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SUMMIT
SOFIA UNIVERSITY MARKING MOMENTUM FOR INNOVATION AND TECHNOLOGICAL TRANSFER

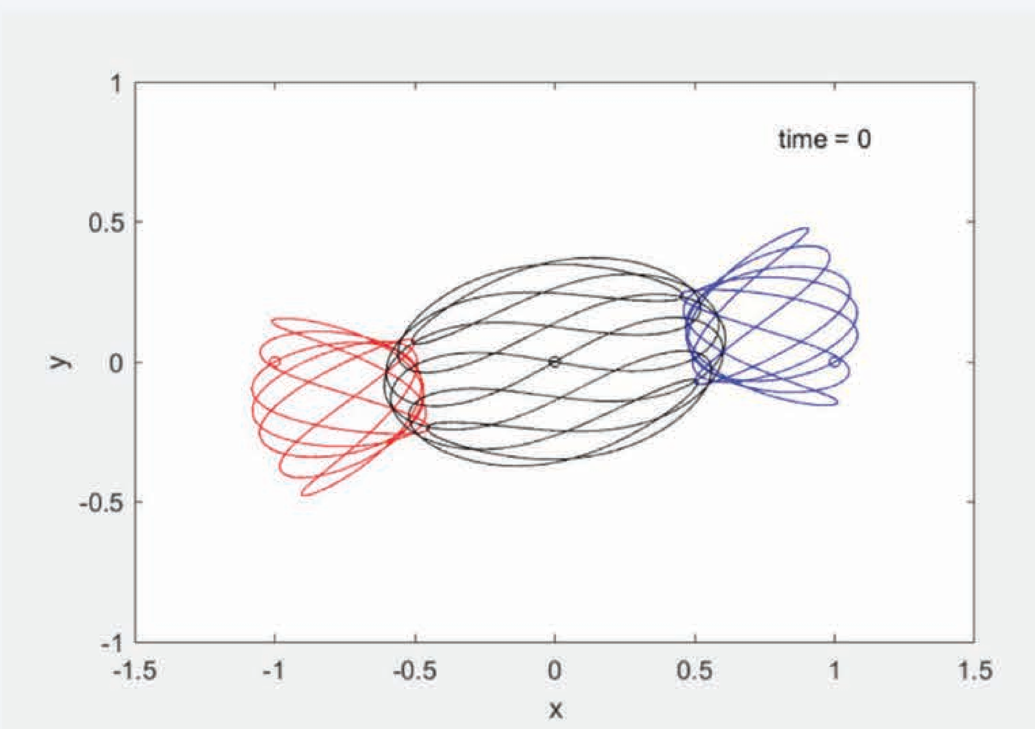
SOFIA UNIVERSITY -
MARKING MOMENTUM
FOR INNOVATION AND TECHNOLOGICAL TRANSFER

National Recovery and Resilience Plan
OF THE REPUBLIC OF BULGARIA

RESEARCH GROUP
MODERN TECHNOLOGIES

RESEARCH AREA
INFORMATICS

Efficient calculations and algorithms



INTRODUCTION

The main goal of the project is to share knowledge from different, but closely related science areas and build collaboration among experts in mathematics, physics, biology and computer science. This is achieved with joint research in the fields of computability theory, algebra and numerical methods in order to address different problems in natural science, such as studying the unstable orbits of material bodies, fluid simulations, gene regulatory networks and fundamental mathematical properties of floating point calculations. Each of this fields is represented by own research group, but several project members work in more than one area, adding to the common progress with their expertise. Following you can learn more about each research area:

