CATALOGUE OF TECHNOLOGIES

IVANNIKOV INSTITUTE
FOR SYSTEM PROGRAMMING
OF THE RAS

ISP RAS

MOSCOW
2023

CATALOGUE
OF TECHOLOGIES

2023

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of the Russian Academy of Sciences

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2023. 75TH ANNIVERSARY OF NATIONAL INFORMATION TECHNOLOGY

ARUTYUN AVETISYAN

Academician of the RAS,
ISP RAS Director

The 2023 collection presents 27 technologies, which are divided into thematic blocks. The section “ISP RAS: Ecosystem of Innovation” provides a detailed description of the model of the institute’s development and lists the current areas of work, followed by the annual results of the activities of ISP RAS-based research centers. But first, on to this year’s main theme.

This year we celebrate the 75th anniversary of national information technology. The term appeared in the late 1950s, but the technology itself appeared earlier. In Russia, the significant starting point is December 4, 1948. On that day, Isaak Bruk, a corresponding member of the Soviet Academy of Sciences, and Bashir Rameyev, a designer, submitted to the State Special Committee of the Soviet Council of Ministers an application for the invention of an automatic digital computer. Copyright Certificate No. 10475 was the first document that marked the beginning of work on the creation of Russian computers.

On June 29, 1948, the Institute of Precision Mechanics and Computing Engineering of the Academy of Sciences (ITMiVT), later headed by the outstanding scientist Sergey Lebedev, was founded, and on December 19 of the same year, the Special Design Bureau No. 245 was established. A number of machines were created in the country: MESM, Strela, M-100, Dnepr, and others, among them BESM-6, the first domestic supercomputer, whose operating speed was one million operations per second. BESM-6 is exhibited in the Science Museum in London as one of the best supercomputers of its time.

In 1949, the Department of Computational Mathematics was opened at the Faculty of Mechanics and Mathematics of Lomonosov Moscow State University, and the first system programmers were trained. In the 1970s, on the initiative of academician Andrey Tikhonov, faculties of computational mathematics and cybernetics began to open all over the country. The emergence and development of the Russian segment of the Internet is also inextricably linked to science. The first domestic network was created at the Kurchatov Institute and connected to the global Internet in 1990.

The results of this work and the established scientific schools ensured the long-term development of the IT industry, which continued to develop in the post-Soviet period. Examples of such successful development are the Viktor Ivannikov Institute for System Programming of the Russian Academy of Sciences, which grew out of Sergey Lebedev's scientific school, world-famous companies such as Yandex, Kaspersky Lab, and others.

The IT industry in Russia remains globally competitive. It is constantly growing: for example, in 2022 the volume of goods and services sold by Russian software companies increased by 27% compared to 2021.

Our institute also continues its harmonious development. In 2023 we have opened the Technology Center for Security Analysis of System Software; we formed a consortium of companies that work with us to test the Linux kernel and key system components (OpenSSL, QEMU + libvirt, NodeJS, etc.). More than 250 bug fixes have been applied to the Linux kernel alone.

The major area of development is artificial intelligence. Research and development is being carried out in three areas. First, AI is being used to extend the capabilities of our security analysis tools. For example, in the Svace static analyzer, we are working on applying machine learning to filter out false positives, as well as exploring the use of large language models - especially to improve the accuracy of analysis. The SafeC secure compiler uses AI technologies to automate the checking of code for compliance with security classes. The Crusher dynamic analysis suite uses AI to improve mutation quality and documentation understanding.

Second, at the Research Center for Trusted Artificial Intelligence (RCTAI) at ISP RAS, we create tools for developing AI solutions, in particular, software tools to combat new threats. We have created trusted versions of the TensorFlow and PyTorch machine learning frameworks, which have already been implemented in Kaspersky Machine Learning for Anomaly Detection v. 3.0. More than 60 fixes suggested by us have been included in the main branches of the frameworks. Tools for evaluating the resistance of trained models to attacks, tools for increasing confidence in pre-trained models and others are being developed. We are also creating a trusted version of Talisman, a platform for building intelligent information analysis systems that integrates more than 50 machine learning models.

Third, AI is actively used in our interdisciplinary projects. The Talisman platform has been implemented in the educational process of the Russian Foreign Ministry's MGIMO University and is used for intelligent data analysis in the field of international relations. A joint project of ISP RAS and MGIMO in 2023 received the Gravity Prize in the special nomination "Discovery of the Year." The project is being developed in the field of digital medicine. The cloud platform of the National Center for Medical Research "Digital Biodesign and Personalized Healthcare" was created and deployed at Sechenov University, providing services for collection, markup and analysis of medical big data. The development and implementation of a neural network model for classification of 12-channel ECGs is underway and is currently being registered as a medical device. The development of DocMarking, a system for improving information security, continues; this is a system for embedding digital watermarks in text documents, based on the results of research in steganography, digital image processing, and machine learning.

The relevance of interdisciplinary research is also reflected in the topics of two of the five PhD theses defended at ISP RAS in 2023: on text analysis for the detection of interlingual plagiarism, and on the construction of a software pipeline for sequence alignment in bioinformatics applications.

Our institute is an organizational structure around a scientific school that has been growing and developing for many years. We continue the traditions of our teachers, and the great history of national science inspires us to new successes and achievements.

ISP RAS: AN INNOVATION ECOSYSTEM

ISP RAS activities are aimed at deploying fundamental research results in industry. The institute's business model consists of three closely related activities producing a synergistic effect:

- project-oriented fundamental and applied research aimed at creating new technologies (under contracts with Russian and foreign companies, the Ministry of Science and Higher Education of Russia, RAS programs, grants from Russian Science Foundation and from Advanced Research Foundation, etc.);
- deploying new technologies in partner companies and developing innovations based on industry feedback;
- educating students and postgraduates based on developed technologies (while participating in the institute's research and industrial projects).

This model of industrial research plus education is well known and applied in research laboratories of leading universities (Stanford, MIT, Berkeley, Carnegie Mellon) and industrial giants (IBM, Intel), as well as in state research centers (INRIA, Fraunhofer). When implemented effectively, the model solves the problem of the gap between science and industry, and produces highly qualified specialists in system programming.

FUNDAMENTAL RESEARCH

Fundamental research and experimental works are necessary elements of the institute's activities, allowing it to move in line with the latest trends in the IT world, as well as generate its own ideas for projects with its business partners. ISP RAS works on a large number of scientific and educational programs and cooperates with leading Russian and foreign universities and scientific centers. This allows to provide high quality research results, while ISP RAS reputation in academic and university circles makes it possible to introduce domestic technologies to international markets.

ISP RAS publishes its own journal called "Proceedings of ISP RAS," indexed in the Russian Science Citation Index (RSCI).

The institute is also responsible for publishing and editing the RAS journal called "Programming". Both are included in the journal list of Higher Attestation Commission (the VAK).

DEPLOYMENT

ISP RAS deploys its research results in various industrial and research enterprises, which use and promote the institute's technologies. Most of the work is carried out under contract with long-term partners, the most important of which are Samsung, Kaspersky Lab, Security Code (Kod Bezopasnosti), Open Mobile Platform, SberTech, JSC NPO RusBITech, Gos-NIIAS, and Bazalt SPO. Currently, the Institute's technologies are used in more than 100 companies.

SCIENTIFIC COLLABORATION

Long-term cooperation with ISP RAS can be organized in a form of a joint laboratory. Having permanent funding, they allow planning flexibly available resources as well as increasing competencies in the newly emerging areas of system programming and organizing the training of young specialists with the skills needed by partners.

Since 2009, the institute has operated a joint laboratory with Samsung (aimed at program analysis, including security in the context of Android and Tizen OS, as well as research on the application of artificial intelligence and data analysis methods to software engineering tasks). In 2019, joint laboratories with Huawei were opened. There is also a laboratory for solving continuum mechanics problems that implements research projects requested by industrial enterprises. Since 2021, ISP RAS has operated the intelligent digital foresight and media data lab.

The institute also has a linguistic laboratory based on the Lingvodoc platform, documenting endangered languages. This research is carried out jointly with the RAS Institute of Linguistics, Tomsk State University, and other universities and research centers. In 2023, four groups of researchers from several Russian cities took part in additional training courses on "Using the features of the Lingvodoc platform in the work of linguists" (including at the Bashkir State University and the People's Friendship University of Russia). At the open sessions of the All-Russian Forum of Young Native Language Teachers in St. Petersburg and Saransk, master classes on the use of the learning platform in the classroom were held in cooperation with the Institute for Educational Development Strategy.

CENTERS

The important mission of ISP RAS is creating and moderating multidisciplinary communities. Three such centers have been launched and are currently in operation:

- World-class Research Center (WCRC) "Digital biological design and personalized healthcare," jointly with Sechenov University, Institute of Biomedical Chemistry, Yaroslav-the-Wise Novgorod State University, Institute for Design-Technological Informatics of RAS;

- Trusted AI center, jointly with Ministry of Economic Development, academia (MIPT, Skoltech, Medical Scientific Center and the Faculty of Mechanics and Mathematics of Moscow State University, Innopolis University, Lobachevsky University, Psychology Institute of RAS, Joint Supercomputer Center of RAS) and industry (Kaspersky Lab, EC-leasing, InterProCom, Technoprom).
- Technology center for security analysis of system software, jointly with FSTEC of Russia and with active participation of leading Russian IT companies. The software includes the Linux kernel and critical open source system components. In 2023, a consortium of organizations for collaborative research has been established based around the Technology Center.

INTELLECTUAL PROPERTY

ISP RAS business model suggests that IP rights are either retained by the institute or transferred to an open source developer community under special agreements. Taking into account the specifics of this model, ISP RAS developed a unique license based on the direct financing by the customer of the research and development for the licensed technology (instead of paying royalties). The customer gets non-exclusive rights for using the technology, and the institute retains the exclusive IP rights. For some cases, decisions on managing IP rights are made individually based on long-term collaboration perspectives. An example of such an exception is the collaboration with Advanced Research Foundation, which assumes transferring all IP rights to the customer.

OPEN SOURCE

One of the most important components of the created ecosystem is the widely used open source software that is absolutely necessary for modern system programming. Open source is considered as:

- a tool that provides legitimate free access to all modern technologies, including ready-to-use software products and open standards;
- an ability to ensure the institute innovative research without outsourcing contracts but interacting with global market of products and services;
- a powerful educational resource, as the environment and infrastructure of international open source projects can be used to train engineers.

Scientific activity implies the result's openness and the visibility of its author, which often contradicts IT corporate policies. For ISP RAS, the openness of research results is both motivation for work, and a tool for promoting the institute's technologies. Open research means that each young researcher is visible in the international IT community. Their contribution and reputation are their capital, and the institute does everything to ensure that this capital grows as quickly as possible.

EDUCATION

The ISP RAS innovation ecosystem cornerstone is educational activity, which is performed in several directions:

- Cooperating with leading universities. Institute specialists are working on system programming departments of MSU, MIPT, and HSE. Starting from their first year, students attend system programming lectures and corresponding practical lessons. In the third year, students join the departments for system programming and, while continuing to attend lectures, start to work in special seminars, get acquainted with the institute's scientific directions, participate in projects and receive a special scholarship. By the time of graduation, many students have scientific publications and become system programming experts.

ISP RAS researchers are constantly advancing cybersecurity field as a scientific direction, which results in updating education courses and bachelor programs. For example, in 2021 ISP RAS started academic advising to modernize the software engineering bachelor program at the Faculty of Computer Sciences at Higher School of Economics. In 2022 an agreement was signed with the Chuvash State University and CaseSystems-Security LLC (Cheboksary). The parties will jointly participate in the development of academic disciplines of the Faculty of Informatics and Computer Science. A laboratory for system programming and secure software development will be opened at ChSU.

Cooperation with Bauman Moscow State Technical University is expanding. The IU-10 chair has launched a specialization course "Information Security Certification System," a seminar for students interested in a systematic approach to various aspects of cybersecurity, and plans are underway to optimize specialization curricula so that courses devoted to cybersecurity and code analysis are studied in the first years of study. ISP RAS cooperates with Saratov State University: students in Saratov write theses and papers under the supervision of the Institute's staff, and also participate in projects, in particular, in the development of a secure compiler. In 2022, a cooperation agreement was signed between ISP RAS and the Moscow Power Engineering Institute (MPEI).

Work is also underway in other areas. In 2022, together with the Russian Foreign Ministry's State University of International Relations (MGIMO), a master's program "Data Analysis and Dynamics of International Processes" was launched to train specialists in data analysis, artificial intelligence, and modeling of socio-economic processes. Work is being carried out within the joint laboratory of intelligent data analysis. In 2023, the joint project of ISP RAS and MFA MGIMO of Russia received the Gravity Prize in the special nomination "Discovery of the Year." The project is dedicated to the deployment of the ISP RAS Talisman platform in the educational process of MGIMO.

In addition, ISP RAS has launched a joint project with the Russian-Armenian University (RAU) and the company Antiplagiat to develop methods for automatic detection of plagiarism in text documents in different languages. The work will use deep neural network models, which will help to analyze

texts in more detail, as well as to develop universal analysis methods. In 2023, with the support of ISP RAS, a joint research group was established at the Matrosov Institute of Dynamics and Theory of Systems of the Siberian Branch of the Russian Academy of Sciences. The main activities include the development of software tools for the analysis of electronic documents and natural language processing. The participants of the group are researchers of the Institute of Dynamics of Systems Theory of the Siberian Branch of the Russian Academy of Sciences and fellows of the joint program of ISP RAS and the Institute of Mathematics and Information Technologies of ISU.

In 2022 ISP RAS has become a partner of the Moscow Aviation Institute, MAI, in the federal project “Advanced Engineering School” dedicated to the development of a new generation of aircraft. It is planned to open a joint laboratory and launch a new master’s program on UAVs. Together with the MAI and other organizations, the Institute has joined the New Aerospace Markets consortium as part of the Priority 2030 program. As part of the same program, in 2023 ISP RAS employees participated in the MAI Digital Chair educational project in the areas of “Artificial Intelligence in Earth Remote Sensing” and “Digital Modeling and Supercomputing Technologies.” In addition, representatives of ISP RAS supervised graduate students at MAI and took exams.

Starting from 2017, ISP RAS has been actively working with Samsung at the Samsung IT Academy. In particular, employees of the Institute are on the jury of the Interuniversity Project Competition, which is held annually to demonstrate the best practices and results of educational activities implemented in the Academy’s partner universities.

- Scholarship program. In support of educational processes, ISP RAS launched a special scholarship program for students and postgraduates of MSU, MIPT, HSE, Novgorod State University, Russian-Armenian University and others.
- ISP RAS postgraduate study helps gain practical experience and learn new technologies at the same time. Postgraduates are actively involved in education: they organize seminars and practical classes for students, supervise term papers and theses. With that kind of experience, they usually become leaders of small research groups.
- System programming labs network. Currently, ISP RAS external labs are working in Yerevan, Veliky Novgorod, Orel, Plekhanov Russian University of Economics. The laboratories attract successful students (including postgraduate students), and involve them in the development of promising technologies in close cooperation with industry.

CONFERENCES

ISP RAS organizes a number of annual events:

International ISP RAS Open Conference:
https://www.isprasopen.ru/en

OS DAY, a conference on science and practice (jointly with other organizers): https://www.osday.ru/

International Ivannikov Memorial Workshop:
https://www.ivannikov-ws.org/en

International Conference On Data Science In Medicine (jointly with other organizers): https://digital-med.ru/en

SYRCoSE Software Engineering Colloquium:
http://syrcose.ispras.ru/

The “System Programming as a Key Direction for Counteracting Cyberthreats” roundtable (International Military-Technical Forum “Army”)

2023. WORLD-CLASS RESEARCH CENTER (WCRC)
DIGITAL BIODESIGN AND PERSONALIZED HEALTHCARE

JOINTLY WITH SECHENOV UNIVERSITY, INSTITUTE OF BIOMEDICAL CHEMISTRY, YAROSLAV-THE-WISE NOVGOROD STATE UNIVERSITY, AND INSTITUTE FOR DESIGN-TECHNOLOGICAL INFORMATICS OF RAS

MOST IMPORTANT RESULTS OF 2023 INCLUDE THE FOLLOWING:

CLOUD PLATFORM WCRC "DIGITAL BIODESIGN AND PERSONALIZED HEALTH CARE" WAS CREATED AND DEPLOYED AT SECHENOV UNIVERSITY.

The WCRC platform developed by ISP RAS offers the following services:

- basic cloud services (e.g., on-demand virtual servers and blockchain appliances);
- services for collecting, storing and analyzing big medical data;
- services for medical data annotation and for applying machine learning algorithms to solve problems in the biomedical domain;
- services to support collaborative research processes.

The platform is implemented on the basis of the Asperitas cloud environment (ISP RAS). In 2023, the platform includes functionality for the formation of a scientific knowledge base in medical research using technologies for the collection and analysis of large amounts of data, implemented on the basis of the Talisman information and analysis system (ISP RAS). Testing of cloud services was performed on the example of web-labs for analysis of electrocardiogram data and histological images. By the end of 2024, it is planned to enable full-scale pilot operation with the possibility of connecting external participants.

The WCRC platform can be deployed on the basis of the ISP RAS cloud infrastructure or third-party cloud infrastructure for current biomedical tasks developed within the WCRC, or adapted to the tasks of other medical domains.

FURTHER WORK ON DEVELOPMENT AND IMPLEMENTATION OF THE NEURAL NETWORK MODEL OF 12-CHANNEL ECG CLASSIFICATION IS IN PROGRESS.

The neural network model of 12-channel ECG classification was trained on data from different regions (Republic of Tatarstan, Moscow, Velikiy Novgorod), integrated into the "Unified Cardiologist" system, and tested on ECG data from the Republic of Tatarstan. A cooperation agreement was signed with A.S. Puchkov Emergency and Urgent Medical Aid Station. Several tens of thousands of ECGs received from the station were analyzed. The quality of prediction models is comparable to 10-second 12-channel ECGs. Test protocols have been signed. The product is currently undergoing registration as a medical device.

