OPINION

on the dissertation for awarding

the educational and scientific degree "Doctor"

Topic: "Optimization and Parallelization of Algorithms Related to Coding Theory"

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Scientific Field: 4. Natural Sciences, Mathematics, and Informatics

Professional Direction: 4.6. Informatics and Computer Science

Doctoral Program: Informatics

Prepared by: Assoc. Prof. Dr. Yuri Lyubchov Borissov - IMI - BAS

By order № 456/03.12.2024 of the Director of the Institute of Mathematics and Informatics (IMI) at BAS, I was appointed as the chairman of the Scientific Jury for the procedure, and at the first meeting of this jury, I was elected to prepare this

opinion. I have been provided with all materials in accordance with the requirements of the regulatory documents, which are regular and comply with the ZRASRB. I have no information about violations of the procedure, and I am not aware of any plagiarism in the dissertation.

1. **Data for the PhD Candidate**

The PhD candidate Maria Rumenova Pashinska-Gadzheva received her bachelor's degree from VTU "St. St. Cyril and Methodius" in the educational program "Computer Science" in 2019 and a master's degree from VTU "St. St. Cyril and Methodius" in the educational program "Mathematical Structures in Information Security" in 2020. Unfortunately, the attached CV does not contain data on her participation in scientific projects. The list of participations in scientific forums includes 9 reports, six of which are at international conferences, two at national seminars on coding theory "Acad. Stefan Dodunekov", and one at the seminar on high-performance computing.

2. **Data for the Doctoral Studies**

The PhD candidate was enrolled in a full-time form of study from 01.01.2021 with a study period of 3 years and was discharged with the right to defend with a decision of the NS of IMI (Protocol No. 14/21.12.2023). The preliminary discussion of the dissertation, which I attended, took place on 23.11.2024 at an extended meeting of the MOI section in the conference hall of the "Sevastokrator" hotel, Arbanasi. By order of the director of IMI, a scientific jury and a defense date of 25.02.2025 were

determined. I consider the procedure to be regular and without violations.

3. Data for the Dissertation and the Abstract

The dissertation submitted for review is written in Bulgarian and consists of: an introduction (8 pages), the main text (75 pages) divided into 5 chapters, separated into sections. The dissertation includes lists of scientific and applied contributions, publications (six in total), and presented reports (nine in total). Although citations are not required by ZRASRB, a list of two citations is attached to the dissertation. The used literature consists of 83 titles, and the tables and figures are ten and five in number, respectively. The work meets the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria (ZRASRB) and the regulations for the application of ZRASRB (PPZRASRB), as well as the Regulations for the conditions and procedures for acquiring scientific degrees and occupying academic positions at BAS (PBAN). The abstract (30 pages) adequately reflects the main ideas and significant final results described in the dissertation.

4. General Description of the Dissertation

In Chapter 1 of the dissertation, some basic concepts and definitions related to coding theory are presented, as well as methodologies for optimizing and parallelizing algorithms. The main characteristics of linear codes are defined, their weight characteristics and significance are described. Self-complementary codes and their properties are presented. In the section dedicated to the optimization and parallelization of algorithms, the main techniques for parallelizing algorithms are described, which include both task and data

partitioning. Vectorization is thoroughly examined as a method for parallelization, using extended registers and corresponding instructions of central processors.

Chapter 2 is dedicated to the development and optimization of algorithms for finding the weight spectrum of linear codes. The presented algorithms for finding the weight spectrum apply a method for generating the next codeword through a linear combination of the rows of the generating matrix, using only vector addition. Various implementations of functions for vector addition over a finite field and finding the weight of a vector over a finite field using extended registers and specialized instructions of central processors for x86 architecture are described. In the section dedicated to experimental results, data demonstrating the effectiveness of the developed algorithms are presented. An analysis of the effectiveness of different compilers in applying vectorization in the proposed algorithms is also made.

Chapter 3 examines the specific features of vectorizing algorithms using the extended instructions of central processors. Some subcategories of AVX512 instructions for x86 architecture and their application for optimizing vector operations are thoroughly examined. NEON instructions for ARM architecture and their specifics are described. Algorithms for vector addition using unsigned data types and extended instructions with saturation are presented. The results of the conducted experiments, demonstrating the effectiveness of the optimizations with AVX512 and NEON instructions, are analyzed.

