

Research report

2019

I. Introduction

The annual report on the research of IT4Innovations Centre of Excellence (CE IT4I) gives an overview of the activities and results achieved by all the Research Programmes (RP) in 2019. The year 2019 was the fourth year of the so-called sustainability phase of the Center of excellence IT4Innovations project which was financed from EU funds under Operational Programme Research and Development for Innovations.

In this report, research activities and results achieved during 2019 are summarized. Special attention is paid to commitments, especially to those that were formulated quantitatively. The report also shows the fulfilment of all quantitative indicators specified in the Research plan of CE IT4I for 2019. All the aggregate objectives were significantly overstepped with respect to the plan, except the income from international projects. The detailed analysis is carried out in *Part II. Summary of results and general comments*.

The report is organized as follows. After this introduction, we give a brief overview of the results achieved in 2019. The main part of the report, *Part III. Research Report by Programmes*, gives a detailed view of the results obtained by each individual research programme. The report of the results of each RP has the following parts:

- A. Overview of the RP, its main research objectives, and structure of the research team are briefly outlined.
- B. Research activities are described in more detail by research teams. The description typically includes the most important results and activities achieved during the year. Key persons responsible for research activities are mentioned.
- C. This part includes a table with selected quantitative indicators approved in the plan for 2019. Particularly, numbers of journal papers on WoS and Scopus and other (typically conference) papers are reported and compared with the plan. Publication activities are complemented with results of applied research, which include patents, software products, and others. The list of 10 top research outcomes accompanies these quantitative indicators.
- D. In this part, national and international projects and volume of contract research are summarized in the tables.

II. SUMMARY OF RESULTS AND GENERAL COMMENTS

1 Quantitative aggregate indicators

From the global perspective, the achieved research results of aggregated quantitative indicators in the third year of the project sustainability phase overstepped significantly the plan in most categories. The only category which were not fulfilled in the monitored period is the income from international projects. This is caused mainly by its reduced use due to starting a few new national projects. The following table summarises all monitored indicators and presents the rate of fulfilment of the original plan. In the next paragraphs the individual indicators will be discussed in more details.

Selected indicators summary (reported 2019)

Selected indicators	Unit	Plan	Reality	Fulfilment
Journal papers	number	67	176	263%
Other papers (conference proceedings, ...)	number	131	160	122%
Applied research outcomes (patents, software,...)	number	27	30	111%
Contract research	thousands CZK	21801	24358	112%
Volume of R&D funds obtained from abroad	thousands CZK	54050	51717	96%
Income from national grants / specific support	thousands CZK	117207	131264	112%
Human resources in R&D	FTE	196,61	194,95	99%

Publications

All indicators in term of number of publications were exceeded. The number of journal papers on WoS and Scopus was about 163% higher than the plan and number of publications in conference proceedings overstepped the plan about 22%. This significantly higher number of publications in journals shows that our research is recognized and well received by the research community. It should be mentioned that many of those papers were published in high quality journals. The contributions of individual RPs to those indicators during the last 5 years 2015-2019 and in detail in 2019 are presented in Figures 1-2 for journal publications and in Figures 3-4 for other papers.

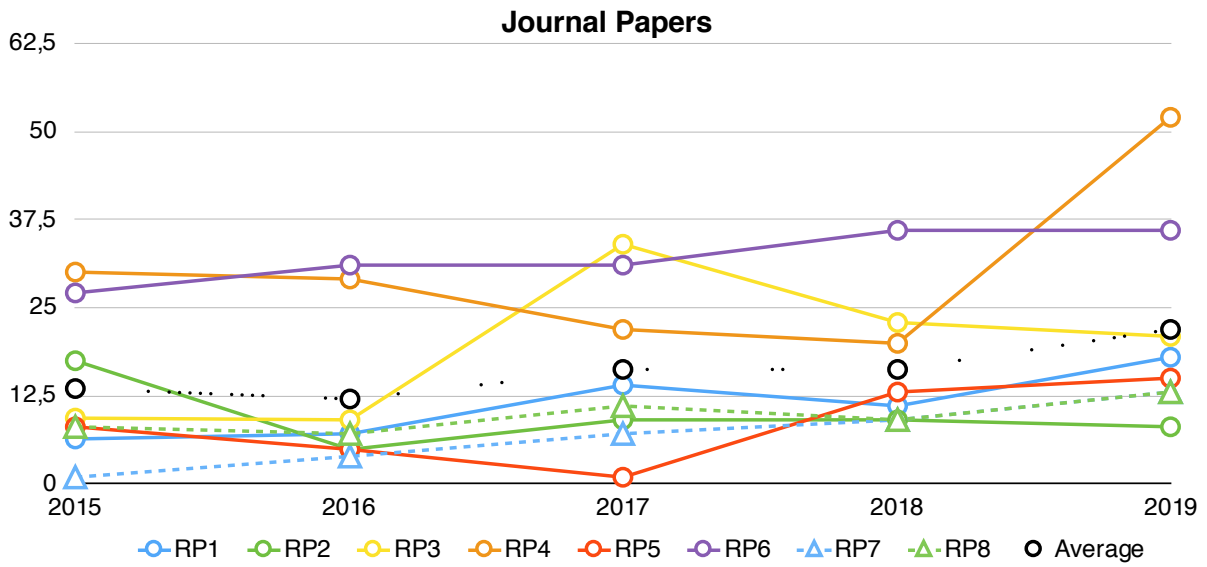


Figure 1

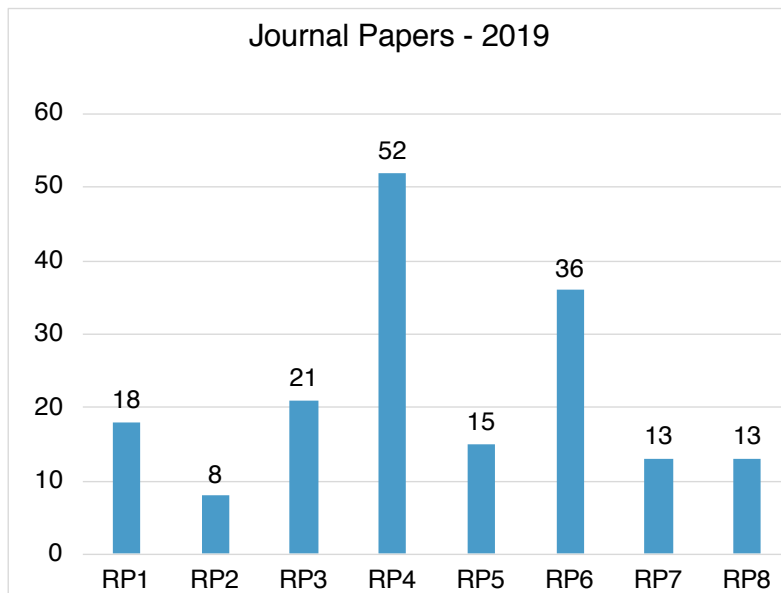


Figure 2

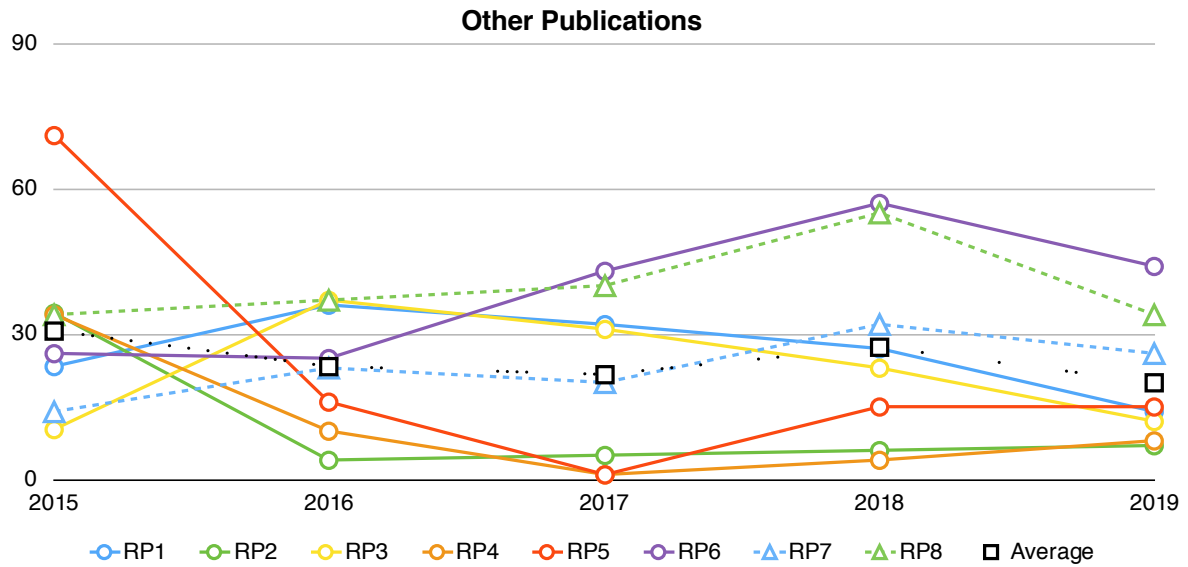


Figure 3

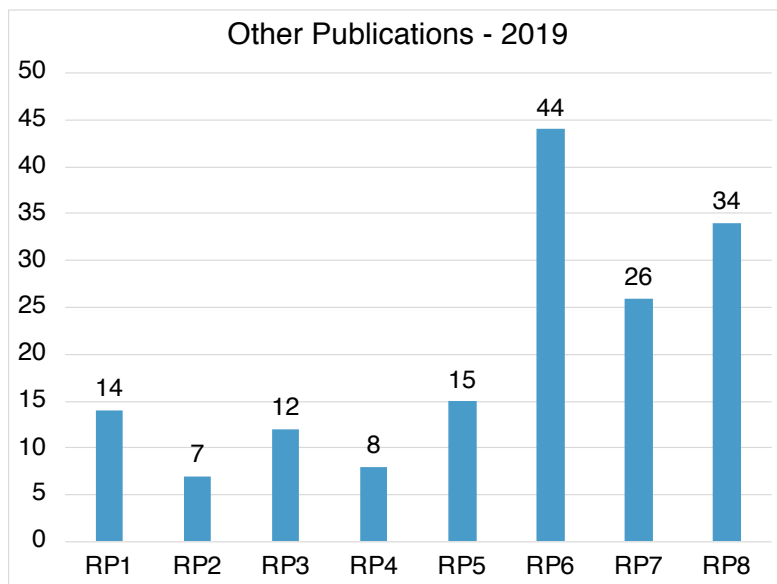


Figure 4

Applied research outcomes (patents, software, pilot plants, prototypes, etc.)

From the CE IT4I project perspective, patents, methodologies, functional samples and software were the only results of applied research that were produced by RPs. This is the same also in the sustainability period. The number of applied research outcomes overstepped the plan about 11%. The contributions of individual RPs to this indicator during the last 5 years 2015-2019 and in detail in 2019 is presented in Figures 5-6.

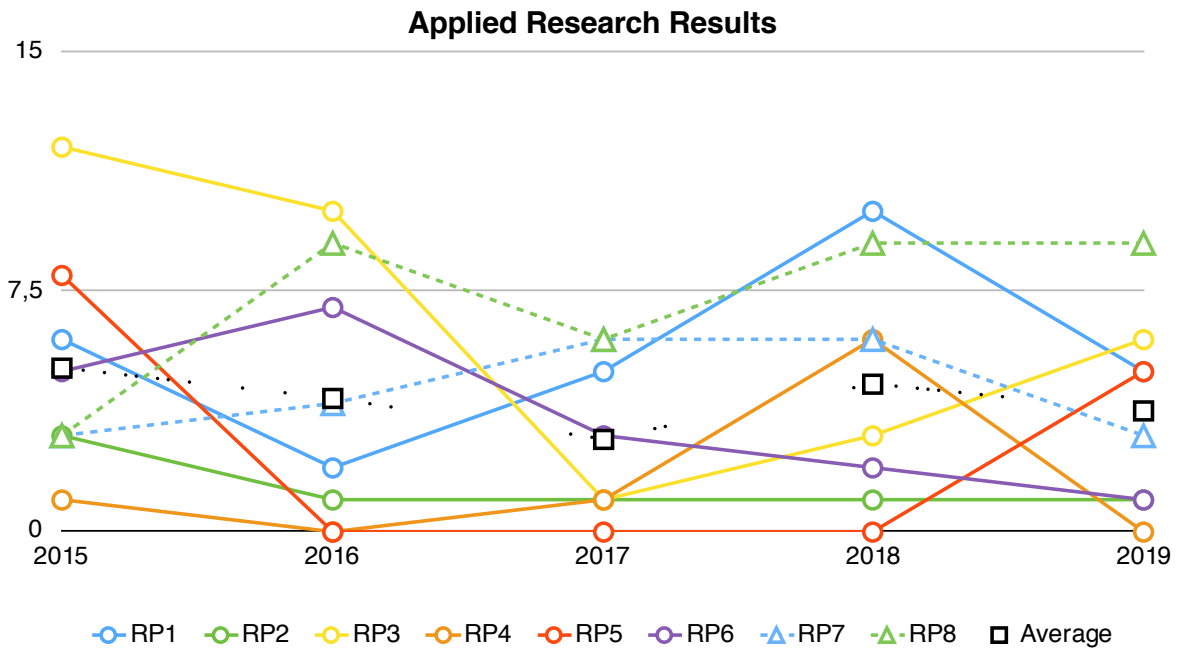


Figure 5

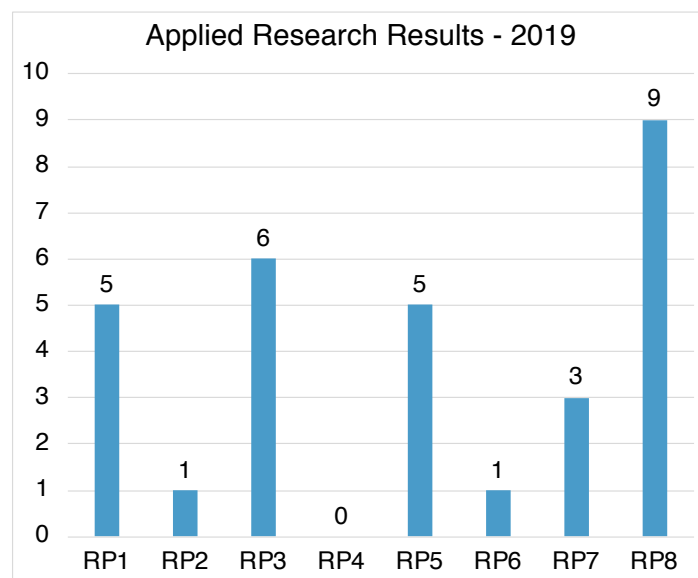


Figure 6

Contract research

As every year, the biggest challenge in 2019 was to reach planned volume of contract research. A good news is that the plan was overstepped about 12% and moreover, the achieved volume of contract research is 19% higher than the previous year. The contributions of individual RPs to this indicator during the last 5 years 2015-2019 and in detail in 2019 is presented in Figures 7-8. Main contributor is RP7 which significantly outperforms other RPs.

This clearly demonstrates that IT4I becomes more and more known among Czech and foreign companies which follows also from increasing number of collaborators and customers. The companies we have already had collaboration with or new customers is a mix of local Small and Medium Enterprises and the large international or national companies from industry, security, IT, etc. (The German Aerospace center, K2 atmitec s.r.o., Bayncore Labs Limited, Steinbeis BzHWT, Continental, Siemens s.r.o., Continental Powertrain Czech Republic s.r.o., National Office for Cyber and Information Security, EAGO systems spol. s r.o., Honeywell,

CadWork Informatik a.g., Raytheon BBN Technologies, LORELEI, Alliu, s.r.o., ROI Hunter, a.s., NTT Corporation, ŠKODA AUTO a.s., TESCANA 3DIM, s.r.o., Avast Softw., TESCANA Brno, s.r.o., ŠKODA AUTO a.s., ONEPROVE s.r.o., CAMEA spol. s r.o., Ericsson, GEODROM, s.r.o., Cesnet, KPB Intra s.r.o., CZ.NIC).