PREVIOUSLY AT WCRC:

A MOCK-UP OF A 12-CHANNEL ECG MARKUP SYSTEM HAS BEEN DEVELOPED (HTTP://ECG1.ISPRAS.RU)

High-quality standardized markup based on a predetermined list of pathologies helps achieve a high degree of agreement between specialists. The layout of the markup system has been prepared for integration into the ISP RAS Asperitas cloud platform for transparent scaling of ECG storage and analysis capacities, but it can be also integrated into a third-party cloud ecosystem.

A NEURAL NETWORK MODEL OF ENDONET CELL NUCLEI DETECTION ON HISTOLOGICAL PREPARATIONS WAS TRAINED

The neural network was trained on the EndoNuke marked histological data set assembled jointly with the partners (PFUR, State Clinical Hospital No 31, V.I. Kulakov Institute of General Medicine, Novgorod State University, and the Research Institute of Human Morphology). The core detection model is embedded in the open software platform for bioimage analysis QuPath using the ISP RAS Fanlight technology. The modified QuPath platform and the open source CVAT image markup system are prepared for integration into the ISP RAS Asperitas cloud platform.

2023. TECHNOLOGY CENTER FOR SECURITY ANALYSIS

JOINTLY WITH FSTEC OF RUSSIA AND LEADING COMPANIES
PORTAL.LINUXTESTING.RU

MOST IMPORTANT RESULTS OF 2023:

ORGANIZATIONAL ACHIEVEMENTS:

- consortium formed to support the Linux Kernel Security Research Technology Center, with 33 organizations joining;
- infrastructure for open source research into critical components of system software has been established;
- a unified center for system software security research has been formed on its basis.

METHODOLOGICAL ACHIEVEMENTS:

- methodologies were prepared for conducting research on Linux kernel, OpenSSL, NGinx, QEMU, libvirt, podman, .NET6 Runtime, ASP.NET Core;
- recommendations were prepared on how to configure the kernel to improve its security;
- recommendations were prepared for configuration of trusted kernel boot.

TECHNOLOGICAL ACHIEVEMENTS:

- maintenance of the second branch of the Linux kernel based on the 6.1 stable version began;
- 17 thousand warnings of the Svace static analysis tool (developed by ISP RAS) were analyzed;
- more than 250 patches have been prepared and merged into the main kernel branch;
- patches were prepared and merged into the main branches of OpenSSL, QEMU, libvirt, CPython, Lua, .NET6 Runtime components.

TECHNOLOGY CENTER PARTNERS:

- JSC Aladdin R.D.
- OOO Aideco
- OOO ANKAD
- OOO “Basalt SPO”
- JSC Baikal Electronics
- OOO BELLSOFT
- ZAO ZET
- JSC IVK
- OOO Inferit
- JSC InfoTeX
- ITB LLC
- “Kod bezopasnosti” LLC
- “Confident” Ltd.
- JSC NTTs “Module”
- JSC MCST
- JSC NPPKT
- Open Mobile Platform LLC
- OOO Otkrytaya mobilnaya platforma
- OOO PLC Technology
- RASU JSC
- RED SOFT LTD.
- RusBITech-Astra LLC
- FSUE RFYaTs–VNIIEF
- JSC MVP “SVEMEL”
- OOO TekhArgos
- LLC “Factor TS”
- JSC FINTEKH
- OOO Usergate
- JSC NPO Echelon
- OOO “YANDEX.CLOUD”

EDUCATION PARTNERS:

- Lomonosov Moscow State University
- Moscow Institute of Physics and Technology
- HSE University
- Vologda State University
- Moscow Power Engineering Institute
- Bauman Moscow State Technical University
- Voronezh State University
- Ilya Ulyanov Chuvashia State University

2023. RESEARCH CENTER FOR TRUSTED ARTIFICIAL INTELLIGENCE

IN COOPERATION WITH THE MINISTRY OF ECONOMIC DEVELOPMENT OF RUSSIA,

THE ACADEMIC COMMUNITY (MIPT, SKOLTECH, MOSCOW STATE UNIVERSITY MEDICAL RESEARCH AND EDUCATION CENTER, MOSCOW STATE UNIVERSITY FACULTY OF MECHANICS AND MATHEMATICS, INNOPOLIS UNIVERSITY, NIZHNY NOVGOROD LOBACHEVSKY STATE UNIVERSITY, PSYCHOLOGY INSTITUTE OF THE RUSSIAN ACADEMY OF SCIENCES, JOINT SUPERCOMPUTER CENTER OF THE RUSSIAN ACADEMY OF SCIENCES),

AND THE IT INDUSTRY (KASPERSKY LAB, EC-LEASING, INTERPROCOM, TECHNOPROM).

THE MOST IMPORTANT ACHIEVEMENTS OF 2023:

- An alienable methodology for developing trusted machine learning frameworks (TensorFlow, PyTorch) has been created.
- A team has been formed that can quickly patch vulnerabilities in the underlying machine learning software, ensuring technological independence in the development of artificial intelligence systems.
- Over 60 patches have been incorporated into major framework releases.
- Trusted versions of frameworks tested on solutions of RCTAI's industrial partners are implemented in Kaspersky Machine Learning for Anomaly Detection v. 3.0. Certification for a new customer, KT Unmanned Systems JSC, is in progress.
- A trusted version of the Talisman platform for building intelligent information and analytics systems has been created, integrating more than 50 machine learning models and meeting the criteria for trust in systems using AI technologies (criteria developed under the RCTAI program). The trusted version is currently being tested by industrial partners: CJSC EC-Leasing and Interprocom.
- A cloud-based platform is being created to analyze and develop trusted systems using AI technologies. The platform combines software tools and techniques to address fundamentally new threats that arise at all stages of the life cycle of relevant technologies:
  - trusted machine learning frameworks and libraries;
  - tools for checking for anomalies in data sets;
  - tools to assess the resilience of trained models to attacks;
  - tools for increasing confidence in pre-trained models;
  - methods for protecting models from attack in production;
  - methods for explaining models;
  - methods to detect data drift;
  - methods for detecting model bias.

1 PROGRAM ANALYSIS AND CYBERSECURITY

ASTRAVER TOOLSET: A VERIFICATION TOOLSET

AstraVer Toolset is a deductive verification system for key software components. It allows developing and verifying security policy models as well as proving the correctness of software modules written in the C programming language. AstraVer is essential for ensuring the required trust levels from ADV_SPM and ADV_FSP assurance families as defined in the ISO/IEC 15408 standard.

FEATURES AND ADVANTAGES

AstraVer Toolset is a set of tools designed for industrial use. It is based on many years of scientific research and combines two verification approaches: at the model level and at the code level. Parts of the AstraVer Toolset are similar to Microsoft VCC and Frama-C WP, but unlike those AstraVer is specifically designed to support the key security components' verification in the Linux kernel. AstraVer Toolset is free and open source, available at http://linuxtesting.org/astraver.

AstraVer provides:

- An integrated approach to verification, supporting the formalization of high-level requirements and analyzing the C source code behavior.
- Modeling and formalizing functional requirements, proving internal consistency and unreachability of insecure states. Testing whether functional requirements are satisfied in an implementation, using their formal models to check the correctness of the observable behavior and to evaluate the quality of testing and generated test cases.
- Verification of critical components written in C (requirements' formalization, correctness proof on all possible input values).
- Support for real industrial C code (GCC compiler extensions, arithmetic operations with bitwise precision, address arithmetic including the container_of intrinsic, function pointers, casting).
- Adhering to the protection profile requirements (ISO/IEC 15408), such as
  - formal security policy modeling;
  - formal verification of internal consistency of a security policy model;
  - formal proof that the target system cannot reach an insecure state;
  - a formal or a semi-formal functional specification development;

- a formal/semi-formal proof of correspondence between the security policy model and the functional specification; a formal/semi-formal proof of correspondence between different representations of target software, like functional specification, design and source code.
- Ability to adjust the toolset for a specific customer to perform the C source code components verification.

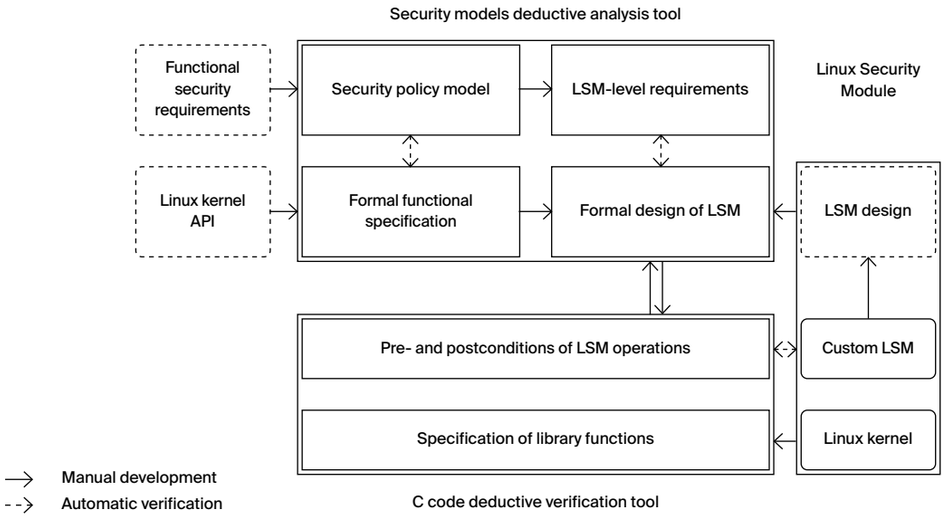
WHO IS ASTRAVER TARGET AUDIENCE?

- Companies developing critical systems, including software in aviation, railway, medical and nuclear power industries.
- Companies that need to certify their software as guided by the ISO/IEC 15408 standard.
- Certification laboratories for information protection software.

ASTRAVER DEPLOYMENT STORIES

AstraVer Toolset was used in the development of access control mechanisms for Astra Linux Special Edition (RPA RusBITech JSC). As a result, this Astra Linux edition has passed the certification for compliance with the FSTEC information security requirements, which are defined for operating systems of the 2A protection profile. Both the security policy model and the access control mechanisms source code were successfully verified using AstraVer Toolset. The verification work for the new security model features is constantly ongoing.

ASTRAVER WORKFLOW



KLEVER: INDUSTRIAL SOFTWARE MODELS VERIFICATION SYSTEM

Klever is a framework for verifying models that are automatically extracted from large software systems' source code written in the C programming language. Klever allows specifying various security and safety requirements and verifying them automatically with the preconfigured precision level.

FEATURES AND ADVANTAGES

Klever is a result of advanced research and development in the field of automated extraction and verification of program models. The framework base includes per-component verification, environment modeling, and requirements specification methods. This allows applying formal methods to the industrial software of hundreds of thousands or millions of lines of the C source code. Klever is an open-source project (https://forge.ispras.ru/projects/klever).

Klever provides:

- Thorough sound analysis of industrial software (allows detecting all possible errors of specified types and proving program correctness under explicitly stated assumptions).
- Scalability. Modular program verification allows applying the most rigorous program analysis methods to the large code base. The methods are model checking and symbolic execution.
- Adapting software verification framework to customer needs. Developing specifications for modeling target programs' environments and for detecting violations of program specific requirements. This specific customization is performed in addition to checking regular safe programming rules for the C language.
- Comprehensive representation of found faults. When an error is detected, the verification system provides the detailed error trace that includes concrete variable values and called functions' arguments.
- A convenient multi-user web-interface for setting and running verification and for expert analysis of verification results.

WHO IS KLEVER TARGET AUDIENCE?

- Companies developing safety-critical and security-critical software.
- Certification laboratories.

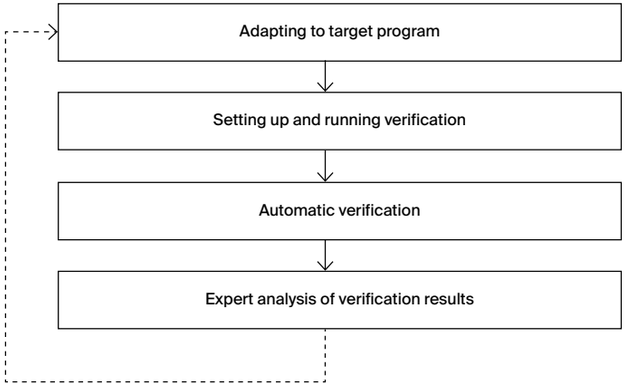
KLEVER DEPLOYMENT STORIES

The Klever verification system is mostly used for thorough checking of various operating system kernels and drivers. To showcase Klever features, it was used for verification of Linux kernel device drivers. As a result more than 400 errors of the following types have been found: buffer overruns, null pointer dereferences, uninitialized memory usages, double or incorrect memory deallocations, memory leaks, race conditions and deadlocks, incorrect function calls (depending on a certain context), incorrect initialization of Linux kernel data structures etc. Linux kernel developers have acknowledged these errors.

SYSTEM REQUIREMENTS

Ubuntu 18.04/20.04, at least 4 x86-64 CPU cores, 16 GB of memory, 100 GB of disk space.

WORKFLOW



MASIW: SUPPORT FOR DESIGNING HIGHLY RELIABLE SOFTWARE SYSTEMS

MASIW is a toolset for developing highly reliable hardware and software systems for avionics, medicine, and other safety critical areas. It is designed for engineers creating airborne hardware/software systems that are developed using the integrated modular avionics (IMA) approach. MASIW can be easily adapted for other application areas.

FEATURES AND ADVANTAGES

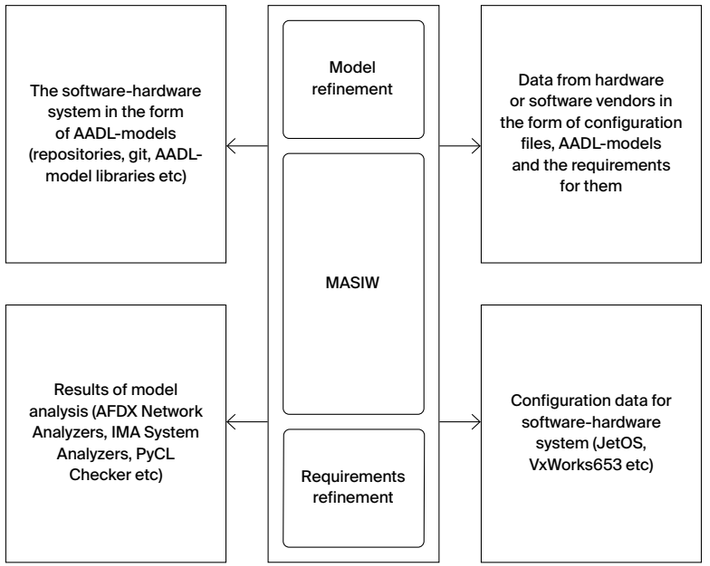
MASIW is the technology for optimizing the development and verification process of complex hardware/software systems. It allows performing a preliminary quality assessment of the product before making the first prototype, as well as performing the fault tolerance analysis. This reduces the risk of errors and defects. MASIW is being developed jointly with GosNIIAS. Despite the presence of the OSATE tool at the start of development, MASIW currently is more functional in the areas of verification, static, and dynamic analysis.

MASIW provides:

- Creation, editing and management of models based on the AADL modeling language:
  - creation and editing of models using the text and diagram editors;
  - support for team development with the ability to track and modify individual elements of a model;
  - support for the third-party AADL models reuse.
- Model analysis:
  - hardware+software system structure analysis: hardware resources sufficiency, interfaces consistency, etc.;
  - verification of the developed system for compliance with the requirements;
  - transmission characteristics analysis for the AFDX networks: message latencies, port queue depth, etc.;
  - generation and analysis of fault trees (FTA) to determine probabilities of high-level fault events;
  - architecture-model based analysis of failures and their consequences, including generation of special descriptive tables;
  - simulation of hardware+software system model with user reports generation including software-in-the-loop execution of on-board partitions with RTOS co-emulated with QEMU and with a universal AADL model simulator.

- Model synthesis:
  - distribution of software applications by computational modules taking into account hardware resource limitations and additional restrictions regarding reliability and security;
  - processor schedule generation (in particular, for ARINC-653 compatible real-time operating systems).
- Configuration data generation:
  - development of specialized configuration data tools based on the provided software interface (API);
  - configuration data generation for the VxWorks653 RTOS and for the AFDX network equipment.
- The ability to extend the toolset by creating own modules.

MASIW WORKFLOW



MICROTESK: TEST PROGRAM GENERATOR

MicroTESK is a reconfigurable and extendable framework for generating test programs for functional verification of microprocessors. MicroTESK allows automatically constructing test program generators based on formal specifications of microprocessor architectures. MicroTESK supports a wide range of architectures including RISC, CISC, VLIW, and DSP. MicroTESK supports online test program generation.

FEATURES AND ADVANTAGES

MicroTESK is a set of technologies for industrial use that includes the basic modeling framework (building microprocessor models based on formal specifications) and the generation framework (building test programs based on test templates). MicroTESK delivers value similar to its global competitors (e.g., Genesys Pro and RAVEN) but outperforms them via increased usability and performance. Also, it is distributed under the open-source Apache 2.0 license. MicroTESK is available at the ISP RAS website: https://forge.ispras.ru/projects/microtesk. The technology is also presented at http://www.microtesk.org.

