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

Content

[1. Excellence 2](#_Toc146724107)

[1.1 PROJECT OBJECTIVES 2](#_Toc146724108)

[1.2 RELEVANCE, QUALITY AND NOVELTY OF THE PROJECT 2](#_Toc146724109)

[1.3 METHODOLOGY 3](#_Toc146724110)

[1.4 EXCELLENCE OF THE RESEARCHER 3](#_Toc146724111)

[1.5 EXCELLENCE OF THE APPLICANT/HOST ORGANISATION 5](#_Toc146724112)

[2. Impact 6](#_Toc146724113)

[2.1 THE WIDER IMPACT OF THE PROJECT 6](#_Toc146724114)

[2.2 MEASURES TO MAXIMISE IMPACT – DISEMINATION AND COMMUNICATION, EXPLOITATION OF RESULTS 6](#_Toc146724115)

[3. Implementation 7](#_Toc146724116)

[3.1 PROJECT PLAN AND DELIVERABLES 7](#_Toc146724117)

[3.2 IMPLEMENTATION RISKS AND PROPOSED MEASURES 10](#_Toc146724118)

[3.3 OPERATIONAL CAPACITY OF THE APPLICANT/HOST ORGANISATION 10](#_Toc146724119)

Title of the project: Complexity and algorithmic issues in automata and formal languages

Short title of the project/Acronym: *CAIAFL*

Category of researcher: R2

Researcher’s job type: full-time

Type of research: independent

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 | Mathematical Institute of the Slovak Academy of Sciences | MI SAS | Applicant/ host institution |

## 1. Excellence

### 1.1 PROJECT OBJECTIVES

This project aims to postulate and solve complexity and algorithmic questions in the theory of automata and formal languages. 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 (the Researcher and his cooperators) 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. 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.

These and similar results are still wanted in the scientific community, and they are regularly presented at international conferences such as Developments in Language Theory (DLT), Conference on Implementation and Application of Automata (CIAA), or Descriptional Complexity of Formal Languages (DCFS). Our results were also published in indexed scientific journals in CC, WoS or Scopus. The aim of this project is to publish at least two conference papers and two journal articles.

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. explore 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.

In our research, we will use lemmas from literature, including some lemmas present in papers by the Researcher published in recent years, namely Lemmas 5, 8 and 9 in paper *Power, positive closure, and quotients on convex languages. Theor. Comput. Sci. 870: 53-74 (2021)*. With these lemmas we can solve other problems concerning operational and descriptional complexity of regular and subregular languages. This is considered as going beyond the state of the art, and we expect to provide more such lemmas in the future.

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 problems 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.

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): https://im.saske.sk/hospodar/

**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

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. This has a practical impact in having broader scope for possible collaborations and publications, since the Researcher can publish in journals and conference proceedings aimed at both mathematics and computer science. The host organization is able to ensure additional training to the Researcher, as it was already done in cooperation with the Albertina Icome Bratislava institute which provided access to Charlesworth webinars. In the future, the Researcher is supposed to create his own research team based on his Bc., Mgr., or PhD. students.

The working environment of the Researcher at MI SAS is a creative place with high quality of research. It regularly receives grants from Slovak Scientific Grant Agency (VEGA) and repeatedly received also a grant from Agency for the Support of Research and Development (APVV). The Researcher will work with his colleagues and other scientists from abroad, inform them about their new results and preliminary ideas on scientific seminars, and thus ensure the two-way knowledge transfer between him and the applying organization.

## 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.

## Implementation

We divided the implementation of the project into three work packages WP1, WP2, WP3. The activities in them are directly determined by the tasks listed below in the tables for individual topics. The duration of each work package is set to 8 months and we allocate the personnel costs and the research and indirect costs accordingly. The research costs will be used for traveling expenses for conferences and research visits, books, and necessary equipment including computers or rental of computation time.

The **feasibility** of the research plan results from the nature of the mathematical work, the processes we use at MI SAS, experiences of the researcher and negligible implementation risks.

The **quality** of the project is guaranteed by the following facts:

* the fulfilment of the project's goals is a contribution to the development of European science,
* we emphasize the public presentation of the achieved results,
* MI SAS outputs.

The **efficiency** is guaranteed by the fact that each of these work packages represents the researcher's concentration on exactly one topic from the project's objectives. The operational capacity of MI SAS is the important factor of efficiency.

