStation 3 games console. This architecture was optimized for math intensive computing.

CBEA architecture is new and is derived from 64-bit PowerPC architecture. CBEA consists a Power PC processor (PPE - PowerPC Processor Element), and eight processors dedicated to intensive computing (SPE - Synergistic Processor Element).

These processors communicate between them, with the main memory system and with the I/O system through a high-speed bus, called EIB (Element Interconnect Bus). EIB can support more than 100 simultaneous requests for DMA transfer between main memory and the SPE processors with a peak bandwidth of 204.8 GB/s.

Each SPE processor has 256KB of local memory for instruction and data. For this reason, an application that is running on an SPE processor must fit in 256KB in terms of required memory for instruction and data. In Fig. 2 is presented an overview of Cell Broadband Engine Architecture.

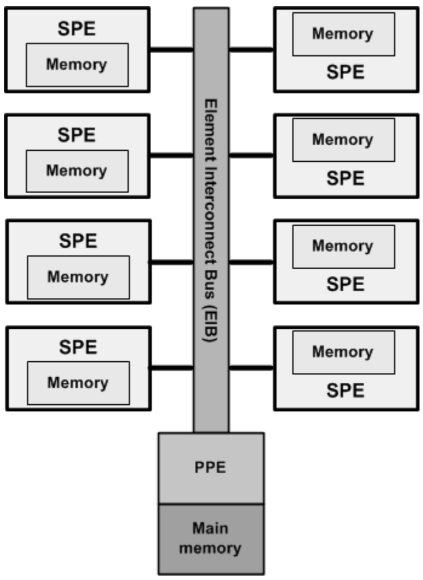

Fig. 1 Cell Broadband Engine Architecture

When the application that is running on a SPE processor needs data stored in the main memory, this information is transferred to the local memory by a DMA request. Moreover, DMA transfer is used to transfer data from local memory to main memory. This mechanism, with local memory storage, is more efficient than conventional processors with cache memory. A DMA transfer of a data block takes only two processor cycles, in comparison with the time for cache update, which can take several hundred of processor cycles, during which the CPU cannot execute instructions.

From the programmer's perspective, the Cell BE processor looks like a multiprocessor with nine cores. PPE processor is more efficient for task's control and quickly at task's commutation while the SPE processor is faster on the execution of arithmetic operations.

In order to obtain an efficient usage of the computing resources provided by the CBEA processor, the applications must be optimized for this type of processor.

3. FLAME ALGORITHM

The FLAME algorithm (Fuzzy clustering by Local Approximation of MEmbership) was proposed by Fu and Medico [10] in 2007 for the analysis of DNA microarray data. According to [10], this algorithm captures nonlinear relationships between objects and can automatically determine the number of clusters for de input data set. This clustering algorithm is a combination of KNN classification algorithms and fuzzy classification algorithms.

In this paper, we propose to use this algorithm to perform a first prediction of patients with PD.

This prediction is achieved by applying the FLAME algorithm on speech signals acquired from the patients. In this case, the classification results should be two clusters: patients suspected of PD disease or patients who are not suspected of this disease.

For this purpose, it is used the Oxford Parkinson's Disease Detection Dataset [8]. This dataset is composed of a range of biomedical voice measurements from 31 people, 23 with Parkinson's disease.

Because the data set which will be used in order to test the FLAME algorithm contains multivariate features, we use the Mahalanobis [11] distance to calculate the distance between objects. Unlike the Euclidean distance, this distance takes into account the correlation between two variables.

The Mahalanobis distance between two object X$(x_1, x_2, x_3,...,x_N)$ and Y$(y_1, y_2, y_3,...y_N)$ is given by the following formula:

$$d_M(X,Y) = \sqrt{(X-Y)^T S^{-1}(X-Y)} \quad (1)$$

where S^{-1} is the covariance matrix.