MicroTESK provides:

- Using formal specification as a source of knowledge about the microprocessor under verification:
  - architecture specification in the nML language (registers, memory, addressing modes, instruction logic, text/binary instruction representation);
  - additional memory subsystem specifications in the mmuSL language (memory buffer properties (TLB, L1, and L2), address translation logic, read/write operations logic);
  - an option to make a transition to formal verification and to automatic toolchain generation for the microprocessor under development (disassembler, emulator, etc.).
- Test programs generation based on object-oriented test templates:
  - test templates in the Ruby language (so that the templates are human readable and easy to support);
  - allows using different generation techniques for instruction sequences and test data simultaneously (random generation, combinatorial generation, constrained-based generation, etc.);
  - generation of framework scalability (can develop complex test templates at low cost due to reuse).
- Wide range of supported microprocessor architectures:
  - supporting architecture specific features for various architectures (RISC, CISC, VLIW, DSP) at the generator development framework level;

  - MicroTESK-based test program generators have been developed for RISC-V, ARM, MIPS, and PowerPC architectures;
  - multicore architectures are supported.
- Quick framework adaptation for new microprocessor architectures with minimal costs and automatic information extraction for test situations (due to formal specifications).
- Convenient language for developing test templates that allows describing complex verification scenarios quickly.
- Support for online test program generation for performing post-silicon verification of the target microprocessor. The online generation is performed by an executable generator included into MicroTESK. The generator constructs test sequences using formal specifications, and then modifies the sequences by making functionally equivalent substitutions. It also allows repeated execution of the test sequences on the target microprocessor.

SYSTEM REQUIREMENTS

Windows or GNU/Linux-based OS, Java 11.

MICROTESK DEPLOYMENT STORIES

MicroTESK has been in development since 2007. It was used in various Russian and international projects on developing modern industrial microprocessors, including production projects on verifying ARMv8, MIPS64, and RISC-V microprocessors.

WORKFLOW

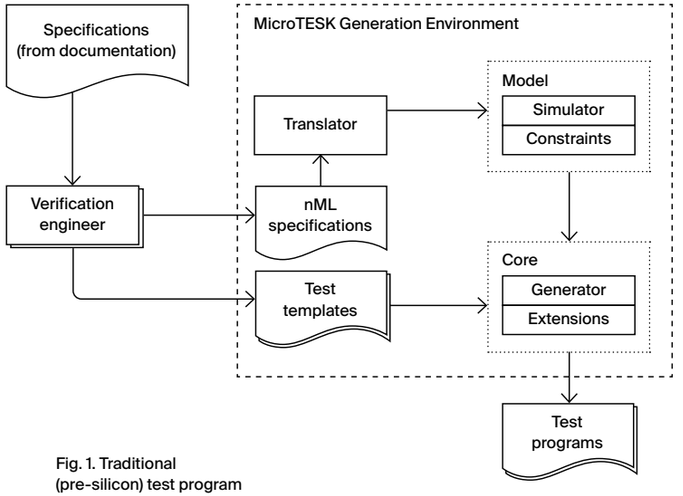


Fig. 1. Traditional (pre-silicon) test program generation flow

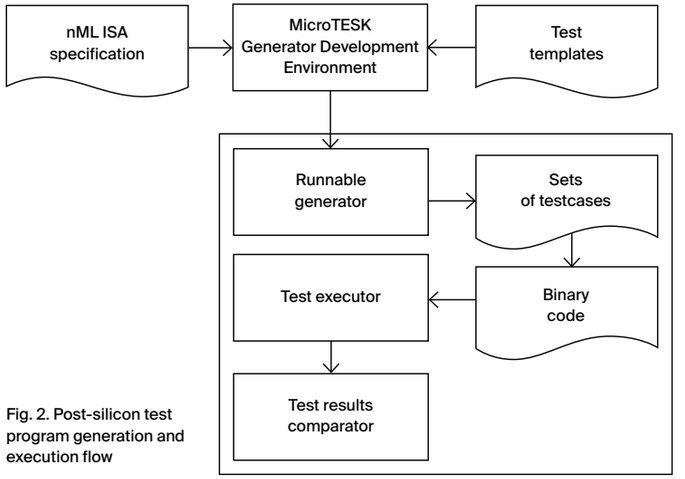


Fig. 2. Post-silicon test program generation and execution flow

SAFEC: SAFE COMPILER

The SAFEC safe compiler avoids introducing new vulnerabilities in program's binary code when aggressively optimizing (e.g., when making use of source code constructs exhibiting undefined behavior). The compiler tries to avoid excessively restricting optimizations, which allows to avoid the significant performance drop compared to all optimizations being switched off.

FEATURES AND ADVANTAGES

The safe compiler is developed on the basis of the industrial GCC compiler, and can act as a drop-in replacement for GCC (for example, when building the complete Linux distribution). The compiler retains the generated code quality and produces the ready-to-use safe build of a program.

The safe compiler provides:

- Refined compiler optimizations for conservative treatment of source code places with undefined behavior so that for these places program semantics gets defined safely and naturally.
- Forced initialization of uninitialized automatic variables.
- Issuing warnings when detecting constructions with undefined behavior.
- Adding dynamic checks for certain constructs to prevent exhibiting undefined behavior during program execution.
- Diversifying code generation during either compilation or program execution.
- No need to modify either source code or build system configuration, which makes using the compiler as simple as possible.
- Three different safety levels that provide trade-offs between generated code safety and performance. The lowest level is the third; the highest level is the first.

The safe compiler performs the following actions:

On the third level:
- Avoiding integer overflow, accessing objects via pointers of incompatible types, dereferencing null pointers, using compiler built-ins instead of standard library implementations for input/output functions and for functions working with memory.
- Detecting division by zero, incorrect bitwise shifts, accesses beyond stack frames, array loads/stores outside of the memory allocated for the array. Detecting automatic variables that are stored in registers during function calls.

On the second level:
- Analyzing arguments of bitwise shifts, redundant memory operations, data alignment when working with vector instructions, address arithmetic when optimizing memory accesses and changing their order.
- Initializing all automatic variables (with zero) that are not initialized explicitly by the user.
- Treating certain compiler warnings as errors and stopping compilation when they are issued.

On the first level:
- Generating unique memory layout for function code either statically during compilation or when performing dynamic linking.
- Adding machine code that aborts the program when detecting undefined behavior during program execution (sanitization) in the following situations:

1 Integer and floating point operations:
   - loading a non-boolean value in a boolean variable;
   - floating point conversion that results in either integer or floating point overflow;
   - performing a bitwise shift with a negative shift value or with a shift value that is equal or greater than the shifted type width;
   - signed integer operation with the result that is non-representable in the output type;
   - integer division or module with the divisor equal to zero.

2 Pointer and array operations:
   - loads/stores via incorrectly aligned or null pointer;
   - array loads/stores using the address outside of the memory allocated for the array;
   - passing null pointer as a function parameter marked with the nonnull attribute;
   - address arithmetic resulting in integer overflow;
   - returning null value out of function that is marked with the returns_nonnull attribute;
   - allocating an automatic VLA array with incorrect size (zero or negative).

3 Function operations:
   - a function pointer call via a pointer whose declared type does not match the function declaration;
   - returning from a non-void function without actually executing the return statement;
   - calling a compiler built-in with incorrect arguments;
   - reaching a program point during program execution that is marked in the source code as unreachable.

WHO IS THE SAFEC TARGET AUDIENCE?

- Operating system developers.
- Companies developing high-level safe and secure software.

SAFEC DEPLOYMENT STORIES

The safe compiler is deployed in a number of Russian companies and government institutions as an add-on to the ISP Crusher framework.

SUPPORTED PLATFORMS

Linux-based OS on x86 32/64, ARMv7, ARM64, RISC-V 64; Windows (MinGW).

SVACE: STATIC ANALYZER

Svace is an essential tool of the secure software development life cycle, the main static analyzer that is used in Samsung Corp. It detects more than 50 critical error types. Svace supports C, C++, C#, Java, Kotlin, Go; Python support is in beta. Svace is included in the Unified Register of Russian Programs (No.4047). It is distributed with the Svacer web interface (Svace History Server).

FEATURES AND ADVANTAGES

Svace is an innovative technology based on years of research that constantly evolves for customer's needs. It combines the key qualities of foreign competitors (Synopsis Coverity Static Analysis, Perforce Klocwork Static Code Analysis, Fortify Static Code Analyzer) with the unique open industrial compilers usage to provide the maximal support level for new programming language standards.

Svace provides:

- High-quality deep analysis:
  - accurate representation of the source code (due to integration with any build system);
  - symbolic execution: full path coverage taking into account connections between functions when searching for complex defects;
  - calling context sensitivity within interprocedural analysis, data flow analysis, tainted data analysis, call statistics analysis;
- Scalability and high speed:
  - parallel analysis using all available processor cores;
  - ability to analyze software with the code size of tens of millions of lines (analysis of the Tizen 7 mobile OS having 57 million lines of code takes 7-8 hours using the main Svace engine and 9–10 hours using all engines);
  - supporting incremental system analysis in addition to the full analysis mode (performs a quick re-analysis of recently changed source files).
- Accelerated customization (configuring existing detectors as well as writing individual ones available exclusively to the customer; an API for developing user plugins acting as detectors).
- Accelerated adaptation to new environments and tools (adding new compilers within 1-2 weeks, in complex cases up to 2 months).
- Full compatibility with regulatory documents and requirements of regulators (FSTEC of Russia).
- Can be used for adhering to the GOST R 56939-2016 requirements and to the requirements of the FSTEC regulation document mandating software vulnerability detection process (when certifying software within Russia).

- Svacer is an integrated tool that provides the user interface for working with warnings, as well as a server for storing and managing analysis results. Svacer supports the multiuser mode and various data filters.

Svacer provides:

- Review and reports:
  - Extensive features for comparing and reviewing analysis results, user customized filters, code and warning trace navigation;
  - Generating reports in PDF, CSV, JSON formats;
  - Annotating results with user files and attributes;
  - Reviewing directly in source code via custom format comments (editing mode), supporting history of modifications for the comments;
  - Flexible user interface with tab support.
- Sharing, collaboration and management:
  - Rich role model allowing flexible data access rights for users and organizations;
  - Group operations support when working with users, projects, review data etc.;
  - LDAP support for user authentication;
  - API support for accessing any data;
  - Importing and exporting data: reviews, source code, comments, detector configuration (including custom user detectors).
- CI/CD integration:
  - Visual Studio Code integration, standard CI/CD process integration via command-line interface.
  - Support for working in containers.
- SARIF format support allowing to import results of other static analyzers, exporting results, reviews, comments, and source code.

WHAT IS SVACE TARGET AUDIENCE?

- Companies focused on development of highly reliable and secure software.
- Companies that need to certify the developed software.
- Certification laboratories.

SVACE DEPLOYMENT STORIES

Svace is the main static analyzer used in Samsung Corp. since 2015. It is used to check the company's own software based on Android OS as well as the Tizen OS source code. Tizen is used in smartphones, infotainment systems and Samsung home appliances. Since 2017, Svace checks all changes submitted for review and inclusion in the Tizen OS. Since 2020, Svace has been also used by Huawei.

Within Russia, Svace is deployed in more than 100 companies and certification labs, including RusBITech, Kaspersky Lab, Postgres Professional, Security Code, Swemel, and others.

SUPPORTED PLATFORMS AND ARCHITECTURES

- Host platforms for the Svace analyzer: Linux/x64 (version 3.10 and later, glibc version 2.17 and later), Linux/ARM 64 (Ubuntu 18.04), Windows starting with 7 SP1 with update KB2533623) and WSL (versions 1 and 2); macOS on x86-64 (starting from 10.10; C# is not supported); x86 architecture for build capture.
- Target architectures of the analyzed code: for C/C++ that is Intel x86/x86-64, ARM/ARM64, MIPS/MIPS64, Power PC/ Power PC 64, RISC-V 32/64, SPARC/SPARC64, Hexagon (code generation via Clang); Elbrus, AEON, TriCore, HIDSP, OpenRISC (code generation via one of the previous architectures); for Go, Linux-based Intel x86-64; for C#, Java, Kotlin, Python host platforms are supported.
- Platforms and architectures for Svacer: x86-64; OS Linux (version 3.10 and later, glibc version 2.17 and later); OS Windows (starting with Windows 10) and WSL (versions 1 and 2); macOS on x86-64 (starting from 10.12 Sierra).

SVACER

Svacer is an integrated tool that provides the user interface for working with warnings, as well as a server for storing and managing analysis results. Svacer supports the multiuser mode and various data filters.

Svacer is:

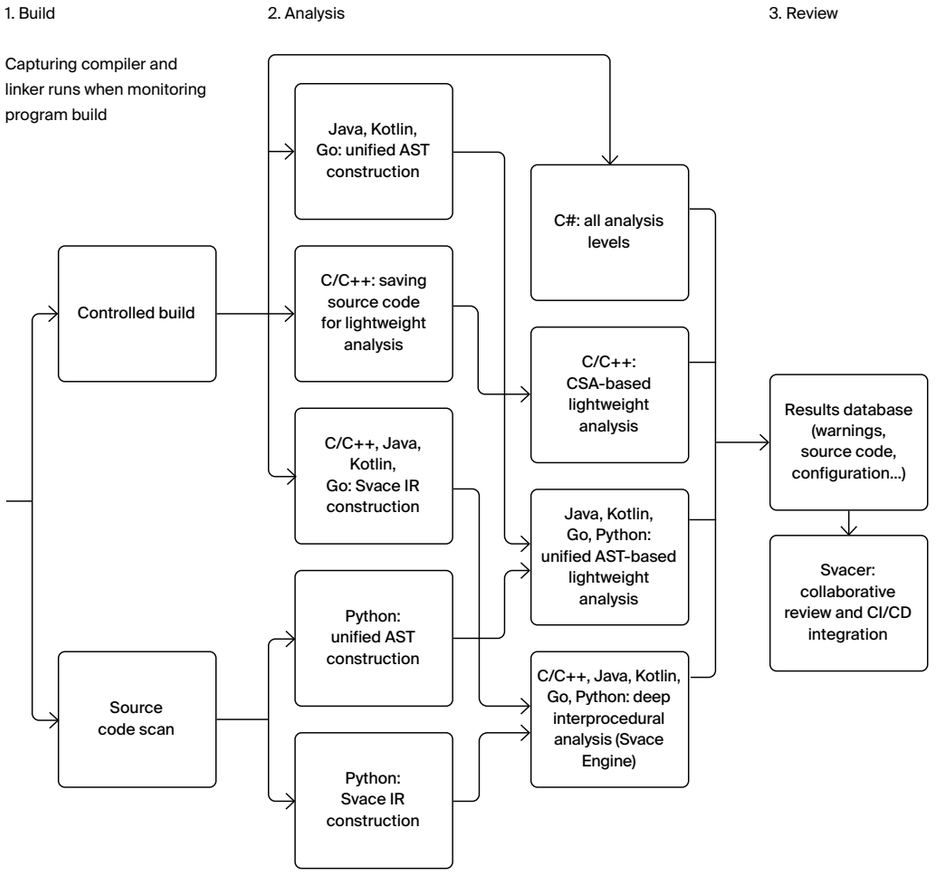
SUPPORTED PLATFORMS AND ARCHITECTURES

- Extensive possibilities for comparison and markup of results, access to results via API, creating reports in PDF, CSV, JSON formats.
- LDAP support for user authentication.
- Integration with Visual Studio Code and providing command line interface for integration into standard CI/CD processes.
- Annotation of work results through user files and attributes.
- Support for the SARIF format which allows to import results of other static analyzers.
- Importing and exporting marked-up results to source code.
- Support for working in containers.

SUPPORTED COMPILERS

- For C/C++ (up to C++20): GCC (GNU Compiler Collection), Clang (LLVM compiler), Microsoft Visual C++ Compiler, RealView/ARM Compilation Tools (ARMCC), Intel C++ Compiler, Elbrus C/C++ Compiler, Wind River Diab Compiler, Keil CA51 Compiler Kit, NEC/Renesas CA850, CC78K0(R) C Compilers, C/C++ Compiler for the Renesas M16C Series and R8C Family, Panasonic MN10300 Series C Compiler, C compiler for Toshiba TLCS-870 and T900 Family, Samsung CalmSHINE16 Compilation Tools, Texas Instruments TMS320C6* Optimizing Compiler, Digital Mars C and C++ Compiler, Green Hills compiler for ARM, TASKING C compiler for TriCore, CEVA Toolbox for CEVA DSP cores, IAR C/C++ Compiler for ARM / Renesas RL78 MCU, CodeWarrior Development Studio for StarCore DSPs, Open Watcom C/ C++ compiler, Freescale CodeWarrior, Cadence Tensilica Xtensa C/C++ Compiler.
- For C# (up to C#10): Roslyn, Mono.
- For Java (up to Java 17): OpenJDK Javac Compiler, Eclipse Java compiler.
- For Kotlin: Kotlin 1.8.
- For Go: Go 1.21.

SVACE ARCHITECTURE



Scanning directories with source code when analyzing interpreted languages

Building intermediate representations for lightweight analysis (unified AST) and deep analysis (Svace IR)

- lightweight analysis of abstract syntax trees;
- interprocedural analysis (context- and path-sensitive based on symbolic execution);
- tainted data analysis (users can specify sources and sinks for tainted data, which includes tainted function arguments and structure fields).

- syntax highlighting and code navigation;
- warning review (marking true/false positives);
- comparing analysis runs and automatically hiding warnings previously reviewed as false ones);
- group operations for users, projects, and review data;
- API support for data access;
- importing/exporting data.

TESTOS: SOFTWARE TESTING ENVIRONMENT

TestOS is an environment for unit testing of software on target hardware. It allows to debug software for critical applications on AArch64, ARM, PowerPC, MIPS, RISC-V, and x86 architectures to perform certification and other activities.

FEATURES AND ADVANTAGES

TestOS makes it possible to replace such critical systems verification tools as LDRA, since it is a more flexible tool with active support for domestic products.

Using TestOS ensures running tests on target hardware and generating reports with the trace for each test, with information about the composition and passing status of the test plan and with the coverage of the tested system code both for one test, and for the whole test plan. A convenient development environment for implementing module tests for C functions (for the C18 standard with GNU and Clang extensions) is provided, supporting test scenarios creation and generating stubs and wrappers. Reports are generated in HTML and TXT formats. Debugging of the code on the target computer is available both with and without use of JTAG.