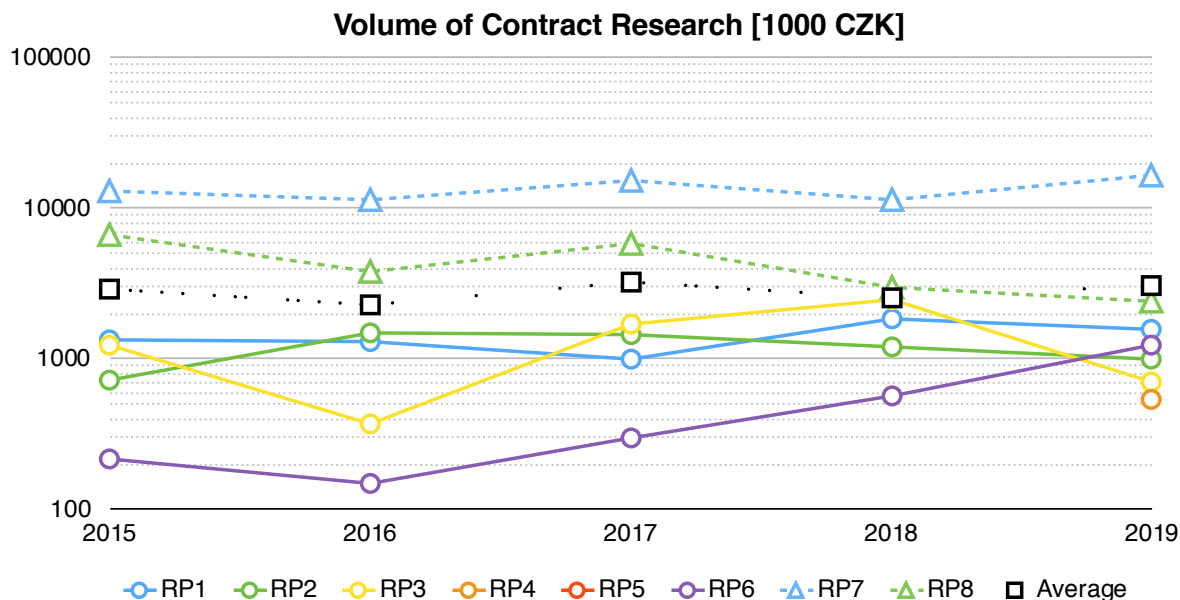


Figure 7

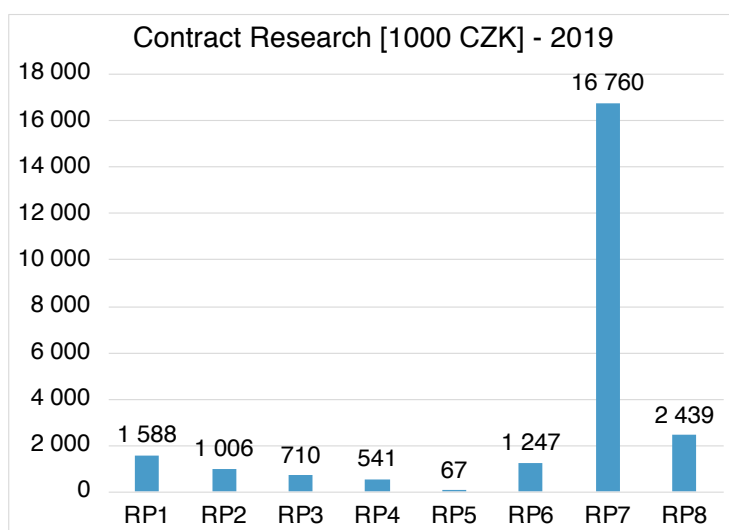


Figure 8

International grants

Another very ambitious and for NPS II project very important target was to receive more than 54 million CZK from the R&D funds from abroad. From the final amount of about 52 million CZK it is clear that we are almost there and moreover, we overstepped about 32% the previous year. This difference between plan and reality is caused by the fact that we reduced the use of the income from international sources due to starting a few new national projects. The

contributions of individual RPs to this indicator during the last 5 years 2015-2019 and in detail in 2019 is presented in Figures 9-10. Main contribution to this target comes from RP1, RP3, RP7, and RP8. The biggest H2020 projects in terms of budget were LEXIS, POP2, PRACE-6IP, EXPERTISE, CloudiFacturing, ExaQute, MegaMaRt2, SPEAKER DICE, ETE SPEAKER, FITOPTIVIS, OCCAM, COMP4DRONES, Cross-CPP, ATCO2, ROXANNE, AQUAS, and PAMMOTH.

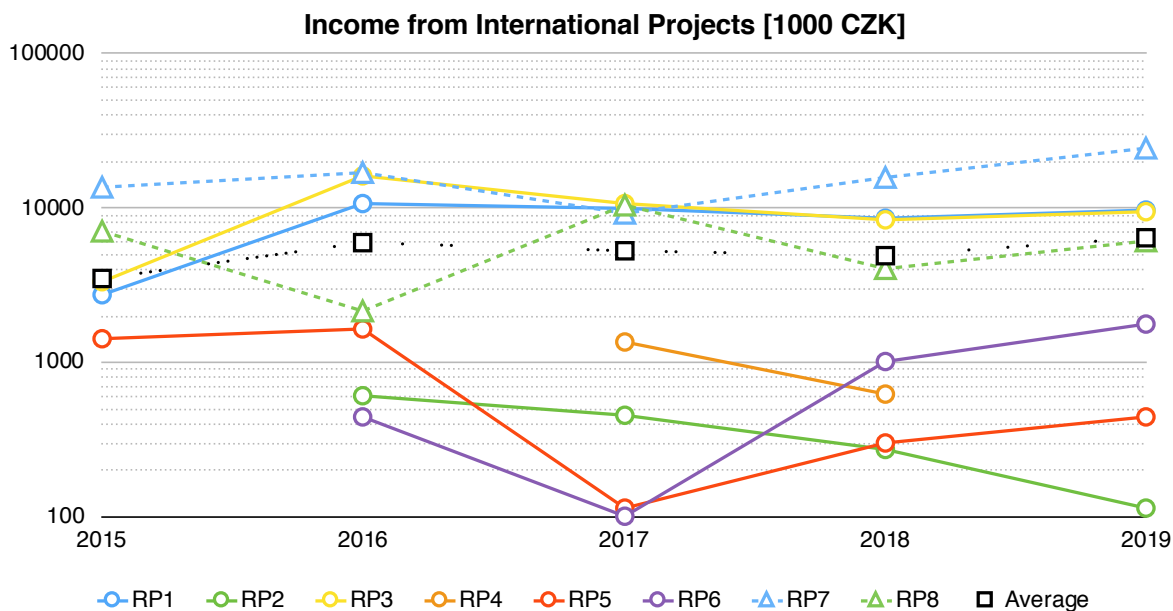


Figure 9

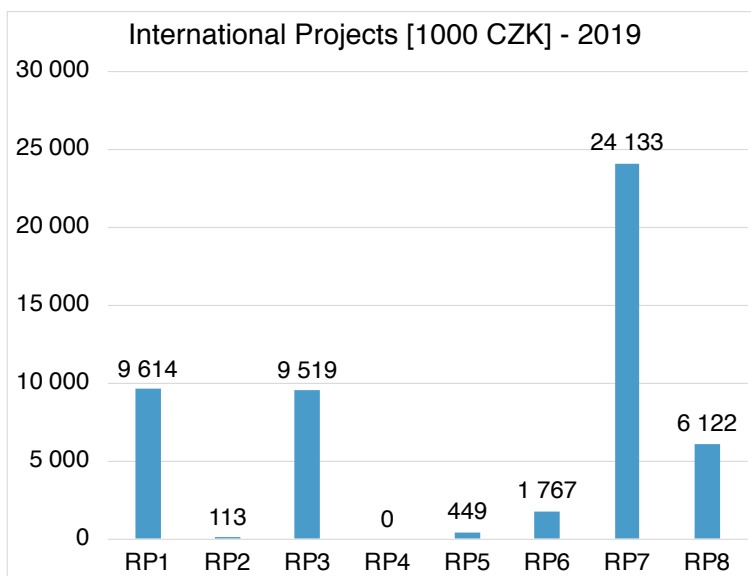


Figure 10

National grants

Another source of IT4Innovations research funding is the income from national grants from Czech grant agencies, such as the Grant Agency of the Czech Republic (GA CR), the Technological Agency of the Czech Republic (TA CR), the Ministry of Education, Youth, and Sports CR (MEYS), the Ministry of Interior CR, etc. In 2019, we received more than 131 million CZK of funding from national sources (the project NPS II is excluded). This amount exceeded planned 117,2 million CZK by more than 12% and the previous year by more than 25%. The main sources of this income were projects such as Center of Competence for

Molecular Diagnostics and Personalized Medicine (TA CR), Large Infrastructures – IT4Innovations National Supercomputing Center (Ministry of Education, Youth, and Sports CR), IT4Innovations – path to exascale (Ministry of Education, Youth, and Sports CR), National Center of Competence for Personalized Medicine - Diagnostics and Therapy (TA CR), National Center for Energy (TA CR), Involvement of artificial intelligence in emergency call reception (Ministry of the Interior CR), Inlet and outlet objects of pumping and turbine stations (Ministry of Industry and Trade CR), Digital twin product at Siemens manufacturing plants (Ministry of Industry and Trade CR), AI & Reasoning (MEYS), Using Semantic Technologies to Access Cultural Heritage Through The Central Portal of Czech Libraries (MC), V3C - Visual Computing Competence Center (TA CR), Information Mining in Speech Acquired by Distant Microphones (Ministry of the Interior CR), Tools and Methods for Video and Image Processing to Improve Effectivity of Rescue and Security Services Operations (Ministry of the Interior CR), Advanced content extraction and recognition for printed and handwritten documents for better accessibility and usability (MC), Neural Representations in multi-modal and multi-lingual modelling (GA CR), Smart Application Aware Embedded Probes (Ministry of the Interior CR), Integrated Platform for Analysis of Digital Data from Security Incidents (Ministry of the Interior CR), Security monitoring of ICS communication in the smart grid (Ministry of the Interior CR), Flexible probe for lawful interceptions (Ministry of the Interior CR). The contributions of individual RPs to this indicator during the last 5 years 2015-2019 and in detail in 2019 is presented in Figures 11-12.

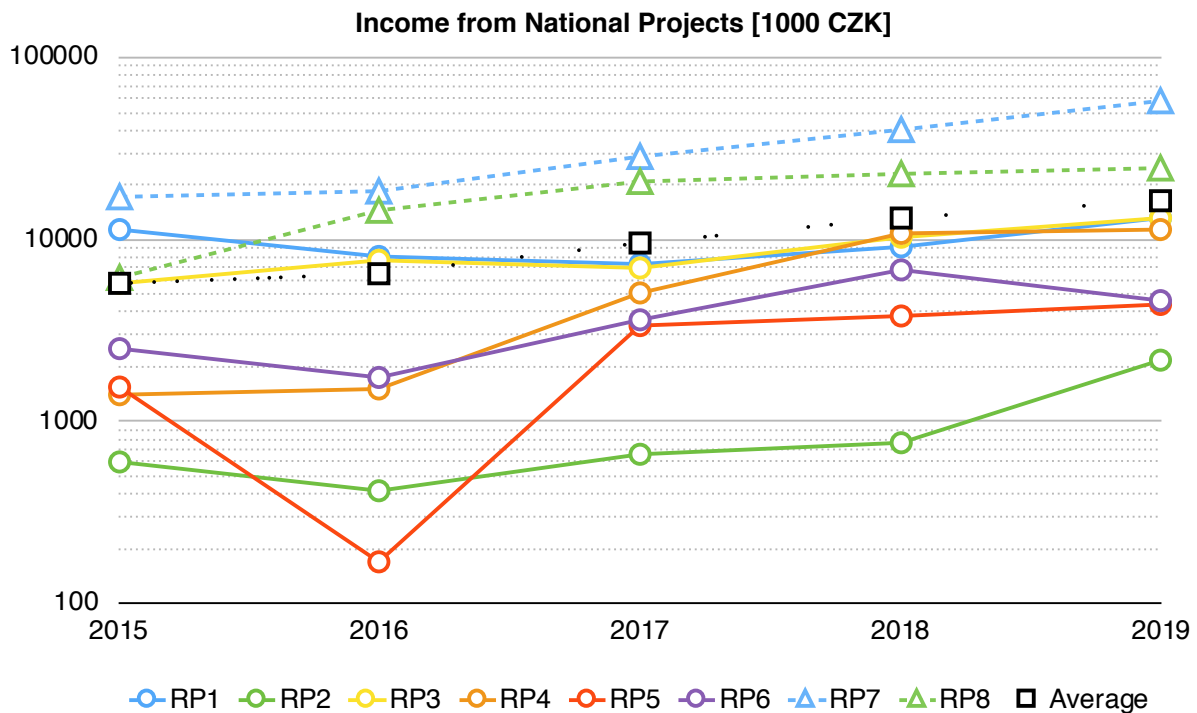


Figure 11

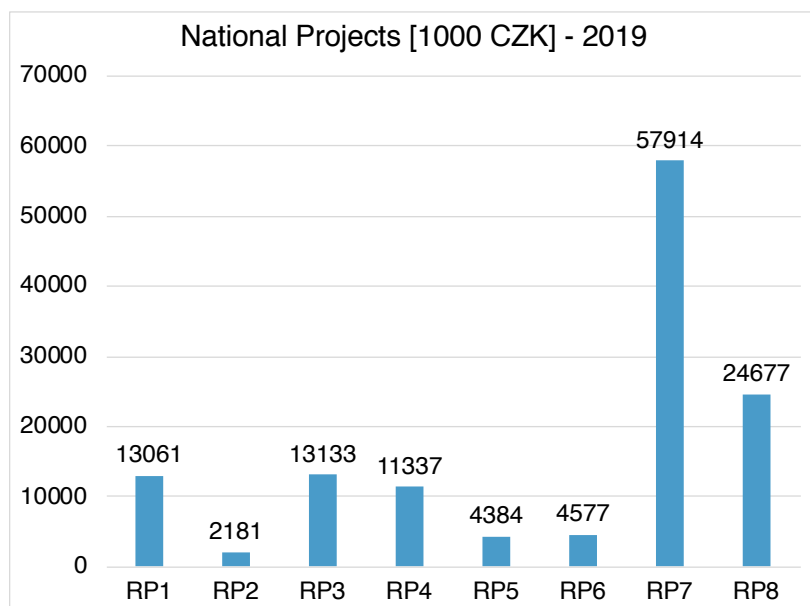


Figure 12

National Programme for Sustainability II

The Ministry of Education, Youth and Sports (MEYS) supports newly established research centres in their sustainability phase through so-called National Programme for Sustainability II (NPS II). CE IT4I is funded from this programme since February 2016 via the project IT4Innovations – Excellence in Science. The total budget of this project for the whole sustainability phase is about 634mil CZK with approx. 50% contribution from MEYS. Remaining 50% must be co-financed from other sources with the specific rule that the minimum 40% of the whole budget must be from non-public or international resources. Such the rule has a crucial influence on the research activities which must strongly focus on the contract research and preferably on the international projects. The budget of the project per partner including used contribution from MEYS in 2019 is shown in Table 1.

Partner	2019		Total budget 2016-2020	
	Budget per partner	Contribution from MEYS	Budget per partner	Contribution from MEYS
VŠB	57 892	28 460	312 668	155 877
VUT	50 726	24 762	238 558	117 514
OSU	3 829	0	39 965	19 410
SLU	4 437	1 969	19 251	9 517
UGN	4 689	2 344	23 445	11 720
Total	121 573	57 535	633 887	314 038

Table 1. Financial support from NPS II per partner in 1000CZK

The NPS II contribution is crucial for sustainability of IT4I because it is approximately a quarter of total budget of research programmes. Other three quarters are co-financing of the project and other sources which cannot be used within NPS II project.

2 Conferences and workshops

The research teams of IT4Innovations were very active in organizing and co-organizing of local and international scientific conferences and workshops during 2019:

- HiVisComp 2019 (High Visual Computing), Šumava ČR, January 30 - February 2, 2019, <http://www.hiviscomp.cz/2019/>.
- EUSFLAT 2019 (European Society for Fuzzy Logic and Technology), 9-13.9.2019, <http://eusflat2019.cz>.
- CISIM 2019, 19-21.9.2019, <http://cisim2019.wi.pb.edu.pl>.
- HPCSE 2019, Soláň, 20-23.5.2019, <http://hpcse.it4i.cz/HPCSE19>.
- NANO Ostrava, 13-16.5.2019, <http://www.nanoostrava.cz>.
- Modelling, 16-20.9.2019, <http://www.ugn.cas.cz/actually/event/2019/modelling/>.

The researchers from IT4Innovations also organized or co-organized minisymposia, specialized sessions, and workshops at international conferences abroad. The annual IT4Innovations conference, with presentations of the most important research results of the IT4I research teams, should be mention here as well.

3 HPC Computing

From 2016, the RPs have no longer any reservation of computing resources and have to apply for access in national Open access calls. Since the Open access call #6 (in Figure 14 it is Call #1) the RPs compete for computational resources with other researchers from the Czech Republic. In this competition, the RPs were quite successful and obtained approximately 57mil. corehours, i.e. about 25% of all resources allocated in all calls opened in 2019.

From Figure 13, where the utilization of the IT4I computing infrastructure by individual RPs in 2019 is shown, one can see that the distribution of infrastructure usage among RPs is very uneven. The same conclusion can be made from Figure 14, where the utilization per individual open access calls and RPs is shown. The dominant users of the IT4I infrastructure among RPs are RP4, RP3, and RP1. Unfortunately, two RPs did not use IT4I supercomputers in 2019 at all.