3.1 PROJECT PLAN AND DELIVERABLES

3.1.1 Work packages

|  |  |
| --- | --- |
| Work package number | WP1 |
| Title of the work package | OSC |
| **Start of implementation of the work package (Mx Month)** | M1 |
| End of implementation of the work package (Mx month) | M8 |
| **Involvement (expressed in Person Months)** | 8 Person Months |
| **Personnel costs (in EUR)** | 33 944 |
| Other eligible costs, excluding personnel costs (in EUR excluding VAT) | 9000 + 4240 (research costs + indirect costs) |
| Objectives | |
| WP1: Operational state complexity (OSC). Examine the state complexity of boundary, cyclic shift, and the ranges of state complexities for the cut operation and proportional removal. | |
| Description of the work package | |
| Task 1.1: Study the relevant literature for the given operations (boundary, cyclic shift, cut, proportional removal)  Task 1.2: Provide automata constructions for the operations  Task 1.3: Provide lower bounds for the operations by describing witness languages | |
| Deliverables | |
| D1: OSC seminar contribution at the regular seminar in Košice  D2: OSC paper in a journal indexed in Scopus | |

|  |  |
| --- | --- |
| Work package number | WP2 |
| Title of the work package | COMC |
| **Start of implementation of the work package (Mx Month)** | M9 |
| End of implementation of the work package (Mx month) | M16 |
| **Involvement (expressed in Person Months)** | 8 Person Months |
| **Personnel costs (in EUR)** | 33 944 |
| Other eligible costs, excluding personnel costs (in EUR excluding VAT) | 8500 + 4240 (research costs + indirect costs) |
| Objectives | |
| WP2: Computational complexity (COMC). Explore the computational complexity of problems concerning definite, comet, ordered and other classes of languages. | |
| Description of the work package | |
| Task 2.1: Study the relevant literature for the given classes of languages (definite, comet, ordered, other)  Task 2.2: Provide algorithms for upper bound on complexity classes  Task 2.3: Provide finite reductions for lower bounds on computational complexity (hardness in classes) | |
| Deliverables | |
| D3: COMC seminar contribution at the regular seminar in Košice  D4: COMC paper in a journal indexed in Scopus | |

|  |  |
| --- | --- |
| Work package number | WP3 |
| Title of the work package | NCA |
| **Start of implementation of the work package (Mx Month)** | M17 |
| End of implementation of the work package (Mx month) | M24 |
| **Involvement (expressed in Person Months)** | 8 Person Months |
| **Personnel costs (in EUR)** | 33 944 |
| Other eligible costs, excluding personnel costs (in EUR excluding VAT) | 8500 + 4240 (research costs + indirect costs) |
| Objectives | |
| WP3: Non-classical automata (NCA). Study the descriptional complexity of operations on alternating finite automata and two-way nondeterministic automata. | |
| Description of the work package | |
| Task 3.1: Study the relevant literature for the given models of automata (alternating, two-way)  Task 3.2: Provide constructions for the respective operations in these automata models  Task 3.3: Provide lower bounds for the operations by describing witness languages | |
| Deliverables | |
| D5: NCA seminar contribution at the regular seminar in Košice  D6: NCA paper in a journal indexed in Scopus | |

3.1.2 List of work packages

|  |  |  |  |
| --- | --- | --- | --- |
| Work package number | Title of the work package | **Start of activities** | **End of activities** |
| WP1 | OSC | M1 | M8 |
| WP2 | COMC | M9 | M16 |
| WP3 | NCA | M17 | M24 |
|  |  |  |  |
|  |  |  |  |

3.1.3 List of deliverables

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Deliverable number | Deliverable | Work package number | Type | Access and dissemination | Method of verification | Delivery (project implementation month) |
| D1 | OSC seminar | WP1 | report | P | Expert feedback | M4 |
| D2 | OSC paper | WP1 | publication | P | Peer review | M8 |
| D3 | COMC seminar | WP2 | report | P | Expert feedback | M12 |
| D4 | COMC paper | WP2 | publication | P | Peer review | M16 |
| D5 | NCA seminar | WP3 | report | P | Expert feedback | M20 |
| D6 | NCA paper | WP3 | publication | P | Peer review | M24 |

3.1.4 List of milestones

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Milestone number | Milestone | Work package number | Method of verification | Expected time to reach the milestone (project month) |
| 1 | New results on operational state complexity of several operations | 1 | Peer review | M8 |
| 2 | Results in computational complexities of problems in selected classes of languages | 2 | Peer review | M16 |
| 3 | Constructions and witnesses for non-classical automata models | 3 | Peer review | M24 |