With plugin application, the following is supported:
- collecting function, operator, and branch coverage using GCOV and LLVM Coverage;
- collecting coverage by MC/DC using COVERest;
- performing static analysis with static analyzers:
  - Clang Tidy;
  - Clang Static Analyzer;
  - Svace.
- Dynamic code instrumentation with LLVM sanitizers:
  - AddressSanitizer (detecting memory handling errors);
  - MemorySanitizer (detecting errors of accessing uninitialized memory);
  - UndefinedBehaviorSanitizer (to detect arithmetic, floating-point, and other undefined behavior errors).

SYSTEM REQUIREMENTS

GNU/Linux distribution on x86_64 architecture (such as Ubuntu 22.04), and Apple macOS 10.12 or newer as the target machine.

Target machine with at least 2MB RAM on architectures:
- AArch64 (Cortex-A53, Cortex-A55);
- ARM (Cortex-A7, Cortex-A9, Cortex-M4), including i.MX6 or STM32F429 processors;
- PowerPC (e500mc, e500v2, 476FP), including the p1010 or p3041 processors;
- MIPS (MIPS Release 1, MIPS Release 2 / MIPS32, COMDIV), including the 1892VM15AF processor;
- RISC-V (RV32 IMA);
- x86 (Intel Prescott and newer).

If necessary, the environment is adapted to the customer's equipment.

TESTOS DEPLOYMENT STORIES

TestOS has been in development since 2019. It is successfully applied for modular software testing for the aerospace industry.

DIVERSIFICATION TOOL: ANTI-EXPLOIT PROTECTION SET

Diversification tool is a set of technologies to prevent mass exploitation of vulnerabilities resulting from bugs or backdoors. If an attacker was able to attack one of the devices with the same software installed, the others will remain protected thanks to the changes made to the code.

FEATURES AND BENEFITS

The diversification tool protects the system from mass exploitation of vulnerabilities by means of various code diversification methods, and makes it possible to build the code of the whole OS distribution.

The diversification tool provides:

- Fine-tuning the balance between the degree of obfuscation and the level of performance (when applied to protect against reverse engineering). Minimum 1.2x slower performance, maximum 8x slower performance.
- Full automation (no special preparation of program source code and no additional efforts on the part of customer's build engineers are required).
- Based on the GCC compiler, which allows to build the full OS distribution code correctly.
- Use of the original control flow integrity method (CFI), which successfully resists most code reuse attacks (ROP, JOP, ret-to-plt, etc.). Implementation of the CFI method based on the GCC compiler resulted in average slowdown on the SPEC CPU2006 test suite of about 2%, which is noticeably lower than that of traditional methods.
- Two diversification methods:
- Dynamic code diversification at program startup. It is used when the customer needs the same code on all devices (for example, due to mandatory certification). This method makes it possible to move up to 98% of the code with a small increase in its size and about 1.5% performance degradation.

The advantages of the Diversification Tool over similar products include:

- shuffling up to a function (as opposed to ASLR and Pagerando technologies, which only move large blocks of code);
- shuffling of functions in the whole system, except for the kernel, and no conflict with anti-viruses (which is an advantage over the similar technology Selfrando developed for the Tor Browser);
- Static code diversification. Each time the code is compiled, depending on the specified key, a new executable file is produced. The advantages of this method include:
  - no increase in binary code size (particularly important for the Internet of Things);
  - performance degradation tends to vanish;
  - due to working inside the compiler rather than ex post facto in the linker, an extended set of diversifying transformations can be applied and tuned with more flexibility;
  - control flow integrity (CFI) method.
- Conflict-free compatibility with other software protection tools (including the ASLR system mechanism).

WHO IS THE DIVERSIFICATION TOOL INTENDED FOR?

- Developers of specialized operating system installation software.
- Application software developers.

DIVERSIFICATION TOOL DEPLOYMENT STORIES

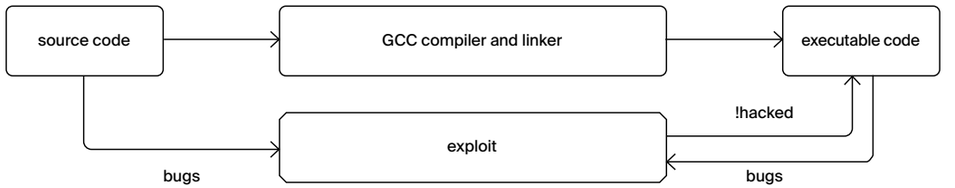
The tool is deployed in OS "Zircon," which is used by Ministry of Foreign Affairs and the Border Guard Service of the Federal Security Service of Russia. Currently, the Diversification Tool is implemented as part of the SAFEC Level 1 secure compiler and is supplied together with it.

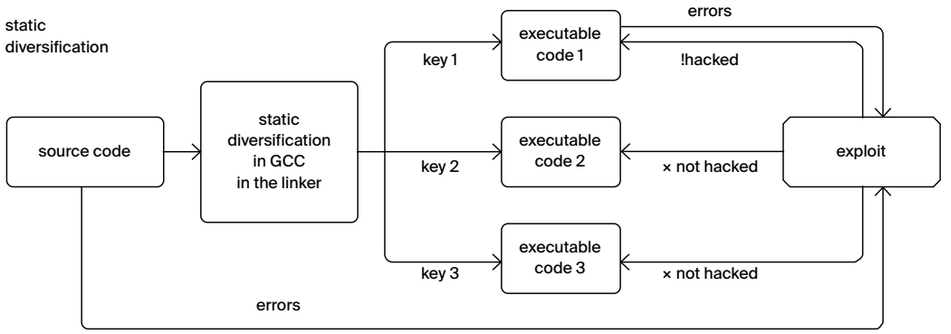
SYSTEM REQUIREMENTS

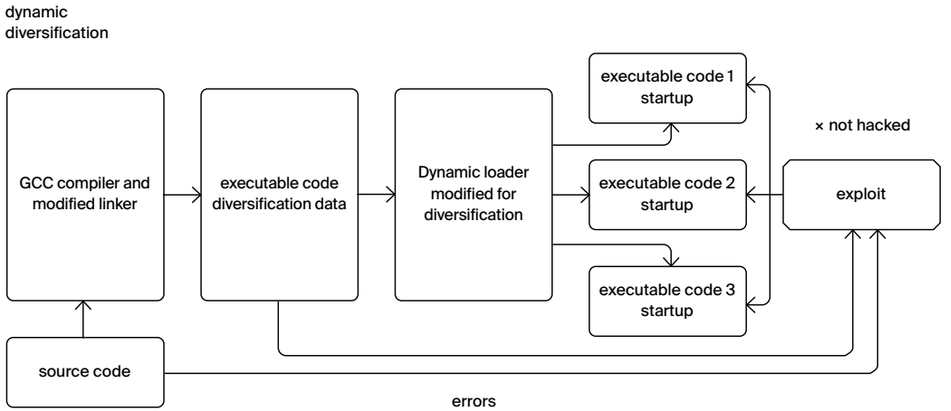
The Diversification Tool is a universal product which can be adapted to any system requirements. Currently, the main version works on Linux kernel-based operating systems (starting with version 2.6) with Intel x86/x86-64 architecture support.

WORKFLOW

usual build







QEMU-BASED SOFTWARE ANALYSIS PLATFORM

ISP RAS Foundation Platform for creating program analysis systems is built on top of open source QEMU emulator. This framework is essential for organizing cross platform development. It supports reverse debugging and introspection features, as well as full system emulation mode for debugging low-level software.

FEATURES AND ADVANTAGES

QEMU supports emulation of more than 10 instruction set architectures (i386 and x86-64, ARM and Thumb, MIPS, PowerPC, etc.). It implements guest debugging via GDB Remote Serial Protocol and is compatible with IDA Pro, GDB, and various IDEs. QEMU supports full system emulation mode that allows debugging low-level software such as a bootloader and an OS kernel. The QEMU source code is regularly checked by static code analysis tools, including Coverity and Svace. Thus performing malware analysis with QEMU is more secure. QEMU with reverse debugging and introspection support is available on the ISPRAS GitHub page: https://github.com/ispras/swat. The developed QEMU automatization tools are available at https://github.com/ispras/qdt, https://github.com/ispras/i3s.

ISP RAS QEMU Foundation Platform provides:

- A record and replay mechanism for a virtual machine:
  - The same VM execution is replayed every time, deterministically. All external events are recorded and replayed by the emulator. It makes finding bugs in multi-threaded applications (race conditions, deadlocks) easier;
  - GDB-compatible reverse debugging is implemented based on the record and replay mechanism. The debugging is performed by restoring previous VM snapshots and searching for the previous breakpoint stop or the previous instruction;
  - The minimum required information is recorded. This allows recording longer for debugging rarely occurring errors;
  - Low performance overhead caused by recording. This enables analysis of software that requires interacting with an uncontrolled external environment in real time.

- VM introspection solution (getting high-level information regarding guest OS work) without any guest OS kernel modifications or installing monitors:
  - Getting the list of executed system calls, accesses to named functions in shared libraries, the list of running processes, the list of open files and loaded modules;
  - Supports all Linux-based virtual machine images as well as embedded software images for various devices;
  - WinDbg server support in QEMU that allows showing guest software information in terms of Windows kernel abstractions. There is no need to enable the OS debugging mode in the guest OS.
- Speeding up QEMU development:
  - Faster development of dynamic analysis tools that can analyze binary code for specific hardware;
  - Automated support for new processor architectures using a machine instruction decoder generator and a C-like language for describing machine instructions semantics;
  - An automatic tool for preliminary virtual machine testing. The tool only requires GNU Binutils and a C compiler;
  - A tool for automating QEMU virtual devices development;
  - VM generation tool in the form of QEMU module source code. The tool can create VMs from both existing devices and new devices out of Python description. The tool provides GUI for sketching the virtual machine;
  - A Python API for an automated debugging via GDB Remote Serial Protocol. It is used to debug QEMU, the guest OS, or both at the same time.
- Convenience and user experience:
  - Easy QEMU extension due to open source code and own ISPRAS toolkit for speeding up development;
  - Binary code analysis without any guest OS modifications;
  - VM introspection mechanism that can be extended using plugins;
  - A convenient API for developing own introspection plugins;
  - Can be easily adapted for specific use cases;
  - Support for latest QEMU versions that have support for newest peripherals and CPUs.

WHO IS ISP RAS FOUNDATION PLATFORM TARGET AUDIENCE?

- Bootloader, driver, OS and other system software developers.
- DevOps teams for software bugs reproduction, cross-platform development, and scalable cloud testing.
- Programmers analyzing potential malware.
- Software certification engineers.

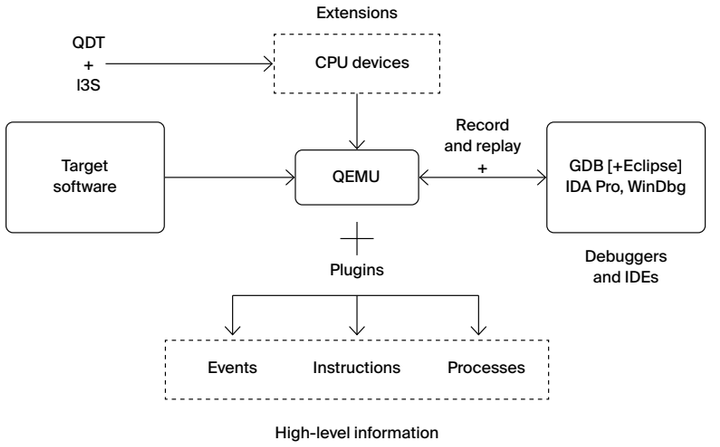
SUPPORTED GUEST PLATFORMS

Emulation of the following ISAs: i386, x86-64, ARM, MIPS, PowerPC, and others.
Guest systems supported by the introspection mechanism: Windows XP (x86), Windows 10 (x86-64), Linux 2.x-5.x (x86, x86-64, ARM, AArch64).

ISP RAS QEMU DEPLOYMENT STORIES

The QEMU community has accepted ISP RAS patches for the record and replay mechanism and added them to the open source QEMU version 3.1.

WORKFLOW



ISP CRUSHER: BINARY CODE DYNAMIC AND STATIC ANALYSIS TOOLSET

ISP Crusher is a toolset that combines various dynamic and static analysis approaches, including fuzzing (using ISP Fuzzer, a fuzzing tool), and symbolic execution (among others, the Sydr tool can act as a symbolic engine). In the near future Crusher will also include the BinSide analyzer, another ISP RAS technology. Crusher allows organizing a development process that is fully compliant with GOST R 56939-2016 and "Methodology for identifying vulnerabilities and undeclared features in software" of FSTEC of Russia.

FEATURES AND ADVANTAGES

The ISP Crusher core is ISP Fuzzer, a fuzzing tool essential for any fuzzing tests on every stage of software development phase, be it coding, testing, or deployment. The fuzzer finds program errors either with or without source code. It solves the same problems as its global competitors (Synopsys Codenomicon, beSTORM, Peach Fuzzer), but it is more convenient for Russian companies in the import phase-out context.

ISP Fuzzer provides:

- Fuzzing a wide class of software:
  - custom applications, kernel and libraries;
  - applications in various programming languages: C/C++, Java, Python, C#;
  - fuzzing of neural networks. The software reveals cases of erroneous neural network predictions when correctly classified input data is distorted; the detection is done via analyzing neuron activation map when the neural network is working. This improves quality and safety of AI systems, including but not limited to:
    - finding errors in the networks for situations that have not been originally included in the training dataset;
    - finding possible backdoors and malware.
  - fuzz-testing through different input data sources: file, command-line arguments, standard input stream, environment variable arguments, network, direct writing to memory;
  - ability to analyze server and client software running on stateful and stateless protocols;
  - fuzzing protocols by modifying the client: this allows to avoid writing a fuzz client or its specification from scratch when fuzzing the server; a mirror scheme with modifying a server to fuzz the client is supported as well;
  - extensive possibilities for fuzzing software of embedded devices through partial emulation and symbolic execution;
  - browser fuzzing: browser control via Selenium, coverage feedback via Frida;
  - fuzzing applications that require isolation in the docker mode, when each fuzzer instance works in a separate docker container;
  - fuzzing applications in rootfs via the chroot mode.
- Large capacity fuzzing:
  - Support for multi-threaded analysis on both a single machine and distributed ones;
  - ability to distribute input data corpus between fuzzer processes to increase efficiency of their work;
  - support for differential fuzzing.
- Support for a large set of tool types:
  - static (mostly for C/C++) with GCC/LLVM;
  - static instrumentation of Python bytecode;
  - dynamic (mostly for ELF, PE): DynamoRIO, Qemu (user-mode), TinyInst;
  - based on partial emulation;
  - using Nyx snapshots and snapshot-API;
  - Java applications;
  - C# applications;
  - remote instrumentation (which makes it possible to perform fuzzing of an application running on a remote device).
- Ability to integrate with a number of necessary tools of secure software development lifecycle tools developed at ISP RAS:
  - the use of dynamic symbolic execution tool Sydr to improve the efficiency of fuzz-testing;
  - ability to receive input data to check errors marked by BinSide static analysis BinSide in automated mode;
  - displaying the trace of the sequence of functions causing crashes in the interface of the Svace static analyzer;
  - using the data generator that is based on ANTLR grammars to generate the input data corpus.
- Integration with other dynamic analysis tools:
  - with third-party fuzzers, allowing to run a set of different synchronized fuzzers within one fuzzing session, which increases the efficiency of testing;
  - with SymCC and Angr dynamic symbolic execution tools, which makes it possible to get new input data to increase the code coverage of target software;
  - working together with the IDA PRO disassembler (saving the coverage for the Lighthouse plugin, which displays the covered basic blocks in the software, as well as displaying the percentage of covered basic blocks);
  - using the Radamsa fuzzer to generate new data.

- Additional analysis of the received input data:
  - Evaluation of the criticality of found abnormal terminations;
  - ability to launch dynamic analysis systems using new input data: Valgrind, DrMemory, QASan;
  - creation of the coverage profile by source code.
- Extensive options for integration of custom extensions:
  - option to add user-side handlers that will automatically run on new input data;
  - option to add custom mutation transformations (to generate new input data and increase testing efficiency);
  - availability of input data pre-processing and post-processing modules to perform constant transformations of data before sending it to the software to be analyzed;
  - support of custom plugins for sending data over network (plugins allow interacting with client or server software and sending mutated data);
  - support of custom Python scripts to modify options (avoids conflicts when multiple fuzzing processes are running simultaneously);
  - support for custom Python plugins to control the environment for launching the target software (which makes it possible to keep an identical environment at each start-up);
  - support for custom instrumentation plugins (which makes it possible to define arbitrary classification rules for input data based on the target software behavior: definition of normal and crash termination, freezing);
  - ability to describe scenarios for fuzzing software with the user interface.
- Easy extensibility and easy adding new methods within the framework of the existing infrastructure; fast adapting to new tasks.

WHO IS ISP CRUSHER TARGET AUDIENCE?

- Companies developing highly reliable and secure software.
- Companies auditing or certifying software.