The execution of FLAME algorithm is divided into three steps. In the first step, the optimal number of clusters is automatically determined by establishing the Cluster Supporting Objects (abbreviated CSOs). For this purpose, density for each object from the data set is computed according to distance from its k nearest neighbor. The objects with the highest density among its neighbors are considered Cluster Supporting Objects and will serve as prototypes for the clusters. In our case, because the data set should be grouped in two classes, the first two CSOs in terms of density will be considered as prototypes for the clusters. The number of clusters is influenced by the number of neighbors used to determine the density of objects. A better value for the number of clusters is obtained by increasing the number of neighbors.

In the second step of this algorithm, an approximation of object membership is performed. In this step, the algorithm was modified in order to be suitable for speech signals analysis. The membership of each CSO is assigned to itself, and the other object's memberships are assigned equally to both clusters that will result after algorithm execution. After these initialization operations, the memberships of each object are updated by the Local/Neighborhood Approximation of Fuzzy Memberships procedure. In this procedure, the fuzzy membership of each object is updated according to its nearest neighbors. In the third step, each object is assigned to the cluster with highest membership. After execution of this algorithm, two clusters are formed.

In the first stage, the proposed changes were introduced in the code provided by [10], and the algorithm was developed only for PPE processor from Cell BE. In the next stage, the algorithm is analyzed in order to identify the points where SPE processor can be used. In fig 1 are illustrated the steps of FLAME algorithm.

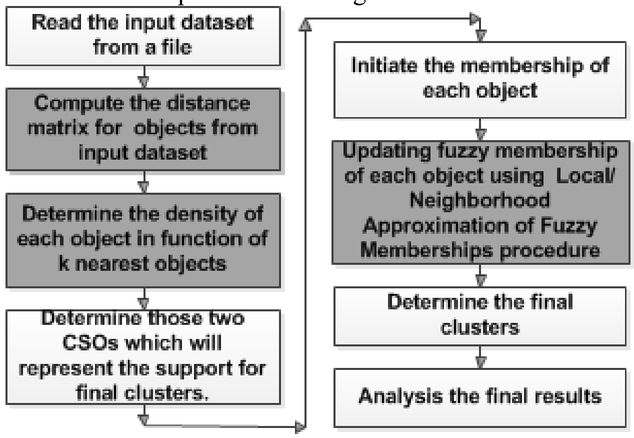

Fig 2. The FLAME algorithm steps

4. OPTIMIZING THE FLAME ALGORITHM FOR CBEA ARCHITECTURE

In order to optimize the algorithm for the Cell BE processor, we chose a strategy in which PPE processor distributes jobs to the SPE processors after that it expected them to finish their execution. Thus, on the PPE processor, the points where the SPE processors can be used are identified (eg. at the computing of the matrix of distances between objects), a command to start the calculations is sent to the SPE processors via a mailbox (are transmitted additional information as the main memory address where the data for computing are storage, and the main memory address where the results will be saved) and the PPE processor expects a signal from SPE processor on job's completion (a mailbox from each SPE processor). On each SPE processor is running an application that expects commands form PPE processor. On receiving a command, data involved in the job required are transferred from the main memory into local memory, the job is performed, and the results are transferred from local memory into main memory. Data transfer between local memory and main memory is performed by DMA service provided by the Cell BE.

From the analysis of the algorithm, we identify the following points where we can activate the SPE processors (operations marked with gray in Fig. 2):

- on the computing of the matrix of distances between objects,
- on the computing of the density of each object,
- on updating fuzzy membership of each object using Local/Neighborhood Approximation of Fuzzy Memberships procedure.

In the last two cases, the objects from input set are distributed equally between the SPE processors.

In order to compute the matrix of distances between objects, matrix elements must be distributed equally between the SPE processors from the Cell BE. In the following is presented a method for distributing the distance matrix to *noSPE* SPE processors. This issue is reduced to split equally the area of a triangle (part above the main diagonal of the matrix, see Fig. 3). For each SPE processor, the number of rows in the matrix assigned and the offset from where these lines are begging should be determined.

