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2025 *Activity Report*

RESEARCH CENTRE: **Inria Centre at Université Côte d'Azur**

IN PARTNERSHIP WITH: **CNRS, Université Côte d'Azur**

Project-Team

KAIROS

Multiform Logical Time for Formal Cyber-Physical System Design

In collaboration with Laboratoire informatique, signaux systèmes de Sophia Antipolis (I3S)

Project-Team KAIROS

Creation of the Project-Team: 2019 July 01

Each year, Inria research teams publish an Activity Report presenting their work and results over the reporting period. These reports follow a common structure, with some optional sections depending on the specific team. They typically begin by outlining the overall objectives and research programme, including the main research themes, goals, and methodological approaches. They also describe the application domains targeted by the team, highlighting the scientific or societal contexts in which their work is situated. The reports then present the highlights of the year, covering major scientific achievements, software developments, or teaching contributions. When relevant, they include sections on software, platforms, and open data, detailing the tools developed and how they are shared. A substantial part is dedicated to new results, where scientific contributions are described in detail, often with subsections specifying participants and associated keywords. Finally, the Activity Report addresses funding, contracts, partnerships, and collaborations at various levels, from industrial agreements to international cooperations. It also covers dissemination and teaching activities, such as participation in scientific events, outreach, and supervision. The document concludes with a presentation of scientific production, including major publications and those produced during the year.

Keywords

Computer sciences and digital sciences

A2.1. – Programming Languages

A2.2. – Compilation

A2.3. – Embedded and cyber-physical systems

A2.3.1. – Embedded systems

A2.3.2. – Cyber-physical systems

A2.3.3. – Real-time systems

A2.3.5. – Cyber-physical systems

A2.5. – Software engineering

A2.5.1. – Software Architecture & Design

A6.1. – Methods in mathematical modeling

A6.3. – Computation-data interaction

Other research topics and application domains

B5.1. – Factory of the future

B5.4. – Microelectronics

B6.1. – Software industry

B6.4. – Internet of things

B6.6. – Embedded systems

B7.2. – Smart travel

B8.1. – Smart building/home

B8.2. – Connected city

B9.5.1. – Computer science

Contents

1 Team members, visitors, external collaborators

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2 Overall objectives

The Kairos ambitions are to deal with the Design of Cyber-Physical Systems (CPS), at various stages, using Model-Based techniques and Formal Methods. Design here stands for co-modeling, co-simulation, formal verification and analysis activities, with connections both ways from models to code (synthesis and instrumentation for optimization). Formal analysis, in turn, concerns both functional and extra-functional correctness properties. Our goal is to link these design stages together, both vertically along the development cycle, and horizontally by considering the interactions between cyber/digital and physical models. These physical aspects comprise both physical environments and physical execution platform representations, which may become rather heterogeneous as in the cases of the Internet of Things (IoT) and computing at the edges of the gateways. The global resulting methodology can be tagged as Model-Based, Platform-Based CPS Design, see Figure 1.

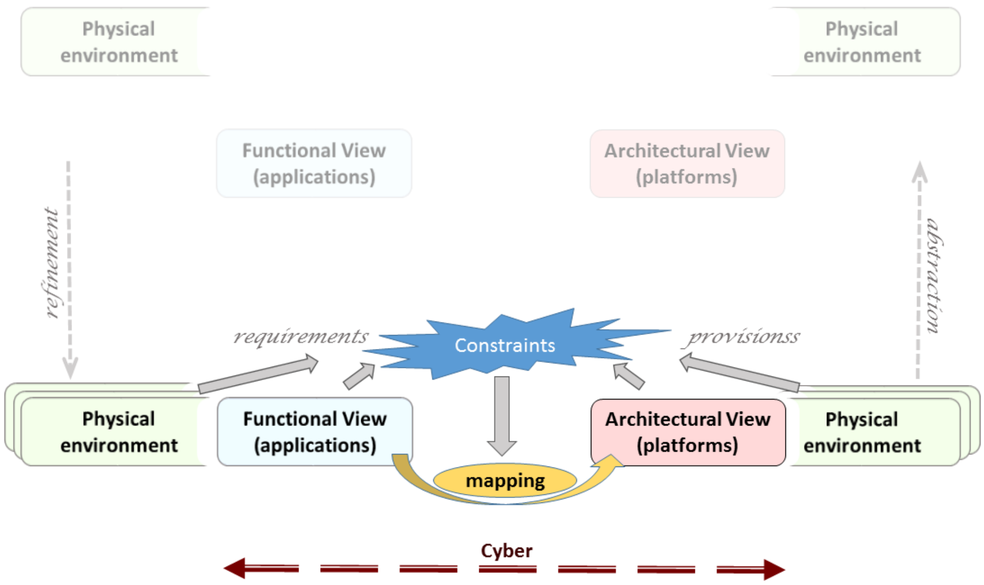

Figure 1: Cyber-Physical generic architectural features

CPS design must take into account all 3 aspects of application requirements, execution platform guarantees and contextual physical environment to establish both functional and temporal correctness. The general objective of Kairos is thus to contribute in the definition of a corresponding design methodology, based on formal Models of Computation for joint modeling of cyber and physical aspects, and using the important central concept of Logical Time for expressing the requirements and guarantees that define CPS constraints.

Logical Multiform Time. It may be useful to provide an introduction and motivation for the notion of Logical Multiform Time (and Logical Clocks), as they play a central role in our approach to Design. We call Logical Clock any repetitive sequence of occurrences of an event (disregarding possible values carried by the event). It can be regularly linked to physical time (periodic), but not necessarily so: fancy processors may change speeds, simulation engine change time-integration steps, or much more generally one may react with event-driven triggers of complex logical nature (do this after 3-times that unless this. . .). It is our belief that user specifications are generally expressed using such notions, with only partial timing correlations between distinct logical clocks, so that the process of realization (or "model-based compilation") consists for part in establishing (by analysis or abstract simulation) the possible tighter relations between those clocks (unifying them from a partial order of local total orders to a global total order).

Kairos defined in the past a small language of primitives expressing recognized constraints structuring the relations between distinct logical clocks [1, 9]. This language (named CCSL for Clock Constraint Specification Language), borrows from notions of Synchronous Reactive Languages [11], Real-Time Scheduling Theory, and Concurrent Models of Computations and Communication (MoCCs) in Concurrency Theory [10] altogether. Corresponding extensions of Timed Models originally based on single (discrete or continuous) time can also be considered. Logical Time is used in our approach to express relation constraints between heterogeneous models, of cyber or physical origin, and to support analysis and co-simulation. Addressing cyber-physical systems demands to revisit logical time to deal with the multi-physical and sometimes uncertain environments.

Kairos is also active in the standardization of cyber-physical systems and the Internet of Things, in the standardization of semantic of general purpose programming languages, and in the standardization of smart contract languages and electronic ledgers, both centralized and distributed (blockchain).

3 Research program

3.1 Cyber-Physical co-modeling

In real-time embedded systems, it is just as important to predict how long tasks will take as it is to make sure they work correctly. This consideration should start from the very beginning of the design process. In addition, Cyber-Physical System modeling requires joint representation of digital/cyber controllers and natural physics environments. Heterogeneous modeling must then be articulated to support accurate (co-)simulation, (co-)analysis, and (co-)verification, with multiple logical time sources and scales.

Figure 1 sketches the overall design framework. It comprises functional requirements, to be met provided surrounding platform guarantees, in a contract approach. All relevant aspects are modeled with proper Domain Specific Languages (DSL), so that constraints can be gathered globally, then analyzed to build a mapping proposal with both a structural aspect (functions allocated to platform resources), but also behavioral ones, scheduling activities. Mapping may be computed automatically or not, provably correct or not, obtained by static analytic methods or abstract execution.

Physical phenomena (in a very broad acceptance of the term) are usually modeled using continuous-time models and differential equations. Then the "proper" discretization opportunities for numerical simulation form a large spectrum of mathematical engineering practices. Note that, this is not at all the domain of expertise of Kairos members, but it should not be a limitation as long as one can assume a number of properties from the discretized version. On the other hand, we do have a strong expertise on modeling of both embedded processing architectures and embedded software (i.e., the kind of usually concurrent, sometimes distributed software that reacts to and control the physical environment). This is important as, unlike in the "physical" areas where modeling is common-place, modeling of software and programs is far from mainstream in the Software Engineering community. These domains are also an area of computer science where modeling, and even formal modeling, of the real objects that are originally of discrete/cyber nature, takes some importance with formal Models of Computation and Communications. It seems therefore quite natural to combine physical and cyber modeling in a more global design approach (even multi-physic domains and systems of systems possibly, but always with software-intensive aspects involved).

Our objective is certainly not to become experts in physical modeling and/or simulation process, but to retain from it only the essential and important aspects to include them into System-Level Engineering design, based on Model-Driven approaches allowing formal analysis (see for example the injection of formal semantics into the Capella System Engineering tool).

This sets an original research agenda: Model-Based System Engineering environments exist, at various stages of maturity and specificity, in the academic and industrial worlds. Formal Methods and Verification/Certification techniques also exist, but generally in a point-wise fashion. Our approach aims at raising the level of formality describing relevant features of existing individual models, so that formal methods can have a greater general impact on usual, "industrial-level", modeling practices. Meanwhile, the relevance of formal methods is enhanced as it now covers various aspects in a uniform setting (timeliness, energy budget, dependability, safety/security. . .).