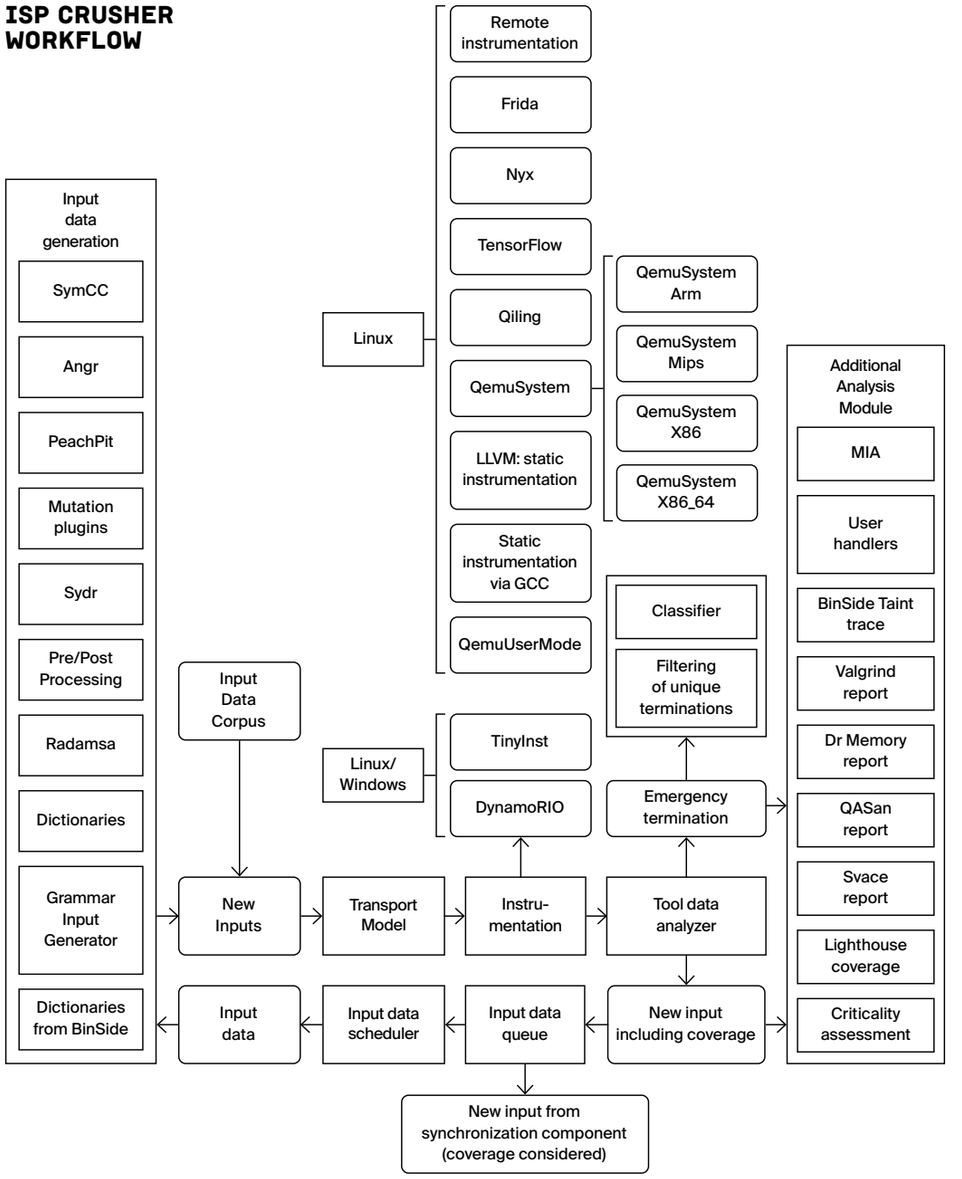
SYSTEM REQUIREMENTS

Fuzzing supported for Linux and Windows OS family. Fuzzing of software available for x86_64, ARM, MIPS architectures. Crusher can also fuzz embedded devices (controllers, IoT devices) as well as Windows services and COM objects.

ISP CRUSHER DEPLOYMENT STORIES

ISP Crusher is used in more than 70 companies and certification labs, including RusBITech, Postgres Professional, Security Code, Swemel, and others.

ISP CRUSHER WORKFLOW



BINSIDE: A BINARY CODE STATIC ANALYSIS TOOL

BinSide is a static program analysis platform for finding defects in binary code. It is useful when checking programs without source code, such as closed source third-party libraries.

FEATURES AND ADVANTAGES

BinSide is a binary code analysis platform based on the BinNavi framework. An executable file is analyzed in IDA PRO or Ghidra representation. BinSide provides various analysis types such as defect detection, code clone detection, dynamic analysis optimization, analysis automation, dynamic testing optimization.

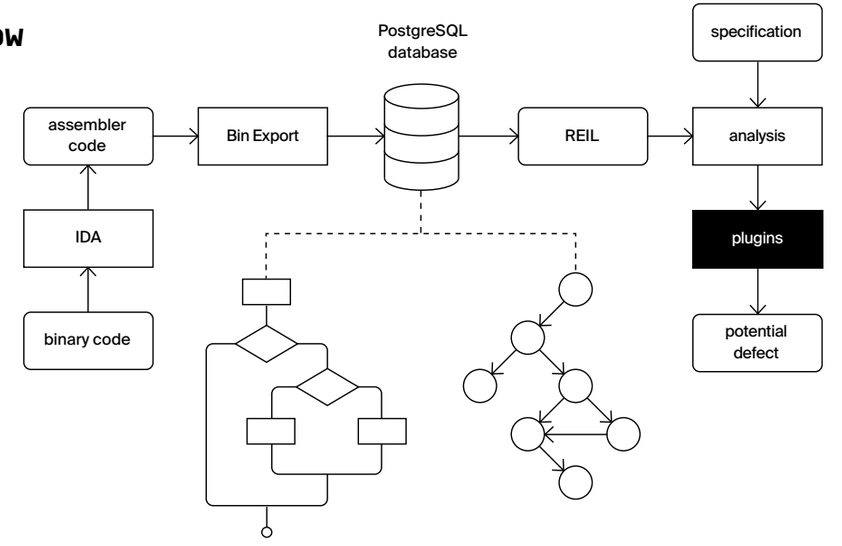
BinSide core provides:

- Easy extension:
  - individual error detectors are written as plugins;
  - the REIL representation of 17 instructions without side effects is used (each assembly instruction is translated into a set of REIL instructions);
  - it is possible to specify the functions' semantics to improve analysis quality.
- Supports analyzing executables and libraries for x86-64, ARM, and MIPS architectures, including drivers.
- Detecting the following CWE types:
  - CWE-121 (Stack-based Buffer Overflow);
  - CWE-122 (Heap-based Buffer Overflow);
  - CWE-134 (Format String Vulnerability);
  - CWE-415 (Double Free);
  - CWE-416 (Use-After-Free);
  - CWE-77 (Command Injection).
- Executing the following tasks:
  - data flow and control flow analysis: retrieval of values and pointers, labeled data propagation, determining possible heap states, determining computable edges of the control flow graph;
  - intraprocedural search for defects: search for defects is performed on the basis of the results of intraprocedural analysis of data and control flow, the results of dynamic analysis and manual code markup by the analyst. This is especially useful when analyzing complex software and embedded systems;
  - analysis of all paths, regardless of code coverage.
- Interaction with ISP RAS technologies:
  - with the Svacer tool (if the source code is available);
  - LibraryIdentifier tool (to search for code clones, e.g. to identify libraries whose code has been used for the executable file);
  - Crusher fuzzing-test tool.
- Operating system analysis:
  - Determining code plagiarism from an open-source OS;
  - Determining dependencies between OS components and within components;
  - Static analysis of the OS source and binary code;
  - Determining the protection of the executable code in the OS components;
  - Determining the coverage of the code in OS components by unit-tests.

WHO IS BINSIDE TARGET AUDIENCE?

- Companies that need to check thoroughly the used third-party software, including situations when there is no access to its source code.
- Developers who need to increase dynamic analysis quality with the data collected by static analysis.
- Reverse engineering experts.
- Companies performing software audition or certification.

BINSIDE WORKFLOW



CASR: CRASH ANALYSIS AND SEVERITY REPORTING TOOL

GitHub → https://github.com/ispras/casr

Casr creates automatic reports for crashes happened during program testing or deployment on Linux. The resulting reports contain the crash's severity and additional data that is helpful for pinpointing the error cause. Casr is open source (https://github.com/ispras/casr).

FEATURES AND ADVANTAGES

Casr could collect crash reports using several approaches (coredump, GDB, Asan, Ubsan) and process exceptions thrown in Rust, Go, Java, or Python programs. Casr can be used to automate analysis of fuzzing results and to submit them to vulnerability management systems.

Casr provides:

- Detecting critical program faults that can lead to hijacking control flow.
- Classifying crashes based on a program state at a crash time (function return address corruption, null pointer dereference etc.). Fatal errors are further grouped based on severity, such as exploitable, potentially exploitable, or denial of service errors.
- An extended crash report containing the fatal error's severity and other data (OS and package versions, executed command line, call stack, open files and network connections, register state etc.).
- Deduplicating and clustering crashes based on their call stack. The detected clusters would likely contain similar reports that describe the same bug.
- Integration with modern fuzzers such as Sydr, AFL++, LibFuzzer (including go-fuzz, Atheris, Jazzer).
- The libcasr library for developing custom analyzers.
- Submitting results to DefectDojo, a vulnerability management system, which allows convenient integration of fuzzing results review into CI/CD.

WHO IS CASR TARGET AUDIENCE?

- Companies that need to receive the data regarding user-deployed programs' crashes to develop high reliability and security software.
- Companies that need to certify the developed software.
- Certification laboratories.

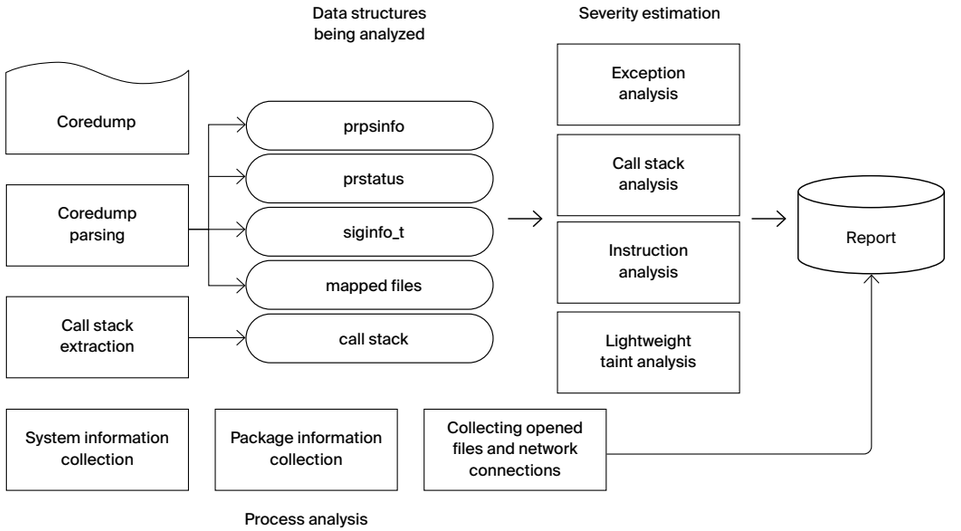
CASR DEPLOYMENT STORIES

Casr is used for crush analysis in the Sydr tool, also by ISP RAS.

SYSTEM REQUIREMENTS

Linux-based OS for x86 (32/64), aarch64, RISC-V 64.

WORKFLOW



NATCH: A TOOL FOR DETERMINING ATTACK SURFACE

Natch is a tool for determining attack surface based on QEMU full-system emulation. Natch utilizes dynamic taint analysis, virtual machine introspection and deterministic replay.

FEATURES AND ADVANTAGES

Natch is aimed for attack surface detection, which is determining executables, dynamic libraries and functions that participate in processing input data (files, network packets) when performing a task. Gathered data is visualized in the SNatch graphical interface that is included in the distribution.

Natch is based on QEMU, a full-system emulator, which allows analyzing all software comprising a system, including the OS kernel and drivers. The important advantage of Natch is unifying key features of competitors in a single tool.

The attack surface detection task can be integrated into CI/CD for organizing system and integration testing, which makes applying fuzzing and functional testing within security development lifecycle more effective.

Natch provides:

- determining attack surface, i.e. processes, functions, and modules that were engaged in processing tainted data when executing a test scenario;
- detecting open files, sockets, and ports, as well as data flows coming through them;
- analyzing programs written on C/C++, Go, and Python;
- automatic downloading of debug information for the kernel and system modules;
- extracting debug information from DWARF data;
- building a graph that shows tainted data flow through all the system crossing process and module boundaries;
- collecting network packet log in the PCAP format;
- calculating binary code coverage;
- collecting data corpus for further fuzzing of selected functions (for simple type arguments).

NATCH WORKFLOW:

- Natch starts with recording a scenario of analyst working session in a virtual machine;
- The analyst marks as interesting certain network traffic or file accesses;
- Natch replays the recorded work scenario and tracks tainted data flows, collects logs with tainted data operations and system events;
- The analyst loads the created log into the SNatch interface for further analysis.

FEATURES OF THE SNATCH GRAPHICAL INTERFACE:

- Graph of processes that were working with tainted data. It allows time tracking tainted data and convenient ordering for scheme elements.
- Time diagram for OS processes.
- Call stacks for tainted functions grouped by process.
- Call stacks for script functions in case they are present in the analyzed program.
- Process flame diagram with color coding for tainted and untainted functions.
- Examining process tree for processes that were executing with filtering just tainted processes if needed.
- Examining resources used by processes.
- Examining read/write accesses for files and sockets.
- Highlighting privileged processes (e.g. running from root) that were working with tainted data.
- Generating function annotations for the Futag tool.
- Forwarding filtered network traffic to Wireshark.
- Convenient search in graphs and keeping view history.
- Generating reports with important data in the PDF format.

WHO IS NATCH TARGET AUDIENCE?

- Russian companies developing secure software.
- Certification labs and regulation authorities.

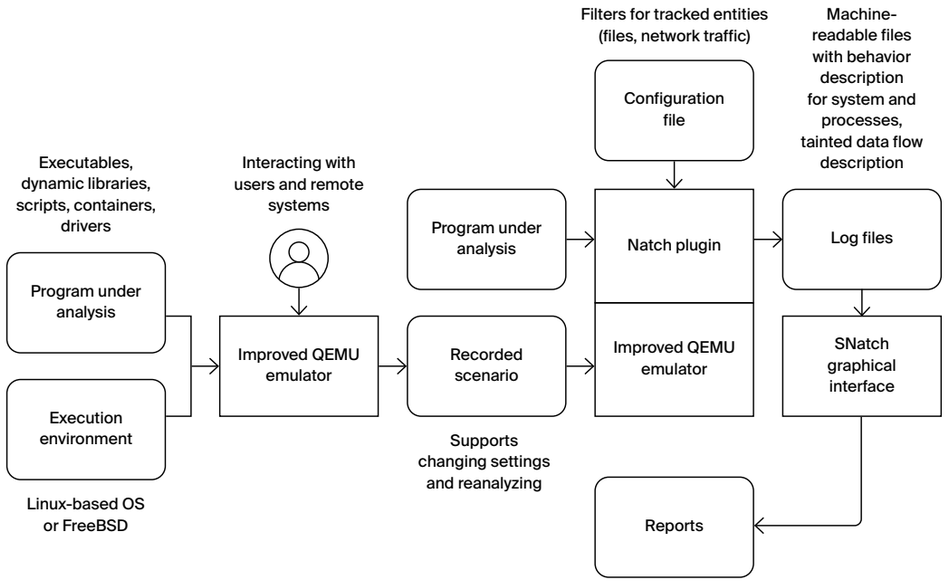
SUPPORTED PLATFORMS AND ARCHITECTURES

- Natch system requirements: OC Linux x86-64, 16+GB memory, 200+GB disk space.
- Target architectures: x86-64.
- Target OS: Linux (all versions), Windows 7-10, FreeBSD (latest versions).

NATCH DEPLOYMENT STORIES

Natch is used for advanced training and skills upgrade.

NATCH WORKFLOW



SYDR + SYDR-FUZZ: HYBRID FUZZING AND DYNAMIC ANALYSIS

GitHub → https://github.com/ispras/oss-sydr-fuzz

Sydr is an automatic test generation tool for complex programs that finds errors and increases code coverage during testing. Sydr constructs the program's mathematical model that allows a fuzzer to explore new execution paths that are hard to discover via classic mutation approaches. Sydr improves dynamic symbolic execution methods proposed in earlier Avalanche and Anxiety analyzers developed in ISP RAS.

Sydr-fuzz is a dynamic analysis tool for security development lifecycle which combines the power of dynamic symbolic execution tool Sydr and modern fuzzers (libFuzzer and AFL++).

FEATURES AND ADVANTAGES

In contrast with similar open source tools, Sydr ensures the correctness of generated input data by checking whether it actually inverts the target branch. Sydr-fuzz provides a convenient fuzzing pipeline:

- Hybrid fuzzing with Sydr and libFuzzer/AFL++: sydr-fuzz run
- Corpus minimization: sydr-fuzz cmin
- Error detection (out of bounds, integer overflow, division by zero, etc.) via symbolic security predicates: sydr-fuzz security
- Collecting coverage: sydr-fuzz cov-report
- Crash deduplication, clustering, and severity estimation with the Casr tool: sydr-fuzz casr.

Sydr provides:

- Hybrid fuzzing with Sydr and either libFuzzer or AFL++. Hybrid fuzzing supports programs written on C/C++, Rust, and Go.
- Fuzzing with Atheris and Jazzer, as well as supporting the full fuzzing pipeline for Python and Java projects.
- Efficiency: continuous benchmarking shows that Sydr-fuzz is on the same level with world-famous competitors (https://sydr-fuzz.github.io/fuzzbench).
- Repository with ready to fuzz projects: 40+ projects (270+ fuzz targets) in OSS-Sydr-Fuzz (https://github.com/ispras/oss-sydr-fuzz).
- Trophies: Sydr-fuzz found 145 new bugs in 28 open source projects (https://github.com/ispras/oss-sydr-fuzz/blob/master/TROPHIES.md); 25 errors are found via safety predicates.
- Inverting all conditional branches that depend on input data.

