Project description (template) for call 09I03-03-V04 Fellowships for excellent researchers R2-R4

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Title of the project: Complexity and algorithmic questions in automata and languages theory

Short title of the project/Acronym: *CAQALT*

Category of researcher: R2

Researcher’s job type (full-time, part-time – in %): 100

Type of research[[2]](#footnote-3): independent, basic, industrial

Identification of the entity involved in the implementation of the project:

|  |  |  |  |
| --- | --- | --- | --- |
|  | Official name of the entity | Abbreviated name of the entity | Role in the project |
| 1 | Matematický ústav Slovenskej akadémie vied  / Mathematical Institute of the Slovak Academy of Sciences | MÚ SAV / MI SAS | Applicant/host organisation |

## 1. Excellence

This project is about postulating and solving complexity and algorithmic questions in the theory of formal languages and their respective automata models, mainly regular languages and finite automata. Its aim is to contribute to this theory by outputs on European or world level.

*Specific aspects that are relevant for this section*:

*The quality and adequacy of the proposed objectives of the project.*

*Relevance of the problems/needs the project is focused on.*

*How the project goes beyond the currently available solutions, procedures, etc. (“beyond the state of the art”).*

*Appropriateness, timeliness and relevance of the proposed methodology to the objectives of the project.*

*The quality and adequacy of the researcher’s professional experience, expertise, competences and skills.*

*The quality and adequacy of the host organisation in relation to the project and the researcher.*

*The quality and adequacy of the conditions that the host organisation will ensure and provide for the researcher (e.g., additional training, supervision/mentoring, possibilities to build its own research team, etc.).*

*The quality of two-way knowledge transfer between the researcher and the host organisation.*

### 1.1 PROJECT OBJECTIVES

The objectives of this project are to study descriptional and computational complexity of formal languages represented by various computational models, such as one-way and two-way deterministic and non-deterministic finite automata, self-verifying, unambiguous, alternating and Boolean automata etc. We aim to investigate the (accepting) state complexity of languages and operations on the class of regular languages and its subclasses, including the ranges of attainable complexities for respective operations and the complexities of languages resulting from Kuratowski’s algebras. For different subclasses of regular languages, we will examine their closure properties and computational complexity of decision problems concerning these language classes. We will also design and implement some algorithms on automata and connect them with various subfields of mathematics. The results of our research will be presented at international conferences such as Developments in Language Theory, Conference on Implementation and Application of Automata, or Descriptional Complexity of Formal Languages, and published in indexed scientific journals in CC, WoS or Scopus. Our aim is to publish at least two conference papers and two journal articles during the 48 months of the project.

1.2 RELEVANCE, QUALITY AND NOVELTY OF THE PROJECT

The current research in theoretical computer science has a vivid stream in formal languages and automata theory, and various new results in this field are presented at several conferences each year. We want to stay active in this stream and provide answer to several open problems from the literature, such as: what is the accepting state complexity of permutation on infinite regular languages, or what is the range of state complexities for the square operation on regular languages. We also want to examine descriptional complexity operations on some new subclasses, such as definite or locally testable languages. This research has impact in practical applications, like string matching in large texts, neural networks design, or microchip optimization.

In particular, our aims are:

1. examine the state complexity of boundary, cyclic shift, and the ranges of state complexities for the cut operation and proportional removal;
2. examine the computational complexity of problems concerning definite, comet, ordered and other classes of languages;
3. study the descriptional complexity of operations on alternating finite automata and two-way nondeterministic automata,
4. investigate the boundary operation on suffix-free languages.

In the literature, some of our problems were never examined or even mentioned because of lack of useful lemmas discovered in recent years. With these lemmas, which are a product of our research so far, we can examine other problems of the same type.

We have a link to the European Research Area. Our occasional cooperators include people from Justis-Liebig-Universität in Giessen, Germany (Markus Holzer, Bianca Truthe), next in the University of Eger (Benedek Nagy), University of Wrocław (Marek Szykuła), Masaryk University in Brno (Ondřej Klíma), with which we have joint publications and open problem for further publications.

1.3 METHODOLOGY

The project will be implemented during seminars where the Researcher will present his ideas to his colleagues and other scientists and searching for the solutions of the postulated problems.

The main methods in our research are: 1) combinatorial analysis of the finite automaton, 2) the method of determinization and minimization of finite automata and 3) the method of fooling sets and its simplifications. Some of these simplifications were provided in publications by the Researcher during his previous research. A successful use of these methods, or finding out their optimization, is expected.