Directions on formalizing CPS should focus on the introduction of uncertainty (stochastic models) in our particular framework, on relations between (logical) real-time and security, and on accounting for resource discovery also in presence of mobility inherent to connected objects and Internet of Things [2].

3.2 Cyber-Physical co-simulation

The FMI standard (Functional Mock-Up Interface) has been proposed for "purely physical" (i.e., based on persistent signals) co-simulation, and then adopted in over 100 industrial tools including frameworks such as Matlab/Simulink and Ansys, to mention two famous model editors. With the recent use of co-simulation to cyber-physical systems, dealing with the discrete and transient nature of cyber systems became mandatory.

Together with other people from our community, we showed that FMI and other frameworks for co-simulation badly support co-simulation of cyber-physical systems; leading to bad accuracy and performances. More precisely, the way to interact with the different parts of the co-simulation requires a specific knowledge about its internal semantics and the kind of data exposed (e.g., continuous, piecewise-constant). Towards a better co-simulation of cyber-physical systems, we are looking for conservative abstractions of the parts and formalisms that aim to describe the functional and temporal constraints that are required to bind several simulation models together.

3.3 Formal analysis and verification

Because the nature of our constraints is specific, we want to adjust verification methods to the goals and expressiveness of our modeling approach [14]. Quantitative (interval) timing conditions on physical models combined with (discrete) cyber modes suggest the use of SMT (Satisfiability Modulo Theories) automatic solvers, but the natural expressiveness requested (as for instance in our CCSL constructs) shows this is not always feasible. Either interactive proofs, or suboptimal solutions (essentially resulting of abstract run-time simulations) should be considered.

Complementarily to these approaches, we are experimenting with new variants of symbolic behavioral semantics, allowing to construct finite representations of the behavior of CPS systems with explicit handling of data, time, or other non-functional aspects [4].

3.4 Relation between model and code

While models considered in Kairos can also be considered as executable specifications (through abstract simulation schemes), they can also lead to code synthesis and deployment. Conversely, code execution of smaller, elementary software components can lead to performance estimations enriching the models before global mapping optimization [3].

CPS introduce new challenging problems for code performance stability. Indeed, two additional factors for performance variability appear, which were not present in classical embedded systems: 1) variable and continuous data input from the physical world and 2) variable underlying hardware platform. For the first factor, CPS software must be analyzed in conjunction with its data input coming from the physics, so the variability of the performance may come from the various data. For the second factor, the underlying hardware of the CPS may change during the time (new computing actors appear or disappear, some actors can be reconfigured during execution). The new challenge is to understand how these factors influence performance variability exactly, and how to provide solutions to reduce it or to model it. The modeling of performance variability becomes a new input.

3.5 Code generation and optimization

A significant part of CPS design happens at model level, through activities such as model construction, analysis, or verification. However, in most cases the objective of the design process is implementation. We mostly consider the implementation problem in the context of embedded, real-time, or edge computing applications, which are subject to stringent performance, embedding, and safety *non-functional requirements*.

The implementation of such systems usually involves a mix of synthesis—(real-time) scheduling, code generation, compilation—and performance (*e.g.* timing) analysis, as introduced in [7]. One key difficulty here is that synthesis and performance analysis depend on each other. As enumerating the various solutions is not possible for complexity reasons, heuristic implementation methods are needed in all cases. One popular solution here is to build the system first using unsafe performance estimations for its components, and then check system *schedulability* through a global analysis. Another solution is to use safe, over-approximated performance estimations and perform their mapping in a way that ensures by construction the schedulability of the system.

In both situations, figuring out how detailed we need to be when describing the complex design options — like what the system does, where it runs, its quality requirements, and how it is implemented — is a major challenge. Another problem is the definition of scalable and efficient mapping methods based on both "exact" approaches (ILP/SMT/CP solving) and compilation-like heuristics.

3.6 Extensions for spatio-temporal modeling and mobile systems

While Time is clearly a primary ingredient in the proper design of CPS, in some cases, Space and related notions of local proximity or conversely long distance, play also a key role for correct modeling, often in part because of the constraints this puts on interactions and time for communications. Once space is taken into account, one has to recognize also that many systems will request to consider mobility, originated as change of location through time. Mobile CPSs (or mCPS) occur casually in real-life, e.g., in the case of Intelligent Transportation Systems, or roaming connected objects of the IoT.

Spatio-temporal and mobility modeling may each lead to dynamicity in the representation of constraints, with the creation-deletion-discovering of new components in the system. This opportunity for new expressiveness will certainly cause new needs in handling constraint systems and topological graph locations. The new challenge is to provide an algebraic support with a constraint description language that could be as simple and expressive as possible, and of use in the semantic annotations for mobile CPS design. We also aim to provide fully distributed routing protocols to manage Semantic Resource Discovery in IoT and to standardize it.

3.7 Foundations of synchronous languages

Concurrency, whether by expression or by implementation, is both a convenient and unavoidable feature of modern software systems. However, this does not mean that we must give up the requirement of functional determinism, which is crucial for maintaining predictability and managing design complexity through simple mathematical models. While the pure λ-calculus is naturally deterministic by design, it cannot model shared memory. Process algebras, on the other hand, can naturally model shared objects but do not guarantee determinism out of the box.

The challenge is to find new process CCS-like algebra with deterministic operational semantics and decidable static semantics (types) able to specify the behavior of synchronous programming languages. The distinctive property of this evaluation strategy is to achieve determinacy-by-construction for multi-cast concurrent communication with shared memory. In particular, it permits us to model shared memory multi-threading with reaction to absence. This new theory lies at the core of the synchronous programming language Esterel. Adding types to such algebras would allow to certify them through *ad hoc* Interactive Theorem Provers (ITP) taking into account time, using our expertise acquired in [8, 12].

3.8 Standardization activities

Under the auspices of the European Telecommunications Standards Institute (ETSI), the International Organization for Standardization (ISO), the European Computer Manufacturers Association (ECMA), and the Association Française de Normalisation (AFNOR), we study communication protocols, programming language semantics, IoT protocol architectures, and their direct applications in the domains of cyber-physical systems, eHealth, smart contracts, and electronic ledgers.

One of Inria's core missions is active involvement in standardization and normalization. To this end, we apply our theoretical and formal methods expertise to improve the quality, usability, and rigor of standards, making them more accessible and reliable for practitioners. We are also engaged with ETSI board management to help bridge the gap between academic research and standardization, thereby fostering better recognition of academic contributions.

4 Application domains

4.1 Cyber-Physical and embedded system design

System Engineering for CPS systems requires combinations of models, methods, and tools owing to multiple fields, software and system engineering methodologies as well as various digitalization of physical models (such as "Things", in Internet of Things (IoT)). Such methods and tools can be academic prototypes or industry-strength offers from tool vendors, and prominent companies are defining design flow usages around them.

We have historical contacts with industrial and academic partners in the domains of avionics and embedded electronics (Airbus, Thales, Safran). We also have new collaborations in the fields of satellites (Thales Alenia Space) and connected cars driving autonomously (Renault Software Factory). These provide us with current use cases and new issues in CPS co-modeling and co-design (Digital Twins) further described in New Results section. The purpose here is to insert our formal methods into existing design flows, to augment their analysis power where and when possible.

4.2 Safe driving rules for automated driving

Self-driving cars will have to respect roughly the same safety-driving rules as currently observed by human drivers (and more). These rules may be expressed syntactically by temporal constraints (requirements and provisions) applied to the various meaningful events generated as vehicles interact with traffic signs, obstacles and other vehicles, distracted drivers and so on. We feel our formalisms based on Multiform Logical Time to be well suited to this aim, and follow this track in several collaborative projects with automotive industrial partners. This domain is an incentive to increase the expressiveness of our language and test the scalability of our analysis tools on real size data and scenari.

4.3 Smart Contracts specifications

In collaboration with local industrial and international standardization partners, we have considered Smart Contracts (SC) as a way to formally establish specification of behavioral system traces, applied to connected objects in an IoT environment and the possibility to introduce a contract versioning electronic signature before the deployment in an electronic ledger.

The ANR project SIM (completed in mid-2023) is based on defining a formal language to describe services for autonomous vehicles that execute automatically based on observations of the vehicle and driver. The key focus is the design of a virtual passport for autonomous cars that registers the main events occurring on the vehicle and uses them to operate automatic services that are trustworthy and reliable.

4.4 Smart Contracts and Electronic Ledger standards

Building on our past expertise in the semantics of programming languages (as referenced in [52]), the ETSI Specialist Task Force (STF655) project (see contract section) aims to establish definitions and requirements for Smart Contracts, as defined by Regulation (EU) 2022/2065 Data Act, and based on Electronic Ledgers, as defined by Regulation (EU) 2023/2854 eIDAS2. We study a novel and as yet not standardized chain of trust, by addressing the role of all involved entities in building, deploying, and executing a Smart Contract on an Electronic Ledger.

To date, the syntax, semantics and pragmatics of the Programming Languages in which Smart Contracts are encoded are not subject to any standardization efforts: this point is critical because "code is law", and the emergence of a precise standardization framework for Smart Legal Contracts is an imperative raised by European Lawmakers as stated in October 2025, according to the ECB's Governing Council, which decided that the Eurosystem will move to the next phase of the digital euro project.