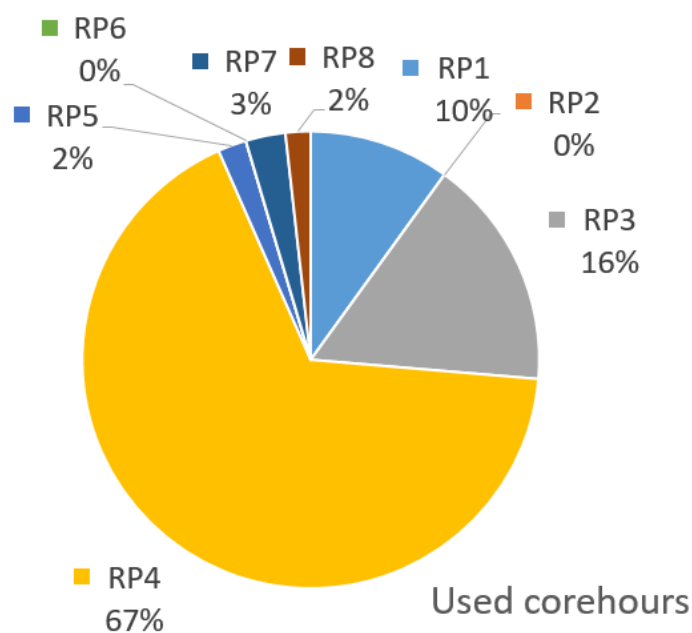


Figure 13

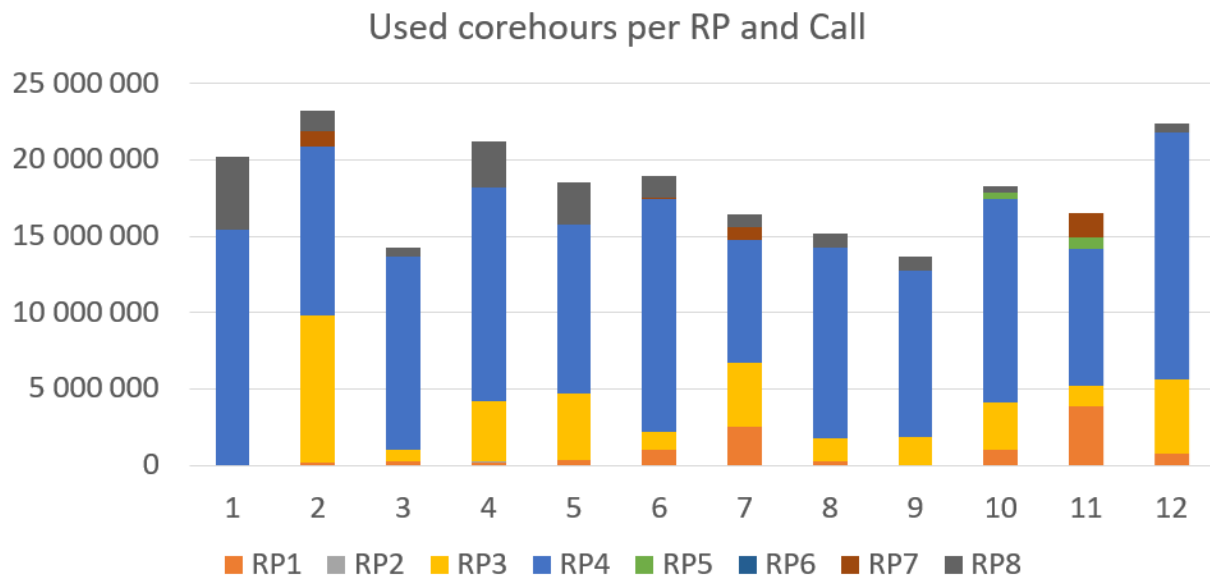


Figure 14

III. RESEARCH REPORT BY PROGRAMMES

4 IT for Disaster and Traffic Management

4.A Research programme overview

The main objective of this research programme is providing advanced data analysis and simulations for industry and crisis management through an HPC platform and specialized programming models. This platform is provided as a service to internal and external users, and utilizes the computing power of HPC infrastructures, collects, stores, and pre-processes data into specialized data structures, and provides user-understandable visualization of results. Developed programming models allow the design of highly efficient parallel advanced data analysis methods, including statistical modelling, machine learning, and cross-validation. Proposed parallel implementations are tested on custom analytical problems, such as resource planning, production pipeline controlling, and research in bioinformatics. An important objective is also the research and development of scalable models to simulate the behaviour of dynamic systems. An example of such systems is modelling in crisis or traffic management. Simulations of such systems are often based on incomplete or inaccurate data and heuristics, therefore the developed models consider the probabilistic aspects of input parameters. Furthermore, implementation of the services for interactive providing and visualization of the results in an accessible and comprehensible form of different levels of detail is another objective. It is focused on providing user interfaces and a specialized application programming framework for specific groups of users. Finally, the application research of the research programme is extended by a topic focused on the combination of HPC, BigData, and Cloud Technologies. The collaboration with the ENET centre was established focusing on solving the problems concerning the field of energy distribution management. The main focus in this area is the creation of algorithms for detection of faults in the energy networks and modelling the energy distribution networks.

Responsible partner: VŠB-Technical University of Ostrava
Head of research programme (HRP): Ing. Jan Martinovič, Ph.D.

RP structure	FTE
Senior researchers & HRP	7,04
Researchers	19,49
Research assistants	7,06
Research support staff	2,39
Total	35,98

Table 4.1 RP structure

4.B Research teams and their activities

- **HPC Platform and related tools and services**
 - HPC Platform tools and services were updated with an emphasis on interoperability, management, deployment and security. Application framework HEAppE Middleware was extended with a package environment deployment, SSH Agent authentication support and Slurm workload management adapter. HEAppE Middleware was also integrated into the Ystia Orchestrator.

- In the context of extending the provisioning of heterogeneous computing resources to the users through HPC-as-a-Service we were developing special platform combining technologies from the HPC, Cloud, and Big Data. This platform extends current software portfolio of developed services including the international reach, where we contribute to development of specialized orchestration of distributed computational workflow.
- Visualization of the current train position as it moves on the rail network has been added into the Floreon+. There has been added the arrival statuses at railway stations (delays, on-time or early arrivals). It has been created prototype layers of measured air pollutant concentrations provided by sensor networks for six basic pollutants. New time dependent JSDI layers have been developed.
- Floreon+ backend was extended to enable continuous monitoring of air quality via a network of measuring sensors. New version of the Floreon+ system frontend was released. It contains an updated version of the visualization framework and data management system.
- HPC Platform spatial database was extended with a new data sources: data from a network of air quality measuring sensors. External sensor's database was also integrated into the HPC Platform for the data preprocessing purposes and for the visualization in the Floreon+ system. The content of road data derived from the OpenStreetMap project, which are intended for routing and graphing tasks, has been extended. Furthermore, data on traffic situation (point and line events) from the JSDI system was integrated.
- Application research topic was extended by a combination of Machine Learning/Deep learning techniques and Blockchain technology for the Urban Earth Observation data analysis.
- Optimisation and extension of the developed programming model for executing different kinds of tasks on the HPC infrastructure. We have improved programming model to support scheduling and running multi-node tasks. It was mainly done for tasks that internally use MPI.
- An upgrade of IT4S1 system (a system for interferometric processing of Sentinel-1 satellite data covering Czechia) has been designed. After a successful implementation it will allow for advanced polarimetric analyzes. A new algorithm for identification of forest damages after a hurricane has been developed and applied on two case studies.
- We worked in close cooperation with industrial partners on the applied research by the means of international cooperation and national contracted research. Basis for this activity were results of the basic research, which increased their utility value by adoption in practice. In the reporting period we strengthened the cooperation with the application partners from meteorological prediction, urgent computing, and aeronautics use cases.
- An important activity was continuation of the transfer of knowledge in the HPC domain toward the public sector and industry. Transfer of knowledge was executed through seminars, training sessions and lectures with usage of HPC infrastructure together with the existing and developed programming packages. Additionally, trainings specially tailored for the industrial partners were performed.
- Refactoring HEAppE Middleware to .NET Core - HEAppE Middleware is our own implementation of the HPC-as-a-Service concept. It provides remote access to HPC computing infrastructure and its easy integration into third-party client applications. The original version of HEAppE Middleware is based on the .NET Framework technology, which is closely tied to Microsoft Windows OS. Therefore, exposing a new instance of HEAppE Middleware for the end-users has always required preparing a Windows-based server to host the application. For this reason, a new cross-platform version of this application framework was created. Thus, the source code from the .NET Framework

version was ported to the .NET Core architecture, allowing easy deployment and maintenance of applications on both Windows and Linux OS. HEAppE Middleware .NET Core version is available on IT4Innovations' GitLab.

Key persons: Ing. Jan Martinovič, Ph.D., Doc. Mgr. Jiří Dvorský, Ph.D., Ing. Václav Svatoň, Ph.D., Ing. Stanislav Böhm, Ph.D.

- **Data Analysis and Modelling of Dynamic Systems**

- Algorithms from the transport optimization domain were tested and adapted for the current heterogeneous HPC architecture. Specifically, genetic, swarm intelligence, machine learning and classical heuristic optimization algorithms were used in the areas of waste management, flow optimization, energy management, and traffic data fusion.
- Classical statistical methods for classification and prediction of noisy time series were studied, tested, and compared to LSTM and convolutional neural networks models. Special preprocessing based on the observations density for the selection of significant observation and their clustering was developed for the time series varying variance and affected by large noise. Thanks to this the dimensionality of the problem is reduced.
- Traffic simulator was extended by newly developed modules and functions. They enrich vehicle navigation by adaptive behaviour. The enhanced traffic simulator includes improved architecture of simulated traffic environment. It also pipelines several routing algorithms (k-alternative path, Probabilistic Time-Dependent Routing, reordering path) to find the best road based on current traffic situation near the vehicle. Number of tests were executed on the simulator with several thousands of vehicles using dynamic graphs of road network of Prague.
- The original betweenness centrality algorithm was expanded by the concept of the vertex importance. It was tested on the map of the city of Ostrava. The algorithm was then further modified to include the notion of the betweenness propagation to better model the real life situations especially in the area of the traffic network.
- The solvers for the Vehicle Routing Problem have been optimized for current heterogeneous HPC infrastructure. Possibilities of using hyperparameter search for solving the Periodic Vehicle Routing Problem (PVRP) for the waste collection were shown. HyperLoom platform was used to define and execute the PVRP hyperparameters sweep pipeline. The platform allowed us to execute a large instance of the problem without the need to parallelize the optimization algorithm for PVRP itself. The heuristic algorithm was tested on a real benchmark of the waste collection in the Czech Republic.
- New results on graph invariants were achieved, namely a general construction of total antimagic labelings of all dense digraphs, certain sparse graphs, DM labelings of 14-regular graphs and a recursive construction of uniform 1-factorizations.
- Dynamic properties of time-space differential equations (matrix time series) were investigated using recurrence plots and recurrence quantification analysis. This type of analysis was applied to the tissue model of cardiac electrophysiology. Using this method, regular as well as the irregular movement of the dynamic system was found.
- We dealt with the field of processing intensive data streams from social networks using Hadoop / Spark technologies.
- IT4Innovations in a cooperation with Research and Development Center “Alfatec”, Niš, Serbia, developed novel AI-based approximations of the Wright omega function for flow friction modelling using the Colebrook equation. Large-scale numerical tests showed that the two developed symbolic regression approximations overperform the classical asymptotic expansion. Few researchers already confirmed that our results

belong to the most accurate and the fastest approximations developed from 1947 to 2019. We applied our findings also for modelling of air-based cooling system for fuel cells.

- The reaction-transport model for improvement of the possibilities of an environmental contamination risk analysis was developed and consequently deployed on the HPC. The research team developed the first version of the reaction-transport model TRM. Model was built on the PhreeqCRM code and was combined with the 2D transport in the regular network of elements. Model was successfully tested (functionality, scalability) and implemented within the HPC environment.
- TSEntropies - For the user community of the TSEntropies a manual was created with detailed description of all the functionality of this R package. During the real tests of the package some improvements had to be implemented. For instance the default behavior of the package was modified which led to significant improvements in the usability of the software. TSEntropies application was registered as open source software, and it is available to the users of the IT4I infrastructure.

Key persons: Ing. Kateřina Slaninová, Ph.D., Doc. RNDr. Marek Lampart, Ph.D., Ing. Michal Podhorányi, Ph.D.

- **Bioimage Informatics on HPC - „OP RDE IT4Innovations - Path to Exascale“**
 - A modified version of Labkit with experimental support for scijava-parallel is now available on update site. Scijava-parallel is a framework being developed on IT4I that provides an access point for using computational resources such as remote computers or HPC clusters.
 - CLIJ platform for Fiji has been released. CLIJ complements core ImageJ operations with reprogrammed counterparts that take advantage of the open computer language (OpenCL) framework to execute algorithms on GPUs. Within CLIJ a wide range of typical image processing functions were implemented.
 - Salomon supercomputer power was used to compute a significant part of silver reference annotations derived from the large dataset of existing results from previous Cell Tracking Challenge results. Cell Tracking Challenges are aimed at fostering the development of novel, robust cell tracking algorithms, and to help the developers with the evaluation of their new developments. Since January 8th, 2020, the silver reference segmentation annotations have been available for nine datasets to further facilitate tuning of competing algorithms, providing denser sets of cell segmentation masks compared to the previously existing reference segmentation annotations.
 - Our Fiji plugin (SPIM Workflow Manager for HPC) has been successfully used for reconstructing light sheet microscopy images of germline differentiation within Arabidopsis plant and we are continuing with processing other datasets.
 - Fiji Hackathon – Parallelization and HPC was held in January 2019. This event focused on parallelization brought the world-wide Fiji community to Ostrava.

Key persons: Mgr. Pavel Tomančák, Ph.D., Mgr. Ing. Michal Krumnikl, Ph.D.

- **Bioinformatics**
 - We continued development of the NGS processing pipeline with its GUI and deployed it at two sites. The pipeline v 5.1 uses GATK HaploypeCaller and Qualimap tools. The former software will provide better predictions of SNP-MNP-ShortInDel mutations while the latter will improve overall quality control of the input datasets with graphical outputs. Further, we processed 12 whole-exome datasets provided to us by Dr.

Fajkusova (Faculty hospital in Brno). Quality controls are based on results from four amplicon-based datasets and acquired using 46 samples in total.

- We continued refining 1.3 Tbp fish genome using sequences from OxfordNanopore sequencing machines. The obtained haploid consensus genomic sequence will provide better scaffold for reference mapping of genomic DNA reads from several individuals from various populations of Europe and Asia.
- Web application for NGS data analysis has been extended according to user requirements. A new version of the analytical pipeline and a tool for result's annotation have been integrated. A duplicate application instance was also deployed on the compute cluster located in Olomouc.
- Commenced implementation of the Python API for software Caver and CaverDock. CAVER is a software tool for analysis and visualization of tunnels and channels in protein structures. CaverDock is a software tool for rapid analysis of transport processes in proteins. Firstly, we have replaced an original PDB file format with a hierarchical RMF format. This change led to a reduction in disk-space demand by a factor 6. We have also implemented a multiprocessing parser of PDB files that gives a 5x speedup on a desktop computer. Besides the improvements in input and output formats, we have designed a basic structure of API for binding Caver and CaverDock (possibly other tools) to cover all the functionality under one roof. The next step is to bind CaverDock into the new API.
- We have started development of a new algorithm for simultaneous docking of more than one molecule using AutoDock Vina in cooperation with MUNI Brno. This is very important for explaining potential inhibitions of substrate and product.

Key persons: RNDr. Martin Mokrejš, Ph.D., Ing. Jan Martinovič, Ph.D., Ing. Ekaterina Grakova, Ph.D.

- **Collaboration with ENET Centre**

- Development of a detector of faults at insulated conductors of overhead lines is a new research activity of IT4Innovations with ENET Centre, VŠB-TUO. The aim was to develop and test methods for contactless scanning of partial discharge patterns and their evaluation using statistical and AI methods. ENET Centre provided the database of measured data and consultations. IT4Innovations tested the following classification algorithms: decision trees, custom statistical approach, and clustering algorithms. First results of classification algorithms were consulted with ENET Centre and also with the following Czech DSOs: ČEZ Distribuce and E.ON Distribuce. As an alternative to the above-described approach for partial discharge identification, a recurrent neural network model using RELU activation functions and logistic output function was prepared. The supercomputers will be used for estimations of the optimal solution.
- In the activity “analysis of the numerical stability of algorithms for electrical network modelling”, the numerical tests were carried out by brute force search. Numerical experiments of IT4Innovations on the benchmark of Columbia University show four possible solutions. The ambiguity of the numerical solution of IT4Innovations was also verified by independent tests using recommended tools of IEEE: Matpower, Pandapower, and OpenDSS. The first IT4Innovations results were also analyzed by power engineering experts, thanks to the cooperation with the ENET Center.

Key persons: Ing. Pavel Praks, Ph.D., Ing. Tomáš Martinovič, Ph.D.

4.C Research outcomes

Type	Plan	Actual
Journal papers (imp)	7	18
Other papers (proceedings, ...)	25	14
Outcomes of applied research (patents, software, etc.)	5	5

Table 4.2 Key performance indicators of the research programme

A list of the 10 most important outcomes of the research programme in 2019:

1. A new version of HEAppE middleware (v 2.0) was released. This version is able to utilize HPC clusters, which uses for planning jobs task scheduler SLURM. A newly developed version of middleware is possible to ease deployment to the different operations systems because middleware used technologies like docker and .NetCore. In the middleware we were improved security mechanism for example mechanism used cluster account via SshAgent. Possibility of orchestrator Ystia (ATOS) functionality was enhanced with connection with HEAppE middleware. This connection of both software has created an extension of workflow management by defining and running the workflows on HPC infrastructures. Usage and integration of new version of HEAppE middleware into orchestrator Ystia contributed to the LEXIS project goals. Deployment of orchestrator (e.g. Ystia) and integration with current IT4I HPC infrastructure using HEAppE middleware were carried out.
2. Finalized design, procurement, and installation of the new LEXIS infrastructure. Deployed high speed 100GBE network in high availability mode, CEPH storage with 120TB raw capacity, VMware vSphere cluster and began deployment of an experimental OpenStack cloud. Part of the deployment was VLAN separation of the support and experimental infrastructure and VPN access for developers. Proof-of-concept deployment of the OpenStack cloud, CEPH and VMware was also performed on the dedicated Anselm cluster computed nodes, the results were used for deployment of the new LEXIS infrastructure.
3. We have implemented ESTEE, an extensible simulator for task graph scheduling (<https://github.com/It4innovations/estee>). We have validated existing algorithms in a complex environment. We have discovered that many published algorithms have under-average performance in an environment with more realistic settings. We have published ESTEE as a poster at conference Super Computing 2019 and a paper describing a whole work is in preparation.
4. Two articles that introduced applied network offloaded computations and streaming message passing paradigm for FPGAs. They were published in proceedings of Supercomputing 2019: i) De Matteis, T., de Fine Licht, J., Beránek, J. and Hoefler, T., 2019, November. Streaming Message Interface: High-performance distributed memory programming on reconfigurable hardware. In Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis. ii) Di Girolamo, S., Taranov, K., Kurth, A., Schaffner, M., Schneider, T., Beránek, J., Besta, M., Benini, L., Roweth, D. and Hoefler, T.: Network-accelerated non-contiguous memory transfers. In Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis (November 2019).
5. Novel AI-based approximations of the Wright omega function for flow friction modelling were developed. The novel results were published in Q1 journal. The novel approach was applied not only to pipes, but also to the system of pipes: i) Brkić, D.; Praks, P. Accurate and Efficient Explicit Approximations of the Colebrook Flow Friction Equation Based on the Wright ω -Function. Mathematics 2019, 7, 34.,

- <https://doi.org/10.3390/math7010034>. IF=1.105, ii) Brkić, D.; Praks, P. Short Overview of Early Developments of the Hardy Cross Type Methods for Computation of Flow Distribution in Pipe Networks. Appl. Sci. 2019, 9, 2019. <https://doi.org/10.3390/app9102019>. IF=2.217.
6. BioimageInformatics on HPC - Articles in journal with high IF: Kožusznik, J., Bainer, P., Klímová, K., Krumnikl, M., Moravec, P., Svatoň, V., Tomančák, P. SPIM workflow manager for HPC, Bioinformatics, Volume 35, Issue 19, 1 October 2019, Pages 3875–3876, <https://doi.org/10.1093/bioinformatics/btz140>. IF=5.481.
 7. Halfar R. (2019). dydea: Detection of Chaotic and Regular Intervals in the Data. R package version 0.1.0. <https://CRAN.R-project.org/package=dydea>.
 8. Engagement into activities of Big Data Value Association (BDVA) and Private Public Partnership in relation to project LEXIS. Active cooperation with the partners in EUDAT collaborative data infrastructure (EUDAT CDI). Involvement at the activities in Research and Innovation Advisory Group (RIAG) of EuroHPC JU.
 9. ESA BLENDED project was accepted: The main goal of the project is to investigate and report on the synergic use of Blockchain and Deep Learning for Space Data. To achieve this the prototype training platform will be developed by the BLENDED Platform Team and Used by the Peers Team to instantiate Time Series Analysis and Prediction algorithm for Urban Expansion Monitoring and train it at three sites.
 10. Successful finalization of H2020 FET-HPC project ANTAREX, publishing of the project results. One of the most important outputs is: Vitali, E., Gadioli, D., Palermo, G., Golasowski, M., Bispo, J., Pinto, P., Martinovic, J., Slaninova, K., Cardoso, J., SILVANO, C. An Efficient Monte Carlo-based Probabilistic Time-Dependent Routing Calculation Targeting a Server-Side Car Navigation System (2019), IEEE Transactions on Emerging Topics in Computing. Article in press.