Chapter 4 focuses on self-complementary codes reaching the Grey-Rankin

bound and their properties, as well as methods for their construction. Subcodes with different dimensions and their properties are described. Various families of codes with two and three weights and their relationships with self-complementary codes are presented. Methods for constructing codes with higher dimensions using codes with lower dimensions are examined. The results of calculations related to the classification of self-complementary codes are presented.

In the concluding Chapter 5, a detailed description of the developed library for finding weight invariants of linear codes is provided. The main functionalities of the *LinCodeWeightInv* library are thoroughly examined. Both the interface of the library and the testing and verification module are presented. The software tools used in the development and documentation of the library, as well as the structure of the files containing its program code and the methods for compiling and installing, are described.

5. Scientific and Applied Contributions

The main scientific and applied contributions of the dissertation are as follows:

- Development of an algorithm for generating non-proportional codewords working on composite fields using only vector addition.
- Development of an algorithm for vector addition using SSE, AVX, and AVX512 instructions with bitwise representation of elements of fields GF(2), GF(4), and fields with characteristic 3.
- Development of an algorithm for vector addition using SSE, AVX, and AVX512 instructions with byte representation for simple and composite fields

with up to 64 elements, and finding the weight of a vector using a single call to the *popcnt* instruction.

- Analysis of the effectiveness of different compilers with SSE and AVX instructions in vectorization.
- Study of the characteristics of AVX512 and NEON instruction sets and analysis of their effectiveness.
- Analysis of the effectiveness of different types of instructions in x86 architectures.
- Development of an algorithm for vector addition using SSE, AVX, and AVX512 instructions with unsigned integer representation of elements of fields with up to 128 elements.
- Definition of families of two- and three-weight codes reaching the Grey-Rankin bound and description of the relationships between the different families of these types.
- Development of a construction for building codes from a given family with dimension k using codes from the corresponding family with dimension k+2.

  Development of mathematical software (*LinCodeWeightInv* library) for finding weight invariants of linear codes over fields with up to 64 elements, using SSE4.1, AVX2, AVX512 instructions for x86 architectures and NEON instructions for ARM architectures.
- Presentation of the features and main highlights in the creation of open-source mathematical software.

I acknowledge the scientific and applied contributions mentioned in the dissertation.

6. Publications and Participation in Scientific Forums

The list of publications related to the dissertation includes 6 articles. Four of these articles are co-authored with the scientific supervisor Prof. Dr. Sc. Ilia Bouyukliev, and one of them has Prof. Dr. Sc. Stefka Bouyuklieva as a co-author. I consider the participation of the PhD candidate in all publications to be equal to that of her co-authors. The number of articles meets the requirements of PPZRASRB.

One of the articles is published in the journal Mathematics 2022 with IF: 2.2 and SJR: 0.592 Q1, and another is published in the series Lecture Notes in Computer Science, Springer, vol. 13952, SJR: 0.606 (2023). Three others are included in the proceedings of international scientific conferences, respectively:

- two in "Innovative STEM Education" IMI-BAS, 2021-2022;
- one in ICAI, Varna, Bulgaria 2022.

The sixth article is submitted for review after the second revision in the journal ACM Transactions on Mathematical Software.

7. Conclusion

In my opinion, the presented dissertation "Optimization and Parallelization of Algorithms Related to Coding Theory" by Maria Rumenova Pashinska-Gadzheva contains scientific and applied results that represent an original contribution to software engineering and informatics. The PhD candidate clearly has in-depth theoretical and practical knowledge in the field of optimizing algorithms used in coding theory, as well as the ability for independent scientific and applied work. With

this opinion, I believe that she fully meets the requirements established by ZRASRB, as well as the regulations of BAS and IMI, and I confidently propose to the esteemed scientific jury to vote for Maria Rumenova Pashinska-Gadzheva to be awarded the educational and scientific degree "Doctor" in the professional field 4.6. "Informatics and Computer Science".

22.01.2025 г. Prepared by: …….

Sofia /Assoc. Prof. Dr. Yuri Borissov/