- Safety predicates that find errors (division by zero, null pointer dereference, buffer overflow, integer overflow, etc.) and generate input data to reproduce detected errors.
- Symbolic execution of multithreaded programs.
- Inverting indirect branches (in switch statements). Sydr implements a method for detecting jump tables and jumps to computed addresses.
- Path predicate slicing. Sydr removes redundant constraints (not influencing the target conditional branch) from the path predicate. This feature solves the problem of under-tainting and speeds up solving.
- Reasoning of symbolic pointers that depend on input data. This allows to find critical errors arising out of taking user input for array index calculation. Supporting symbolic pointers requires additional modeling that is usually absent from similar tools.

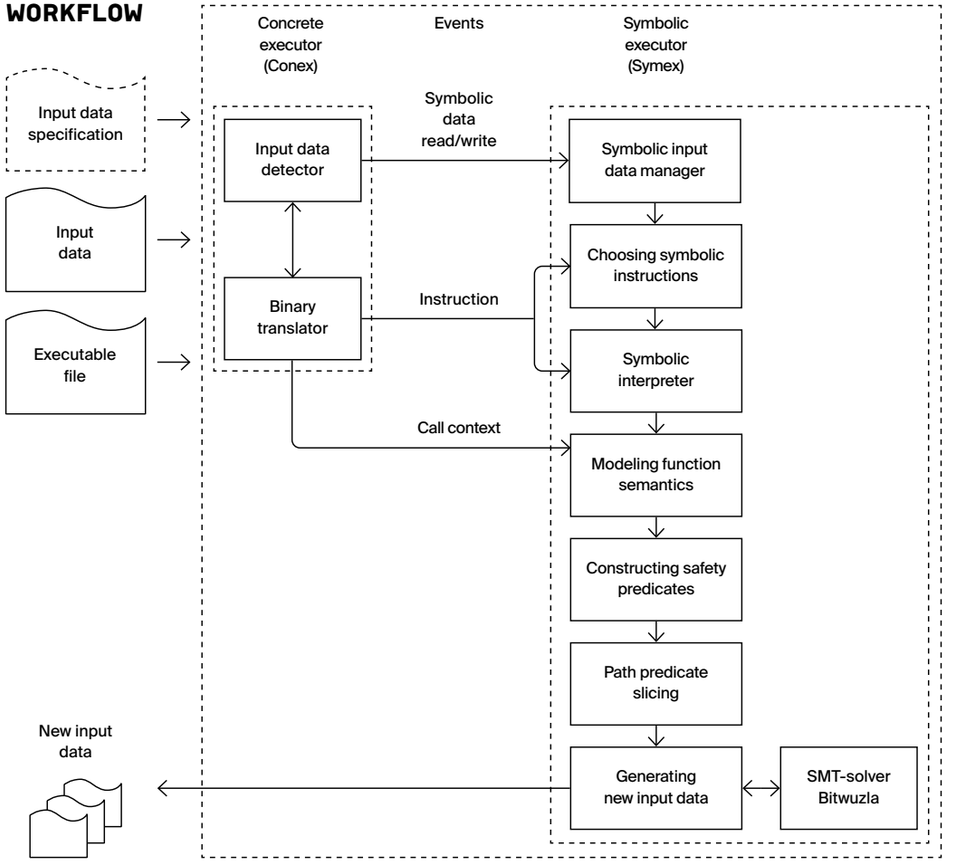
SYSTEM REQUIREMENTS

Sydr runs on x86-64 and aarch64 platforms. Sydr supports 64-bit Linux, including Ubuntu 18.04/20.04/22.04, Astra Linux 1.7, ALT Workstation 10 and similar.

SYDR DEPLOYMENT STORIES

Sydr and Sydr-fuzz are the parts of ISP Crusher system that is used in more than 70 companies and certification labs, including RusBITech, Postgres Professional, Security Code, Swemel, and others. Sydr + Sydr-fuzz is the main dynamic analysis tool in Research Center for Trusted Artificial Intelligence at ISP RAS.

WORKFLOW



PROTOSPHERE: NETWORK TRAFFIC ANALYZER

Protosphere is a system of deep packet inspection (DPI). It can serve as a part of intrusion and information leak protection systems. Protosphere detects inconsistencies between a protocol specification and the actual traffic. It allows you to add support quickly for new protocols (either open or closed) due to the flexibility of its internal representation.

FEATURES AND ADVANTAGES

Protosphere is an innovative system based on the innovative research in the area of network traffic analysis. It combines the key features of similar tools (e.g. Wireshark, Microsoft Message Analyzer, nDPI) with a universal data representation model that enables rapid expansion of analysis capabilities.

Protosphere provides:

- Advanced system core:
  - universal data representation model used when parsing network traffic;
  - processing of corrupted, reordered or duplicated packets, as well as handling of packet loss and processing of asymmetric traffic;
  - compressed/encrypted data analysis;
  - support for tunnels of arbitrary configuration;
  - support for network flows causality.
- Support for all stages of network trace analysis (each stage has a visualization component that are synchronized between stages):
  - network connections localization in the network interaction graph and the network flow tree;
  - detailed view of the selected connections in the timeline diagram;
  - interactive visualization of the parsed network packets in the stream tree;
  - detection of discrepancies between a protocol implementation and the actual traffic in the diagnostic log.
- Extensive list of supported protocols:
  - DNS, RHCP, RIP;
  - TLS, Microsoft RPC, PostfreSQL;
  - FTP, HTTP, IMAP, SMTP, POP3, BitTorrent;
  - GRE, IpSec, PPP, OpenVPN, Wireguard.
- Easy support for new protocols:
  - access to parsing results via API;
  - localize parsing errors;
  - declarative description of network protocols.
- Support for both online and offline analysis modes.
- Support for working in DPI as a Service mode.
- Advanced GUI provides choice of the most convenient way to present the analysis results.
- Numerous options for extending supported features:
  - supporting new programming interfaces;
  - developing various mechanisms for processing results of parsing;
  - adding features to the parsing kernel.
- Adjustment to network bandwidth and available computational resources: flexible configuration allows finding a balance between analysis accuracy and consumed resources.

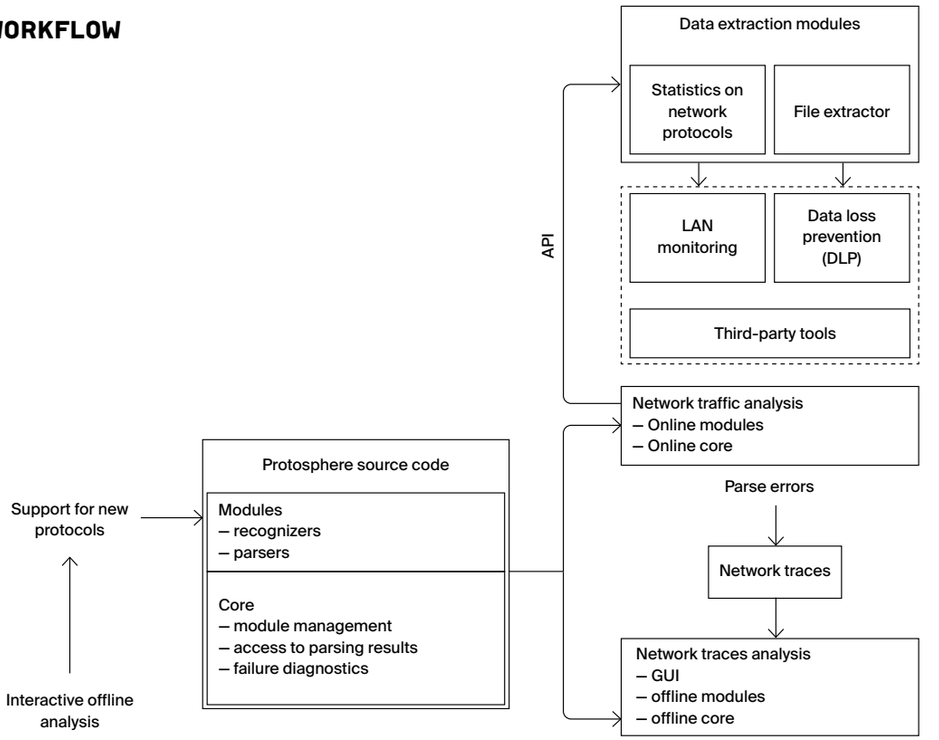
WHO IS PROTOSPHERE TARGET AUDIENCE?

- Companies that are testing network protocol implementations including those in embedded OS and network hardware.
- Developers of network security tools, such as firewalls and IDS/IPS including zero day attack protection.
- Manufacturers of network hardware that must be certified.
- Companies requiring real-time control and monitoring of network channels.

SUPPORTED PLATFORMS AND ARCHITECTURES

Architecture: Intel x86-64, ARM64.
Platforms: Windows OS, Linux-based OSes, Apple macOS.

WORKFLOW



REQUALITY: REQUIREMENT MANAGEMENT TOOL

Requality is an extensible tool for requirements management (mainly in software system development). It allows to develop software requirements from scratch as well as to create requirement catalogues by marking up existing documents and preserving the links between the requirements and the document fragments. It supports hierarchical structure of requirements, provides traceability between requirements of different levels and possibility of collaborative work on requirements using the GIT version control system.

FEATURES AND ADVANTAGES

Requality stands out by featuring the possibility of requirement catalogue creation from the markup of existing documents. Each of the created requirements preserves the link to one or several source document fragments.

The other functionality is close to existing commercial counterparts (IBM DOORS, Jama, Polarion) and surpasses some of the existing open-source products (aNimble, ProR, RMTOO). The tool and user manual are available at the project website: https://requality.ru.

Requality provides:

- Structuring and storing a requirements catalog:
  - A requirements catalog is a structured set of linked requirements and other elements stored within a single workspace. The top level elements are projects in which individual sets of requirements are stored. This capability is used, among other things, to separate upper level requirements from the lower level requirements developed on their basis.
  - The catalogue elements include the requirements themselves as well as various other nodes. The tool supports a basic set of elements, including:
    - requirements containing descriptions of features and limitations of the object being developed;
    - text nodes that are not requirements themselves, but provide context for dealing with requirements (e.g. term definitions or notes);
    - documentary representations of the requirements on the basis of which the catalogue was developed;
    - report settings and the results of their generation;
    - comments.

The set of catalogue elements can be increased by developing extensions.
  - Node identification is supported in several ways, including the use of a unique numeric identifier within the project and a composite human readable hierarchical path;
  - Node properties include both those provided by default tools (node description, short string identifier, and others) and user-defined parameters used to indicate element characteristics;
  - using HTML markup in the text of requirements and in other features makes it possible to use different ways of formatting text and to provide supporting resources, such as images and tables.
- Link management, traceability and coverage analysis:
  - Creating and naming links between catalogue elements. Link names allow defining references of different types;
  - Building links automatically from terminology via enumerating terms used in a requirement and enabling the corresponding attribute for the node defining the term;
  - Making a link between a text fragment and a requirement allows, on the one hand, to determine the origin of an individual requirement, and on the other hand, it makes it possible to automatically transfer such links to new versions of documents;
  - Comprehensive link traceability is the ability to trace both the original requirements and the requirements developed on their basis for an individual requirement, as well as to examine the context of the catalog element within which it is to be considered;
  - Coverage is a collection of data showing degree of implementation or testing completeness for a catalogue of requirements. Coverage is estimated by links between catalogue items and external elements or between internal catalogue items. The tool supports the use of external coverage information in the form of a specific file format, and provides an extensible set of coverage data sources.
- Change management and collaboration support:
  - GIT is supported as the primary system for collaborative work on the requirements catalogue. A simplified set of commands for submitting changes and updating the local version of the project is available in the interface of the tool;
  - The interface of the tool makes it possible to view the versions of a single node as well as those of the requirements catalogue as a whole; it is also possible to compare individual versions;
  - Comparing different project versions and switching to previous versions is also supported.
- Report generation, in particular:
  - Creating various formats of the requirements catalogue, including those that provide using it for offline work (outside the scope of the tool), as well as exchanging catalogue data with other tools or solving non-standard tasks within the development process;
  - Providing traceability data to view information on the relationships between catalog elements;

  - Comparing catalogue versions to manage work progress on requirements via studying the differences in the structure and properties of the project requirements for the selected versions of the catalogue;
  - Coverage analysis to examine the status of individual catalog elements in terms of coverage information obtained from a selected source;
  - Support for user-defined templates using available information on the catalog, its versions, and coverage information.
- A programming interface (API) with the ability to modify stored data and create new projects is supported. It can also be used to exchange data with third-party tools.
- It is possible to develop extensions to define new elements, sources of information on coverage, or to get new functionality.

SYSTEM REQUIREMENTS

Windows OS or GNU/Linux based OS, Java Runtime.

REQUALITY DEPLOYMENT STORIES

Requality has been in development since 2011. It has been used to develop and manage requirements' changes in a project to develop a real-time operating system in compliance with KT-178C processes, as well as to catalog requirements from various standards (including TTCN and POSIX) in order to perform subsequent conformance testing of compatible products.

2 DATA ANALYSIS

ASPERITAS AND CLOUD SOLUTIONS FAMILY

Asperitas is a platform for data storage and performing complex compute-intensive tasks in scientific, educational, and commercial projects. It includes a cloud environment also called Asperitas, as well as Michman, a PaaS orchestrator, and Clouni, a multi-cloud IaaS orchestrator based on TOSCA standard. Fanlight, a web laboratories platform, and Cotea, a system tool intended for programmatic control of Ansible scripts execution, are also a part of ISP RAS cloud solutions family.

ASPERITAS CLOUD ENVIRONMENT

Asperitas cloud environment is based on Openstack and Ceph, which are the modern standard of large private cloud systems. The distribution delivery is provided as a ready-made solution with everything necessary for deployment, including a TUI installer.

Other advantages of Asperitas:

- An onsite installation option (the provided infrastructure can be installed and fully controlled in an isolated environment due to the usage of open standards and software as well as ISP RAS research).
- High security: the environment is built on top of a smaller code base and uses its own know-how solutions that increase security.
- Standard interfaces of virtual and computational clusters management using Keystone, Neutron and Nova systems.
- Block storage and scalable object storage is based on the Ceph distributed file system.
- Adaptation to specific problem classes (e.g. continuum mechanics, big data analysis, program analysis for defect detection etc.).

Asperitas cloud environment is included in the Unified Register of Russian software (No. 5921).

CLOUNI, A MULTI-CLOUD ORCHESTRATOR

GitHub → https://github.com/ispras/clouni

To enhance the capabilities of infrastructure resource management, ISP RAS is developing the Clouni tool, which allows deploying clusters of virtual infrastructure according to TOSCA Simple Profile normative templates using the Ansible configuration management tool.

Main characteristics of Clouni orchestrator include:

- Own approach for translating TOSCA declarative templates to Ansible scripts, which allows users to avoid the need of describing how infrastructure should be deployed;
- No dependency on the cloud platform being used. Currently, Clouni supports Openstack, Amazon AWS, and partially Kubernetes.
- Fine-tuning of virtual machines, security groups, ports and networks.

The TOMMANO framework, a tool for managing network services in arbitrary clouds, is being developed in a close cooperation with Clouni. The main characteristics of TOMMANO are as follows:

- Automatic deployment of virtualized network functions based on their TOSCA declarative descriptions according to the ETSI MANO standard;
- A number of network function templates is already provided for Firewall, NAT, DPI, DNS, DHCP, and traffic analyzers.
- Service function chaining support based on software defined network managed by the OpenDayLight controller. This allows managing complex network services that have different traffic types processed via different network functions.
- Support for network function deployment: in standalone mode with routing configuration from TOSCA template parameters, in service chains with automatic routing between nodes.

MICHMAN, A UNIVERSAL ORCHESTRATOR

GitHub → https://github.com/ispras/michman

Michman is a PaaS services orchestration tool for a cloud environment performing big data analysis, machine learning, load management tools, and other tasks. It supports automatic cluster deployment in cloud environment, taking into account user requirements and parameters. It also provides an interface for deploying sets of services from predefined service templates and managing their lifecycle, including:

- A big data analysis cluster with arbitrary number of nodes having Apache Spark, and Apache Hadoop fully set up for cooperative work;
- A database of various types, from classic relational to distributed analytical DBs;
- file storage and exchange systems, e.g. MiniO, NextCloud, NFS, GlusterFS;
- Slurm, a cluster management and job scheduling system with the option of GPU usage;
- Kubernetes, a flexible container orchestration system, and tools running on top of it;
- Tools for developing machine learning models, including Jupyter, MLflow, and Ray.

The key advantage of Michman is its flexibility and easy extension of supported services due to using TOSCA language and supporting the following mechanisms:

- Substitution Mapping, which allows describing resources of the same type uniformly. For example, one can describe how the deployment on various resources should be performed (in public or private clouds, on dedicated servers or within containers). Also one can describe the way of integrating an application with various DBs, connecting various file systems, etc.
- Select, which allows reusing resources created previously or utilizing external resources (like external repository or common network file system).

Also Michman allows saving the state of all components of a cloud application consistently, scaling nodes, managing cloud application components separately, updating running services.

FANLIGHT

Fanlight is a platform for providing virtual desktops (DaaS - Desktop as a Service). It allows deploying SaaS infrastructure for computing web-laboratories. It was created as a result of ISP RAS participation in the University Cluster program and in the international Open Cirrus project (founded by HP, Intel and Yahoo). Fanlight is based on container technologies, unlike most solutions of this class based on virtual machines. Initially, the platform had been based on the Docker Compose technology. Later on, a Kubernetes-based implementation appeared. It only supports applications developed for Linux kernel-based OS. Fanlight is included in the Unified Registry of Russian Software (No. 6066).