4.D Project activity

International R&D projects:

Project title	Grant agency	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
InnoHPC (High-performance Computing for Effective Innovation in the Danube Region)	Interreg	2017-2019	327	1 110	A
PRACE – 5IP	H2020	2017 - 2019	125	500	A
PRACE – 6IP	H2020	2019 - 2021	147	500	A
ExaQute	H2020	2018-2021	1278	4 100	A
LEXIS	H2020	2019-2021	7737	27 100	A

National grants / specific support:

Project title	Grant	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
Large Infrastructures IT4I	MEYS	2016-2019	1 200	8 000	A
Center of Competence for Molecular Diagnostics and Personalized Medicine (MOLDIMED)	TAČR	2014-2019	1963	11 500	A
PaReTran	TAČR	2017-2019	867	2 337	A
IT4Innovations National Supercomputing Center – path to exascale (IT4I NSC - P2EX)	MEYS	2017-2021	2 860	13 867	A
Science without borders	MEYS	2018-2021	902	917	A
Personalized Medicine - Diagnostics and Therapy	TAČR	2019-2020	2359	5986	A
Optimization of operating parameters of the electrical distribution system using artificial intelligence	TAČR	2019-2021	634	1802	A
Contactless partial discharge detector for HV distribution lines	TAČR	2019-2021	290	1257	A
National Center for Energy	TAČR	2019-2020	1067	3077	A
Smart energy management system for energy networks	TAČR	2019-2020	546	1762	A
Involvement of artificial intelligence in emergency call reception	Ministry of Interior	2019-2022	373	5060	A

Contract research:

Project title	Contracting authority	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (C-contracted, N-negotiated, P-planned)
Contract Change Note N.2 to the Urban TEP (U-TEP)	The German Aerospace center	2019-2020	730	918	C
Testing of inventory optimization module and analysis focused on IT infrastructure optimization	K2 atmitec s.r.o.	2018-2019	100	200	C
Implementation of training and research support	Bayncore Labs Limited	2019	758	758	C

5 Numerical Methods for Engineering

5.A Research programme overview

This research programme's aims are developing, testing, and applying numerical methods for solving complicated large-scale physical-engineering problems. The research focuses on methods for modelling coupled processes (multiphysics) and processes in heterogeneous environments (multiscale). Typical applications include the analysis of coupled thermo-hydro-mechanical (THM) processes related to the underground disposal of spent nuclear fuel. The focus includes challenging simulations of flow in porous media and porous media with fractures, modelling of nonlinear processes in mechanics, development of new algorithms for quantifying uncertainties, and calibration of models. The use of parallel algorithms and the computing capacity of IT4Innovations is involved.

Responsible partner: Institute of Geonics, AS CR
Head of research programme (HRP): Prof. RNDr. Radim Blaheta, CSc.

RP structure	FTE
Senior researchers & RP head	1.75
Researchers	2.10
Research assistants	3.08
Research support staff	0.95
Total	7.88

Table 5.1 RP structure

5.B Research teams and their activities

The specific research aims in 2019 concern:

- **The development, analysis, and application of models including coupled physical processes, namely thermo-hydro-mechanical processes in porous continua applicable for analysis of performance of bentonite based sealing elements.**
 - A model describing thermo-hydro-mechanical processes for simulating the behaviour of a bentonite barrier for the underground storage of spent nuclear waste was formulated within the Decovalex 2019 project. The model includes many nonlinearities due to nonlinear problem of flow in partially saturated media, elasticity and heat transfer depending on saturation. The nonlinearity for flow part of the model consider not only permeability and retention function depending on saturation but also retention function depending on deformation (dry density) and temperature. Despite the complexity of strongly nonlinear and coupled model, the model was implemented with the aid of COMSOL software and realistic results were obtained. The model was validated using FEBEX experiment data from monitoring, partial dismantling and full dismantling after 18 years of the FEBEX experiment operation.

Key persons: Z. Michalec, M. Hasal, R. Blaheta, T. Ligurský

- **The development, analysis, and testing of methods for solving nonlinear THM processes and hydro-mechanical processes in continua with fractures with possible applications in analysis of crystalline rock mass as a natural barrier for the underground repository of the spent nuclear fuel.**
 - The research was motivated by a strong interest in numerical analysis of flow in heterogeneous porous environment, including environment with significant disturbances (faults, fractures) that cannot be considered by homogenization. Faults are represented as lower dimensional objects interconnected with the porous matrix.
 - We formulate and implement the model that uses interconnected flow in failures and porous matrix and coupling of flow to mechanical deformation which includes elastic deformation of the porous matrix and opening / closing of fractures. The mechanical model with constraint to penetration is implemented by the technique of Lagrange multipliers and dual formulation. FETI method of domain decomposition is also used for the solution.
 - An important topic is the iterative interconnection of flow and mechanics with a special type of acceleration of the convergence.

Key persons: M. Běreš, R. Blaheta, S. Domesová

- **The development of efficient and reliable computational techniques for limit analysis and incremental methods in geotechnical stability and analysis of geocomposites.**
 - We focus on solution of geotechnical stability problems by innovative numerical methods and advanced mathematical analysis. In particular, we build on elasto-plastic models and related analysis of critical (limit) loads that cause failure (collapse) of a structure. Finite elements, Newton-like methods, continuation techniques and in-house MATLAB codes are other common features of our results.
 - *The in-house MATLAB codes* have been systematically developed in 2D and 3D since 2014 to illustrate our theoretical results and efficiency of suggested solution schemes. They include various elastoplastic models, several types of finite elements and advanced computation of limit loads. In 2019, we published fully vectorized implementation of elasto-plastic problems including original assembling of tangent stiffness matrices. Some of our codes are publicly available for download. We have also developed a local mesh adaptive technique in 2D and started to use mesh refinement on more complicated 2D domains.
 - *Reliable computation of the limit load* is based on long-time international cooperation with Prof. S. Repin (Jyvaskyla). We have proposed several reliable estimates using a priori and a posteriori error analysis of discretization errors. In 2019, we published a paper focused on cone-shaped yield criteria from geotechnical practice. The so-called inf-sup condition on convex cones was proposed to complete missing mathematical theory. In 2019, we have started to generalize our results to use them in other applications, e.g. in gradient plasticity. We arise from a new international cooperation with Prof. B.D. Reddy (Cape Town).
 - *Solution of model stability problems.* Our numerical solution concept based on limit analysis has been successfully applied on problems representing stability of slopes, foundations or coal-polyurethane composites. Within slope stability, we have focused

on comparison of the shear strength reduction method and limit analysis. We also started to incorporate the influence of porous flow on the stability.

- For better dissemination of our results we have organized minisymposia at the international conferences COMPLAS 2019 (Barcelona) and MODELLING 2019 (Olomouc).

Key persons: S. Sysala, J. Haslinger, Z. Michalec

- **The development of efficient and scalable solvers based on Schwarz DD, FETI, PETSc, and deflation technique.**

- The development of iterative solvers is crucial for demanding simulations of physical processes in geotechnics and other fields of science and technology. Our results are new solvers that accelerate solutions through domain decomposition, parallelization, and the use of multi-level technique. These are multilevel Schwarz methods, FETI methods and deflation methods. For deflation preconditioning, software was created and, after a review procedure, it was included into the worldwide used PETSc library, developed under the coordination of Argonne National Lab, USA.
- Research also includes iterative methods for solving boundary value problems with uncertainty in coefficients. Especially methods for systems resulting from stochastic Galerkin method using stochastic expansions. Specifically, it is a reduced base technique and estimates for a preconditioning technique using a matrix with a modified stochastic part.

Key persons: O. Axelsson, M. Béréš, J. Kružík, D. Horák

- **Investigation of inverse problems with a focus on exploiting tests with multiple data, and evaluation of multiple tests, the development of methods for multiphysics applications, and methods with the involvement of uncertainty.**

- The research results concern mainly effective methods for stochastic Bayesian inversion using surrogate (simplified) models. A focus is on the use of delayed Metropolis Hastings algorithm and construction of surrogate model through the sampling process.
- The Bayesian inversion was applied to identification problems for models of Darcy flow, hydro-mechanics in (heterogeneous) porous medium and hydro-mechanics in porous media with fractures (faults).
- Inverse methods have a lot in common with optimal control problems, which were also considered. Here, the research was devoted to new methods of preconditioning for KKT systems which arise when partial differential equations, considered as a constraint for minimization, are included by using Lagrange multipliers.

Key persons: O. Axelsson, M. Béréš, R. Blaheta, S. Domesová, J. Haslinger

5.C Research outcomes

Type	Plan	Actual
Journal papers (imp)	3	8
Other papers (proceedings, ...)	5	7
Outcomes of applied research (patents, software, etc.)	0	1

Table 5.2 Key performance indicators of the research programme

A list of the 10 most important outcomes of the research programme in 2019:

1. Axelsson, Owe, Liang, Z.-Z. A note on preconditioning methods for time-periodic eddy current optimal control problems. *Journal of Computational and Applied Mathematics*. 2019, 352, 262-277. ISSN 0377-0427 doi: 10.1016/j.cam.2018.11.010. WOS Q1, IF(2018)= 1.883.
2. Axelsson, Owe, Lukáš, D. Preconditioning methods for eddy current optimally controlled time-harmonic electromagnetic problems. *Journal of Numerical Mathematics*. 2019, 27(1), 1-21. ISSN 1570-2820 doi: 10.1515/jnma-2017-0064. WOS Q1, IF(2018)= 3.107.
3. Axelsson, Owe, Liang, Z.-Z. Parameter modified versions of preconditioning and iterative inner product free refinement methods for two-by-two block matrices. *Linear Algebra and Its Applications*. 2019, 582, 403-429. ISSN 0024-3795 doi: 10.1016/j.laa.2019.07.024. . WOS Q2, IF(2018)= 0.977
4. Axelsson, Owe, Salkuyeh, D.K. A new version of a preconditioning method for certain two-by-two block matrices with square blocks. *BIT NUMERICAL MATHEMATICS*. 2019, 59(2), 321-342. E-ISSN 1572-9125 doi: 10.1007/s10543-018-0741-x. WOS Q2, IF(2018)= 1.451.
5. Čermák, Martin, Sysala, Stanislav, Valdman, Jan. Efficient and flexible MATLAB implementation of 2D and 3D elastoplastic problems. *Applied Mathematics and Computation*. 2019, 355(August/2019), 595-614. ISSN 0096-3003 doi: 10.1016/j.amc.2019.02.054. WOS Q1, IF(2018)= 3.092.
6. Haslinger, Jaroslav, Repin, S., Sysala, Stanislav. Inf-sup conditions on convex cones and applications to limit load analysis. *Mathematics and Mechanics of Solids*. 2019, 24(10), 3331-3353. ISSN 1081-2865 doi: 10.1177/1081286519843969. WOS Q2, IF(2018)= 1.791.
7. Axelsson, Owe, Gustafsson, I. A coarse-fine mesh stabilization for an alternating Schwarz domain decomposition method. *Numerical Linear Algebra with Applications*. 2019, 26(3), 1-19), e2236. ISSN 1070-5325 doi: 10.1002/nla.2236. WOS Q1.
8. Tomčala, J., Papuga, J., Horák, D., Hapla, V., Pecha, M., Čermák, M., Steps to increase practical applicability of PragTic software. *Advances in Engineering Software* 129(2019), 57-68. ISSN 0965-9978 doi: 10.1016/j.advengsoft.2018.06.009. WOS Q1, IF(2018)= 4.194.
9. Sysala, Stanislav, Blaheta, Radim, Kolcun, Alexej, Ščučka, Jiří, Souček, Kamil, Pan, P. Computation of Composite Strengths by Limit Analysis. *Key Engineering Materials*. 2019, 810(810), 137-142. ISSN 1662-9795 doi: 10.4028/www.scientific.net/KEM.810.137. Scopus.
- 10.

1. Publications in reviewed proceedings – 6 publications, 3 in the Springer LNEE Series.

2. Organization of conferences – the Research programme team was the main organizer of two conferences:

1. Seminar on Numerical Analysis and Winter School SNA 2019
<http://www.ugn.cas.cz/link/sna19/>.
2. MODELLING 2019 (Mathematical modelling and computational methods in applied sciences and engineering), 130 participants from CR and abroad. See <http://www.ugn.cas.cz/link/modelling19/>.

3. Editorial work

1. Special issue of Appl. of Mathematics devoted to SNA'19, S. Sysala, P. Tichý (eds.). It appears in 2020, No. 2.
2. Special issue MODELLING 2019 R. Blaheta, P. Arbenz, J. Haslinger, J. Kraus, S. Sysala, SI opening 12/2019.

4. Management of Ph.D. study connected to the performed research

5 Ph.D. students were involved in the research work of the RP2.

5.D Project activity

International R&D projects:

Project title	Grant agency	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
EURAD EJP Cofund Action 847593	H2020	2019-2023	113	2000	A

National grants / specific support:

Project title	Grant	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
GAČR 19-11441S	GAČR	2019-2021	1 581	4 743	A
ENDORSE TAČR TK 02010118	TA CR	2019-2022	600	4 907	A

Contract research:

Project title	Contracting authority	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (C-contracted, N-negotiated, P-planned)
Decovalex 2019	TUL	2018-2020	495	947.5	C
LASMO	UJV	2019	108	108	C
DGR research support	UJV	2019	129	129	C
CFD jet analysis	Steinbeis BzHWT	2019	170	170	C
RTG-CT Image analysis	Continental	2019	104	104	C

6 HPC Libraries and Supercomputing for Industry

6.A Research programme overview

The first main objective of the research programme is to further develop in-house libraries of efficient parallel algorithms based on advanced computational techniques and HPC technologies (ESPRESO, BEM4I, scaDD, ACA4BEM, MULTIDYN, MCSIMUL, LIB4NEURO, and PIMCSIMUL). These libraries are used to solve complex and extremely difficult problems in engineering and molecular dynamics, and to support their respective communities. Their development was supported among others by the PRACE-6IP and Grant Agency of the Czech Republic (GACR) research projects in 2019.

The second principal objective is the development of collaboration and support for industrial partners. This goal is fulfilled through contractual research, joint research projects, and capability development. The above in-house libraries and selected commercial and open source third party software packages are applied to solve challenging problems of our industrial partners. HPC services are offered to users from the application area with emphasis on Small and Medium Enterprises (SME). Collaboration with SMEs was supported by the InnoHPC, ClaudiFacturing, and ExaQute international projects as well as a few national projects funded by Ministry of Industry and Trade (MIT).

The third principal objective is development of tools and techniques that increase the quality of the service and the infrastructure of IT4Innovations. The team develops and optimizes the in-house and other open-source tools such as MERIC, RADAR, and CyclesPhi and services such as Solver-as-a-Service and Rendering-as-a-service. The development was supported amongst others by the national project IT4Innovations NSC within the Ministry of Education, Youth and Sports (MEYS) programme to support Large research infrastructures and H2020 Centre of Excellence project POP2.

Responsible partner: VŠB-Technical University of Ostrava
Head of research programme (HRP): Ing. Tomáš Karásek, Ph.D.

RP structure	FTE
Senior researchers & HRP	7,21
Researchers	14,50
Research assistants	12,16
Research support staff	0,66
Total	34,53

Table 6.1 RP structure

6.B Research teams and their activities

- **HPC libraries and scalable algorithms development**
 - Development of libraries for molecular simulations continued in 2019 and existing in-house codes MULTIDYN (non-adiabatic molecular dynamics), MCSIMUL (classical Monte Carlo methods), PIMCSIMUL (quantum Monte Carlo methods), and LIB4NEURO (representation of molecular interactions using artificial neural networks) were enhanced and applied for respective numerical simulations.