4.5 Internet of Things standards

Based on our skills in the "Internet" facet of IoT, and in particular in content-based routing protocols, IoT Semantic Discovery Protocols [50, 49] and content-based network protocols [42, 46], we contribute to the ETSI Technical Committee DATA Solutions (TC DATA) and the oneM2M consortium to define new protocols and standards. In the ETSI Test Task Force (TTF019) project (see contract section), we finished our performance evaluation on open source oneM2M platforms.

4.6 Autonomous and Mobile surveillance standards

Based on our past developed standards on detection and communication of bio-eco-emergencies using IoT overlay networks, we contribute to the ETSI Technical Committee DATA Solutions (TC DATA) in specifying new functionality and communication requirements of an evolution of the already developed standard ETSI TS 103 757, called Asynchronous Contact Tracing (ACT for short).

The ETSI Specialist Task Force (STF697) project (see contract section) aims to enhance the ACT standard with autonomous and mobility features: the new standard, called Autonomous Footprint Service (AFS for short), has as application domains: surveillance, public warning systems and potential defense applications via autonomous entities.

AFS will use an unreliable underlay radio network to assist a mobile overlay alertness and footprint network made of Remotely Operated Vehicles (ROV) and Unmanned x[1] Vehicles (UxV). Entities can enable multiple detection and surveillance platforms to communicate and cooperate together using ETSI oneM2M overlay. Therefore, AFS allows a multi modal communication underlay low-level radio communication using different frequencies in the radio spectrum, e.g. LF, UHF, VHF, just to mention a few.

5 Social and environmental responsibility

5.1 Footprint of research activities

- Julien Deantoni and Frédéric Mallet are members of the I3S Working Group on new practical ways to measure and reduce the impact of our research activity on the environment.
- Julien Deantoni is one of the organizer of the citizens' convention for the reduction of the carbon footprint of the I3S laboratory.
- Barbara Da Silva Oliveira and Marie-Agnès Peraldi-Frati were randomly selected and accepted to participate in the citizens' convention for reducing the carbon footprint of the I3S laboratory.

6 Highlights of the year

6.1 Contract Acceptance

In September 2025, the Engineering Digital Twin program has been accepted by the prime minister and the Kairos team (Julien Deantoni) will lead the first focused project named "Catalyst: the Reliable Hybrid Model Forge". The project brings together eight PhD grants, all co-supervised with various French partners. The kick-off is planned for early spring 2026.

In 2025, ETSI funded the development of a new surveillance standard aligned with Regulation (EU) 2022/2065 (Data Act). This standard has the potential for significant market impact and could be applied to public warning systems as well as potential defense applications. Kairos (Luigi Liquori) will serve as the Principal Investigator.

7 Latest software developments, platforms, open data

7.1 Latest software developments

7.1.1 TimeSquare

Keywords: Profil MARTE, Embedded systems, UML, IDM

[1]With $x \in \{A, U, G\}$ for Aerial, Underwater, and Ground.

Scientific Description: TimeSquare offers six main functionalities:

1) graphical and/or textual interactive specification of logical clocks and relative constraints between them, 2) definition and handling of user-defined clock constraint libraries, 3) automated simulation of concurrent behavior traces respecting such constraints, using a Boolean solver for consistent trace extraction, 4) call-back mechanisms for the traceability of results (animation of models, display and interaction with waveform representations, generation of sequence diagrams...). 5) compilation to pure java code to enable embedding in non eclipse applications or to be integrated as a time and concurrency solver within an existing tool. 6) a generation of the whole state space of a specification (if finite of course) in order to enable model checking of temporal properties on it

Functional Description: TimeSquare is a software environment for the modeling and analysis of timing constraints in embedded systems. It relies specifically on the Time Model of the Marte UML profile, and more accurately on the associated Clock Constraint Specification Language (CCSL) for the expression of timing constraints.

URL: http://timesquare.inria.fr

Contact: Julien Deantoni

Participant: 5 anonymous participants

7.1.2 GEMOC Studio

Name: GEMOC Studio

Keywords: DSL, Language workbench, Model debugging

Scientific Description: The language workbench put together the following tools seamlessly integrated to the Eclipse Modeling Framework (EMF):

1) Melange, a tool-supported meta-language to modularly define executable modeling languages with execution functions and data, and to extend (EMF-based) existing modeling languages. 2) MoCCML, a tool-supported meta-language dedicated to the specification of a Model of Concurrency and Communication (MoCC) and its mapping to a specific abstract syntax and associated execution functions of a modeling language. 3) GEL, a tool-supported meta-language dedicated to the specification of the protocol between the execution functions and the MoCC to support the feedback of the data as well as the callback of other expected execution functions. 4) BCOoL, a tool-supported meta-language dedicated to the specification of language coordination patterns to automatically coordinates the execution of, possibly heterogeneous, models. 5) Monilog, an extension for monitoring and logging executable domain-specific models 6) Sirius Animator, an extension to the model editor designer Sirius to create graphical animators for executable modeling languages.

Functional Description: The GEMOC Studio is an Eclipse package that contains components supporting the GEMOC methodology for building and composing executable Domain-Specific Modeling Languages (DSMLs). It includes two workbenches: The GEMOC Language Workbench: intended to be used by language designers (aka domain experts), it allows to build and compose new executable DSMLs. The GEMOC Modeling Workbench: intended to be used by domain designers to create, execute and coordinate models conforming to executable DSMLs. The different concerns of a DSML, as defined with the tools of the language workbench, are automatically deployed into the modeling workbench. They parametrize a generic execution framework that provides various generic services such as graphical animation, debugging tools, trace and event managers, timeline.

URL: http://gemoc.org/studio.html

Publications: hal-00850770, hal-01355391, hal-01609576, hal-01651801, hal-01152342, hal-03374955, hal-01614561, hal-01616154

Contact: Benoît Combemale

Participant: 3 anonymous participants

Partners: I3S, Université de Nantes

7.1.3 MRTCCSL

Name: Modular Real-Time Clock Constraint Specification Language

Keywords: Embedded systems, Modeling of time, Simulation

Scientific Description: The toolset provides the following features, related to the MRTCCSL language: - textual specification of temporal behaviour using logical (qualitative) and real (quantitative) time, including their stochastic uncertainty, - simulation, producing behaviour traces satisfying the provided textual specification, - constraints solving optimization using a heuristic on constraint order, - polyhedra and induction verification engine, able to verify liveness and emptiness properties on a subset of the RTCCSL constraints, - specification visualization as hypergraph in DOT format, - specification and extraction of functional chains from traces, construction of reaction time distributions, - manipulation of MRTCCSL-native trace format: conversion to other formats and filtering.

Functional Description: A formal toolset implementing the Clock Constraint Specification Language and its stochastic, modular and real-time extensions. The project provides parsing, simulation, some symbolic analysis and behavior debugging of the specifications.

Publications: hal-05224373v1, tel-04933243v1, hal-04639949v1

Contact: Pavlo Tokariev

Participant: an anonymous participant

7.1.4 Idawi

Keyword: Middleware

Functional Description: Idawi is a middleware for the development and experimentation of distributed applications for multi-hop dynamic networks, like the IoT, the Edge, Mobile Ad hoc Networks, etc. The development of Idawi was initially motivated by the need of the COATI Research group to deploy scientific applications in clusters of computers, in order to run large experimentation campaigns of graph algorithms. Idawi is an innovative arrangement of many features found in existing tools into a fresh Open Source Java reference implementation, but in our Research context we were led to introduce new ideas not found in other middleware solutions for distributed computing - such as a fully decentralized network model, and a by-default collective communication/computation model (both naturally matching the very nature of mobile multi-hop networks), the use of digital twins at the core of its network management model, as well as new features making it usable as a Research platform for the experimentation of middleware-level techniques. Idawi defines application elements as components organized into a multi-hop overlay network on top of agnostic transport layers such as TCP, UDP and SSH (SSH being employed to enable component deployment and communication even in the presence of NATs and firewalls). In the usual use case, there will be only one component per device. But, in order to enable the simulation/emulation of large systems, components can deploy other components in their Java Virtual Machine (JVM) or in another JVM(s) in the same device. Idawi proposes a structuring model of distributed applications, which then must conform to a specific Object-Oriented model in the style of SOA: it defines that components expose their functionality via services. Services hold data and implement functionality about the specific concern they are about. Functionality is then exposed via (optionally typed) endpoints, which can be triggered remotely from anywhere in the component overlay. Idawi features a multi-paradigm programming model. Messaging (and hence remote code invocation) can be both synchronous (imperative) and asynchronous (reactive/event-driven). It is powered by a default routing scheme and APIs that are tailored to collective communication, so as to offer native support for parallel processing. Idawi comes with a set of built-in fully decentralized services for automatized quick deployment/bootstrapping of components through SSH, interoperability through a

REST-based web interface, service provisioning and discovery, overlay management, and many other system-level functionality.