A concept is that we take a finite automaton and perform an operation on it. Then we use the specific property of the respective subclass to get an upper bound on the complexity of the resulting language. Simultaneously with getting an upper bound, we provide a lower bound, it is, a witness language who gives the complexity of the operation at least some function. When the upper and lower bound meet, we declare this bound to be tight, and we can examine the ranges of complexities between it and the smallest complexity, which is usually one. In finding upper bounds, results from graph theory were successfully used several times.

The project objectives will be achieved by submitting and accepting scientific papers to both conference proceedings and renowned journals. The only challenge is to prepare papers with enough results in due time of the conference or journal deadline. This can be overcome by submitting papers including preliminary results from several problems together, in order to have enough results to be accepted. After accepting the conference paper, we usually prepare an extended version of it for a scientific journal.

All our research data are of public nature and most of them are included in the paper. Some data can be published at GitHub. We credit all results of our scientists that are used in our research.

Our approach is multi- and interdisciplinary in the way that our results draw from several areas of computer science and mathematics and is again reused and cited. Since finite automata can be viewed as a special type of unary algebras, we also cooperate with experts on algebra (Emília Halušková, Peter Eliaš) and on combinatorial data analysis (Jozef Pócs, Stanislav Krajči). We provide our papers at ResearchGate and Academia.edu, thus promoting open science. We treat women in our team with respect to their maternal duties and provide a flexible work time for them.

Navrhovaná metodika vychádza z tradičných postupov v teórii zložitosti formálnych jazykov, ktorými sú kombinatorická analýza konečného automatu, metóda determinizácie a minimalizácie a metóda klamúcej množiny. Výskumník vo svojich publikáciách poskytol niektoré vylepšenia týchto metód a dá sa očakávať, že ich bude používať aj v ďalších problémoch, prípadne že ich ešte viac vylepší.

Predpokladom tohto očakávania je doterajšia prax výskumníka, ktorý štyri roky po získaní titulu PhD. pracuje na MÚ SAV a má 15 publikácií v zborníkoch a 7 v časopisoch, pričom bol editorom troch zborníkov. Výskumník je tiež nositeľom deleného 2.-3. miesta Ceny akademika Štefana Schwarza za obdobie rokov 2020 a 2021.

1.4 EXCELLENCE OF THE RESEARCHER

The researcher is a suitable professional in the described field of study, as can be shown in the following curriculum vitae.

Curriculum Vitae

**Personal information**

First and last name: Michal Hospodár

Identifier ORCID: 0000-0002-1752-544X

Date of birth: 7 March 1991

Nationality: Slovakia

Website (if relevant):

**Education**

08/2019 – PhD

Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava, Slovakia

06/2014 – Ing. (Master of Engineering)

Faculty of Electrical Engineering and Informatics, Technical University in Košice, Slovakia

**Current position/positions**

09/2019 – research fellow

Department in Košice, Mathematical Institute, Slovak Academy of Sciences, Slovakia

**Scholarships and awards**

09/2017 – 01/2018 – scholarship – Research stay at the Institut für Informatik, Justus-Liebig-Universtät Gießen, Germany (scholarship from the German Academic Exchange Service DAAD, ID 57314022)

2021 – award – Slovak Mathematical Society (section of JSMF), 2nd-3rd place in the Štefan Schwarz Award for mathematicians under 30 years, Slovakia

Student and post-docs supervision (year of actual or planned defence)

2021 – one Master student (Viktor Olejár): Faculty of Science, UPJŠ, Slovakia

2024 – one Bachelor student (Roland Horváth): Faculty of Science, UPJŠ, Slovakia

2025 – one PhD student (Viktor Olejár): MI SAS, Slovakia

**Organisation of scientific meetings (if applicable)**

2019 – member of the Organizing Committee, 24th International Conference on Implementation and Application of Automata (CIAA 2019), 43 participants, Košice, Slovakia

2019 – member of the Organizing Committee, 21st International Conference on Descriptional Complexity of Formal Systems (DCFS 2019), 38 participants, Košice, Slovakia

2018 – member of the Organizing Committee, 10th International Workshop on Non-Classical Models of Automata and Applications (NCMA), 31 participants, Košice, Slovakia

**Institutional responsibilities (if applicable)**

2015 – Academic Staff member, MI SAS, Slovakia

2023 – Program Committee member, 25th International Conference on Descriptional Complexity of Formal Systems (DCFS 2023), Universität Potsdam, Germany

**Reviewing activities (if applicable)**

2020 – 2023 – referee for various journals and proceedings (4 journal articles, 3 conference papers)