Learning Families of Algebraic Structures from Text

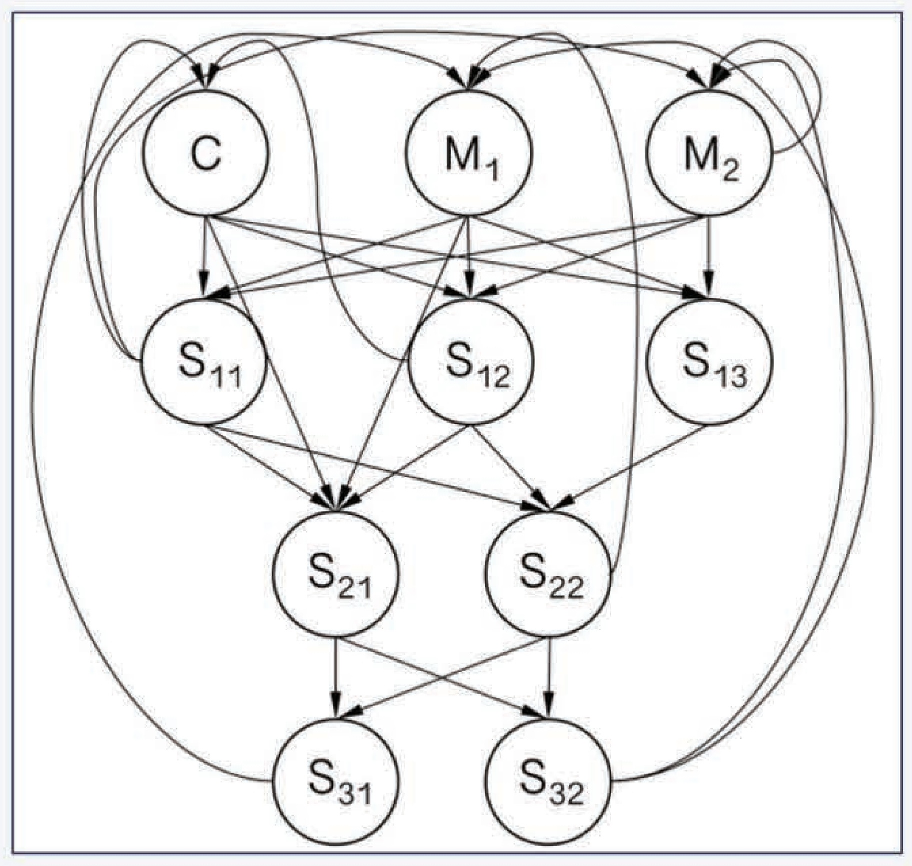
Research group: *Nikolay Bazhenov, Ekaterina Fokina, Dino Rossegger, Alexandra Soskova and Stefan Vatev*

We adapt the classical notion of learning from text to computable structure theory. Our main result is a model-theoretic characterization of the learnability from text for classes of structures. We show that a family of structures is learnable from text if and only if the structures can be distinguished in terms of their theories restricted to positive infinitary Sigma2 sentences.

Efficient generation of synthetic data, representing results from RNA sequencing

Research group: *Petar Armyanov, Ivan Ivanov, Nikolay Shegunov and Dafina Petkova*

Analyzing data retrieved from real cell RNA sequencing is quite expensive. Such data consists of values for the expression of thousands of genes, making it difficult to draw conclusions about any relation among the genes and to build valid gene regulatory networks. In our study, we start with formulating a hypothesis for possible gene relations and regulatory hierarchy and then generate synthetic data that would be expected if the hypothesis is true. This data is then compared to observations from an experiment to either accept or reject the hypothesis with a certain degree of confidence. Another task, we are focused on, is usage of our algorithms to generate gene expression data, following the rules of the observed network and simulating as close as possible the distribution and errors, specific for real RNA sequencing hardware. Then the data is fed into popular algorithms for restoration the network structure. The main goal is to evaluate the level of precision of those algorithms.
As the data size grows exponentially with the number of studied genes, tasks such as data generation, analysis and result comparison require enormous computing power. Specially designed algorithms have to be implemented and then executed on high-performance computing clusters, which is also a focus of this study.
The picture no the top of next column shows a well known from the biologists synthetic boolean network, representing relations among ten genes. This is one of the networks we are experimenting with.