URL: https://github.com/lhogie/idawi

Publications: hal-04878642, hal-03863333, hal-03886521, hal-03562184

Contact: Luc Hogie

7.1.5 ACT

Name: Asynchronous Contact Tracing Framework

Keywords: Contact tracing, Iot, Standards, Routing

Scientific Description: Implementation of standard ETSI TS 103757

Functional Description: ACT consists in 3 modules: 1) an ETSI/oneM2M communication infrastructure, 2) a mobile application (android), and 3) a web application.

Release Contributions: First open-source and public version available on gitlab inria

URL: https://gitlab.inria.fr/act/

Publications: hal-02989793, hal-02989404, hal-03127890, hal-03935906

Contact: Luigi Liquori

Participant: 4 anonymous participants

Partners: ETSI, Université Côte d'Azur (UCA)

7.1.6 CoPubli

Name: Co-Publications Inria

Keywords: Geolocation, HAL

Scientific Description: The pipeline consists of three software components.

One software extracts an Excel file from HAL using the AUREHAL APIs. Each record in the Excel file contains the following information: Teams, Research Centre, Author_FR, Co-author(s), Co-author Institution, Address, City, Country, AUREHAL_ID, EU (flag), Year, HalID, Domain(s), Keywords, Abstract. The output is reproducible for all of Inria's scientific output and can be applied to other time periods.

Another software retrieves the Latitude and Longitude based on the cities of the co-authors and adds this geolocation data to the Excel file.

A third software component enables user-friendly, interactive visualization of all or part of the Excel file through a web-based interactive dashboard. The dashboard allows filtering of co-publications by city, co-author institution, year, and Inria team.

Functional Description: It is possible to extract this information from HAL.

One limitation concerns the city. The city can be identified in the address, which is a free-text field in HAL's database. Therefore, a method will be needed to determine the city using its latitude and longitude based on the address provided.

Another limitation of the HAL database is that it does not require specifying the hierarchy of foreign institutions. For example, an author may affiliate their publication with the Dipartimento di Matematica (DiMa) without specifying that DiMa is under the supervision of the University of Genova (UniGe), or they may directly affiliate the publication with UniGe.

Release Contributions: stable

URL: https://github.com/INRIA/datalake/tree/main/POC%20-%20R%C3%A9seaux%20de%20copublications

Publication: hal-05432240v1

Contact: Luigi Liquori

Participant: 5 anonymous participants

7.2 New platforms

7.2.1 Future of Industry Platform

Participants: Gerald Rocher, Grégory Jeannin, Nicolas Ferry.

In order to both teach and foster research on Digital Twin engineering, we have started developing a replica of an Industry 4.0 factory. On the hardware side, this platform is based on a *fischertechnik* system, complemented by (*Controllino*) open-source Arduino-based programmable logic controllers. On the software side, we have begun experimenting with Digital Twin solutions built on a modular, microservice-based architecture leveraging the Robot Operating System (ROS) ecosystem and its native simulation capabilities. In particular, the use of physics-based simulators and visualization tools enables the co-execution of simulated and physical components, providing opportunities to teach the full spectrum of digital twin reference architectures, ranging from digital models, through digital shadows, up to fully bidirectional digital twins. This fully open experimental platform preserves the ability to address low-level programming concerns such as real-time operating systems (RTOS), formal verification, and the tight integration between control, simulation, and execution layers (covering CPS architectures, autonomous intelligent system, edge computing and embedded OS for edge computing teaching modules and opening the door to student projects and internships). Beyond its pedagogical value, this platform also offers significant opportunities for academic research. In particular, it enables the implementation, comparison, and validation of hybrid digital twin approaches combining deductive (physics-based) and inductive (data-driven) models. Such hybridization provides a suitable framework to explicitly address the reality gap between simulated and physical systems by continuously confronting model assumptions with real operational data. Moreover, the modular microservice architecture allows controlled fault injection at multiple levels (sensor, actuator, communication, and model layers), thereby supporting research on robustness, diagnosis, resilience, and fault-tolerant control strategies within digital twin environments. Finally, the platform naturally supports perspectives toward the interconnection of multiple production systems and factories, enabling the study of distributed and federated digital twins. This opens the door to research on system-of-systems digital twins, cross-site optimization, and coordinated decision-making across interconnected industrial assets.

7.2.2 CoPubli

Participants: Luigi Liquori, Kumar Guha *(DGD-S - DCIS, Inria)*, Maria Kazolea *(CARDAMON Team, Inria)*, Andrea Nebot *(DGD-S - DCIS, Inria)*, Daniel Da Silva *(DGD-S - DCIS, Inria)*.

This year we build CoPubli (see Section 7.1.6) [40] [27], a software solution created to retrieve Inria publications involving foreign co-authors from the HAL open archive, in order to help identify and develop international cooperation between Inria and research institutions from around the world. The software uses the XML-TEI rendering of the HAL open archive API and analyzes, with Python Jupyter Notebook, the contents to determine the city of each stated institution. A Dashboard offers different views of the results, such as a map, a keyword cloud, four year evolution of copublications. The views can be refined combining different filters (Research team, foreign institution, city, country, etc.).

8 New results

8.1 Formal Aspects of Time in CPS

Participants: Frédéric Mallet, Marie-Agnès Peraldi-Frati, Paul Somson.

In collaboration with the University of Sherbrooke, we studied the complementarity of CCSL (Clock Constraint Specification Language) and TASTD (Timed Algebraic State Transition Diagrams), and demonstrated how they can be jointly employed to specify real-time embedded systems [18]. The idea is to annotate TASTD with logical clocks to orchestrate them with CCSL constraints.

In collaboration with East China Normal University, and in order to support the verification of polychronous specifications, we extended classical temporal logics with a clock-based temporal logic compatible with CCSL semantics–eliminating the need for a global step–and thereby investigated the compositionality of verification procedures [22].

In the scope of the ANR TAPAS project (see Section 10.3), Paul Somson has been hired as a PhD student since November 10, 2025, focusing on the creation of a hierarchical time model for driving Event-B specifications. He has studied multiple temporal specification languages, such as CCSL, the Tagged Event Specification Language (TESL), Signal, and ESTEREL, and has modeled CCSL clock and constraint concepts within Event-B.

This model utilizes two theories developed using the Theory plug-in for Rodin. The first allows for the specification of a system of clocks constrained by a set of relations, while the second defines the execution traces of that system. So far, it is possible to reason using these two theories and to create reusable theorems for proving other properties. Moving forward, this work will be extended to include time concepts similar to TESL and applied to realistic case studies.

Another topic we are investigating is the definition and formalization of temporal patterns that can be instantiated in Event-B. The objective is to improve, through methodological advances, both the modeling process and the verification of temporal behaviors in cyber-physical systems (CPS). This work was initiated by relying on temporal patterns defined in the Time Augmented Description Language (TADL) from the automotive industry.

8.2 Safety rules for autonomous driving

Participants: Frédéric Mallet, Maksym Labzhaniia, Marie-Agnès Peraldi-Frati, Julien Deantoni.

We previously addressed the formal modeling of automotive driving Safety Rules in a prior PhD thesis [41]. In the current PhD work of Maksym Labzhaniia, we are revisiting this language in light of logical multi-dimensionality, particularly with respect to time and space (interconnected through speed). While we have published initial results on the formal spatio-temporal framework in [45], we are now exploring how this framework can be integrated with a Domain-Specific Language (DSL) on the one hand, and with execution/simulation traces on the other hand. The ultimate goal is to develop a DSL through which scenarios can be validated, either offline or online, serving as an AI safety guard. The PhD manuscript of Maksym Labzhaniia is in its last stage of development

8.3 Engineering Digital Twin for Cyber Physical Systems

Participants: Julien Deantoni, Nicolas Ferry, Gerald Rocher, Barbara Da Silva Oliveira, Luc Hogie.

Early 2025, we published about the engineering of Digital Twin to better manage uncertainty [15]. Later during the year, we wrote a paper depicting a research road map for this specific engineering [16].

Additionnally, we consolidated the definition of the *Influence* concept, initiated in the previous years. We have defined influences as a relation that captures how a set of participants (design artifacts, environmental factors, and/or system response properties) connects to system response properties, which can directly or indirectly affect the satisfaction of requirements. We have refined the formal definition of an Influence, clarifying its core concepts and its semantics, and implemented a domain-specific language to express influences and analyze them. These analyses provide feedback for the developers in their working models, helping them to make better decisions and coordinate in collaborative CPS development. This work has been accepted for publication [20]. Note that further experiments may be based on the industry 4.0 platform newly developed (see Section 7.2).

As an experiment linked with the Engineering of Digital Twin, and based on the Idawi software (see Section 7.1.4), we studied the feasibility of using digital twins (DTs) for the decentralized management of large heterogeneous dynamic networks (LHDNs), such as vehicular, IoT, battlefield, and drone networks. We designed a recursive object-oriented model in which each network node maintains a DT of its surrounding network, with nodes represented as (sub-)DTs of their physical counterparts and continuously updated through network traffic and broadcast descriptions. This approach allows routing and resource management algorithms to operate on DTs via both offline analysis and simulated execution, using a unified API for physical nodes and DTs. The feasibility of the architecture was validated through the implementation of a dedicated DT service within the Idawi middleware [17].

Note that, on the Engineering of Digital Twins, we are part of a joint laboratory between I3S and the Docaposte company (see Section 9.1).

8.4 Uncertainty in Cyber Physical Systems

This year we explored two different works contributing to the explicit mangement of uncertainty in the development of Cyber Physical Systems.