2020 – opponent of one Bachelor thesis, Faculty of Electrical Engineering and Informatics, TUKE, Slovakia

2022 – opponent of one written thesis for dissertation exam, Faculty of Science, UPJŠ, Slovakia

2023 – reviewer for Mathematical Reviews, American Mathematical Society, United States

**Memberships of scientific societies (if applicable)**

2020 – Member, Slovak Mathematical Society (section of the Unity of Slovak Mathematicians and Physicists, JSMF)

**Major collaborations (if applicable)**

1. Markus Holzer, ranges of number of states of finite automata, Institut für Informatik, Justus-Liebig-Universität Giessen, Germany
2. Juraj Šebej, trade-offs between models of finite automata, Institute of Computer Science, Faculty of Science, Pavol Jozef Šafárik University in Košice, Slovakia

**Overview of the researcher’s most important projects in the last 5 years** (max. 5)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Project name/identification** | **Source of funding** | **Budget (EUR)** | **Project period** | **The role of the researcher in the project** |
| VEGA 2/0132/19 | VEGA | 26 236 | 01/2019 – 12/2022 | Deputy leader |
| VEGA 2/0096/23 | VEGA | cca 28 000 | 01/2023 – 12/2026 | Deputy leader |
| APVV-15-0091 | APVV | cca 200 000 | 07/2016 – 12/2020 | Member of project |
| Future planned | APVV | cca 40 000 | 07/2024 – 06/2028 | Member of project |
|  |  |  |  |  |

**Overview of the researcher’s most important outputs** (max. 5)

|  |  |  |  |
| --- | --- | --- | --- |
| **Output name/identification** | **Type of output** *(e.g., publication, dataset, software, patent, service, product, etc.)* | **Short description** | **The role of the researcher** |
| [doi:10.1016/j.tcs.2018.12.027](https://doi.org/10.1016/j.tcs.2018.12.027)  M. Hospodár, G. Jirásková, P. Mlynárčik (2019) | Publication | Nondeterministic state complexity of six operations on sixteen subclasses of convex languages | Corresponding author |
| [doi:10.1142/S0129054120420083](https://doi.org/10.1142/S0129054120420083)  M. Hospodár, M. Holzer (2020) | Publication | Accepting state complexity of five operations on regular languages, continuation of a work by J. Dassow | Corresponding author |
| [doi:10.1016/j.tcs.2021.02.002](https://doi.org/10.1016/j.tcs.2021.02.002)  M. Hospodár (2021) | Publication | Five more operations on sixteen subclasses of convex languages | Single author |
| [doi:10.1016/j.tcs.2023.114050](https://doi.org/10.1016/j.tcs.2023.114050)  M. Hospodár, V. Olejár (2023) | Publication | A complete overview of state complexity of the cut operation on sixteen subclasses of convex languages | Corresponding author |
| [doi:10.1016/j.tcs.2023.114075](https://doi.org/10.1016/j.tcs.2023.114075)  M. Hospodár, V. Olejár (2023b) | Publication | New results on nondeterministic state complexity on eleven classes, which were not considered for this complexity measure before | Corresponding author |

The researcher is one of the top world researchers in the investigation of operational complexity on deterministic (DFA) and nondeterministic finite automata (NFA). In the beginning of his career, he provided the exact value of complexity of concatenation on alternating finite automata. Next, he provided a description of the range of state complexities of languages resulting from the cut operation, and of the ranges of accepting state complexities for some other operations. The looking for these ranges is called the magic number problem: a number is magic if it is not in the range respective for the operation and automata model. The magic number problem is still open for many operations, but for the cut operation, it is completely solved in a paper by the Researcher. In the sixteen subclasses of convex languages (four ideal, free, closed, and proper convex classes), the author provided an almost complete overview of both NFA and DFA complexity of six basic operations (intersection, union, concatenation, Kleene star, reversal, complementation) in a 2019 paper with Jirásková and Mlynárčik, and of five more operations (power, positive closure, right quotient, left quotient, left quotient by a regular language) in a single-authored 2021 paper. Both these papers were published in Theoretical Computer Science, a journal with Impact Factor 1.1. The 2021 paper also provided several simplifications of the fooling set method, which is used for examining nondeterministic state complexity since the 1990’s. With these simplifications, several old proofs can be rewritten, and new results in previously not examined classes can be easily obtained. The simplification uses reachable and co-reachable sets in an NFA instead of strings.