Non-commutative theory of invariants

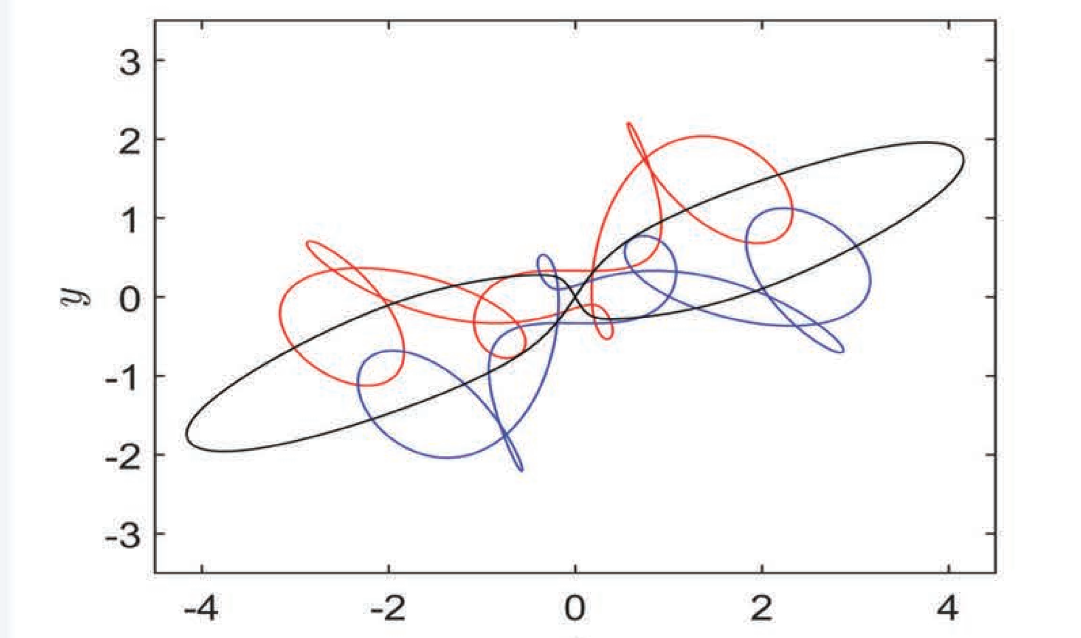
Research group: *Silvia Boumova, Deyan Dzhundrekov*

Noncommutative invariant theory began with the work of Margaret Wolf in the first half of the 19th century on noncommutative symmetric polynomials. Subsequently, the theory developed a lot, generalizing many of the classical results, many of which look different in the non-commutative case. Recent years have seen a return to the study of concrete algebras of invariants, calculation of Hilbert series, finding generating elements, determining ratios, and more. The goal of our research is to find the generating elements of the algebra of the invariants of the free algebra of **d** variables, under the action of some group (*dihedral*, *alternative*, and others) and under the additional Koryugin action.
The case of the symmetric group is solved and the results are published in two papers. Cases depending on the characteristic of the main field should be considered. Our goal is to replace the symmetric group with the alternative group.

Improvement of numerical algorithms for searching for new periodic planar three-body orbits

Research group: *Ivan Hristov, Radoslava Hristova, Petar Armyanov, Nikolay Shegunov*

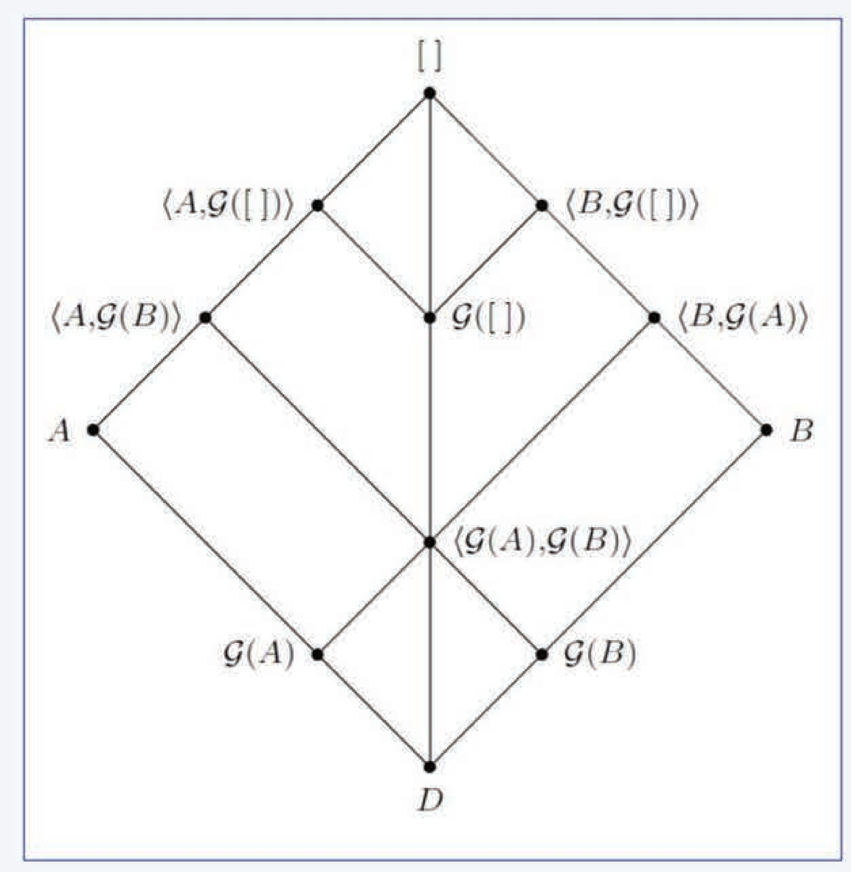
We are interested in the periodic orbits of the classic gravitational three-body problem. The stable periodic orbits are astronomically very important and are not so difficult to be found numerically, but all periodic orbits are important for the theory. Particularly, the unstable periodic orbits give us a good knowledge of the system and provide crucial information in chaotic regions. Hence, one of the important tools for the study of chaos for this problem is periodic orbit search algorithms. Although thousands of new periodic orbits have been discovered in the last decade, search algorithms are far from exhaustive and need to be improved. This is one of the goals of our research. In the last year several interesting properties of these orbits are found, including symmetry and periodicity conditions, which enables development of much more efficient algorithms. As a result thousands of new solutions are discovered and their initial states are described. Some of the properties, observed empirically was formally proved by the famous american mathematician prof. Richard Montgomery.
The picture at the beginning of the poster is so called *Butterfly* orbit, which is a stable solution of the problem. The picture below presents the plot of one of the many found new unstable periodic solutions.