Other advantages of Fanlight:

- High efficiency of work with cloud calculations due to the use of containers:
  - comfortable work with heavy engineering CAD-CAE applications requiring 3D graphics hardware acceleration support for complex visualization;
  - Support for running MPI, OpenMP, CUDA applications through access to HPC clusters, multicore processors, and NVIDIA graphics accelerators.
- Extended computing capabilities at the PaaS level through connecting hardware resources (HPC/BigData clusters, storage systems, graphic accelerator servers).
- Possibility of customization for a given application area due to integration of specialized calculation application packages and the easy way to add them. In particular, the following have been implemented:
  - in the field of MSS: OpenFOAM, SALOME, Paraview, etc;
  - in the field of Gas&Oil: tNavigator, Eclipse, Roxar, Tempest, etc.
- Operation via any thin client (including mobile devices) without any auxiliary software.

– Deployment on a server, computing farm, cloud (from the IaaS layer), in a Kubernetes cluster, or in dedicated cloud data center. The Kubernetes-based version also provides the opportunity to use different CRI container execution engines.

COTEA
GitHub →
https://github.com/ispras/cotea

Cotea is a tool that makes it possible to run Ansible programmatically and control its execution (Ansible is one of the most popular software deployment systems). Cotea allows to:

– use software control of running Ansible by iterating over the component parts of the Ansible script;
– embed Ansible into other systems;
– debug Ansible runs, including interactive mode; switching to interactive mode occurs in case of a task (part of the Ansible script) execution failure. Examples of functions provided in interactive mode:
  – restart a task that resulted in an error;
  – continue executing the Ansible script without the failed task;
  – add a new Ansible variable during runtime;
  – add a new Ansible task during runtime.

Interactive mode makes it possible to refrain from executing a script all over again in case of errors, which is especially important when working with large scripts.

Cotea is currently used in the deployment of the Asperitas platform. A part of Corea included in Michman and Clouni is called grpc-corea. Grpc-cotea enables these orchestrators to control the deployment process of cloud applications.

CLOUD SOLUTIONS DEPLOYMENT STORIES

The computing cluster based on Asperitas supports a number of ISP RAS technologies (e.g. analyzing Android OS using Svace). The following projects were also implemented: a joint project with Huawei (large graphs analysis using big data processing), and the Tizen OS lifecycle support infrastructure that allows organizing joint development of OS components and automating regular build and testing of OS images. In addition, a number of projects are performed jointly with the Ministry of Education and Science of Russian Federation. Asperitas serves as a foundation for the cloud platform of the National Center for Medical Research “Digital Biodesign and Personalized Healthcare.”

The Fanlight platform was used in a number of joint projects for web laboratory deployment, including Russian Federal Nuclear Center of the All-Russian Scientific Research Institute of Experimental Physics, OOO RRS-Baltika, Keldysh Institute of Applied Mathematics (developing a technology for increasing and using efficiently the hydrocarbon raw materials resource potential of the Union State of Russia and Belarus), ISP RAS Laboratory of Continuum Mechanics (https://unicfd.ru).

TALISMAN: PLATFORM FOR CONSTRUCTING INTELLECTUAL ANALYTICAL SYSTEMS

Talisman is a unified set of tools that automate typical data processing tasks, such as data retrieval, integration, analysis, storage and visualization. It ensures the fast development of specialized multi-user intellectual analytical systems that merge and work uniformly with the data from private databases and Internet sources (including social networks).

FEATURES AND ADVANTAGES

Talisman unifies the tools necessary for big data and cutting-edge AI tools, using them to extract information from random sources. It makes it possible to quickly create intelligent analytical systems using low-code and no-code approaches. It is constantly learning from the results of analyst work without the need for additional labor.

Talisman provides:

– A rich set of reusable components that have APIs for easy management and integration:
  – Data retrieval components. They include a framework for Internet data collection, namely, from social media (Facebook, VKontakte, Twitter, Instagram, Odnoklassniki, YouTube, LinkedIn etc.), blogs, news, MediaWiki sites, developer portals etc. There is also a system for importing data from file storages and databases.
  – Automatic data analysis components. A set of tools allowing to transform input data of any format into a unified universal representation (in particular, Dedoc, developed by ISP RAS, is used). The documents in this representation are subjected to analysis with the help of machine learning methods. It is possible to add your own handlers as containers with REST API. The processing sequence is managed by Talisman.Stream system (No. 6045 in the Unified Registry of Russian Software).
  – Storage and indexing components. These include a number of databases and information search engines that store source data, automatic analysis results, and results of manual user work.

- An easy to use web interface that unifies all components requiring user interaction.
- A flexible modular architecture that allows adding new features to the interesting components without changing others.
- A scalable architecture that allows processing and storing more data just by adding more hardware without any software change.
- Specialized components that monitor system status, manage event log, perform deployment, authentication and authorization, access control, and unidirectional data transfer.
- Tools and methods for training machine learning models as well as for transferring existing algorithms to other knowledge domains.
- A configurable knowledge domain scheme that can be changed by a user when the system is in operation.
- Complete alienability of the systems under development. Each system can be deployed at the customer's site, either on existing hardware or as part of a hardware-software system.
- Integration with private customer systems via provided APIs managing all components.
- License purity. Talisman is based on open source and know-how ISP RAS tools.

TALISMAN APPLICATION AREAS

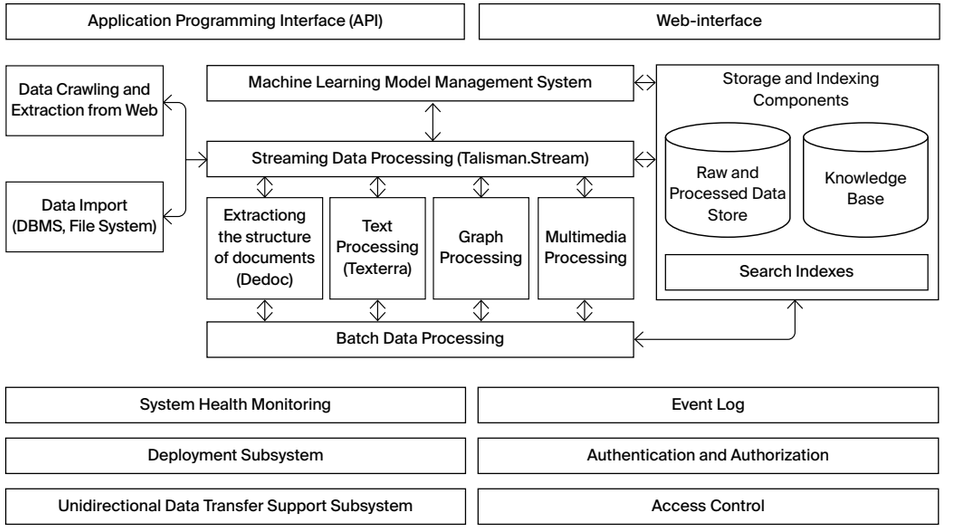
Talisman makes it possible to create analytical systems for a wide range of applications. Application examples:

- Automated knowledge base construction for a given knowledge domain and non-stop monitoring for new information regarding objects of interest (analogous to Palantir Gotham).
- Competitor intelligence based on open sources (OSINT), analogous to Maltego.
- Monitoring media for performing analytics tasks (analogous to LexisNexis).
- Optimization of personnel management: effective selection of employees, verification of questionnaire data, detection of incorrect behavior in the open information space (Talisman. Biography system, No. 5547 in the Unified Register of Russian Software).
- Identification of information campaigns that manipulate the opinion of the target audience, as well as determining the target audience the campaign is aimed at.
- Identifying and analyzing the specifics of information distribution infrastructure (resources, users, bots), as well as analyzing the typical roles of community members in communication (source, opinion leader, distributor, moderator, bot, commentator).
- Managing the business reputation of people and organizations: monitoring relevant messages, identifying problems that cause dissatisfaction, monitoring leaks and internal information disclosure.
- Objective evaluation of performance and testing strategies on target audiences for feedback.
- Management of social tension points; detection and timely prevention of conflict escalation.

SUPPORTED LANGUAGES

Talisman uses advanced artificial neural networks to analyze data. The tools used make it possible to extract information from more than 100 natural languages.

TALISMAN WORKFLOW



TRUSTED MACHINE LEARNING FRAMEWORKS

A machine learning framework is an environment and a set of tools that allow rapid development of ML programs. TensorFlow and PyTorch are the most popular frameworks. The work on creating trusted versions of these frameworks within the Research Center for Trusted Artificial Intelligence (RCTAI) at ISP RAS is ongoing. The project goal is to find and fix software defects that could result in incorrect functioning of the frameworks, which in turn would lead to issues in target applications.

DEPLOYED INFRASTRUCTURE

A hardware-software infrastructure for analyzing frameworks is deployed. The infrastructure is used to perform the following activities:

- static analysis, dynamic analysis and fuzzing for the framework code;
- constantly checking recent code changes;
- synchronization with upstream open source repositories.

ANALYZERS BEING USED (DEVELOPED AT ISP RAS)

Svace is a static analysis tool supporting more than 50 critical error types. Svace supports C, C++, C#, Java, Kotlin, Go; Python support is in beta. Svace is distributed with the Svacer web interface (Svace History Server).

Sydr is an automatic test generation tool for complex programs that finds errors and increases code coverage during testing. Sydr constructs the program's mathematical model that allows a fuzzer to explore new execution paths that are hard to discover via classic mutation approaches. Sydr-fuzz is a dynamic analysis tool for security development lifecycle which combines the power of dynamic symbolic execution tool Sydr and modern fuzzers (libFuzzer and AFL++).

ANALYSIS RESULTS (AS OF NOVEMBER 2023)

- A number of errors is found, developed fixes are applied to the trusted framework versions and mostly accepted upstream:
  - 27 errors in TensorFlow (4 are found via Sydr+Sydr-fuzz, 23 are found by Svace), 26 patches are committed to upstream.
  - 39 errors in PyTorch (26 are found via Sydr+Sydr-fuzz, 13 are found by Svace), 36 patches are committed to upstream.
  - 10 errors are found in 3rd party components (LLVM, oneDNN, miniz, torchvision, openjpeg).
  - A methodology for developing trusted frameworks is created.
  - The developed trusted versions of ML frameworks are deployed within solutions made by RCTAI industrial partners and integrated to Kaspersky Machine Learning for Anomaly Detection version 3.0.

WHO ARE THE TARGET AUDIENCE FOR TRUSTED FRAMEWORKS?

Trusted frameworks are intended for companies that develop highly reliable and secure software based on machine learning technologies.

LINGVODOC: VIRTUAL LAB FOR DOCUMENTING ENDANGERED LANGUAGES

GitHub →
https://github.com/ispras/lingvodoc

Lingvodoc is a system intended for collaborative multi-user documentation of endangered languages, for creating multi-layered dictionaries and performing scientific work with the received sound and text data. This is a joint project with the Institute of Linguistics of the Russian Academy of Sciences and Tomsk State University. Lingvodoc is under active development since 2012 and can be found on lingvodoc.ispras.ru.

FEATURES AND ADVANTAGES

Lingvodoc is an open source cross-platform system based on an innovative research (https://github.com/ispras/lingvodoc, https://github.com/ispras/lingvodoc-react).

Lingvodoc provides:

- Collaborative work on adding new information to dictionaries (as opposed to the similar Starling project that does not support this feature).
- Saving full history of user actions.
- Working with audio-textual corpuses and dictionaries simultaneously based on the integration with the ELAN system developed by Max Planck Institute of Psycholinguistics (Netherlands).
- Creating and editing unidirectional and bidirectional connections between lexical entries within dictionaries as well as external connections between dictionaries.
- Recording, playing and storing marked-up sounds (in WAV, MP3 and FLAC formats), as well as constructing vowel formants followed by data visualization.
- Advanced search supporting multiple parameters (as opposed to the similar TypeCraft project).
- Ability to search data on a map with automatic demarcation of isoglosses.
- Conflict-free bilateral delayed synchronization.
- High automation level (compared to the similar Kielipankki project): ability to carry out automatic etymological and phonetic analysis.
- Creating dictionaries of any structure, such as typical two-layer dictionaries with lexical entry layer and paradigms layer or multi-layer dictionaries. Importing existing dictionary structures is also supported.
- Algorithms mimicking the scholars' work on phonetic and etymological analysis.
- Support for refining language and dialect classification and building 2D and 3D diagrams via glottochronology, morphology, etymologic and phonetic features.
- Support for storing text corpora in Word format, and dictionaries in the Excel format.
- Built-in morphological analysis for the languages of the ethnicities of Russia in the Aperitum format.
- A convenient interface for disambiguating homonyms after completing morphological analysis.
- Either using the ISP RAS cloud infrastructure resources or locally deployed resources with data isolation.
- Desktop and web-based versions.
- Open registration (confirmation required).
- Fast development for extending the system features as well as easy adapting to other fields of knowledge.

A prototype version of a learning platform hosted at edu.ispras.ru is created using Lingvodoc glossed corpora and analysis programs. The platform contains 10,000 exercises on 9 languages and allows:

- creating exercises for languages used in Russia for any age or language proficiency level (a teacher can create own exercises and avoid checking them by himself);
- doing exercises in either own or foreign languages, and the platform will tailor the exercises based on the proficiency level of a pupil.

WHO IS LINGVODOC TARGET AUDIENCE?

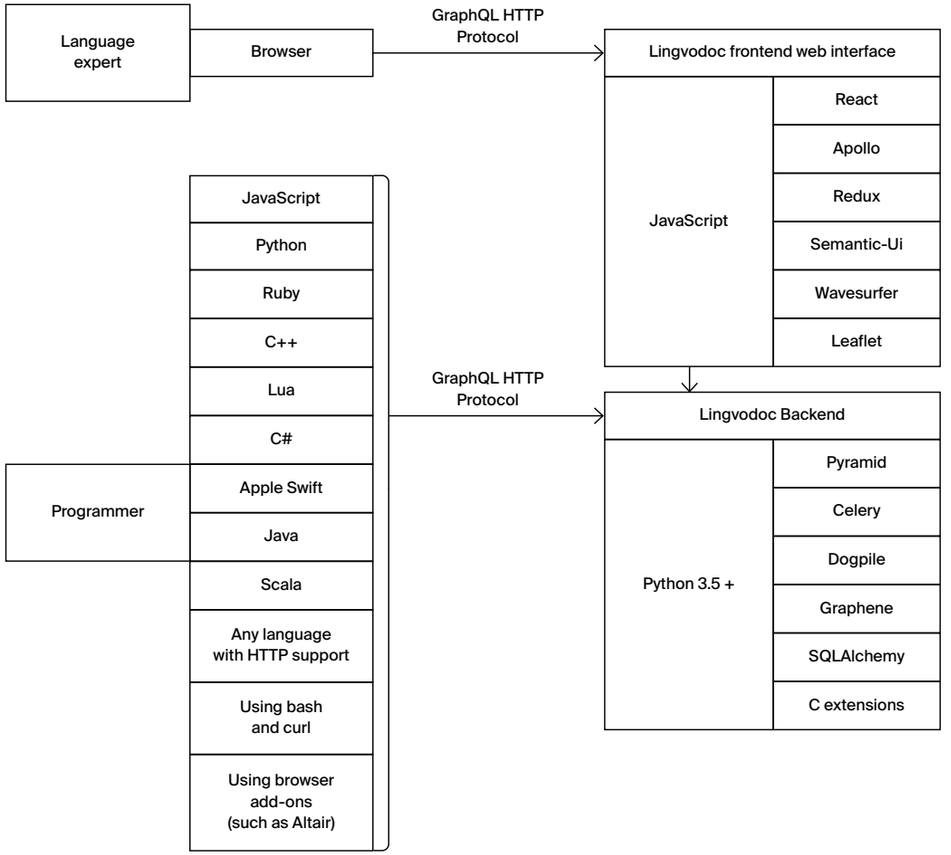
Lingvodoc is designed primarily for linguists performing a research in the area of documenting the endangered languages of Russian ethnicities. However, it is possible to adapt the technology for other purposes.

LINGVODOC DEPLOYMENT STORIES

Lingvodoc is currently used by philologists in 29 universities and scientific centers of 16 cities, including Tomsk State University, Institute of Philology (Siberian Branch of RAS). Institute of history, language and literature (Ufa scientific center of RAS), Udmurt Federal Research Center UB RAS, North-Eastern Federal University, Ugra State University, Institute of Linguistics, Literature and History (Karelian Research Centre of RAS), Murmansk Arctic State University. Specialists using the platform are ready to teach master classes for their colleagues.

In 2023, four groups of researchers from several Russian cities took part in additional training courses on "Using the features of the Lingvodoc platform in the work of linguists" (including at the Bashkir State University and the People's Friendship University of Russia).

LINGVODOC WORKFLOW



DEDOC: DOCUMENT STRUCTURE RETRIEVAL SYSTEM

Dedoc is an open universal library for converting documents to a unified output format. It extracts a document's logical structure and content, its tables, text formatting and metadata. The document's contents are represented as a tree storing headings and lists of any level. Dedoc can be integrated in a document contents and structure analysis system as a separate module.

FEATURES AND ADVANTAGES

Dedoc is implemented in Python and works with semi-structured data formats (DOC/DOCX, ODT, XLS/XLSX, CSV, TXT, JSON) and unstructured data formats like images (PNG, JPG etc.), archives (ZIP, RAR etc.), PDF and HTML formats. Document structure extraction is fully automatic regardless of input data type. Metadata and text formatting is also extracted automatically.

Dedoc provides:

- An open source Python library (https://github.com/ispras/dedoc).
- Extensibility due to a flexible addition of new document formats and to an easy change of an output data format.
- Support for extracting document structure out of nested documents having different formats.
- Extracting various text formatting features (indentation, font type, size, style etc.).
- Working with documents of various origin (statements of work, legal documents, technical reports, scientific papers) allowing flexible tuning for new domains.
- Working with PDF documents containing a text layer:
  - Support to automatically determine the correctness of the text layer in PDF documents;
  - Extract content and formatting from PDF-documents with a text layer using the developed interpreter of the virtual stack machine for printing graphics according to the format specification.
- Extracting table data from DOC/DOCX, PDF, HTML, CSV and image formats:
  - Recognizing a physical structure and a cell text for complex multipage tables having explicit borders with the help of contour analysis.