- BEM4I (bem4i.it4i.cz): in 2019 distributed Adaptive Cross Approximation (ACA) method for solution of Helmholtz equation describing wave distribution in space was implemented. For composite domains local Multitrace Formulation (MTF) was selected because this method leads to the unambiguously and stably solvable discrete system. The method is parallelized at several levels, i.e. the evaluation of singular boundary integrals is vectorized, local contributions are assembled in parallel in shared memory and boundaries of individual sub-regions are distributed among computational nodes.
- BESTHEA: Implementation of the BESTHEA library was launched within the project 'Space-time methods of boundary elements for solving heat equation' (GACR + FWF). The package includes test code implemented in MATLAB, the final parallel and optimized library is implemented in C++. Currently, the C++ library enables the solution of Dirichlet's or Neumann's problem with a general initial condition using full matrices. The assembly of these matrices is vectorized and the local contributions of the elements are calculated in parallel using shared memory.
- FETI-H: Implementation of the FETI-H domain decomposition method for highly parallel solution of the Helmholtz equation and harmonic analysis is being developed within the project module 'FEM / BEM based domain decomposition solvers' of PRACE-6IP WP8 Forward Looking Software Solutions project. Final implementation will be done within ESPRESO library. Test code is implemented in MATLAB MATSOL library. Currently, individual aspects of the FETI-H method, i.e. local regularization using Robin's condition and the introduction of an artificial gross problem, have been tested on smaller tasks in the MATSOL library.

Key persons: Prof. Ing. Tomáš Kozubek, Ph.D., Doc. RNDr. René Kalus, Ph.D.

• Supercomputing for Industry

- In 2019, cooperation with the industrial partner Glass Service was expanded. With this company the issue of modeling processes in the glass industry using artificial neural networks was solved in the form of a contracted research. Based on this cooperation, the project within the call of the TACR grant agency was submitted.
- At the beginning of 2019 the cooperation with Siemens s.r.o (branch of electric motors Frenštát) was initiated by solving two projects of contracted research (i) development of methodology for calculation of active cooling of electric motor - phase 2, (ii) development of methodology for calculation of modal properties of electric motor. The cooperation continued in 2019 by submitting a joint project “Digital twin of electric motor” within the call of the MIT APPLICATION. This project was recommended for funding and officialy started in August 2019.
- In cooperation with Sigma Lutín, the MIT TRIO project started in 2018 continued. In this project a methodology for CFD simulation of fluid flow in open channel using open source tools was developed.
- Within the WP8 Forward Looking Software Solutions project PRACE-6IP, a FEM / BEM module has been developed that will extend the functionality of the ESPRESO software package to address specific engineering problems tackled by industry.
- Within the H2020 calls, the SPACE CoE (INFRAEDI-05-2020) and Artifact (DT-ICT-03-2020) projects were submitted. The Artifact project being coordinated by IT4Innovations.

Key persons: Ing. Tomáš Karásek, Ph.D., Ing. Tomáš Brzobohatý, Ph.D.

- **Large Infrastructures – IT4Innovations National Supercomputing Center (LM2015070)**

- ESPRESO (espreso.it4i.cz). During year 2019 was improved highly scalable module for processing of finite-element meshes. New input and output formats were added (ABAQUS, EnSight, VTK). The module was also separated from the original ESPRESO library into new application that can be used by users for efficient data converting between various data formats. Important improvement is also integration of open-source libraries for parallel domain decomposition of input mesh among available processes (Pt-Scotch, KaHIP). By this integration, the tool can be used by users that require a fully open-source tool.

Besides parallel decomposers parallel solvers for sparse matrices (SuperLU, Watson) were also implemented. These libraries can be used to get solutions of some specific tasks more efficiently. Their integration improves variability of the ESPRESO library for given problem that allows more efficient utilization of the infrastructure.

Another part of the development focuses on the structural mechanic module that newly contains harmonic analysis for simulations of component behaviour for different frequencies; and new type of elements (TDNNS) that provide more accurate simulations than previously used element types in the case of coarse finite-element meshes. Another new module is the module for topological optimization that allows a component shape optimization with preserving its required properties. The FETI solver that is the core of ESPRESO newly supports acceleration of Schur complement computation on GPU that are often installed on new supercomputers.

MESIO tool developed from I/O module of the ESPRESO library was registered as open source software, and it is available to the users of the IT4I infrastructure.

- MERIC. During the year 2019 we focused on automatization of the process of analysis of a parallel application behavior provided by MERIC library, that is built for energy measurements and hardware parameters tuning during an application run with a goal in reduction of its energy consumption. We removed requirement of the application code manual instrumentation and manual exhaustive search of the state space.

The library now provides two tools (to provide support of wide range of hardware platforms) based on Dyninst or MAQAO, respectively to identify regions of the analyzed application that may bring possible savings when tuned with MERIC library. In the next step the tools will do automatic binary instrumentation of the application, which makes the application ready for MERIC's analysis.

MERICwrapper is another new tool that automatize an application analysis. It provides information which hardware parameters can be tuned on the current platform and also provides three algorithms for state space search (exhaustive search, genetic algorithm, or particle swarm optimisation). When using genetic algorithm or particle swarm optimisation, MERICwrapper significantly reduces time that is necessary to find optimal configuration for each tuned region of the analyzed application.

Beside new tools, the MERIC library has been also extended by adding support for GEOPM and msr-safe libraries to tune hardware parameters (the MERIC library can be used on servers where these libraries are available) which made possible also extension of the MERIC library by the possibility to specify maximum power consumption (using Intel RAPL powercap system). Another new feature is updated I/O subsystem that now

stores the data in HDF5 binary data format. It replaces system of storing the data into many small text files that are highly demanding for contemporary server filesystems. New data format of the MERIC's output data has been implemented also in RADAR visualizer, which is GUI tool for an application behavior visualization in several parameters configuration at the same time. During this year the tool has been also extended by power samples timeline visualization.

RADAR visualizer was registered as open source software and is now available at IT4I infrastructure, as well as the MERIC library.

- Visualization and Virtual Reality.
Based on our developed tool for parallel rendering on a cluster (CyclesPhi), several other tools have been implemented and a service called Rendering-As-A-Service (RAAS) was prepared for launch. This service will allow users to utilize a supercomputing centre's infrastructure for rendering purposes. Main advantage of such service is elimination of user's expertise in the setup of a computational task for the cluster and arrangement of accelerated rendering for broader community of users. Whole service consists of three main parts (front end, middleware and CyclesPhi). User's front end is integrated into Blender's environment (software for creation and visualization of 3D content) and facilitates direct communication with the user over the final 3D scene. User who wants to do the rendering is then directed to the middleware which communicates with the cluster. Rendering job that is created by the middleware is then performed by CyclesPhi software which is installed on the cluster.

CyclesPhi application has been registered as a publicly available software and it can be used by users of IT4Innovations infrastructure.

In the area of rendering, we have implemented concept of multi-GPU rendering where GPUs share their own memory under so-called CUDA unified memory. Total available memory for rendering is therefore sum of each individual GPU's memory. The aim of such technique is to provide accelerated rendering on GPU for scenes that do not fit to the memory of a single GPU card. Recently purchased system DGX-2 with 16 GPUs is used for the development of this method. In the future it will be possible to apply this rendering concept also on the new cluster Barbora, which is also equipped by GPU accelerated nodes.

Key persons: Ing. Lubomír Říha, Ph.D., Ing. Petr Strakoš, Ph.D.

6.C Research outcomes

Type	Plan	Actual
Journal papers (imp)	10	21
Other papers (proceedings, ...)	20	12
Outcomes of applied research (patents, software, etc.)	8	6

Table 6.2 Key performance indicators of the research programme

A list of the 10 most important outcomes of the research programme in 2019:

1. Kravčenko, M., Merta, M., Zapletal, J.: Distributed Fast Boundary Element Methods for Helmholtz Problems. Applied Mathematics and Computation.
2. Zapletal J., Bouchala J.: Shape optimization and subdivision surface based approach to solving 3D Bernoulli problems. Computers & Mathematics with Applications.
3. S. Dohr, J. Zapletal, G. Of, M. Merta, M. Kravčenko. A parallel space-time boundary element method for the heat equation. Computers & Mathematics with Applications.
4. C. Van de Steen, M. Benhenni, R. Kalus, R. Čosić, S. Iléssová, F.X. Gadea, M. Yousfi, Cross-sections, transport coefficients and dissociation rate constants for Kr²⁺ molecular ion interacting with Kr. Plasma Source Sci. Technol.
5. C. Van de Steen, M. Benhenni, R. Kalus, R. Čosić, F.X. Gadea, M. Yousfi, Mobility and dissociation of electronically excited $\{\mathrm{Kr}\}_{-2}^{+}$ ions in cold krypton plasma. Plasma Source Sci. Technol.
6. C. Van de Steen, M. Benhenni, R. Kalus, R. Čosić, S. Iléssová, F.X. Gadea, M. Yousfi, Calculations of cross-sections, dissociation rate constants and transport coefficients of Xe²⁺ colliding with Xe. Phys. Chem. Chem. Phys.
7. Zapoměl J., Ferfecki, P., Kozánek J.: The mathematical model for analysis of attenuation of nonlinear vibration of rigid rotors influenced by electromagnetic effects, Journal of Sound and Vibration, Volume 443, 17 March 2019, 167-177.
8. Haslinger, J., Kučera, R., Šátek, V.: Stokes system with local Coulomb's slip boundary conditions: Analysis of discretized models and implementation. Computers and Mathematics with Applications.
9. Z. Dostál, O. Vlach, T. Brzobohatý: Scalable TFETI based algorithm with adaptive augmentation for contact problems with variationally consistent discretization of contact conditions, accepted in Finite Elements in Analysis & Design.
10. Brzobohatý T., Jarošová M., Kučera R., Šátek V. Path-following interior point method: Theory and applications for the Stokes flow with a stick-slip boundary condition. Advances in Engineering Software, roč. 2019, č. 129, s. 35-43. ISSN 0965-9978.

6.D Project activity

International R&D projects:

Project title	Grant agency	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
InnoHPC	INTERREG	2017 - 2019	303	2 500	A
EXPERTISE	H2020-MSCA	2017 - 2020	1546	5 900	A
PRACE – 5IP	H2020	2017 - 2019	86	2 000	A
PRACE – 6IP	H2020	2019 - 2021	1202	3 000	A
CloudiFacturing	H2020	2016 - 2019	1089	6 500	A
ExaQute	H2020	2018-2021	1011	4 100	A

POP2	H2020	2018-2021	3040	11 233	A
LEXIS	H2020	2019-2021	1242	3 000	A

National grants / specific support:

Project title	Grant	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
Large Infrastructures	MEYS	2016-2019	6 200	30 000	A
Math-In-HPC.EDU	MEYS OP RDE	2017-2022	828	2 450	A
Science without borders	MEYS	2018-2021	1 500	3 266	A
Techniques for the Future	MEYS OP RDE	2017-2022	1000	1700	A
Inlet and outlet objects of pumping and turbine stations	Ministry of Industry and Trade	2018-2021	1901	3921	A
Digital twin product at Siemens manufacturing plants	Ministry of Industry and Trade	2019-2022	367	8373	A
Space-time methods of boundary elements for solving the heat conduction equation	GAČR	2019-2021	975	3573	A
Optimization of operating parameters of the electrical distribution system using artificial intelligence	TACR	2019-2021	132	1802	A
Contactless partial discharge detector for HV distribution lines	TACR	2019-2021	230	1257	A

Contract research:

Project title	Contracting authority	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (C-contracted, N-negotiated, P-planned)
Optimization of proposal of asynchronous electric motor ventilation node design with respect to air volume, mechanical losses and noise	Siemens s.r.o.	2019	385	385	C
Maximum operating speed of the asynchronous electric motor	Siemens s.r.o.	2019	325	325	C

7 Modelling in Nanotechnology

7.A Research programme overview

Research programme activities are oriented towards HPC applications in the theoretical and experimental aspects of nanotechnologies. The research branches are as follows:

- Electronic structure modelling of solid states based on quantum mechanics.
- Theoretical and experimental study of new materials and surface structures for a new generation of photovoltaic cells.
- Research and development of spin lasers for electronics applications.
- Nonlinear optical effects in nanostructures.
- Theoretical and experimental terahertz spectroscopy.
- Plasmonics effects in semiconductors.
- Nanocomposites modelling and design for broad applications.

Responsible partner: VŠB-Technical University of Ostrava
Head of research programme (HRP): Prof. Ing. Jaromír Pištora, CSc.

RP structure	FTE
Senior researchers & HRP	1,60
Researchers	8,65
Research assistants	5,62
Research support staff	0,55
Total	16,42

Table 7.1 RP structure

7.B Research teams and their activities

- **Modelling for nanotechnology**

- Modelling of plasmonic phenomena in highly doped semiconductors focusing on SPR sensorics; the outstanding properties of surface plasmon polariton (SPP) in gradient layers of semiconductors and the theoretical possibilities of plasmon manipulation using the electrons drift velocity in the material were proved.
- Modelling of diffraction on pyramids using the numerical integration of the Stratton-Chu-Silver diffraction integral for photovoltaic application.
- “Fano resonance” between the waveguide modes of the planar structures and the polariton wave generated by the surface plasmons was theoretically studied.
- The Mach-Zehnder interferometer for the terahertz sensor was described, and its sensitive parameters were specified.
- Modelling of amplifiers with nanostructure waveguide in a terahertz wave area has been realized.
- A plasmonic sensor combining highly doped silicon with a metallic grid for the mid-infrared region was described.
- Modelling of interactions between electromagnetic waves and plasmonic Ag nanotubes with optical coupling to the magneto-optical planar structure. The conditions of the “Fano resonance” were specified.

- Study of pure and surface-modified Mxenes materials (2D layers based on transition metal carbides from MAX phases with excellent electrochemical and mechanical properties).

Key persons: Prof. Ing. Jaromír Pištora, CSc., Doc. Dr. Mgr. Kamil Postava, Ing. Dominik Legut, Ph.D.

- **New materials and surfaces for nanooptics**

- In-situ Mueller spectroscopic ellipsometry was applied in monitoring of the growth of silicon nanowires prepared by the PVCD method.
- Plasmonic resonance in the InSb and InAs semiconductors in the terahertz area was experimentally confirmed, including the plasmon resonance modulation with external magnetic field in the transverse configuration.
- A general model for description of vertical-cavity surface-emitting lasers including the anisotropic phenomena.
- The optical properties of the III-V semiconductors were theoretically and experimentally specified and the extreme magneto-optical phenomenon of the InSb semiconductors in the terahertz area was experimentally proved.
- Ab initio quantum mechanics calculation of electron structure oriented towards the magnitude of the magnetic interactions in low-dimensional and multi-ferroic materials.
- Experimental Gouy phase shift compensation in Terahertz time-domain spectroscopy.
- High sensitive Z-shaped fiber interferometric refractive index sensor: Simulation and experiment.
- High-resolution THz gain measurements in optically pumped ammonia.

Key persons: Prof. Ing. Jaromír Pištora, CSc., Doc. Dr. Mgr. Kamil Postava

- **Modelling and design of nanocomposites for wide use**

- Theoretical study of the interaction and properties component of nanocomposites by the means of simulation and modelling for further use in medicine and various technical fields.
- The development of new forms of cordierite-steatite ceramics with functional nanoparticles of metal oxides and a porous structure developed on the basis of modified clay mixtures continued.
- Testing of the photocatalytic activity of a kaolin/ZnO composite prepared by calcination.
- Experimental research of thin layer with graphene prepared by calcination P/M nanocomposites.
- Study of conductive polymer/graphite nanocomposites.
- Study of protective 2D films from graphene, hex. BN, silicone, phosphorene and other materials for Li/Na anodes with respect to sufficient strength.
- The study of S-C cathode composite material was focused on the monitoring of the material interaction and changes in composite conductivity. Different types of carbon nanomaterials were used for research of their use as cathode materials.

Key persons: Doc. Ing. Gražyna Simha Martynková, Ph.D., Doc. Ing. Jonáš Tokarský, Ph.D.

7.C Research outcomes

Type	Plan	Actual
Journal papers (imp)	15	52
Other papers (proceedings, ...)	6	8
Outcomes of applied research (patents, software, etc.)	1	0

Table 7.2 Key performance indicators of the research programme

A list of the 10 most important outcomes of the research programme in 2019:

1. Z. H. Fu; N. Wang, D. Legut, C. Si, Q. F. Zhang, S. Y. Du, SY T. C. Germann, J. S. Francisco, R. F. Zhang: Rational Design of Flexible Two-Dimensional MXenes with Multiple Functionalities. CHEMICAL REVIEWS 119, no. 23, DOI: 10.1021/acs.chemrev.9b00348 (2019).
2. R. Illa, R. Jesko, R. Silber, O. Zivotsky, KM. Kutlakova, L. Matejova, M. Kolencik, J. Pistora, J. Hamrle: Structural, magnetic, optical, and magneto-optical properties of CoFe₂O₄ thin films fabricated by a chemical approach. MATERIALS RESEARCH BULLETIN, Vol. 11, pages 96-102, DOI: 10.1016/j.materresbull.2019.05.002 (2019).
3. V. Jandieri, K. Yasumoto, J. Pištora, D. Erni: Analysis of Scattering by Plasmonic Gratings of Circular Nanorods Using Lattice Sums Technique. SENSORS 19, no. 18, DOI: 10.3390/s19183923 (2019).
4. N. Nguyen-Huu, J. Pištora, M. Cada: Dual broadband infrared absorptance enhanced by magnetic polaritons using graphene-covered compound metal gratings. OPTICS EXPRESS 27, no. 21, DOI: 10.1364/OE.27.030182 (2019).
5. J. Vlček, J. Pištora, M. Lesňák: Design of Plasmonic-Waveguiding Structures for Sensor Applications. NANOMATERIALS 9, no. 9, DOI: 10.3390/nano9091227 (2019).
6. Y. Q. Guo, S. H. Zhang, B. Zhan, I. J. Beyerlein, D. Legut, S. L. Shang, Z. K. Liu, R. F. Zhang: Synergetic effects of solute and strain in biocompatible Zn-based and Mg-based alloys. ACTA MATERIALIA 181, DOI: 10.1016/j.actamat.2019.09.059 (2019).
7. Y. C. Fan, T. S. Wang, D. Legut, Q. F. Zhang: Theoretical investigation of lithium ions' nucleation performance on metal-doped Cu surfaces. JOURNAL OF ENERGY CHEMISTRY 39, DOI: 10.1016/j.jechem.2019.01.021 (2019).
8. H. T. Chen, A. D. Handoko, J. W. Xiao, X. Feng, Y. C. Fan, T. S. Wang, D. Legut, Z. W. Seh, Q. F. Zhang: Catalytic Effect on CO₂ Electroreduction by Hydroxyl-Terminated Two-Dimensional MXenes. ACS APPLIED MATERIALS & INTERFACES 11, DOI: 10.1021/acsami.9b09941 (2019)
9. J. W. Xiao, G. M. Zhou, H. T. Chen, X. Feng, D. Legut, Y. C. Fan, T. S. Wang, Y. Cui, Q. F. Zhang: Elaboration of Aggregated Polysulfide Phases: From Molecules to Large Clusters and Solid Phases. NANO LETTERS 19, no. 10, DOI: 10.1021/acs.nanolett.9b03297 (2019).
10. R. F. Zhang, S. H. Zhang, Y. Q. Guo, Z. H. Fu, D. Legut, T. C. Germann, S. Veprek: First-principles design of strong solids: Approaches and applications. PHYSICS REPORTS-REVIEW SECTION OF PHYSICS LETTERS 826, DOI: 10.1016/j.physrep.2019.09.004 (2019).