**Each milestone is equivalent to the publication denoted by deliverable with even number.**

3.2 IMPLEMENTATION RISKS AND PROPOSED MEASURES

3.2.1 Risks of implementation

|  |  |  |
| --- | --- | --- |
| **Description of the risk of implementation** | **Work package** *(one or more)* | Proposed measures for risk mitigation or elimination |
| Publication delay (low) | All WPs | Choose a journal for publication with not so long publication time. Submit the paper earlier than in the last month of the work package. |
| Complicated task (low) | All WPs | Propose the task to the cooperators and ask them for help. Study new approaches from literature and discuss them on seminars. If no progress is made, modify or skip the task. |
| Pandemic (medium) | All WPs | Use videocalls and shared storage for seminars during home office. Attend online conferences. |
| War (low) | All WPs | Use shared storage for seminal results of the research and access them when in safe environment (after the war or in refuge). |

3.3 OPERATIONAL CAPACITY OF THE APPLICANT/HOST ORGANISATION

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

|  |  |
| --- | --- |
| Name of infrastructure or equipment | Short description |
| Office equipment | Desk, computer, internet access |
| Research papers | Access to Springer and Elsevier papers is granted by CVTI SR |
| Shared storage | A server with a disk station will serve for sharing preliminary and seminal results of our research, as well as of our published papers. |

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)

|  |  |  |
| --- | --- | --- |
| Project name/identification | Programme/scheme/grant provider | Short description |
| VEGA 2/0096/23 Automata and formal languages: Descriptional and computational complexity | VEGA | This project is in its start: it already solved some problem for the NFA-to-DFA trade-offs for regular operations. |
| VEGA 2/0132/19 Descriptional and computational complexity of formal languages | VEGA | This project studied nondeterministic complexity and closure properties in some subclasses of regular languages, next the problems in permutation automata and the complexity of power and positive closure. |
| APVV-15-0091 Effective algorithms, automata and data structures | APVV | This project examined the complexity of operations on alternating and Boolean automata, the cut operation, and complexity problems in biautomata. |
| VEGA 2/0084/15 Descriptional complexity of formal systems | VEGA | This project investigated the state complexity of concatenation with half states final, operational complexity on nondeterministic finite automata, complexity trade-offs for the forever operation between six models of automata, and accepting state complexity. |

3.3.3 List of maximum five most important outputs of the applicant/host organisation relevant to the submitted project

|  |  |  |
| --- | --- | --- |
| Output name/identification | **Type of output** | Short description |
| [doi:10.1016/j.tcs.2018.12.027](https://doi.org/10.1016/j.tcs.2018.12.027)  Michal Hospodár, Galina Jirásková, Peter Mlynárcik: Nondeterministic complexity in subclasses of convex languages. Theor. Comput. Sci. 787: 89-110 (2019) | Publication | Nondeterministic state complexity of six operations on sixteen subclasses of convex languages |
| [doi:10.1142/S0129054120420083](https://doi.org/10.1142/S0129054120420083)  Michal Hospodár, Markus Holzer: The Ranges of Accepting State Complexities of Languages Resulting from Some Operations. Int. J. Found. Comput. Sci. 31(8): 1159-1177 (2020) | Publication | Accepting state complexity of five operations on regular languages, continuation of a work by J. Dassow |
| [doi:10.1016/j.tcs.2021.02.002](https://doi.org/10.1016/j.tcs.2021.02.002)  Michal Hospodár: Power, positive closure, and quotients on convex languages. Theor. Comput. Sci. 870: 53-74 (2021) | Publication | Five more operations on sixteen subclasses of convex languages |
| [doi:10.1016/j.ic.2021.104778](https://doi.org/10.1016/j.ic.2021.104778)  Galina Jirásková, Ondřej Klíma: On linear languages recognized by deterministic biautomata. Inf. Comput. 286: 104778 (2022) | Publication | A hierarchy of linear languages accepted by different models of biautomata is presented and closure properties under operations is provided for them, along with some computational complexity problems. |
| [doi:10.1016/j.tcs.2023.114050](https://doi.org/10.1016/j.tcs.2023.114050)  Michal Hospodár, Viktor Olejár: The cut operation in subclasses of convex languages. [Theor. Comput. Sci. 969](https://dblp.org/db/journals/tcs/tcs969.html" \l "HospodarO23): 114050 (2023) | Publication | A complete overview of state complexity of the cut operation on sixteen subclasses of convex languages |