8.4.1 Probabilistic Modeling of Spiking Neural Networks with Contract-Based Verification

Participants: Robert de Simone, Zhen Yao, Elisabetta de Maria.

This work was conducted in the context of the M2 Ubinet Master internship of Zheng Yao, under the main supervision of Elisabetta de Maria, assistant professor at Univ. Côte d'Azur.

Spiking Neural Networks (SNNs) form a distinct class of AI deep-learning networks, focused more on real-time occurrences of spikes/events, that have a probabilistic nature in general. Our work focuses on defining a formal modeling framework for such SNNs that addresses two main concerns:

- provide a natural way to model basic neuronal components (such as the Leaky Integrate-and-Fire (LIF) famous representation);
- allow easy and provably sound translation into input formats for existing analysis software environments.

In practice, we targeted two main such analysis tools, namely PRISM and Nengo. PRISM is a well-recognized general-purpose stochastic model-checker, while Nengo is a simulation environment specific to SNNs. To achieve our goal, we defined an intermediate representation format named SNN-RF, with the relevant expressiveness and "naturality".

We conducted a number of experiments, going across these translations for establishing properties on LIF models: proving stochastic temporal logic formulae in PRISM on the one hand; then conducting extensive probabilistic simulations in Nengo to support the behavioral "profile" on the other hand. Results were reported in a conference article [25].

8.4.2 Understandable Uncertainty in Timing Analysis

Participants: Julien Deantoni, Irman Faqrizal, Pavlo Tokariev.

Early in 2025, we published a journal paper about the management of different sources of uncertainty in [15]. Later in the year, in the context of the HAL4SDV European project (see Section 10.2.1), we developed a Domain-Specific Language (DSL) for modeling application architectures built on a Hardware Abstraction Layer (HAL). The DSL represents software as services with dependencies defined via Vehicle Signal Specification (VSS) signals. It captures complex service interdependencies, triggering policies, and critical timing annotations—such as periods, execution times, and latencies—to abstract the influence of the underlying hardware and infrastructure.

To manage inherent system uncertainties, all timing parameters are modeled using truncated normal distributions. The framework leverages these descriptions to perform batch abstract simulations, allowing developers to derive reaction-time distributions across end-to-end functional chains; identify synchronization bottlenecks, such as excessive data waiting times; optimize resource usage by detecting redundant activations (activations without fresh input data).

The framework was described in [21]. It is mostly implemented using open source tools (MRTCCSL described in Section 7.1.3 and PTSV) and integrated as a VS Code extension, available at: SDVML

8.5 Security and Resilience of Cyber Physical Systems

Participants: Nicolas Ferry, Gérald Rocher.

This activity is conducted in the context of the DYNABIC HEU project (see Section 10.2.1) in connection with SINTEF and Montimage. The objective of the project is to increase the resilience and business continuity capabilities of European critical services in the face of advanced cyber-physical threats. In this context, we investigated:

1. The landscape and state of the art of existing solutions for: (i) secure orchestration and automated responses in face of cyber attacks [19]; (ii) secure data sharing; (iii) patterns and architectures for IoT security.
2. How the behavior of an IoT system can drift at runtime compared to the expected behavior as specified during design. The focus is on delivering multi-concerns (e.g., economics, social, technical) resilience metrics and curves as indicators of the effectiveness of resilience solutions.

Lately, we explored how the behavioral drift analysis solution can be integrated with state-of-the-art security monitoring systems delivering a comprehensive resilience dashboard. This integration aims to enhance the understanding and detection of security attacks, as well as their root causes. The integrated solution developed in DYNABIC was evaluated in the context of the DYNABIC Hackathon we organized in Nice early 2025 with 100 participants.

8.6 Performance evaluation in ETSI oneM2M standard

Participants: Luigi Liquori, Marie-Agnès Peraldi Frati.

This year, we performed an upgrade and consolidation of the work previously carried out in [54]. The updated work [34] strengthens the alignment between the ETSI perspective and oneM2M technical bodies by refining deployment scenarios through closer liaison and consultation. It enhances the use of simulation and profiling tools to support performance evaluation of IoT platforms, enabling stakeholders and customers to assess platform behavior under realistic deployment conditions. The upgraded demonstrators [39] build on the OMNeT++-based simulation library and the profiling tool connected to real open-source oneM2M implementations. The resulting measurements are reused as simulator inputs, allowing more accurate Key Performance Indicator analysis. Overall, this upgrade improves the relevance, usability, and impact of the tools for industrial stakeholders and open-source communities.

8.7 Asynchronous Contact Tracing ETSI standard

Participants: Luigi Liquori, Egan Perais.

In the recent past, we standardized [51] a novel contact tracing protocol, called Asynchronous Contact Tracing (ACT), also using our previous experience on structured overlay networks [44, 47, 53]. ACT traces the presence of Covid19 virus via the IoT connected sensors and makes those informations available anonymously.

This year, we produce the following outputs:

- We presented ACT results in [23] and we submitted an HORIZON-HLTH-2025-01-DISEASE-04 proposal (output expected in 2026) whose objectives and ambitions are to strengthen pandemic preparedness and response by developing and equitably deploying a dynamic, AI-enhanced, One Health platform that, by harnessing the transformative potential of vast open-source data streams, shifts pandemic preparedness from a reactive to a proactive and adaptive system for pandemic early warning and rapid intelligence.
- We also made significant advances in the ACT proof of concept 7.1.5 with the internship of Egan Perais [29]: sources of the web application (front-end and back-end) and the running android app are fully available on gitlab inria, while the web front-end can be run by now on gitlab pages. We also scale up the application to a bigger Technology Readiness Level. Those results will continue in the new activity of the Specialist Task Force (STF 697) funded by ETSI.
- We disseminate ACT througt an article on the oneM2M portail [28].

8.8 Autonomous Footprint ETSI standard

Participants: Luigi Liquori.

The new standard called Autonomous Footprint Service (AFS for short), funded by the ETSI STF697 contract and managed by the ETSI Technical Committee DATA, will enhance the ACT standard in the following points:

1. AFS underlay transport network can manage network failure in offering communication between entities;
2. AFS entities can be mobile and autonomous and can accept multi-cast/broad-cast messages instead of a simple ID (like the Wi-Fi BSSID in ACT);
3. AFS broad-cast is not limited to Wi-Fi communications;
4. AFS provides an interface with an overlay and peer-to-peer communication between services as in e.g. Kademlia and Gnutella;
5. AFS provides an interface with the ETSI Multi-access Edge Computing (MEC) via oneM2M API;
6. AFS provides an interface with the ETSI 3GPP protocols via oneM2M API;
7. AFS provides an interface with the Emergency Public Warning System (PWS) protocols via oneM2M API;

8. AFS allows a multi modal communication underlay low-level radio communication using different frequencies in the radio spectrum, e.g. LF, UHF, VHF, just to mention a few.

Note that, to promote the widespread adoption of the AFS protocol, we do not mandate the use of a specific underlay communication protocol. The choice depends on the use case in which AFS is applied.

This year, we produced the following outputs: [33] presented a number of case studies that cannot be captured by ACT and [38] introduced the new AFS architecture and the oneM2M communication requirements.

8.9 Smart Contract and Electronic Ledgers ETSI Standards

Participants: Luigi Liquori.

In the context of the ETSI Specialist Task Force (STF655) project in the Technical Committee Electronic Signature and Trust Infrastructure (TC ESI), we conducted a standardization activity on Smart Contracts and Electronic Ledgers, aiming specifically to support the EU Data Act and eIDAS2 proposal directives. This year, we mention the following outputs:

- We published the standardization requirements for Smart Contracts based on Electronic Ledgers [37];
- We published the policy and security requirements for Smart Contracts using Electronic Ledgers [31];
- We published how to use of EU Digital Identity Wallets and Electronic Signatures for identification with Smart Contracts [32];
- We presented our results in the EthCC 2025 - 8th Ethereum Community Conference [36];
- We presented a Chain of Trust for writing, deploying and executing Smart Contracts on Electronic Ledgers to EISMEA - the European Innovation Council and SMEs Executive Agency.
- As a student research project, we are designing and implementing an experimental Ethereum pattern, called *Constellation Pattern* in Ethereum in order to create a mechanism to dynamically modify a Smart Contract logic. Evolving business requirements, bug fixes or new features and performance optimizations often necessitate the ability to dynamically upgrade a Smart Contract.
- As a student research project, we designed an experimental blockchain allowing dynamic method override in Smart Contract languages à la Ethereum together with the above mentioned chain of trust, following the research line suggested in [43];

8.10 Copublication

Participants: Luigi Liquori, Kumar Guha *(DGD-S - DCIS, Inria)*, Maria Kazolea (CARDAMOM Team, Inria), Andrea Nebot *(DGD-S - DCIS, Inria)*, Daniel Da Silva *(DGD-S - DCIS, Inria)*.

Starting from an explicit request from our Inria centre direction — *"Who is working with whom within the Genoa research plateau?"* — we attempted to answer this question querying the French national open archive platform, HAL. However, one of the HAL limitations concerns the identification of co-authors' cities. City information is embedded in the address field, which is stored as free text in HAL's database.