7.D Project activity

International R&D projects:

Project title	Grant agency	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)

National grants / specific support:

Project title	Grant	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
New fuel materials for nuclear reactors of IV-th generation	GAČR	2017-2019	1066	2414	A
IT4Innovations National Supercomputing Center – path to exascale (IT4I NSC - P2EX)	MEYS	2017-2021	9 740	40 000	A
Science without borders	MEYS	2018-2021	531	917	A

Contract research:

Project title	Contracting authority	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (C-contracted, N-negotiated, P-planned)
BPF / BPA hydrophobicity adjustment	Continental Powertrain Czech Republic s.r.o.	2019	541	541	C

8 IT for Knowledge Management

8.A Research programme overview

The research programme has three major research areas – big data analysis, internet of things, and cybersecurity. During the year, the activities in the field of big data were more concentrated in the usage and improvement of the modern data analysis method on real data than only on the development of the new approaches. The field of big data analytics methods is vast and still provides wide possibilities of application of research.

The second research area dealt with IoT, where we have implemented a tool collecting data on IoT gateways, and the tool is deployed in LoRaWAN IoT Campus Network. Based on the collected data, we are able to detect several threats in IoT. We focused our intent also on energy harvesting in 5G mobile networks and modeling outage and energetic budget in wireless transmission channels.

As regards cybersecurity, we have started a new H2020 project in the field of quantum communications where we deal with QKD (Quantum Key Distribution). We also continue in speech processing and related security issues.

Responsible partner: VŠB-Technical University of Ostrava
Head of research programme (HRP): Prof. Ing. Miroslav Vozňák, Ph.D.

RP structure	FTE
Senior researchers & HRP	1,42
Researchers	6,17
Research assistants	0,41
Research support staff	0,29
Total	8,29

Table 8.1 RP structure

8.B Research teams and their activities

- **Bigdata analysis**
 - In the field of AI in complex systems and big data, the team had focused research in 2019 on path planning and trajectory optimization for robotics. The optimization aimed at reducing the energy consumption of six degrees of freedom robotic arms. We had also optimized the movement on a fixed trajectory by selecting the proper placement of a manipulator in the available workspace. Our results show significant improvement in comparison with default planners available today. All the algorithms were finely tuned and optimized for performance. Achieved results were published, and even more, papers are in development for publishing in top-rated journals.
 - In the past operational period, the Big data analysis group was also focused on several areas of data analysis and prediction. Specifically, researchers created a novel model for the traffic flow description and prediction. The model is based on the usage of a mixture of Von Mises distribution, where researchers developed or used and compared several techniques for finding optimal parameters of this distribution – Expectation-

Maximization algorithm, differential evolution methods, and machine learning approach with fuzzy evolutionary rules. Further researchers worked on the analysis of data from Social and Business science, where they presented a novel method for visualization of data with a ranking system. Researchers started cooperation in the area of Antropokinetics, where they study the structural and functional markers of young people in the Czech Republic. Researchers published and presented their results in journals and conferences.

- The Big Data Analysis team also dealt with processing location and operational data of mobile networks, and we finished and have launched a Mobility Atlas of the Czech Republic. It is a result of research cooperation with T-Mobile CZ, and we provided access to this portal for the needs of the government with the approval of TM CZ. In the portal, users can observe movements of population in the territory, repeated patterns of behavior, commuters, flows of traffic, etc.

Key persons: Prof. Ing. Miroslav Vozňák, Ph.D., Ing. Jakub Šafařík, Ph.D.

- **Internet of Things**

- We developed three types of security detectors for IoT networks. The first one concerns a violation of duty cycle time at 868MHz, where users must obey a regulation of maximal period transmitting on the channel, and our detector is able to identify such devices and exclude them from other communication. The second detector at IoT GW protects GW from replay-attacks, and the last one is the mechanism locating sensors in IoT network without GPS equipment.
- The next subtopic in IoT was more theoretical; we dealt with modeling energy harvesting relay-enabled cognitive radio wireless sensor networks. We expressed closed-form expressions for the successful transmission probability, and the achievable data rate derived analytically. Furthermore, we verified the theoretical analysis obtained independently in a Monte Carlo simulation; finally, we published our results in several journals.

Key persons: Prof. Ing. Miroslav Vozňák, Ph.D.

- **Cybersecurity**

- Within the H2020 project on quantum cryptography, we proposed a novel QoS architecture, and the article was published in FEB 2020 in the top-rated journal IEEE/ACM Transactions on Networking.
- We proposed a DeepVoCoder, which uses convolutional neural networks (CNN) to compress speech, and it is a promising way for the channel coding. Based on this experience, we were able to show how to clone a human voice with the aid of AI. We demonstrate the efficiency of CNN speech vocoder model to compromise voice biometric authentication systems in our article, which has been recently published in the excellent journal IEEE Communications Magazine.

Key persons: Prof. Ing. Miroslav Vozňák, Ph.D.

8.C Research outcomes

Type	Plan	Actual
Journal papers (imp)	4	15
Other papers (proceedings, ...)	6	15
Outcomes of applied research (patents, software, etc.)	0	5

Table 8.2 Key performance indicators of the research programme

The list of 10 most important outcomes of the research programme in 2019:

1. Huynh, V.-V., Nguyen, H.-S., Hoc, L.T.T., Nguyen, T.-S., Voznak, M. Optimization issues for data rate in energy harvesting relay-enabled cognitive sensor networks (2019) *Computer Networks*, 157, pp. 29-40. DOI: 10.1016/j.comnet.2019.04.012 (IF 3.03)
2. Nguyen, T.N., Tran, M., Nguyen, T.-L., Ha, D.-H., Voznak, M. Multisource power splitting energy harvesting relaying network in half-duplex system over block rayleigh fading channel: System performance analysis (2019) *Electronics*, 8 (1), art. no. 67, . DOI: 10.3390/electronics8010067 (IF 1.764)
3. Chamorro, H.R., Sanchez, A.C., Pantoja, A., Zelinka, I., Gonzalez-Longatt, F., Sood, V.K. A network control system for hydro plants to counteract the non-synchronous generation integration (2019) *International Journal of Electrical Power and Energy Systems*, 105, pp. 404-419. DOI: 10.1016/j.ijepes.2018.08.020 (IF 4.418)
4. Nguyen, T.N., Tran, M., Ha, D.-H., Nguyen, T.-L., Voznak, M. Energy harvesting based two-way full-duplex relaying network over a rician fading environment: Performance analysis (2019) *Proceedings of the Estonian Academy of Sciences*, 68 (1), pp. 111-123. DOI: 10.3176/proc.2019.1.11 (IF 0.51)
5. Keles, H.Y., Rozhon, J., Gokhan Ilk, H., Voznak, M. DeepVoCoder: A CNN Model for Compression and Coding of Narrow Band Speech (2019) *IEEE Access*, 7, art. no. 8730308, pp. 75081-75089. DOI: 10.1109/ACCESS.2019.2920663 (IF 4.098)
6. Do, D.-T., Le, A.-T., Le, C.-B., Le, S.-P., Nguyen, H.-N., Sevcik, L., Voznak, M. Outage performance analysis of cell-center/edge users under two policies of energy harvesting (2019) *Elektronika ir Elektrotechnika*, 25 (4), pp. 75-80. DOI: 10.5755/j01.eie.25.4.23974 (IF 0.684)
7. Vantuch, T., Zelinka, I., Adamatzky, A., Marwan, N. Perturbations and phase transitions in swarm optimization algorithms (2019) *Natural Computing*, 18 (3), pp. 579-591. DOI: 10.1007/s11047-019-09741-x (IF 1.33)
8. Skanderova, L., Fabian, T., Zelinka, I. Self-adapting self-organizing migrating algorithm (2019) *Swarm and Evolutionary Computation*, 51, art. no. 100593, . DOI: 10.1016/j.swevo.2019.100593 (IF 6.33)
9. Chamorro, H.R., Riaño, I., Gerndt, R., Zelinka, I., Gonzalez-Longatt, F., Sood, V.K. Synthetic inertia control based on fuzzy adaptive differential evolution (2019) *International Journal of Electrical Power and Energy Systems*, 105, pp. 803-813. DOI: 10.1016/j.ijepes.2018.09.009 (IF 4.418)
10. Snasel, V., Kromer, P., Safarik, J., Platos, J. JPEG steganography with particle swarm optimization accelerated by AVX (2020) *Concurrency Computation*, 32 (8), art. no. e5448, DOI: 10.1002/cpe.5448 (IF 1.167)

8.D Project activity

International R&D projects:

Project title	Grant agency	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
TETRAMAX	H2020	2017-2021	325	2 300	A
OPENQKD	H2020	2019-2022	124	6 100	A

National grants / specific support:

Project title	Grant	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
AI & Reasoning	MEYS OP RDE	2017-2022	2 116	12 175	A
Other Projects	Faculty Sources	2019	2 200	-	A
Smart energy management system for energy networks	TACR	2019-2020	68	1762	A

Contract research:

Project title	Contracting authority	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (C-contracted, N-negotiated, P-planned)
Research for needs in ICT sphere for National Authority in Cybersecurity	National Office for Cyber and Information Security	2019-2021	67	3595	C

9 Soft Computing Methods with Supercomputing Applications

9.A Research programme overview

The focus of the research on the development of soft computing methods and their software implementation continued also in 2019. The research is based on the development of the fundamental theories standing behind the considered methods and their applications. The basic strategy is to apply our original and scientifically well justified methods. The following specific goals were fulfilled in 2019:

- Research in fusion of mathematical tools of fuzzy modelling with probabilistic methods and tools of classical mathematics (e.g., numerical or functional analysis, optimization tasks, and others).
- Selected problems in fuzzy natural logic and its theoretical foundations.
- Theoretical foundation of methods for computer vision on the basis of fuzzy modelling.
- Theoretical foundations of methods for mining information from data and forecasting of future development of systems on the basis of the principles of fuzzy modelling.
- Study of aggregation functions, topology and its generalizations including applications.
- Theoretical research in simple multi-agent biologically inspired systems (P colonies).
- Research and modelling of evolving cell-inspired systems with defined geometrical and spatial arrangement of components (morphogenetic systems).
- Decision-support information systems using medical image processing and recognition.

Responsible partner: University of Ostrava, Silesian University in Opava
Head of research programme (HRP): Prof. Ing. Vilém Novák, DrSc.

RP structure	FTE OU	FTE SLU
Senior researchers & HRP	8.42	2.41
Researchers	16.42	2.19
Research assistants	3.58	0
Research support staff	0.30	0.61
Total	28.72	5.21

Table 9.1 RP structure

9.B Research teams and their activities

University of Ostrava

- **Dept. of Theoretical Research (Team 1)**
 - We continued the study of the properties of fuzzy natural logic (FNL). We focused on the study of properties of further selected fuzzy quantifiers (such as „a little, a few, several“, on their position in hexagon of opposition and on the semantics of intermediate quantifiers in the case of missing values.
 - On the basis of the developed partial logical systems and functions we have developed a theory of variable-domain fuzzy sets.
 - We received further results in the theory of dynamical systems and characterized minimal ones including those with infinite entropy and characterized systems belonging

to the generic class. We also proved that any Cantor system can be perturbed in a very special way.

- We proposed a new approach for the interval-valued Choquet integral that takes into account every possible permutation fitting to the considered ordinal structure of data.
- We characterized ordinal sums of t-norms and t-conorms on bounded lattices.
- We significantly contributed to numerical analysis of differential equations (specially BVPs) and fuzzy-valued integral equations. Our machinery is based on Sobolev spaces with weak differentiable functions, Galerkin-type methodology where test functions correspond to eigen functions of the F-transform operator.
- We showed that fuzzy soft sets and fuzzy soft approximations can be naturally used in the color segmentation method, where reliable and fully automated methods do not exist yet.

Key persons: Prof. Irina Perfiljeva, Prof. Jiří Močkoř, Prof. Vilém Novák, Dr. Michal Holčapek

- **Dept. of Applied Research (Team 2)**

- We studied behavior of the classical PbLD method with its extended versions.
- We designed special algebra called dragonfly algebra that serves for the purpose of incorporation of missing values in the compositions. This algebra employs the lower estimation approach and it is designed in order to preserve as many properties from the residuated lattices as possible. The application potential is demonstrated on a real example of the taxonomical classification of dragonflies.
- We proposed a preprocessing technique for neural networks that enrich the original image data using local intensity information; this technique is motivated by human perception. To encode this information into an image, we introduced a new image structure named Image Represented by a Fuzzy Function. Based on our benchmark consisting of three well-known datasets and five neural network architectures, we show that the proposed preprocessing can, in most cases, decrease classification error compared with a baseline and two other preprocessing methods.
- We proposed a method how to optimize parameters of the fuzzy transform of higher degree to obtain a good estimation of the trend-cycle of a financial time series.
- We introduced fuzzy relational modalities of possibility and necessity for handling propositions that can be truth-valueless. We identified several important types of these modalities.

Key persons: Doc. Martin Štěpnička, Dr. Michal Holčapek, Doc. Antonín Dvořák, Prof. Irina Perfiljeva

- **Dept. of Software Development**

- We developed software rmake for processing of complex statistical analyses in R language.
- Implementation of fuzzy transform with undefined values for images in MATLAB.
- We developed a novel approach to task planning based on an intelligent expert system that makes it possible to obtain a conclusion on the basis of linguistically characterized knowledge.
- We continued with the development of LFL Forecaster and LFL Controller as a WEB service.
- Creation of SW for simulation of generalized syllogisms with intermediate quantifiers.

- We developed a new data pre-processing method for neural networks. It combines F-transform with PCA methods.
- We have developed an effectively working technique for realtime detection of objects in the automotive environment.
- We have developed a special technique „style transfer“ enabling to transform a given image in a different global style.
- We developed an original method for finding monotonous intervals inside time series that are equally evaluated using special linguistic expressions.

Key persons: Dr. Viktor Pavliska, Dr. Michal Burda

Silesian University in Opava

• The team for the development of autonomous agents

- New results in the area of multiagent models of membrane systems called P colonies. The research was focused on computational systems with creation of agents and with so-called verifier agents.
- New results – logical representation of multiagent systems by means of P colonies.
- Research of evolving morphogenetic systems with explicit geometrical structure, new results focused on their comparison with Lindenmayer systems. Extension of functionality of software modelling tool Cytos for morphogenetic systems, modelling morphogenesis of bacterial colonies of selected species (E. Coli, L. Acidophilus, S. Lactis).
- Online medical information system for decision-making support for evaluation of atherosclerotic plaques from b-images and histological patterns.

Key persons: Doc. Ing. Petr Sosík, Ph.D., Ing. Jiří Blahuta, Ph.D., Prof. Ing. Dušan Marček, CSc., RNDr. Lucie Cencialová, Ph.D., Doc. RNDr. Luděk Cenciala

9.C Research outcomes

University of Ostrava and Silesian University in Opava

Type	Plan OU	Actual OU	Plan SLU	Actual SLU
Journal papers (imp)	15	35	3	1
Other papers (proceedings, ...)	20	36	4	8
Outcomes of applied research (patents, software, etc.)	1	0	0	1

Table 9.2 Key performance indicators of the research programme

The list of 10 most important outcomes of the research programme in 2019:

1. Perfiljeva, I. a Vlašánek, P. Total variation with nonlocal FT-Laplacian for patch-based inpainting. *Soft Computing*. 2019, 23(6), s. 1833-1842. ISSN 1432-7643.
2. Kupka, J., Rusnok, P. Fuzzy four-fold tables: their properties and use in fuzzy association analysis. *INT J APPROX REASON*. 2019, 108(May), s. 89-106. ISSN 0888-613X.

3. Močkoř, J. F-transforms and Semimodule Homomorphisms. *Soft Computing*. 2019, 23(17), s. 7603-7619. ISSN 1432-7643.
4. Hurtík, P., Dyba, M., Madrid, N. Sensitivity analysis for image represented by fuzzy function. *SOFT COMPUT.* 2019, 23(6), s. 1795-1807. ISSN 1432-7643.
5. Oprocha, P. Double minimality, entropy and disjointness with all minimal systems. *DISCRETE CONT DYN S.* 2019, 39(1), s. 263-275. ISSN 1078-0947.
6. Štěpnička, M., CAO, T. H. N., Běhounek, L., Burda, M., Dolný, A. Missing Values and Dragonfly Operations in Fuzzy Relational Compositions. *INT J APPROX REASON.* 2019, 113(October), s. 149-170. ISSN 0888-613X.
7. Hurtík, P., Tomasiello, S. A Review on the Application of Fuzzy Transform in Data and Image Compression. *SOFT COMPUT.* 2019, 23(23), s. 12641-12653. ISSN 1432-7643.
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13. Ciencialová, L., Cienciala, L.: Two notes on APCol systems. *Theoretical Computer Science.* Elsevier, online. ISSN 0304-3975.