1.5 EXCELLENCE OF THE APPLICANT/HOST ORGANISATION

This part will be written by the team of Prof. Jenčová. Here I (Michal Hospodár) provide some proposals.

Mathematical Institute of the Slovak Academy of Sciences is an excellent institution in the field of automata and formal languages theory. This field is investigated by the group consisting of the Researcher, his former PhD advisor Galina Jirásková and her other former and current PhD students. This group cooperates with other scientists, both from MI SAS and from the Faculty of Sciences of UPJŠ.

The comparative advantage of MI SAS is in synergy of mathematicians and computer scientists, dealing with the problems of formal languages, combinatorial data analysis and algorithmic graph theory together, and such taking them from different perspectives.

Pracovné prostredie výskumníka na MÚ SAV je tvorivé a kvalitné, jeho skupina pravidelne získava granty z VEGA a opakovane získala aj grant z APVV. Vo vzťahu k výskumníkovi je priaznivé a podporuje ho. Výskumník bude pracovať spolu s členmi skupiny aj s externými spoluautormi. MÚ SAV výskumníkovi poskytuje vhodné pracovné podmienky. Obojsmerný prenos znalostí medzi výskumníkom a MÚ SAV je zaručený pravidelnými vedeckými seminármi.

Describe the applicant/host organisation and its excellence.

*What is the comparative advantage of implementing this project within the given host organisation, why is the applicant the ideal hosting organisation to implement the project?*

*Describe the conditions that the applicant/host organisation will create and provide for the researcher for the implementation of the project. In the case of supervision/mentoring, describe the person of the supervisor/mentor, his/her quality and adequacy in relation to the researcher and the project.*

*Describe the conditions the researcher will be provided with to build his/her own team (particularly relevant for R3 and R4 researchers’ categories).*

*Describe the quality and how two-way knowledge transfer between the applicant/host organisation and the researcher will be ensured.*

## Impact

### 2.1 THE WIDER IMPACT OF THE PROJECT

The expected impact of this project is in holding a position for an excellent Researcher for at least two years and sending him for scientific cooperation to partner institution in Slovakia abroad, both for scientific conferences and seminars, where he can present the work of his research group to a broad audience. In the short term, this can include visiting the Department of Computer Science of the University of Porto, where a cooperation recently began. In the long term, it is planned to participate at two scientific conferences each year, present own recent results and bring new ideas for solving open problems in mathematics and computer science.

The impact on the career of the Researcher can only be positive. He can improve his skills and use them for the rest of his life, and also teach them to young researchers, including his present and future students.

The impact on the host organisation is in holding a quality researcher who makes a good name for the host organisation and for Slovakia. His activity will also bring money for publications and citations.

The target groups that will benefit from the activities and achievement of the project objectives include the current and future PhD students of MI SAS who will have a role model of a young and successful researcher and will use the results and experiences of this project for their own research.

There is no direct and relevant societal or environmental impact of this project.

A potential negative impact is only in fixing the position for the Researcher who would maybe like to change his job.

The quantitative impact on the monitored data:

* One PhD candidate is currently working under the Researcher.
* One current Bachelor student will be a Master at the end of the project (Summer 2026) and potentially become a PhD candidate.
* There are not patent applications planned.
* The expected number of publications in this project is between four and six.
* We plan to add one or two international collaborations during the project.

All this is based on a qualified guess stemming from eight-year experience of the Researcher.

* Potential obstacles to the planned impact of the project

There are no obstacles to the impact.

### 2.2 MEASURES TO MAXIMISE IMPACT – DISEMINATION AND COMMUNICATION, EXPLOITATION OF RESULTS

Dissemination and communication of project results will be conducted by the Researcher who makes them available through ResearchGate portal and other networks, both online and via personal meetings with academicians.

Eventual commercialisation of the results will be ensured by a spin-off company of the MI SAS and a private investor.

After the completion of this project, the results will be exploited for further research in theoretical computer science, conducted at MI SAS or at other institutions. All research data will be public.

============================== From this down there is nothing added ==============================

## Implementation

*Specific aspects that shall be taken into account in this section*:

Quality and efficiency of the project plan, feasibility of planned activities.

The coherence and logical framework of the work packages and the adequacy of the resources allocated to them, the adequacy of the proposed milestones and deliverables.

Estimation of implementation risks, quality of proposed measures.

Capacities (personnel, professional, technical, infrastructure, other) of the applicant/host organisation.

3.1 PROJECT PLAN AND DELIVERABLES

Describe the overall structure of the project plan, which consists of individual work packages, their interconnection, logical and chronological relation.