- Working with scanned black-and-white documents (image formats and PDF without text layer):
  - Using Tesseract, an actively developed OCR engine from Google, together with image preprocessing methods.
  - Utilizing modern machine learning approaches for detecting a document orientation, detecting single/multicolumn document page, detecting bold text and extracting hierarchical structure based on the classification of features extracted from document images.
  - Enabling binarization to process documents with a background watermark.

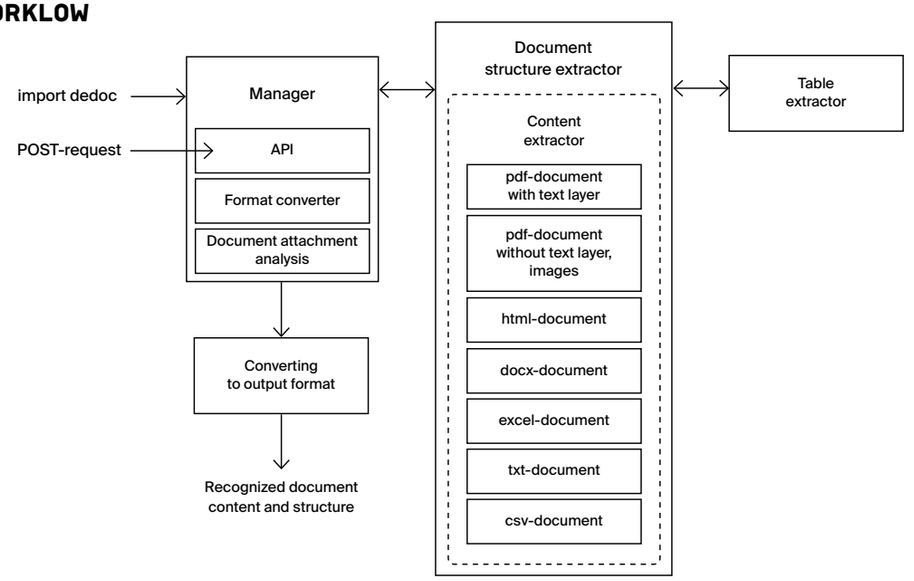
WHO IS DEDOC TARGET AUDIENCE?

- Developers of document content analysis and management systems.
- Developers of intellectual text analysis algorithms.
- Developers of automatic document processing systems.

SUPPORTED LANGUAGES

Russian and English.

WORKLOW



DOCMARKING: DOCUMENT LEAKAGE PREVENTION

DocMarking is a unique system for embedding digital watermarks into text documents. It allows creating a digital or physical document copy that is almost indistinguishable from the original yet exactly identifies the user or the device that was the intended recipient.

FEATURES AND ADVANTAGES

DocMarking is based on research results in the areas of steganography, digital image processing, and machine learning. The marking system builds on the methods for text detection and classification in images and uses statistical features of document images.

DocMarking has a number of advantages compared to competing technologies. Watermark extraction does not require the original document. The system supports embedding a watermark in the same scanned document multiple times, and the previous watermark is erased when the new one is being embedded.

DocMarking provides:

- Marking algorithms based on machine learning.
- Support for documents of all formats.
- Working with any application.
- Protecting documents either when a document is displayed on a screen or printed.
- Watermark extraction without access to original unmarked documents.
- Standalone setup and work on the client side.
- Centralized 24/7 monitoring of the connected devices.

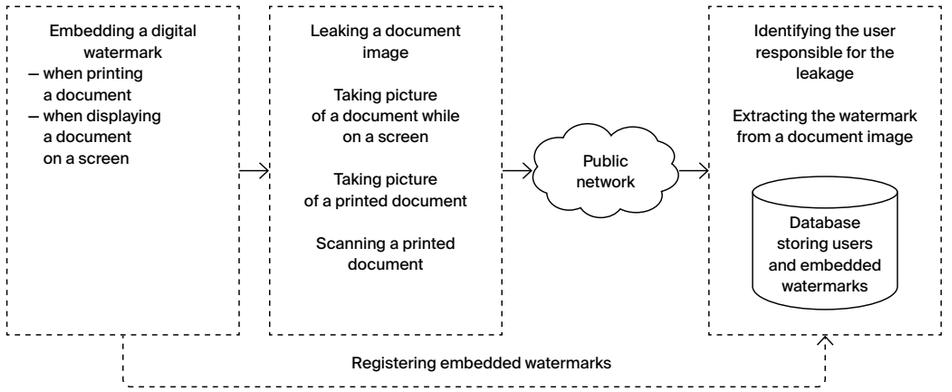
WHO IS DOCMARKING TARGET AUDIENCE?

- Government entities and public offices.
- Companies that would like to enforce their guides for handling classified documents.

SUPPORTED OPERATING SYSTEMS

Windows (32-bit, 64-bit), Linux (64-bit), including Astra Linux 1.6/1.7 SE.

DOCMARKING WORKFLOW



ECGHUB: IN-DEPTH ANALYSIS OF DIGITAL ECG

EcgHub is a 12-lead ECG labeling system and neural network models' collection for pathology prediction. The system allows to predict the presence or absence of several pathologies, as well as to perform and review the syndromic ECG markup based on the verified questionnaire, thus providing a dataset for further development of neural network models.

FEATURES AND ADVANTAGES

EcgHub is based on research results in the areas of digital signal processing and machine learning algorithms. The pathology classification system is based on deep neural networks. The expert-verified approach provides consistent ECG labeling for training and further development of predictive models for screening and diagnosis of cardiovascular diseases.

EcgHub provides:

- Trained neural networks for pathology prediction of digital ECG;
- Continuous development and refinement of neural network models, including fine-tuning for relatively small medical datasets;
- Adaptation of trained neural network models for pathology prediction of single-lead ECGs (cardiac chair, smart watches) as well as 24-hour ECGs (Holter monitoring);
- A consistent syndromic markup system to provide qualitative data for training predictive models;
- Integration of neural network models into the customer's digital circuit or remote access to the service at ISP RAS;
- Applying the markup system in the education of modern functional diagnostics professionals;
- Development of an automated population screening system.

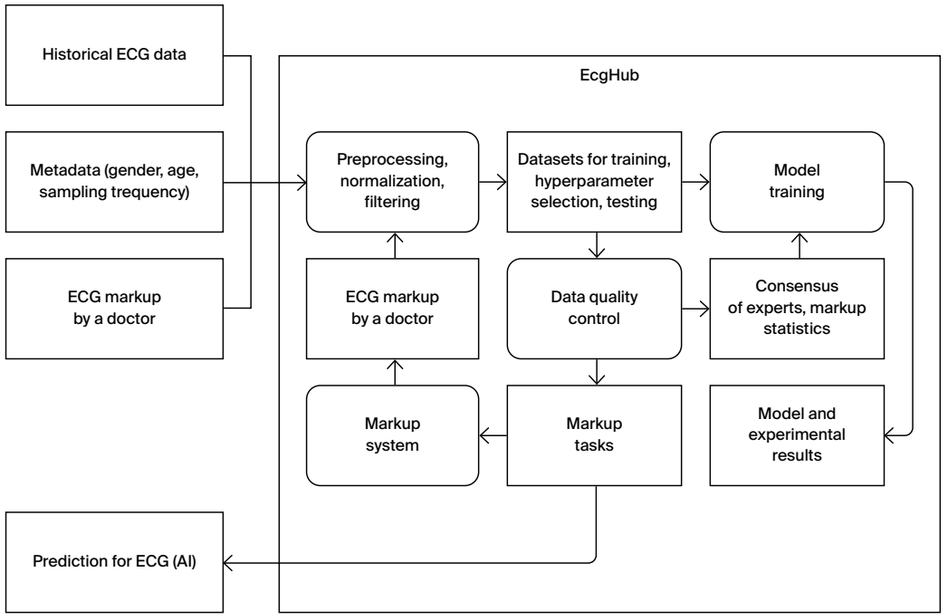
WHO IS ECGHUB TARGET AUDIENCE?

- Medical institutions: the prediction of neural network models can be used as a second opinion;
- Educational institutions: verified datasets allow evaluating the knowledge of students or novice doctors of relevant specialties;
- Developers of devices and applications that perform ECG diagnostics autonomously.

ECGHUB DEPLOYMENT STORIES

The neural network model of 12-channel ECG classification was trained on data from the Republic of Tatarstan, integrated as a proof of concept into the “Unified Cardiologist” system, and tested on ECG data from different regions (Republic of Tatarstan, Moscow, Velikiy Novgorod).

WORKFLOW



3 OTHER TECHNOLOGIES

CONSTRUCTIVITY 4D: INDEXING, SEARCHING, AND ANALYSIS OF LARGE-SCALE SPATIAL/ TEMPORAL DATA

Constructivity 4D is a technology for creating innovative software services that are capable of processing highly dynamic scenes and vast arrays of spatial and temporal data. It performs visual analysis of millions of objects with individual geometry and dynamic behavior. Constructivity is deployed within the Synchro system (Bentley Systems) that is used for 4D modeling of extremely large construction sites.

FEATURES AND ADVANTAGES

Constructivity 4D is a production level technology that puts together original methods of spatio-temporal indexing, search and qualitative and quantitative data analysis. Developed methods account for the specifics of objects' geometric representation, complex organization and the apriori known nature of their dynamic changes.

Constructivity 4D provides:

Support for a well-developed set of operations:

— Temporal operations implement classical interval algebra introduced by Allen with respect to time stamps of discrete events and their intervals.
— Metric operations allow determining the individual properties of geometric objects and the characteristics of their mutual arrangement. Diameter, area, volume, center of mass, planar projections, and distances between objects can be calculated for solid geometric objects.
— Topological operations are intended to classify the relative location of objects and to establish the facts of their coincidence, intersection, coverage, touch, overlap or collision. In contrast with known topological models such as DE-9IM, RCC-8, RCC-3D, these operations allow constructive implementation and are applicable for the analysis of complex objects.

  - Orientational operations generalize known Frank's and Freksa's relative orientation calculi, cardinal direction calculi (CDC), oriented point relation algebra (OPRA) and are applicable for the analysis of objects with extended boundaries.
- Efficient query execution and typical problems solving, in particular, queries for reconstructing a scene at a given point in time, retrieving objects in a given spatial region, finding nearest neighbors, determining static and dynamic collisions, and conflict-free routing in a global dynamic environment are effectively resolved.
- A spatial-temporal indexing system including binary event trees, spatial decomposition trees, bounding volume trees, object cluster trees, space occupation trees.
- A hybrid computational strategy for determining collisions in scenes that combines methods for precise collision determination, collision localization methods using spatial decomposition, methods of hierarchies of bounding volumes, temporal coherence methods.
- An object-oriented library implemented in C++ that includes extensible set of classes, interfaces and related methods for specifying spatial-temporal data and executing typical queries.
- An original method for navigation in global dynamic environment that is based on extracting spatial, metric and topological information from geometric representation of 3D scenes and its concerted usage on path planning.
- Various options for extending the library so that it can be used both in new software applications development and in legacy applications.

WHO IS CONSTRUCTIVITY 4D TARGET AUDIENCE?

The technology is used for creating application systems in vastly different fields, including but not limited to: computer graphics and animation, geoinformatics, scientific visualization, design and manufacturing automation, robotics, logistics, project management and scheduling.

CONSTRUCTIVITY 4D DEPLOYMENT STORIES

The technology has been successfully deployed within the Synchro software system (https://www.bentley.com/en/products/brands/synchro) that is designed for visual 4D-modeling, planning and management of large-scale industrial projects in the construction and infrastructure areas, as well as others. Synchro is used in more than 300 companies in 36 countries.

VALIDBIM: A SERVICE FOR INFORMATION MODEL VERIFICATION IN ARCHITECTURE AND CONSTRUCTION

VALIDBIM is a service for verifying information models that are used in construction and architecture works. The models should be written in the IFC SPF format and support functional compatibility for applications on the Building Information Modeling (BIM) Level 3. This level of technological maturity in the Bew & Richards model assumes BIM application interoperability and integration into advanced multidisciplinary software systems that are used for various design activities in architecture, engineering, construction and buildings and structures management.

FEATURES AND ADVANTAGES

VALIDBIM is a service that is capable of bringing the advanced software, which satisfies requirements of technical, syntax and semantic interoperability and BIM maturity, to the new level.

VALIDBIM provides:

- Verifying whether construction and architecture information models comply with international and national Industry Foundation Classes (IFC) standards (ISO 16739; GOST R 10.0.02: 2019) and STEP Physical File (SPF) standards (ISO 10303-21; GOST R ISO 10303-21: 2002, 2022).
- Checking syntax and link consistency of models' file data.
- Complete and mathematically rigorous checking model data semantics based on a formal scheme set up using the EXPRESS language of object-oriented modeling.

The following correctness checks are performed:
- object types (ENTITY),
- number and types of object attributes, including enumeration attributes (SELECT),
- mandatory and optional attributes (OPTIONAL),
- length limits for symbol and binary strings (STRING, BINARY),

- collection sizes (BAG, SET, LIST, ARRAY),
- mandatory and optional collection attributes (OPTIONAL ARRAY),
- uniqueness, when collection elements represent sets (SET, LIST OF UNIQUE),
- collection size and contents, when collections are inverse attributes (INVERSE).

The following satisfiability checks are performed:
- rules for ranges of simple types (TYPE WHERE),
- rules for coherency of object attributes (ENTITY WHERE),
- rules for uniqueness of object attributes (ENTITY UNIQUE),
- global rules for coherency of object collections (RULE).

- Verifying software for which technical, syntax and semantic interoperability of BIM Level3 is claimed.
- Supporting latest IFC standard versions including IFC 2x3, IFC 4, and IFC 4.3.
- Recording detected errors and mailing to registered users.
- Quick processing user verification jobs.

WHO ARE VALIDBIM TARGET AUDIENCE?

- BIM software developers that want to create advanced interoperable programs and are in need of reliable BIM verification tools.
- BIM users wanting to ascertain the quality and completes of their information models and to ensure that the models can be processed by tools coming from different vendors.

VALIDBIM DEPLOYMENT STORIES

VALIDBIM is developed and deployed as a part of BIM National Platform on bim.ispras.ru. The service is actively used by Russian developers and users of BIM software.

DIGITEF: COMPUTER MODELING PLATFORM

DigiTEF is a software platform for developing digital modeling applications, performing computer modeling and engineer analysis for industrial technical and scientific tasks. DigiTEF allows solving various application problems of gas dynamics, aerodynamics, hydrodynamics, and acoustics as well as performing coupled calculations.

DigiTEF is included in the Unified Register of Russian Programs (No. 5377).

FEATURES AND ADVANTAGES

DigiTEF is being developed based on open source software and ISP RAS know-how libraries and modules. Using own research results allows, for certain problem types, to calculate solutions that are more precise and correct compared to the state of the art counterparts. DigiTEF core performance and accuracy evaluations compared with ANSYS Fluent and Star CCM+ showed similar (and in some cases lower) computational costs with the same accuracy.

DigiTEF provides:

- open source code (allows improving data safety as well as controlling and adapting implemented algorithms for specific problems);
- intuitive graphical user interface that can be adapted for a specific enterprise and problems being solved;
- no limitations on user number, computational cores, cell number in meshes, which allows to decrease costs for computations and usage;
- modern algorithms on models via synchronizing technical level with international community;
- automation tools for computation and model integration that allow integrated research of technical objects;
- developing additional components according to custom requirements;
- using high-performance distributed systems (like clusters and supercomputers) for speeding up computations.

WHO ARE DIGITEF TARGET AUDIENCE?

DigiTEF is designed for use in companies and enterprises of resource-intensive industries. Using DigiTEF allows increasing engineering efficiency and profit margins as well as reducing costs and complexity when implementing industrial projects.

DEPLOYMENT STORIES

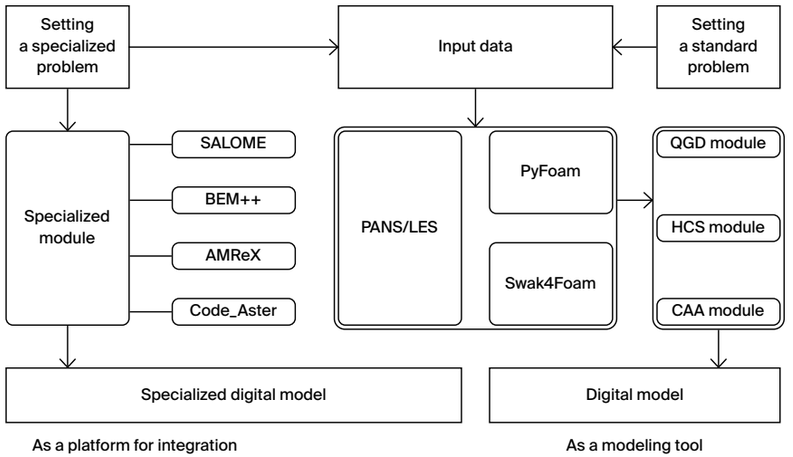
DigiTEF is used in several projects in the fields of wind energy, aerospace, aviation, shipbuilding, metallurgy, as well as in the oil and gas industry. DigiTEF open source modules are successfully used in Institut Pprime (France), Korea Atomic Energy Research Institute (Korea), Universität der Bundeswehr München (Germany), Northwestern Polytechnical University (China), Ocean University of China, Embry-Riddle University (USA), California Institute of Technology (USA), etc.

SYSTEM REQUIREMENTS

DigiTEF supports Linux OS, including Astra Linux, and Microsoft Windows 10. DigiTEF requires at least 4-core x86-64 processor, 16 GB RAM, and 100 GB disk space.

DigiTEF supports parallel computing. Using up to 1536 computational cores was tested.

WORKFLOW



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Ivannikov Institute for System Programming of the RAS 2023