9.D Project activity

University of Ostrava

International R&D projects:

Project title	Grant agency	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
The Lump Sum related to the Visegrad/V4EaP Scholarship for Oleksii Tyshchenko"	International Visegrad Fund (Slovensko) 51700967	2017-2019	15	76	A
EUSFLAT travel grants	EUSFLAT	2019	38	38	A
ERASMUS+ EPP-1-2008 - A2 -Strengthening Teaching Competences in Higher Education in Natural and Mathematical Sciences	ERASMUS+ KA2	2019-2021	241	1 190	A

National grants / specific support:

Project title	Grant	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
New approaches to aggregation operators in analysis and processing of data	GAČR 18-06915S	2018-2020	797	1320	A
New approaches to financial time series modelling based on soft computing	GAČR 18-13951S	2018-2020	952	2856	A
Complex topological structures	IRP 201824	2018-2020	1716	5720	A
Use of transdisciplinary synergy data science and fuzzy modeling tools and social work: Multidimensional Evidence Informed Practice	IRP 201821	2018-2020	531	2100	A

Contract research:

Project title	Contracting authority	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (C-contracted, N-negotiated, P-planned)
Consulting services in the area of case mathematical analysis and to modeling data supporting process management	EAGO systems spol. s r.o.	2019-2021	1 046	3 000	C
Statistical processing of data series 1 from measurement of Galvanic Skin Response using fyziometric mouse	Connexia elektric, s.r.o.	2019	155	155	C
Formation of a function in PHP for processing of measured data in R	Connexia elektric, s.r.o.	2019	22	22	C
Consulting and testing of the GAM method for the analysis of relations in the quality of atmosphere	Zdravotní ústav se sídlem v Ostravě	2019-2020	24	40	C

Silesian University in Opava

International R&D projects:

Project title	Grant agency	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
ERASMUS+ 2016-1-CZ-01-KA103-022932	House of international collaboration	2018-2019	1473	2420	A

National grants / specific support:

Project title	Grant	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
Development of methods of theoretical and applied computer science	MEYS	2019-2021	466	1350	A
Usage of information sources in society	MEYS	2019-2021	85	232	A
Participation at Int. Conf. on Quantitative and Qualitative Methods in Libraries	MEYS	2019	30	30	A

Contract research:

Project title	Contracting authority	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (C-contracted, N-negotiated, P-planned)

10 Multimedia Information Recognition and Presentation

10.A Research programme overview

The main objective of the Multimedia Information Recognition and Presentation research programme remained, as also mentioned in the previous report, unchanged throughout the whole funded period of the project while towards the end of the funded start-up phase the goals, as also planned, were focusing on robustness and applicability of the methods. In 2019, the applicability and exploitation remained the main focus of the research programme and it will likely remain the same for the rest of the duration of the project. Such a goal remains to keep in mind research in processing of multimedia data with respect to its properties at the signal level and it continues to be connected with other research activities (especially RP5 but also RP8 and RP1 ones). A specific goal of the activity mainly related to HPC is efficient computation in applications of the above algorithms. Image, video, and speech analysis, mining knowledge from documents and multimedia data, presentation, visualization and modelling, acceleration, and techniques of semantic web, languages as well as grammars are the main objects of focus from the algorithm research point of view. The results of the research programme update include new types of applications which have not been feasible for technological or economic reasons until recently. The results are being published and applied in the form of conference and journal publications, software, functional models, and services.

Responsible partner: FIT, Brno University of Technology
Head of research programme (HRP): Prof. Dr. Ing. Pavel Zemčík

RP structure	FTE
Senior researchers & HRP	11.10
Researchers	15.97
Research assistants	6.81
Research support staff	0
Total	33.88

Table 10.1 RP structure

10.B Research teams and their activities

- **Processing of Information from multimedia data (NPUII)**
 - In 2019, we performed in-depth further research of exploitation of the algorithms of extraction and understanding, data mining, visualization, and rendering in selected applications. It mostly involved research in the area of convolutional neural networks (CNNs).
 - We performed also analysis of video footage of unknown source with the aim to understand the scene contents and camera placement. Detection, recognition and orientation of objects present in the video footage for statistical purposes and for the purposes of understanding the scene as a whole and understanding the camera placement in the scene was of interest as well.
 - Similarly to the previous period, the research was executed mainly with focus on non-supervised robust methods that have the best application potential due to avoidance of human work.

Key persons: prof. Ing. Adam Herout, Ph.D., prof. RNDr. Alexander Meduna, CSc.

- **Industrial applications of advanced Information technology (NPUII)**

- The research we conducted in 2019 involved CPS and IoT in applications, such as “Smart Cities”, traffic, and “Smart Homes”. The most actual areas were speech data mining in transportation applications. The research does not involve direct deployment of applications in industry but rather infrastructure and its protective components.
- We continued working with Ericsson on speech diarization and NTT on speaker-aware speech recognition. We did, as planned, actively seek for other opportunities in collaboration with companies. A new area (link analysis) has been opened in synergy with the newly started EU H2020-Security project Roxanne. In all scenarios, we evaluated the CPU/GPU/memory needs and possibility of applying HPC and non-conventional acceleration platforms.
- The research was applied also in conjunction with the newly started National Centre of Competence for Cybersecurity.

Key person: doc. Ing. Lukáš Burget, Ph.D.

- **Processing of videosequences and speech**

- In 2019, research did continue, as planned, with focus on techniques for multi-lingual robust data mining from speech data in adverse conditions. In speaker recognition (SR), activities focused NIST 2019 Speaker recognition evaluation targeting conversational telephone speech (CTS) and audio from video (AfV). We investigate the performance of i-vector and x-vector models, and performed system fusion. In automatic speech recognition, attention was mostly paid to the basics of neural ASR systems (temporal resolution, representation levels, and fusion with other modalities) – this work is running concurrently with the newly started NEUREM3 project funded under the GACR “EXPRO” scheme and also H2020 ROXANNE and CleanSkyATCO2 and DARPA Lorelei and IARPA Material. In addition to basic research, we provided a set of applicable results, mainly acoustic models for ASR of several languages (some new, in some of them upgrade of existing models) for industrial partners, such as those with whom the collaboration exists, including Phonexia (Czech Republic), Raytheon BBN (USA), NTT (Japan), and Ericsson (Sweden).

Key persons: Doc. Dr. Ing. Jan Černocký, Ing. Ondřej Glembek, Ph.D., Ing. Pavel Matějka, Ph.D.

- **Computer vision and recognition**

- The research performed in 2019 focused on acceleration of new and robust algorithms of scene understanding and object detection/recognition on modern platforms such as embedded platforms, multi-CPU and/or GP-GPU, and also FPGA combined with CPUs. The research continued to use non-traditional image sources, such as multiexposure HDR and multispectral images. Experiments and evaluation of the algorithms and the acquired data was carried out and the methods were further refined. We newly researched LightFields (also in conjunction with the LookingGlass display technology). Parts of the results were made publicly available. We also managed to obtain participation in new research projects, such as TACR National Centre of Competence in Cybersecurity or Penta MuSiC project, H2020 ECSEL FitOptiVis and TACR BOREC projects as well as Ministry of Culture PERO project.

Key persons: Prof. Dr. Ing. Pavel Zemčik, Ing. Tomáš Starka, Ing. Jan Pečiva, Ph.D., Ing. David Bařina, Ph.D., Ing. Markéta Juránková, Ph.D, Ing. Michal Kula, Ing. Martin Kolář, Ph.D.

- **Knowledge Mining from Documents and Multimedia**

- In 2019, we continued research in the document information extraction area as planned. The focus was on experimental evaluation of the proposed methods and improvements on large data sets. The research also focused, as planned, linking of the data contained in web documents to existing semantic databases such as DBPedia. Our research in the area of querying and mining data extracted from video continued as well with the focus on supporting infrastructure. We further focused the hidden sub-process analysis with use of advanced techniques, such as declarative mining approach. Part of the research was done in conjunction to the research carried out in the Ministry of Interior as well as Ministry of Culture and part of the results was released in the form of open software tools.

Key persons: Doc. Ing. Jaroslav Zendulka, CSc., Ing. Radek Burget, Ph.D., Ing. Vladimír Bartík, Ph.D.

- **3D geometric modelling**

- More research and development, performed in 2019, was done in robust algorithms and applications of 3D environment perception and modelling in robotic, especially for shared workspace applications where humans and robots collaborate. We focused on 3D geometry modelling from CT scans with applications in medicine. Novel approaches for learning and modelling tissue geometry based on deep learning techniques were explored as planned. The goal was to learn a tissue geometry from 3D image data in order to recover the optimal 3D geometry after an injuries. A software in the form of an open source was prepared. We continued the cooperation with GEODROM, s.r.o. especially on outdoor 3D mapping. The collaboration with the industrial partner TESCAN 3DIM (Czech Republic) continued also quite successfully.

Key persons: Ing. Zdeněk Materna, Ing. Martin Veřas, Ing. Michal Španěl, Ph.D., Ing. Oldřich Kodym.

- **Data presentation and visualization**

- In 2019, we made further progress with the algorithms of real-time rendering of realistic visual effects such as rain, snow, hail. We continued the research of automatic calibration of surveillance cameras for the purpose of visualization of data by augmented reality into the surveillance scenes. The impact is mostly targeted on traffic surveillance but we investigated also the possibility of application of the techniques in other surveillance domains. We continued the research in development of automatic calibration of cameras on rigid objects in order to provide data e.g. for augmented reality applications and we experimented with images with radial distortions and non-central optical axis. The algorithms were tested on real and simulated data and evaluated.

Key persons: prof. Ing. Adam Herout, Ph.D., Ing. Vítězslav Beran, Ph.D., Ing. Michal Matýšek

- **Acceleration in specialised hardware**

- Further research in high performance using heterogeneous architectures and energy consumption efficiency continued in 2019 and we studied algorithms in real situation applications, specifically in mapping of algorithms between FPGA and CPU in “connected” structures. We further investigated the real-time image processing and recognition in FPGA. Moreover, in 2019 we paid more attention on the possibilities of automated design tools, such as High Level Synthesis (HLS) in order to increase productivity of work and optimization of the circuit features. The results were evaluated on real life applications.

Key persons: Doc. Dr. Ing. Otto Fučík, Doc. Ing. Richard Růžička, Ph.D., MBA, Ing. Václav Šimek

- **Semantic web technologies**

- Efficiency of the parallel and distributed machine learning was one of key targets of our research in 2019, as also planned. We focused on advanced on-line learning mechanisms that can update the model based on newly available data in a fast update procedure. We also researched stream processing linked to distributed messaging platforms, such as Aeron or Apache Kafka, and attempted interconecion the results with advanced machine learning frameworks, such neural networks of Transformer types. We kept particular attention on GPU-based acceleration mechanisms that can overcome limits of standard distributed environments with loosely coupled GPU nodes. Without the GPU acceleration (using the standard CPUs), the results would not be possible to achieve.

Key persons: Doc. RNDr. Pavel Smrž, Ph.D., Ing. Lubomír Otrusina, Ing. Jaroslav Dytrych, Ph.D., Mgr. Petr Škoda

- **Formal languages and grammars**

- In 2019, inspired by the previous non-continuous approach, we investigated new coding of context dependencies in order to decrease the number of necessary context-sensitive rules without a drop of the expressiveness in the studied formal models. The models included scattered context grammars and tree-controlled grammars. Besides this, we continued our research of non-continuous processing of context information using jumping and regulated formal models. Furthermore, we developed additional models and methods of processing of loosely coupled context information in the grammars and automata. Moreover, we participated in a study of vulnerabilities of password-protected computer systems.

Key persons: Prof. RNDr. Alexander Meduna, CSc., Doc. Dr. Ing. Dušan Kolář, Ing. Zbyněk Krivka, Ph.D.

10.C Research outcomes

Type	Plan	Actual
Journal papers (imp)	5	13
Other papers (proceedings, ...)	21	26
Outcomes of applied research (patents, software, etc.)	6	3

Table 10.2 Key performance indicators of the research programme

A list of the 10 most important outcomes of the research programme in 2019:

1. NOVOTNÝ Ondřej, PLCHOT Oldřich, GLEMBEK Ondřej, ČERNOCKÝ Jan a BURGET Lukáš. Analysis of DNN Speech Signal Enhancement for Robust Speaker Recognition. *Computer Speech and Language*, roč. 2019, č. 58, s. 403-421. ISSN 0885-2308. IF = 1.857.
2. KŘIVKA Zbyněk, KUČERA Jiří a MEDUNA Alexander. Jumping Pure Grammars. *The Computer Journal*, roč. 62, č. 1, s. 30-41. ISSN 0010-4620. IF=0,980.
3. MUSIL Petr, JURÁNEK Roman, MUSIL Martin a ZEMČÍK Pavel. Cascaded Stripe Memory Engines for Multi-Scale Object Detection in FPGA. *IEEE Transactions on Circuits and Systems for Video Technology*, roč. 2020, č. 1, s. 267-280. ISSN 1051-8215. IF = 4.046.
4. DIEZ Sánchez Mireia, BURGET Lukáš, LANDINI Federico Nicolás a ČERNOCKÝ Jan. Analysis of Speaker Diarization based on Bayesian HMM with Eigenvoice Priors. *IEEE/ACM TRANSACTIONS ON AUDIO, SPEECH AND LANGUAGE PROCESSING*, roč. 2019, č. 11, s. 1-14. ISSN 2329-9290. IF = 3.531.
5. SZŐKE Igor, SKÁCEL Miroslav, MOŠNER Ladislav, PALIESEK Jakub a ČERNOCKÝ Jan. Building and Evaluation of a Real Room Impulse Response Dataset. *IEEE Journal of Selected Topics in Signal Processing*, roč. 13, č. 4, s. 863-876. ISSN 1932-4553. IF = 6.688.
6. ROHDIN Johan A., SILNOVA Anna, DIEZ Sánchez Mireia, PLCHOT Oldřich, MATĚJKA Pavel, BURGET Lukáš a GLEMBEK Ondřej. End-to-end DNN based text-independent speaker recognition for long and short utterances. *Computer Speech and Language*, roč. 2020, č. 59, s. 22-35. ISSN 0885-2308. IF = 1.857.
7. ŽMOLÍKOVÁ Kateřina, DELCROIX Marc, KINOSHITA Keisuke, OCHIAI Tsubasa, NAKATANI Tomohiro, BURGET Lukáš a ČERNOCKÝ Jan. SpeakerBeam: Speaker Aware Neural Network for Target Speaker Extraction in Speech Mixtures. *IEEE Journal of Selected Topics in Signal Processing*, roč. 13, č. 4, s. 800-814. ISSN 1932-4553. IF = 6.688.
8. KOČMAN Radim, KŘIVKA Zbyněk a MEDUNA Alexander. On Double-Jumping Finite Automata and Their Closure Properties. *RAIRO - Theoretical Informatics and Applications - Informatique Théorique et Applications*, roč. 52, č. 2, s. 185-199. ISSN 0988-3754. Scopus CiteScore=0,52.
9. VELAS Martin, ŠPANĚL Michal a HEROUT Adam. Indoor and Outdoor Backpack Mapping with Calibrated Pair of Velodyne LiDARs. *Sensors*, roč. 2019, č. 18, s. 34. ISSN 1424-8220. Dostupné z: <https://doi.org/10.3390/s19183944>. IF = 3.031.
10. Software: LENGÁL, Tomáš, BURGET Radek, ZELENÝ Jan: Implementace segmentačního algoritmu BCS, Projekt představuje novou implementaci algoritmu Box clustering segmentation. Tento algoritmus zajišťuje rychlou a přesnou segmentaci webových stránek pro jejich další zpracování. Implementace je poskytována jako samostatný rozšiřující modul stávajícího rámce FitLayout. (<https://www.fit.vut.cz/research/product/615/>).