Subrecursive representations of irrational numbers

Research group: *Ivan Georgiev, Lars Kristiansen*

We investigate the structure of the subrecursive degrees of representations of irrational numbers with respect to subrecursive reducibility. We say that a representation R_1 is subrecursive in a representation R_2, if given any R_2-representation of an irrational number α, we can produce an R_1-representation of α by an algorithm with no unbounded search. For example, let **D** be the Dedekind cut, which given a rational q decides whether $q < \alpha$ or $q > \alpha$ and let **[ ]** be the continued fraction, which given n returns the n-th partial quotient an of α. Then the representation **D** is subrecursive in **[ ]**, but **[ ]** is not subrecursive in **D**. In fact, a recent paper by Georgiev shows a profusion of subrecursive degrees, which lie strictly subrecursively between **D** and **[ ]**:
One of the main goals of the present project is to enrich the knowledge about different complexity classes of irrational numbers: 1) by exploring the subrecursive degrees of new representations and 2) by considering the graphs and the boolean combinations of already known representations.



Fluid flow simulations inside random porous mediums

Research group: *Oleg Iliev, Nikolay Shegunov, Petar Armyanov*

In this group our research is focused on the problem of reactive transport inside a random porous medium. The main driving force of the transport is the processes of convection and diffusion, which are influencing the reaction. This type of simulations has practical applications in oil recovery, soil pollution and remediation, as well as in several industrial and biomedical processes. A steady-state two-dimensional convection-reaction-diffusion equation with random coefficients is considered. It describes reactive transport in random porous media consisting of sand, gravel, and other soils. The equation is considered in its dimensionless form. The applicability and superiority of MLMC method for solving such problems with a huge parametric space is studied, particularly the coarse grain strategies used for constructing the MLMC model.
Lognormal distribution of the permeability is considered, based on numerous experimental observations. Essential part of the algorithm is the fact that the random coefficients for the flow problem and for the reactive transport are not independent. In fact, random coefficients are generated for the flow problem, and the coefficients for the reactive transport are derived based on the standard models for flows in porous media and heterogeneous reactions.
The research group studies several variations of popular MLMC algorithm for process simulations, implemented efficient software modules, designed to work in massively parallel environment and to utilize the computational resources of the modern multiprocessor high performance computing clusters as well as graphical processing units accelerators.

Head of the research group:
assoc. prof. Petar Armyanov
Members of the group:
prof. Aleksandra Soskova,
assoc. prof. Ivan Georgiev,
assistant Stefan Vatev,
assoc. prof Silvia Bumova
assoc. prof. Ivan Hristov

For further information, one can reach members of our research group at Faculty of Mathematics and Informatics. The head of the research group can be contacted via email at *parmyanov@fmi.uni-sofia.bg*

CONTRACT BG-RRP-2.004-0008 FOR THE FINANCING OF PROJECT "SOFIA UNIVERSITY - MARKING MOMENTUM FOR INNOVATION AND TECHNOLOGICAL TRANSFER" UNDER PILLAR 2 "ESTABLISHING A NETWORK OF RESEARCH HIGHER EDUCATION INSTITUTIONS IN BULGARIA", COMPONENT "INNOVATIVE BULGARIA" FROM NATIONAL RECOVERY AND RESILIENCE PLAN PART OF THE PROGRAM TO ACCELERATE ECONOMIC RECOVERY AND TRANSFORMATION THROUGH SCIENCE AND INNOVATION