Toward hybrid platform for evolutionary computations of hard discrete problems

Dominik Żurek¹, Kamil Piętak¹, Marcin Pietroń¹, and Marek Kisiel-Dorohinicki¹

AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Krakow, Poland
{dzurek,kpietak,pietroń,doroh}@agh.edu.pl

Abstract
Memetic agent-based paradigm, which combines evolutionary computation and local search techniques in one of promising meta-heuristics for solving large and hard discrete problem such as Low Autocorrelation Binary Sequence (LABS) or optimal Golomb-ruler (OGR). In the paper as a follow-up of the previous research, a short concept of hybrid agent-based evolutionary systems platform, which spreads computations among CPU and GPU, is shortly introduced. The main part of the paper presents an efficient parallel GPU implementation of LABS local optimization strategy. As a means for comparison, speed-up between GPU implementation and CPU sequential and parallel versions are shown. This constitutes a promising step toward building hybrid platform that combines evolutionary meta-heuristics with highly efficient local optimization of chosen discrete problems.

Keywords: evolutionary computing, GPU computing, memetic computing, LABS

1 Introduction

In the paper, as a follow-up of the research presented in [13], the next step in solving Low Autocorrelation Binary Sequence with efficient techniques is shown. LABS, one of the hard discrete problem despite wide research, is still an open optimization problem for long sequences. The paper introduces a very efficient, parallel realization of local optimization for LABS implemented at GPU. The implementation is thought as a part of a hybrid computational environment that utilize agent-based evolutionary meta-heuristics. The integration of the environment and proposed components will be a topic for further research.

There is a lot of various methods that tries to solve LABS problem. The simplest one is exhaustive enumeration (ie. brute-force method) that provides the best results, but can be applied only to small values of $L$. Some researchers use a partial enumeration, choosing so called skew symmetric sequences[14] that are the most likely solutions for many lengths (eg. for $L \in [31,65]$, 21 best sequences are skew symmetric).

However, enumerative algorithms (complete or partial) are limited to small values of $L$ by the exponential size of the search space. Heuristic algorithms use some plausible rules to locate...
good sequences more quickly. Examples include simulated annealing, evolutionary algorithms, local optimization techniques – the list of heuristic algorithms can be found in [7]. A well-known method of local optimization for LABS is Tabu Search [9, 8] – the best results have been obtained using some variations of this technique [11]. All these methods give relatively good solutions for \( L < 200 \), but fail for larger lengths. As a result of this fact LABS problem found its place in CSPLIB list, a library of test problems for constraint solvers [18]. The best known results (BKV) for LABS can be found in [3].

The paper concentrates on solving LABS problem using efficient parallel computations on GPU which will be further combined with evolutionary meta-heuristics. The authors introduce the basic concept of hybrid computational environment that combines CPU and GPU computations and widely presents the way of solving LABS problem on GPU using one of local search strategies called Steepest Descend Local Search (SDLS) [2].

The paper is organized as follows: introduction to LABS problem together with optimized algorithm for energy computation are presented to show a background for GPU algorithm. Then short introduction to the concept of evolutionary multi-agent systems (EMAS) with local optimization techniques has been provided, followed by an overview of a platform allowing to run such systems in a hybrid environment comprised of CPU and GPU. The next section presents details about LABS evaluation and local optimization implemented on GPU, which constitutes the central point of the paper. Than, the sample results are presented to compare efficiency between pure CPU and GPU computations and to compute speed-up we gain using GPU. At last, after the conclusions, the future work such as integration of CPU and GPU in the shape of hybrid computational platform is presented.

2 LABS problem

Low Autocorrelation Binary Sequence (LABS) is an NP-hard combinatorial problem with simple formulation. It has been under intensive study since 1960s by physics and artificial intelligence communities. It consists in finding a binary sequence \( S = \{s_0, s_1, \ldots, s_{L-1}\} \) with length \( L \), where \( s_i \in \{-1, 1\} \) which minimizes energy function \( E(S) \):

\[
C_k(S) = \sum_{i=0}^{L-k-1} s_i s_{i+k} \\
E(S) = \sum_{k=1}^{L-1} C_k^2(S)
\]  

M.J Golay defined also a so called merit factor [10], which binds LABS energy level to the length of a given sequence:

\[
F(S) = \frac{L^2}{2E(S)}
\]  

The search space for the problem with length \( L \) has size \( 2^L \) and energy of sequence can be computed in time \( O(L^2) \). LABS problem has no constraints, so \( S \) can be represented naturally as an array of binary values. One of the reason of high complexity of the problem is, that in LABS all sequence elements are correlated. One change that improves some \( C_i(S) \), has also an impact on many other \( C_j(S) \) and can lead to big changes of solution’s energy.
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