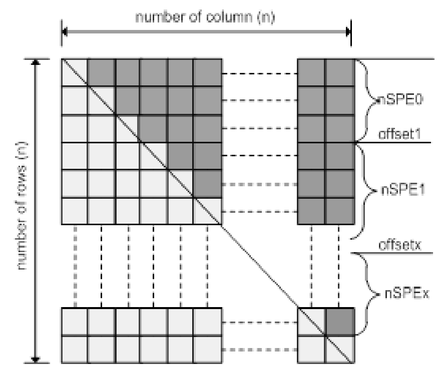

Fig. 3 Distribution of the matrix of distances to the SPE processors

It is considered that the matrix has n rows and n columns, so the area of the triangle above the main diagonal is *(n*n)/2*. The area associated with each SPE processor is *(n*n)/(2*noSPE)*.

In order to determine the number of rows assigned to the first SPE processor (nSPE0), we must solve the next equation:

$$\frac{(n - offset0 + n - offset0 - nSPE0) * nSPE0}{2} = \frac{n * n}{2 * noSPE} \quad (2)$$

$$nSPE0^2 - 2(offset0) * nSPE0 + \frac{n^2}{noSPE} = 0 \quad (3)$$

We similarly determined the number of rows assigned to the other SPE processor by replacing the *offset0* with the value of offset associated with each processor.

It should be noted that all data used in executing the algorithm on the Cell BE are 128-bit aligned in memory, in order to use DMA transfers between main memory and SPEs local memory.

5. EXPERIMENTAL RESULTS

Algorithm development and testing were performed on a PlayStation 3 game console and a QS22 blade server. The input dataset is composed of a range of biomedical voice measurements from 31 people, 23 with Parkinson's disease. For each patient, it is recorded the age, average vocal fundamental frequency, maximum and minimum vocal fundamental frequency, measures of ratio of noise to tonal components in the voice, nonlinear measures of fundamental frequency variation, measures of variation in fundamental frequency, measures of variation in amplitude.

This dataset contains 197 instances (records), six or seven records with speech signal information were acquired for each subject. For this reason, the algorithm was executed in two ways. In the first case, for each subject was performed an averaging of features for records associated with each patient, resulting 31 records. The FLAME algorithm, with modifications described in this paper, was executed on these objects.

In the second case, the algorithm was executed on all 197 records from input data set, and at the end, each patient was associated with the cluster in which has more objects. The algorithm was executed several times, changing the number of neighbors (k) used to compute the density of an object.

In the first case, we obtained a classification accuracy of 83,87% (26 subjects were classified correctly, for k = 4), and in the second case, we obtained an accuracy of 90.23% (26 subjects were classified correctly, for k = 19). Using other algorithms, accuracy obtained is between 71% and 91.4% [12][13]. In terms of performance, tests were performed on both systems, just executing the algorithm on PPU processor; then, algorithm's execution was reloaded, on all cores of Cell BE (PPU and SPU). One should mention that concerning the PlayStation 3 console, only 6 SPU kernels are enabled (from which, one is disabled from factory, and one is used by the operating system so as to run special operations, such as cryptography). On QS22 server, tests were performed by using 16 SPU kernels (for an application, all SPU kernels can be used at one time by those two PowerXCell 8i processors on QS22 server). Analyzing these results, we conclude that as concerns PlayStation 3 console, 2.93 speedup can be achieved by enabling the SPU cores; as concerns the QS22 blade server, 9.98 speedup is achieved by enabling 16 SPU cores.

6. CONCLUSIONS

In this article, in order to perform a prediction of patients suspected of PD, we presented the optimization of FLAME clustering algorithm on Cell BE processor. The results are encouraging; the FLAME algorithm can be integrated into an information system [14], and used with algorithms for analysis of other clinical symptoms such as tremors or position, in order to obtain a better prediction of suspected PD patients.

7. FUTURE WORK

In order to use datasets from a larger number of patients[15], the algorithm can be developed and optimized for a CBEA based cluster (supercomputer)[16]. In this case, the jobs distribution must be performed on two levels. On the first level, the jobs are distributed to the computing nodes (to each Cell BE processor), by using the MPI standard. The second level intervenes on Cell BE processor,

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