This limitation led to a fruitful collaboration with the CARDAMOM Inria research team and the Inria DGD-S – DCIS – *Information et Édition Scientifiques* service. Together, we introduced a minimal software pipeline to extract, browse, and geolocate HAL co-authors. Beyond the initial use case, the pipeline addresses a more general problem, namely: *"for each Inria Centre (or Inria Team, or Inria Researcher), compile a list of foreign co-publishing researchers along with their research institutions, city, and country over a specified time frame"*. CoPubli (see Section 7.1.6), [40], and [27] can be useful to Inria International Department and Inria General Management.

8.11 Broadcast and Rendez-vous in CCS

Participants: Luigi Liquori.

Building on the classical theory of process algebra with priorities, we identified a new scheduling mechanism, called *sequentially constructive reduction*, which is designed to capture the essence of synchronous programming. The distinctive property of this evaluation strategy is to achieve determinism-by-construction for multi-cast concurrent communication. In particular, it permits us to model shared memory multi-threading with reaction to absence as it lies at the core of the programming language Esterel [48].

This year we introduced an extension of Milner's CCS, denoted SynpaTick, that brings together the concepts of action priorities, broadcast action and rendez-vous action in an uniform framework. For this language, we introduce a Labeled Transition System semantics (also called SOS à la Plotkin) and a Term Rewriting System semantics (also called small step semantics), and we prove the well-known Sangiorgi-Walker's Harmony Lemma. This work was presented at the Workshop Synchron 2025 [24].

8.12 Fuzzy Type Theories

Participants: Luigi Liquori.

This year, we introduced in [26] a combination of Fuzzy Logic and Constructive Higher Order Type Theory. Fuzzy Logic is more than 60 years old. It is a form of many-valued logic in which the truth value of propositional variables may be any real number between 0 and 1, and it has been extensively used in control systems, in artificial intelligence, probabilistic proof assistants and recently in LifeTech.

Although Fuzzy Logic is more than 60 years old, and Fuzzy Type Theories have been studied in the classical case of Church's Theory of Types, there is yet no satisfactory understanding of how to deal with judgments of the shape $\Gamma \vdash M :_e A$, stating that in the context Γ, term M has type A with a fuzzy degree of confidence e. Addressing this issue is important in view of the growing interest in quantitative and non-idempotent type theories. Taking into account our expertise acquired in [6, 5], we introduce fuzzy type assignment systems in order to investigate how minimal fuzzy formulae behave as types, according to some fuzzy proposition-as-types paradigm.

8.13 Program Recognition using Graph Neural Networks

Participants: Sid Touati, Markus Puura.

8.13.1 Program Recognition via Code Variant Generation

This activity is the result of the master thesis of Markus Puura [30], currently PhD student under the direction of Sid Touati. This activity is part of the ANR MLOpt project. Program recognition is a long-standing problem in computer science, and recent advances in AI have enabled powerful approaches using large language models and graph-based code representations. However, existing benchmarks used for training and evaluation typically contain human-written programs that are not guaranteed to be semantically equivalent, lack diversity, and rarely include transformed or obfuscated variants, which limits the robustness of current tools. To address these limitations, we introduce an automatic code variant generation tool that produces syntactically diverse but semantically consistent implementations of the same program. Using these generated variants, we build scalable training datasets represented through data-dependence graphs and train a graph neural network for code clone detection and semantic code classification. Experimental results show that adding automatically generated code variants significantly improves robustness to obfuscation and often increases the overall performance of state-of-the-art program recognition tools. A submitted article is currently under review.

8.13.2 Machine learning-based program recognition

This is a joint work with Christophe Alias (Inria researcher in the Cash team). We started an Inria exploratory research action called ProgReco. We hired a new PhD student named Grégoire Aubertin, currently based at ENS-Lyon. The research plan seems close to the ANR MLOpt project but there are main differences with the work presented above. First, we tackle the specific application class of static control programs, under the polyhedral compilation model. These programs are better adapted to acurate formal analysis compared to general purpose programs. So we plan to propose a method with some guarantee: either the tool is able to guarantee the program equivalence, or the inverse, guarantee of non equivalence, or not answering. While the method above always gives an AI answer with a continuous score, without a formal guarantee of correctness.

9 Bilateral contracts and grants with industry

9.1 Joint Lab

Participants: Nicolas Ferry, Gerald Rocher, Julien Deantoni.

In 2025, the I3S laboratory has launched a joint laboratory with the Docaposte company, and the Kairos team contributes to research on the Engineering of Digital Twins. Concrete research activities have not yet begun. Legal signature is expected early 2026.

9.2 European Standardization Telecommunication Institute (ETSI)

9.2.1 Specialist Task Force 697.

Participants: Luigi Liquori.

This new contract with the ETSI Technical Committee DATA and their members will provide us a support to extending and a generalizing of the ETSI Asynchronous Contact Tracing Standard (TS 103757), with the aims to develop a breakthrough global detection and Communication Network: the new standard will be called Autonomous Footprint Service (AFS for short) and will have as application domains: surveillance, public warning systems and potential defense applications via autonomous entities.

9.2.2 Specialist Task Force 655.

Participants: Luigi Liquori.

This contract with the ETSI Technical Committee ESI and their members (Universitat Politecnica Catalunya, Infocert, Obserwatorium.biz, SSA ltd, CCC ltd) provided us a support to explore the requirements of Smart Contrats according to the UE Data Act directive, where Smart Contracts should support the exchange of data and their remuneration. Compliance with the new European Digital Identity and Electronic Ledger directive eIDAS2 is also addressed.

9.2.3 Task Testing Force 019.

Participants: Luigi Liquori, Marie-Agnès Peraldi Frati.

This contract with ETSI Technical Committee SmartM2M and their members (CNRS, Telecom Italia, Exacta Global Smart Solutions) provided us a support to conduct the performance evaluation, analysis, planning and deployment for some (but not all) oneM2M open source initiatives. A systematic comparative study has been done to compare connectivity, interoperability, data management, security, and complex architecture issues.

10 Partnerships and cooperations

10.1 International research visitors

10.1.1 Visits of international scientists

Other international visits to the team

Furio Honsell

Status (Professor)

Institution of origin: University of Udine

Country: Italy

Dates: August 2025

Context of the visit: Work on a paper on Fuzzy type theories

Mobility program/type of mobility: (research stay)

Besik Dundua

Status (researcher)

Institution of origin: KIU - Kutaisi International University

Country: Georgia

Dates: August 2025

Context of the visit: Work on a paper on Fuzzy type theories

Mobility program/type of mobility: (research stay)

10.1.2 Visits to international teams

Research stays abroad

Robert De Simone

Visited institution: East China Normal University

Country: China

Dates: September 20th to October 14th

Context of the visit: research collaboration; keynote on *Logical Time In Real-Time Embedded Design* and shared visit to the TACL intelligent car battery company.

Mobility program/type of mobility: research stay

Frederic Mallet

Visited institution: East China Normal University

Country: China

Dates: November 9th to November 18th

Context of the visit: research collaboration on the use of formal methods to build safe guards for ensuring safety of intelligent transportation systems that uses more and more AI-based decision components.

Mobility program/type of mobility: research stay

10.2 European initiatives

10.2.1 Horizon Europe

HAL4SDV

Participants: Julien Deantoni, Pavlo Tokariev, Irman Faqrizal, Maksym Labzhaniia.

HAL4SDV project on cordis.europa.eu

Title: Hardware Abstraction Layer for a European Software Defined Vehicle approach

Duration: From April 1, 2024 to March 31, 2027

Partners:

- UAB TERAGLOBUS, Lithuania
- RESILTECH SRL (RESILTECH), Italy
- INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE (INRIA), France
- VSB - TECHNICAL UNIVERSITY OF OSTRAVA (VSB - TU Ostrava), Czechia
- VOLVO TECHNOLOGY AB (VOLVO), Sweden
- ECLIPSE FOUNDATION EUROPE GMBH (ECL), Germany
- Verband der Automobilindustrie e.V. (Verband der Automobilindustrie e.V.), Germany
- RENAULT SAS (RENAULT SAS), France
- UNIVERSITE COTE D'AZUR, France
- Aurora Labs Ltd. (Aurora Labs LTD), Israel
- ROBERT BOSCH GMBH (BOSCH), Germany
- FZI FORSCHUNGSZENTRUM INFORMATIK (FZI), Germany
- OULUN YLIOPISTO (UOULU), Finland
- ELEKTROBIT AUTOMOTIVE GMBH (EB), Germany
- STTECH GMBH, Germany
- UNIKIE OY (UNIKIE), Finland
- MERCEDES-BENZ AG, Germany
- FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV (Fraunhofer), Germany
- TECHNISCHE UNIVERSITAET MUENCHEN (TUM), Germany
- TRUSTINSOFT, France

- COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES (CEA), France
- SYSGO GMBH, Germany
- INFINEON TECHNOLOGIES AG (IFAG), Germany
- DASSAULT SYSTEMES, France
- INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO (ISEP), Portugal
- SYSGO S.A.S (SYSGO), France
- ARM FRANCE SAS, France
- CRITICAL SOFTWARE SA (CSW), Portugal
- TENSOR EMBEDDED GMBH, Germany
- NXP SEMICONDUCTORS FRANCE (NXP-FR), France
- VALEO COMFORT AND DRIVING ASSISTANCE (VALEO COMFORT AND DRIVING ASSISTANCE), France
- AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS (CSIC), Spain
- VECTOR INFORMATIK GMBH (VECTOR), Germany
- DIMECC OY (Digital Internet Material and Engineering Co-Creation Ltd.), Finland
- AMPERE SOFTWARE TECHNOLOGY, France
- TECHNISCHE UNIVERSITAT BERLIN (TUB), Germany
- TTTECH AUTO GERMANY GMBH (TTTech Germany GmbH), Germany
- DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV (DLR), Germany
- VIRTUAL VEHICLE RESEARCH GMBH (VIF), Austria
- NXP SEMICONDUCTORS CZECH REPUBLIC SRO (NXP SEMICONDUCTORS CZECH REPUBLIC SRO), Czechia
- KARLSRUHER INSTITUT FUER TECHNOLOGIE (KIT), Germany
- ETAS GMBH (ETAS), Germany
- NXP SEMICONDUCTORS NETHERLANDS BV, Netherlands
- POLITECNICO DI TORINO (POLITO), Italy
- ROVIMATICA SL (ROVIMATICA), Spain
- STATINF (Statinf), France
- TTTECHAUTO SPAIN S.L.U. (TTTechAuto Spain), Spain
- AVL LIST GMBH (AVL), Austria
- TTTECH AUTO GMBH, Austria
- POLITECNICO DI MILANO (POLIMI), Italy
- TWT GMBH SCIENCE & INNOVATION (TWT GMBH SCIENCE & INNOVATION), Germany
- TTTECH COMPUTERTECHNIK AG, Austria
- ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA (UNIBO), Italy
- CONTINENTAL AUTOMOTIVE TECHNOLOGIES GMBH, Germany
- UNIVERSITY OF STUTTGART (USTUTT), Germany
- ZF FRIEDRICHSHAFEN AG, Germany
- FORD OTOMOTIV SANAYI ANONIM SIRKETI, Türkiye
- TECHNISCHE UNIVERSITEIT EINDHOVEN (TU/e), Netherlands
- STMICROELECTRONICS SRL, Italy

- AVL SOFTWARE AND FUNCTIONS GMBH, Germany
- UNIVERSITA DEGLI STUDI DI MODENA E REGGIO EMILIA (UNIMORE), Italy
- FAURECIA SERVICES GROUPE, France
- BAYERISCHE MOTOREN WERKE AKTIENGESELLSCHAFT (BMW GROUP), Germany
- BARCELONA SUPERCOMPUTING CENTER CENTRO NACIONAL DE SUPERCOMPUTACION (BSC CNS), Spain

Inria contact: Julien Deantoni

Coordinator: Andreas Eckel (TTTech)

Summary: The HAL4SDV proposal aligns with the EU Strategic Research and Innovation Agenda 2022 on Electronic Components and Systems. It aims to pioneer methods, technologies, and processes for series vehicle development beyond 2030, driven by anticipated advancements in microelectronics, communication technology, software engineering, and AI.

HAL4SDV envisions a future where vehicles are fully integrated into smart cities, intelligent highways, and cyberspace, blurring the lines between inside and outside the vehicle. Assumptions include data-centricity, code portability, efficient data fusion, unlimited scalability, real-time capabilities, and robust cybersecurity.

The objectives encompass unifying software interfaces, creating a hardware abstraction framework, enabling Over-The-Air (OTA) updates, designing platform architectures, ensuring hardware abstraction and virtualization, offering hardware support, automating integration, supporting safety features, harnessing edge computing, implementing security measures, and providing essential development tools.

By focusing on these objectives, HAL4SDV aims to establish a unified ecosystem for software-defined vehicles, positioning Europe's automotive industry for continued leadership post-2030 while leveraging existing results and technologies to accelerate progress.

DYNABIC

Participants: Nicolas Ferry, Gérald Rocher.

We participate to the DYNABIC HEU project, jointly with Sparks team at I3S/Univ. Côte d'Azur. DYNABIC stands for: Dynamic business continuity of critical infrastructures on top of adaptive multi-level cybersecurity. The project aims at delivering socio-technical methods, models and tools for resilience management [55]. It will produce and validate a framework that enables system operators to forecast, assess and mitigate in real time business continuity risks and their possible cascading effects. Gérald Rocher is the main contributor to WP4 and 5, whilst Nicolas Ferry is WP7 leader and contributes to WP4 and 5 (Critical infrastructure monitoring and security adaptation).

10.3 National initiatives

ANR Project TAPAS

Participants: Frédéric Mallet, Marie-Agnès Peraldi, Julien Deantoni, Paul Somson.

The ANR PRC TAPAS (Timed-Aware Proof Assistant System) is a PRC project funded by ANR (AAPG 2024) for 48 months. The national coordinator is I3S (UMR CNRS) and the other partners are LIPN, LMF, IRIT and LACL. The goal is to provide a formal framework to conduct proofs and a formal verification with a continuous refinement from requirements to code. We intend to build on the refinement process of Event-B and extend it to be able to deal with different models of time, logical time, real-time clocks from timed automata and an hybrid model of time coming from tagged signal model. Université de Sherbrooke is an external international partner of this project but is not funded by ANR. Frédéric Mallet is the PI of the project.

ANR-NSF PRCI Project MLOpt

Participants: Sid Touati, Christophe Aliasfrom CASH team (INRIA Lyon) , Ali Jannesari(from University of Iowa, USA) .

Due to the emergence of High-Performance Computing (HPC) systems, there is an increasing demand for codes that leverage the powerful architecture of such systems. One way to achieve high level performance is to parallelize sequentially written programs. Automatic parallelization is a programmer-friendly way to achieve this goal. However, such approaches are often fragile, restricted and lack scalability. Another way to achieve performance is to use fine hand-tuned kernels from high-performances libraries. However finding where to call libraries is highly bug prone and needs to be automatized as well. The goal of the MLOPT project is to investigate how machine learning techniques might enable scalable automatic parallelization with a special focus on high-level task recognition.

CNRS GDRs

We are registered members of three GDR funded by CNRS : **SoC**^{2}, on topics of Hardware/Software codesign and Non-Functional Property modeling for co-simulation; **LTP**, on verification and language design for reactive CPS systems; **GPL**, on software engineering and Domain-Specific Languages.

ProgReco Exploratory Action

Since September 2024, we started a new Inria Research Exploratory Action called Program Recognition through Machine Learning and Application to Program Optimization. It is a collaboration between Sid Touati from Kairos team and Christophe Alias from Cash team (Inria-Lyon). We are planning to co-advise a master and a PhD student together on the following subject. Program comprehension is a fundamental problem in computer science, with numerous applications (reverse engineering, refactoring, code optimization, etc.) and yet, full automation remains a distant goal. ProgReco aims to explore the specific case of program recognition, that is, the ability to automatically determine the computation performed by a program from a database of standard computations. This is a specialization of program equivalence—which is generally undecidable. The objective is to find the right balance between complexity and recognition power, based on a supervised learning model. In a second phase, we will explore applying program recognition to code optimization by replacing a recognized program with a more efficient version from an optimized library.

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organization

Member of the organizing committees

- Nicolas Ferry was co-organizer of the DYNABIC workshop at the Barcelona Cybersecurity Congress (large event with 500+ participants).
- Marie-Agnès Peraldi-Frati was co-organizer as publicity chair of ICTERI2025.

Chair of conference program committees

- Frédéric Mallet was co-program chair of ICTERI2025 organized in Nice.

11.1.2 Scientific events: selection

Member of the conference program committees / Reviews

- Nicolas Ferry was member of the program committees of ANNSIM 2025, IEEE Cloud 2025, STAM 2025.
- Marie-Agnès Peraldi-Frati was member of the program committee of ICTERI2025.
- Frédéric Mallet was a member of program committees and reviewer for international conferences: ABZ 2025, ICECCS 2025, ICFEM 2025, FDL 2025.
- Julien Deantoni was a member of the program committees of ANSIMM25, FDL25, SLE25, VSTTE25.

11.1.3 Journal/Conferences

Reviewer - reviewing activities

- Frédéric Mallet has reviewed articles for the following international journals: ACM TOSEM, ACM TECS, ACM TODAES, Elsevier SCP, Elsevier JSA, Springer Nature, Elsevier Software: Practice and Experience.
- Julien Deantoni has reviewed articles for the ACM Transaction on Embedded Computing Systems.

11.1.4 Editorial Work

- Nicolas Ferry is one of the editor of the DYNABIC Book entitled: "Enhancing Resilience and Business Continuity of Critical Infrastructures". The book will be published by Springer in open access and summarize the main results of the DYNABIC HEU project.

11.1.5 Invited talks

- Julien Deantoni was invited in a one week seminar about Model Hybridization for Digital Twins in the Bellairs Research Institute of McGill University.

11.1.6 Leadership within the scientific community

- Luigi Liquori is elected member of IFIP Working Group 1.6 Rewriting.
- Luigi Liquori is elected member of oneM2M - *oneM2M Sets Standards For The Internet Of Things*, Academia-Relationship Group [35].
- Luigi Liquori is the Inria contact point for ECMA TC 39, ISO TC 307, ETSI TC DATA, ETSI TC ESI, ETSI TC eHEALTH, AFNOR CN Blockchain, and AFNOR CN Langages de programmation.
- Julien Deantoni is the Principal Investigator of the *Catalyst* focused project, part of the “Engineering Digital Twin” program, which was accepted for funding in September 2025. Beyond the funding, the goal is to build a scientific community around the engineering of model hybridization.