10.D Project activity

International R&D projects:

Project title	Grant agency	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
MegaMaRt2 -MegaModelling at Runtime - scalable model-based framework for continuous development and runtime validation of complex systems.	H2020 ECSEL	2017-2020	266	5,721	A
SPEAKER DICE -Robust SPEAKER Diarization systems using Bayesian inferenCE and deep learning methods	H2020	2017-2019	1,321	3,855	A
ETE SPEAKER - Robust End-To-End SPEAKER recognition based on deep learning and attention models	H2020	2019-2021	2,031	3,142	A
FITOPTIVIS -From the cloud to the edge - smart IntegraTion and OPTimisation Technologies for highly efficient Image and Video processing Systems	H2020 ECSEL	2018-2020	779	9,134	A
OCCAM –OCR - ClassificAtion & Machine Translation	CEF	2019-2021	5,456	10,865	A
COMP4DRONES - Framework of key enabling technologies for safe and autonomous drones' applications	ECSEL	2019-2022	2,417	14,746	A
Cross-CPP -Ecosystem for Services based on integrated Cross-sectorial Data Streams	H2020-ICT	2018-2020	4,144	8,856	A
ATCO2 - Automatic collection and processing of voice data from air-traffic communications	H2020	2019-2022	2,005	3,714	A
ROXANNE -Real time network, text, and speaker analytics for combating organized crime	H2020	2019-2022	5,714	7,755	A

National grants / specific support:

Project title	Grant	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
CPK - Using Semantic Technologies to Access Cultural Heritage Through The Central Portal of Czech Libraries	MC	2016-2020	3,538	17,581	A

IT4Innovations Centre of Excellence
31st March, 2020

V3C - Visual Computing Competence Center	TA CR	2012-2019	6,725	53,374	A
Information Mining in Speech Acquired by Distant Microphones -DRAPÁK	Ministry of the Interior CZ	2015-2020	1,999	10,020	A
VRASSEO - Tools and Methods for Video and Image Processing to Improve Effectivity of Rescue and Security Services Operations	Ministry of the Interior CZ	2017-2020	6,445	23,165	A
PERO - Advanced content extraction and recognition for printed and handwritten documents for better accessibility and usability	MC	2018-2022	4,037	19,700	A
Neural Representations in multi-modal and multi-lingual modeling	GA CR	2019-2023	4,610	24,328	A
Improving Robustness in Automatic Speaker Recognition	GA CR	2017-2019	1,556	4,611	A
Research and development of diagnostic unit for forming machines - 4dot	Ministry of Industry and Trade CZ	4/2017-2019	600	1,820	A
BOREC - Colour Image in "Realtime Embedded Computing"	TA CR	2018-2020	1,364	4,104	A
SMARTCarPark - Surveillance Monitoring, Analysis and Re-identification of Traffic for Enhanced Car Parking	TA CR	2018-2020	2,715	8,145	A
System for image data analysis to attend needs of Police of the Czech Republic	Ministry of Industry and Trade CZ	2017-2018	-125		A
Employment of artificial intelligence into an emergency call reception	Ministry of Interior of the Czech Republic	2019-2020	972	5,343	A
MuSiC - Multi-level Security for Critical Services	MEYS CZ INTER EXCELLENCE	2018-2020	1,963	5,073	A
enetCollect- Large-Scale Information Extraction and Gamification for Crowdsourced Language Learning	MEYS CZ INTER COST	2018-2021	1,397	3,888	A

Distant Reading for European Literary History	MEYS CZ INTER COST	2018-2021	1,328	4,666	A
NOSICI - Neural networks for signal processing and speech data mining	TA CR	2018-2019	2,028	4,057	A
Collaborative robot 2.0: cognition of the work environment, augmented reality-based user interface, simple deployment and reconfiguration	TA CR	2017-2019	1,642	4,726	A
Computer-Aided Analysis and Prediction of Child Growth and Development	TA CR	2018-2021	452	1,350	A
Progressive Image Processing Algorithms	TA CR	2018-2021	1,285	3,138	A
SECURe SENSors and data	TA CR	2019-2020	962	6,908	A
TRACTOR: TRaffic Analysis and seCuriTy OpeRations for ICS/SCADA	TA CR	2019-2020	1,214	3,191	A
Artificial Intelligence Driven Autonomy - NaCCAS - AIDA	TA CR	2019-2020	4,890	11,140	A
AI for Traffic and Industry Vision - AITIV	TA CR	2019-2021	704	4,750	A
Flight Training Evaluation Software	TA CR	2019-2021	2,968	9,183	A
Development of indoor software for cycling - Rouvy AR	Ministry of Industry and Trade of the CZ	2017-2020	889	3,883	A
Deep-Learning Approach to Topographical Image Analysis	Ministry of Education, Youth and Sports CZ	2019-2022	639	3,900	A
Research and development of the monitoring part of forging presses –Sensory (4dot)	Ministry of Industry and Trade of the CZ	2019-2022	250	2,800	A
Test-it-off: Robotic offline product testing	Ministry of Industry and Trade of the CZ	2019-2021	867	6,110	A

Contract research:

Project title	Contracting authority	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (C-contracted, N-negotiated, P-planned)
Auto-Navigation for Urban Air Mobility	Honeywell	2019	940	940	C
Research and development for CadWork Informatik a.g.	CadWork Informatik a.g.	continuing	1,560		C
Research and Development	Raytheon BBN Technologies	continuing	3,748		C
Exploiting Language Information for Situational Awareness (ELISA)	LORELEI	2015-2019	1,172		C
Recognition, extraction and analysis of information in images	Alliu, s.r.o.	10/2019-3/2020	350	650	C
Project SRE - Speaker REcognition	ROI Hunter, a.s.	1/2019-12/2019	265	265	C
Speech enhancement frontend for robust automatic speech recognition with large amount of training data	NTT Corporation	1/2019-12/2019	665	665	C
Framework for Highly Integrated Advanced Systems AP2	ŠKODA AUTO a.s.	11/2019-12/2019	1,941	1,941	C
Deep learning methods for 3D image processing	TESCAN 3DIM, s.r.o.	1/2019-12/2019	870	870	C
Methods for extracting and detecting patterns in the program code	Avast Softw.	9/2017-8/2021	540	2,016	C
Image segmentation for mineralogical analysis	TESCAN Brno, s.r.o.	1/2019-12/2019	375	375	C
Development of VRUT application for Škoda auto	ŠKODA AUTO a.s.	3/2018-12/2019	1,173	1,736	C
Research of computer vision algorithms, enhanced reality and related user interfaces	ONEPROVE s.r.o.	ongoing	898	898	C
Configuration and security of an embedded sensor data acquisition system	CAMEA spol. s r.o.	11/2019-12/2020	600	1,500	C

IT4Innovations Centre of Excellence
31st March, 2020

Speaker Change Point Detection (SCPD) in media content	Ericsson	4/2018-9/2019	1,288	1,288	C
Improvements of the precision for mobile 3D mapping system	GEODROM, S.r.l.	6/2019-12/2019	375	375	C

11 Secure and Safe Architectures, Networks, and Protocols

11.A Research programme overview

The research is focused on advanced methods of modelling, design, validation, verification, simulation, adaptation, and testing of computer-based systems (including embedded systems), primarily considering the aspects of safety and security, and accenting parallel processing (multi- and many-core systems, accelerators based on specialized chips and FPGAs), high speed communication (high speed networks, internet of things), smart and adaptive systems, and low power solutions. Particular research goals are formed by the goals of the research projects the team members are involved in. The applied research and development is conducted under the umbrella of contract research. For 2019, the research objectives were formulated via the research objectives of NPU II, 15 national projects and EU projects (AQUAS, Arrowhead Tools, TETRAMAX, and PAMMOTH).

Responsible partner: FIT, Brno University of Technology
Head of research programme (HRP): Prof. Ing. Lukáš Sekanina, Ph.D.

RP structure	FTE
Senior researchers & HRP	11.65
Researchers	7.35
Research assistants	5.04
Research support staff	0
Total	24.04

Table 11.1 RP structure

11.B Research teams and their activities

- **Security of multi-agent systems, wireless sensor networks, and biometric systems**
 - In the area of biometric systems, we focused mainly on damaged fingerprints and face analysis. In the case of damaged fingerprints, the work consisted of capturing new fingerprints (we prepared a new scanning workplace for the University Hospital Brno, Department of Dermatovenerology), analysis (we developed algorithms for the detection of damage in the fingerprint image and determining whether it is accidental damage or a disease), production of fakes (the use of different materials and production methods) and the generation of synthetic fingerprints with various damages. For face technology, we have prepared a generator of various rotations of the 3D model of the real face and recognition of the 3D position of the head in a 2D image. We completed and evaluated a system based on multi-agent system principles that are applied in the context of wireless sensor networks.

Key persons: Prof. Ing. Martin Drahanský, Ph.D., Doc. Ing. František Zbořil, Ph.D.

- **Embedded systems, networks, and protocols**
 - The research was mainly focused on the design of new techniques for analysis of communication in industrial and IoT networks with respect to possibilities of security threat detection based on identified anomalies in network traffic. In this context, various

methods based on profile creation, statistical modeling and the use of machine learning methods for traffic classification have been explored. Big data processing methods for processing and advanced analysis of computer communication was our other research focus. In particular, we studied a combination of big data processing techniques with machine learning methods to identify and classify encrypted connections on the Internet. In the field of digital forensic analysis, we created interesting results in the detection of mining nodes of cryptocurrency networks and improved methods for distributed and GPU accelerated password recovery from secure documents.

Key persons: Doc. Ing. Ondřej Ryšavý, Ph.D., Ing. Petr Matoušek, Ph.D., M.A.

- **Computer architectures and diagnostics**

- In the area of fault tolerant systems implemented into FPGA, the resistance of control electronics of an electromechanical system based on a soft-core processor running on FPGA was compared with the application-specific control unit implemented with the use of VHDL. The resistance against faults of FPGA hardware reconfiguration controller was also investigated. In the area of networking hardware, we used approximate computing techniques to accelerate fast pattern matching in order to detect signatures of network attacks. New hardware architectures have been designed to accelerate IDS and lawful interception systems. We started to work on the hardware acceleration of encrypted traffic analysis. The goal was to get more information about the encrypted communication and detect security threats in network traffic.

Key persons: Doc. Ing. Zdeněk Kotásek, CSc., Ing. Jan Kořenek, Ph.D., Ing. Josef Strnadel, Ph.D., Ing. Tomáš Martínek, Ph.D.

- **HW/SW co-design**

- In the area of processor optimization automation for a specific application, we focused on searching for an optimal setting of different applications running on the same processor. As the proof of concept, we chose the parameterizable RISC-V processor. We developed an algorithm providing an optimal configuration of the processor under design. With the support of the aggregated Pareto front for common aggregated applications running on the processor, we tested various settings of the evolutionary algorithm which was employed to find the target solution. The method of Pareto front aggregation was published in 2019.

Key persons: Prof. Ing. Tomáš Hruška, CSc.

- **Evolvable hardware**

- The research was oriented to new applications of evolutionary circuit design. Excellent results were obtained, in particular, in approximate circuit design. Approximate circuits were employed to reduce power consumption in deep neural network accelerators. We also improved the algorithms exactly computing the error metrics in the context of approximate circuits. A co-evolutionary version of Cartesian genetic programming was proposed which enabled us to significantly reduce the time of evolution for challenging

symbolic regression tasks. We developed an FPGA-based accelerator capable of efficient randomness testing of bit sequences by means of evolving specialized circuits. Finally, evolutionary algorithms were employed to discover interesting implementations of Boolean functions relevant for cryptography.

Key persons: Prof. Ing. Lukáš Sekanina, Ph.D., doc. Ing. Zdeněk Vašíček, Ph.D., Ing. Michal Bidlo, Ph.D.

- **Automated verification**

- A lot effort was invested into research on efficient techniques for dealing with logics and automata as a basic building block of various verification approaches. In particular, we have proposed a new decision procedure for the WSkS logic (awarded by the best paper award of CADE 2019) as well as a new decision procedure for a rich class of formulae over strings (awarded the best paper award of ATVA 2019). We have also proposed an improved way of complementing Büchi automata with applications in software verification. Significant results have also been obtained in the area of automated synthesis of probabilistic systems where a novel approach based on automatically refined abstraction was proposed. Further, our experience with automata has been exploited for developing new techniques for approximate reduction of non-deterministic automata used for hardware-accelerated network traffic monitoring. Finally, in cooperation with Microsoft Research Redmond (USA), we have proposed a new approach for determinizing automata with bounded counters paving a way for efficient pattern matching with regular expressions extended with bounded repetition constraints (applicable, e.g., when analyzing security-critical logs).

Key persons: Prof. Ing. Tomáš Vojnar, Ph.D., doc. Mgr. Adam Rogalewicz, Ph.D., Ing. Ondřej Lengál, Ph.D., RNDr. Milan Češka, Ph.D., Ing. Bohuslav Křena, Ph.D., Ing. Aleš Smrčka, Ph.D.

- **Modelling, simulation, and optimization**

- Research was focused on the specification and implementation of distributed control systems using various variants of Petri nets. A potential application of Petri nets variants in the design and implementation of IoT was further investigated. The purpose of these activities is to gradually improve our concept of modeling and development of control applications with respect to reliability and security.

Key persons: Doc. Ing. Vladimír Janoušek, Ph.D., Ing. Radek Kočí, Ph.D.

- **Supercomputing technologies**

- The Supercomputing research group carried out research in the area of ultrasound propagation and photoacoustic imaging of the breast within the H2020 PAMMOTH project. The group focused on advanced techniques of photoacoustic image reconstruction employing progressive grid refinement during the gradient descent solver computation. The solver starts from a coarse resolution providing rough estimations of the photoacoustic image very quickly and then gradually finer the grid resolution to

obtain a high quality image. This method significantly decreases the computational requirements. The group also worked on acceleration of the gradient solver using multi-GPU systems, such as Nvidia DGX-2 which achieved excellent results in scaling. The group also improved and extended the platform for automatic scheduling, executing, and monitoring of particular computations during the photoacoustic tomography further minimizing the user intervention.

Key persons: Doc. Ing. Jiří Jaroš, Ph.D.

11.C Research outcomes

Type	Plan	Actual
Journal papers (imp)	5	13
Other papers (proceedings, ...)	24	34
Outcomes of applied research (patents, software, etc.)	6	9

Table 11.2 Key performance indicators of the research programme

A list of the 10 most important outcomes of the research programme in 2019:

1. ABDULLA Parosh A., ATIG Mohamed F., BUI Phi Diep, HOLÍK Lukáš a JANKŮ Petr. Chain-Free String Constraints. In: Proceedings of ATVA'19. Cham: Springer International Publishing, 2019, p. 277-293. ISBN 978-3-030-31783-6. **Best paper award at ATVA 2019.**
2. ČEŠKA Milan, HAVLENA Vojtěch, HOLÍK Lukáš, KOŘENEK Jan, LENGÁL Ondřej, MATOUŠEK Denis, MATOUŠEK Jiří, SEMRIČ Jakub a VOJNAR Tomáš. Deep Packet Inspection in FPGAs via Approximate Nondeterministic Automata. In: Proceedings of the 27th IEEE International Symposium on Field-Programmable Custom Computing Machines (FCCM). San Diego, CA: IEEE, 2019, p. 109-117. ISBN 978-1-72811-132-2.
3. DRAHANSKÝ Martin a KANICH Ondřej. Influence of Skin Diseases on Fingerprints. Biometrics under Biomedical Considerations. Singapore: Springer Nature Singapore, 2019, p. 1-39. ISBN 978-981-1311-44-4.
4. DRAHOŠOVÁ Michaela, SEKANINA Lukáš a WIGLASZ Michal. Adaptive Fitness Predictors in Coevolutionary Cartesian Genetic Programming. Evolutionary Computation, Vol. 27, No. 3, p. 497-523, 2019. ISSN 1063-6560.
5. HAVLENA Vojtěch, HOLÍK Lukáš, LENGÁL Ondřej a VOJNAR Tomáš. Automata Terms in a Lazy WSkS Decision Procedure. In: Proceedings of 27th International Conference on Automated Deduction (CADE-27). Natal: Springer Verlag, 2019, s. 300-318. ISSN 0302-9743. **Best paper award at CADE-27.**
6. HRANICKÝ Radek, ZOBAL Lukáš, RYŠAVÝ Ondřej and KOLÁŘ Dušan. Distributed password cracking with BOINC and hashcat. Digital Investigation, Vol. 2019, No. 30, p. 161-172, 2019. ISSN 1742-2876.
7. MRÁZEK Vojtěch, SEKANINA Lukáš, DOBAI Roland, SÝS Marek a ŠVENDA Petr. Efficient On-Chip Randomness Testing Utilizing Machine Learning Techniques. IEEE Transactions on Very Large Scale Integration (VLSI) Systems, Vol. 27, No. 12, p. 2734-2744, 2019. ISSN 1063-8210.
8. VAŠÍČEK Zdeněk. Formal Methods for Exact Analysis of Approximate Circuits. IEEE Access, Vol. 7, No. 1, p. 177309-177331, 2019. ISSN 2169-3536.
9. VESELÝ Vladimír and ŽÁDNÍK Martin. How to detect cryptocurrency miners? By traffic forensics!. Digital Investigation, Vol. 2019, No. 31, p. 1-25, 2019. ISSN 1742-2876.

10. WISE Elliott S., COX Ben T., JAROŠ Jiří and TREEBY Bradley E. Representing arbitrary acoustic source and sensor distributions in Fourier collocation methods. The Journal of the Acoustical Society of America, Vol. 146, No. 1, p. 278-288, 2019. ISSN 1520-8524.

11.D Project activity

International R&D projects:

Project title	Grant agency	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
AQUAS: Aggregated Quality Assurance for Systems	ECSEL JU	2017-2020	684	22,995	A
TETRAMAX: TEchnology TRAnsfer via Multinational Application eXperiments	H2020	2018-2021	452	3,937	A
Arrowhead Tools - Arrowhead Tools for Engineering of Digitalisation Solutions	ECSEL	2019-2022	1,369	11,494	A
PAMMOTH - Photoacoustic/Ultrasound Mammoscopy for evaluating screening-detected lesions in the breast	H2020	2017-2020	3,617	10,395	A

National grants / specific support:

Project title	Grant	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (A-accepted, S-submitted, P-planned)
Designing and exploiting libraries of approximate circuits	GA CR	2019-2021	2,241	6,936	A
Automata for Decision Procedures and Verification	GA CR	2019-2021	1,797	5,538	A
ROBUST - veRificatiOn and Bug hUnting for advanced SofTware	GA CR	2017-2019	1,714	4,920	A
IotCloud - Intelligence for IoT systems	TA CR	2017-2019	731	2,192	A
IRONSTONE - IoT monitoring and forensics	TA CR	2016-2019	2,062	6,991	A
Smart Application Aware Embedded Probes -SProbe	Ministry of the Interior CZ	2015-2019	2,975	21,691	A
Integrated Platform for Analysis of Digital Data from Security Incidents- TARZAN	Ministry of the Interior CZ	2017-2020	4,754	16,756	A
Security monitoring of ICS communication in the smart grid - BONNET	Ministry of the Interior CZ	2019-2022	621	11,195	A

Flexible probe for lawful interceptions - FlexProbe	Ministry of the Interior CZ	2019-2022	2,776	17,958	A
Advanced Methods of Nature-Inspired Optimisation and HPC Implementation for the Real-Life Applications	MEYS CZ – INTER COST	2018-2020	780	1,381	A
DEMOS - Possibilities for creation of community genealogical database with semantic information and uncertainty	TA CR	2018-2021	1,157	3,471	A
Validated Data Storage	Ministry of Industry and Trade of the CZ	2019-2021	704	2,818	A
KYPO4Industry	TA CR	2019-2020	112	2,295	A
Survey and education of citizens of the Czech Republic in the field of biometrics	TA CR	2019-2021	753	2,480	A
AuFoVer - Automated Formal Verification	TA CR	2019-2021	1,500	4,497	A

Contract research:

Project title	Contracting authority	Total implementation period	Funds used for RP in 2019 (1000 CZK)	Total funds planned for RP (1000 CZK)	Status (C-contracted, N-negotiated, P-planned)
Implementation and Debugging of Systems	Cesnet	ongoing	1,440		C
User interface of EV charge station	KPB Intra s.r.o.	4/2019-8/2019	360	360	C
Acceleration of the DNS collector	CZ.NIC	ongoing	639		C