Describe the timeline of the project – specify project duration and the time frame for the implementation of each work package (e.g., Gantt diagram).

Describe the planned work packages (template of the table below) and add a separate table for each work package. The number of work packages should reflect the scale and complexity of the project.

3.1.1 Work packages

Template of the table for the work package (1 work package = 1 table):

|  |  |
| --- | --- |
| Work package number |  |
| Title of the work package | Provide the name of the work package, which will have a maximum of 20 characters. This name should be stated same throughout the application and its annexes. |
| **Start of implementation of the work package (Mx Month[[3]](#footnote-4))** |  |
| End of implementation of the work package (Mx month) |  |
| **Involvement (expressed in Person Months)[[4]](#footnote-5)** |  |
| **Personnel costs (in EUR)[[5]](#footnote-6)** |  |
| Other eligible costs, excluding personnel costs (in EUR excluding VAT) |  |
| Objectives | |
|  | |
| Description of the work package | |
| Where appropriate, please also provide a breakdown per task level. | |
| Deliverables | |
| Identify deliverables in numbered list and describe each deliverable in more detail | |

3.1.2 List of work packages (template):

|  |  |  |  |
| --- | --- | --- | --- |
| Work package number | Title of the work package | **Start of activities** *(specify month of project implementation)* | **End of activities** *(specify month of project implementation)* |
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3.1.3 List of deliverables (template):

Mandatory deliverables shall be at least:

* Interim report on the implementation and achievements of the project submitted at mid-term of project implementation
* Final report on the achievements of the project presented at the end of the project implementation
* Researcher’s publications in scientific and/or professional journals
* Outputs in the conference proceedings with the active participation of the researcher
* Submission/award of a research project(s)/grant(s) with the involvement of the researcher

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| --- | --- | --- | --- | --- | --- | --- |
| Deliverable number | Deliverable | Work package number | Type | Access and dissemination | Method of verification | Delivery (project implementation month) |
|  |  |  | Report, publication, prototype, software, patent, other (please specify) ... | P= public  N= non-public, limited only to team/host organisation, grant provider for reporting purpose |  |  |
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The applicant shall define the number of planned mandatory deliverables and define other deliverables relevant to its project.

3.1.4 List of milestones (template):

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Milestone number | Milestone | Work package number | Method of verification | Expected time to reach the milestone (project month) |
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3.2 IMPLEMENTATION RISKS AND PROPOSED MEASURES

Describe the approach to risk management in the implementation of the project.

3.2.1 Risks of implementation (template):

|  |  |  |
| --- | --- | --- |
| **Description of the risk of implementation[[6]](#footnote-7)** | **Work package** *(one or more)* | Proposed measures for risk mitigation or elimination |
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3.3 OPERATIONAL CAPACITY OF THE APPLICANT/HOST ORGANISATION

Describe the capacities (staff, professional, technical, infrastructure and others) of the applicant/host organisation that are necessary for the successful implementation of the project. Describe their relevance to the project and how they will be made available to the researcher or how the access to them will be ensured during the implementation of the project.

3.3.1 Description of the research/innovation infrastructure of the applicant/host organisation that is necessary for the implementation of the project (template):

|  |  |
| --- | --- |
| Name of infrastructure or equipment | Short description |
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3.3.2 List of the five most important projects of the applicant/host organisation and their relevance to the proposed project (in the last 5 years) (template):

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| --- | --- | --- |
| Project name/identification | Programme/scheme/grant provider | Short description |
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3.3.3 List of maximum five most important outputs of the applicant/host organisation relevant to the submitted project (Template):

|  |  |  |
| --- | --- | --- |
| Output name/identification | **Type of output** *(e.g., publication, dataset, software, patent, service, product, etc.)* | Short description |
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1. After completion of the document, update the content. [↑](#footnote-ref-2)
2. Choose one type of research. [↑](#footnote-ref-3)
3. The months are indicated ascending from the start of the project, i.e., the month in which the project started is M1. [↑](#footnote-ref-4)
4. In case of involvement of the research team in the project implementation, it is necessary to identify the individual positions, identify the category of researcher R1-R4 for researchers and determine the level of involvement for all members of the research team. [↑](#footnote-ref-5)
5. Where the research team is involved in the project implementation, the personnel costs will include personnel costs of the researcher and the members of the research team. [↑](#footnote-ref-6)
6. Indicate the probability of risk occurrence (low, medium, high) and the severity of the risk (low, medium, high) [↑](#footnote-ref-7)