11.1.7 Scientific expertise

- Frédéric Mallet is the scientific advisor for Université Côte d’Azur on the 3-year MOVE2DIGITAL Digital Europe project of European Digital Innovation Hub. This project includes two main parts. One for test before invest, the other one on academic training. It aims at leveraging the academic expertise of the University on Artificial Intelligence, High-Performance Computing and Cybersecurity to help small and medium entreprises of the region increasing their Competitivity in Europe by performing a digital transformation of their working process.
- Frédéric Mallet is elected in the steering committee of the cluster AKTANTIS (ex Systèmes Communicants Sécurisés).

- Luigi Liquori was reviewer of a COST european proposition.
- Julien Deantoni was expert for the French national research agency (ANR AAPG 2025), i.e., reviewed collaborative research project proposal.

11.1.8 Standardization committees

- Luigi Liquori and Marie-Agnès Peraldi-Frati are members of oneM2M Consortium - *oneM2M Sets Standards For The Internet Of Things*.
- Luigi Liquori and Marie-Agnès Peraldi-Frati are members of ETSI TC DATA - *DATA*.
- Luigi Liquori is member of ETSI Technical Committee - *Electronic Signatures and Trust Infrastructures* (ETSI TC ESI).
- Luigi Liquori is member of ETSI Technical Committee (ETSI TC eHEALTH).
- Luigi Liquori is member of AFNOR, *Langages de Programmation* Commission Nationale.
- Luigi Liquori is member of AFNOR, *Blockchain* Commission Nationale.
- Luigi Liquori is member of ISO, TC 307 *Blockchain and distributed ledger technologies* WG1 (Foundations) and WG5 (Governance).
- Luigi Liquori is member of ISO, JTC1/SC22 *Programming languages, environments and system software interfaces* WG14 and WG22 (C/C++).
- Luigi Liquori is member of ECMA TC 39: *Specifying JavaScript*.

11.1.9 Research administration

- Since January 1st 2025, Luigi Liquori is responsible of International Relation for Inria Center at Université Côte d'Azur and member of National Inria International Relations Department.
- Since January 1st 2022, Frédéric Mallet is the Director of I3S research unit, a joint research unit between CNRS and Université Côte d'Azur, of 270 staff, including 135 permanent staffs.
- Since 2022, Julien Deantoni is a member of the I3S laboratory council.

11.2 Teaching - Supervision - Juries

11.2.1 Teaching Administration

- Nicolas Ferry is head of the computer Science department at IUT Nice Côte d'Azur.
- Gerald Rocher is head of the IoT-CPS master 2 minor at Polytech.
- Marie-Agnès Peraldi-Fratiis coordinator of the second year of the BUT in Computer Science (apprenticeship program)

11.2.2 Teaching

- Master: Sid Touati, Architectures de processeurs hautes performances, 30h eq TD, Master 1 informatique, Université Côte d'Azur.
- Master: Sid Touati, Advanced operating systems, 30h eq TD, Master 1 informatique, Université Côte d'Azur.
- Master: Sid Touati, Programmation efficace, 30h eq TD, Master 1 informatique, Université Côte d'Azur.

- Master: Sid Touati, Calculs avancés et performances, 30h eq TD, Master 2 informatique, Université Côte d'Azur.
- Master: Luigi Liquori, Peer-to-peer systems, 32h eq TD, M2, Polytech Nice Sophia, Université Côte d'Azur.
- Master: Julien Deantoni, Domain Specific Languages, 32h eq TD, M2, Polytech Nice Sophia, Université Côte d'Azur.
- Master: Julien Deantoni, Operating System for Edge Computing, 32h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- Master: Nicolas Ferry, Web services for the Internet of Things, 4h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- Master: Nicolas Ferry, Digital Twins, 4h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- Master: Nicolas Ferry, Engineering Software Architecture, 20h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- Master: Frédéric Mallet, Programmation Synchrone, 32h eq TD, M1, Université Côte d'Azur.
- International Master: Frédéric Mallet, Safety-Critical Systems, 32h eq TD, M1, Université Côte d'Azur.
- International Master: Frédéric Mallet, Software Engineering, 32h eq TD, M1, Université Côte d'Azur.
- License: Luc Hogie, Distributed programming, 28h eq TD, DUT Informatique, Université Côte d'Azur.
- Licence: Sid Touati, Architecture machine, 50h eq TD, L3 informatique, Université Côte d'Azur.
- Licence: Sid Touati, Compilation, 87h eq TD, L3 informatique, Université Côte d'Azur.
- Licence: Sid Touati, Systèmes d'exploitation, 18h eq TD, L2 informatique, Université Côte d'Azur.
- BUT3: Marie-Agnès Peraldi Frati, Virtualisation avancée (30h), Programmation avancée (30h) - IUT Université Côte d'Azur.
- BUT2 : Marie-Agnès Peraldi Frati, Bases de la Virtualisation, 30h eq TD,
- BUT2 : Marie-Agnès Peraldi Frati, SAE, Situations Apprentissages et d'Études 30h eq TD IUT Université Côte d'Azur.
- Licence: Julien Deantoni, Introduction à la Programmation 1, 150h eq TD, DS4H portail science, Université Côte d'Azur.
- BUT1: Nicolas Ferry, Software Quality, 46h eq TD,
- BUT2: Nicolas Ferry, Web Programming, 35h eq TD, IUT Nice Côte d'Azur, Université Côte d'Azur.
- BUT2: Nicolas Ferry, Advanced Web Programming, 20h eq TD, IUT Nice Côte d'Azur, Université Côte d'Azur.
- BUT2: Nicolas Ferry, Software Quality, 20h eq TD, IUT Nice Côte d'Azur, Université Côte d'Azur.
- BUT2: Nicolas Ferry, Software Architecture, 20h eq TD, IUT Nice Côte d'Azur, Université Côte d'Azur.
- BUT3: Nicolas Ferry, Continuous Delivery, 20h eq TD, Université Côte d'Azur.
- BUT3: Nicolas Ferry, SAE (large semester project), 35h eq TD, Université Côte d'Azur.
- SI5: Gérald Rocher, Conception Logicielle: du Smartphone aux Wearable Computers, 3h eq TD, Polytech Nice Sophia, Université Côte d'Azur.

- SI5: Gérald Rocher, Conception Systèmes Cyber-Physiques, 4h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- SI5: Gérald Rocher, Développement Logiciel d'Applications IA embarquées, 34h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- SI5: Gérald Rocher, Développement de Systèmes Cyber-Physiques, 28h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- SI5: Gérald Rocher, Full-Stack Software Engineering for IoT, 8h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- SI5: Gérald Rocher, Architectures à Microservices, 10h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- SI5: Gérald Rocher, Systèmes Intelligents Autonomes, 4h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- PEIP1: Gérald Rocher, Environnements Informatiques, 35h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- BAT3: Claude Stolze, Bâtiment intelligent, 64.5h eq TD, Polytech Nice Sophia, Université Côte d'Azur.
- BAT3: Claude Stolze, Initiation à Programmation VBA, 26.75h eq TD, Polytech Nice Sophia, Université Côte d'Azur.

11.2.3 Supervision

Most of the Kairos members are supervising several tutored students and internships every years.

PhD student supervision:

- Joao Cambeiro was supervised by Julien Deantoni
- Barbara Da Silva Oliveira is supervised by Nicolas Ferry and Julien Deantoni
- Anna Di Placido is supervised by Nicolas Ferry and Julien Deantoni
- Paul Somson is supervised by Frédéric Mallet and Frédéric Boulanger (Laboratoire Méthodes Formelles-LMF from Centrale Supelec)
- Maksym Labzhaniia is supervised by Frédéric Mallet and Julien Deantoni
- Markus Purra is supervised by Sid Touati
- Grégoire Aubertin is co-supervised by Sid Touati, with Christophe Alias (main supervisor)

11.2.4 Juries

- Sid Touati was the PhD referee and a Phd committee member of Clément Rossetti in computer science at Université de Strasbourg (December 18th, 2025).
- Sid Touati was a a PhD committee member of Orhan Diane in computer science at Université de Bordeaux (December 9th, 2025).
- Frédéric Mallet was the referee for the PhD Committee of Mohamed ABDELSALAM of Université Grenoble Alpes on November 10th 2025.
- Nicolas Ferry was a referee at the UNINA ITEE PhD final exams - 37th cycle commitee.
- Julien Deantoni was the president of the PhD committee of Nassim Bounouas at Université Côte d'Azur in 2025.

- Julien Deantoni was participating to the PhD committee of Mazen Ezzeddine at Université Côte d'Azur in 2025.
- Julien Deantoni the president of a selection committee for hiring an associate Professor at Université Côte d'Azur in 2025.
- Marie-Agnès Peraldi-Frati co-presided a selection committee for hiring an associate Professor at Université Côte d'Azur in 2025.

11.3 Popularization

11.3.1 Terra Numerica

Kairos is involved into Terra Numerica, where it manages the development of many educational software (games portal), and participates to public events. This implies the recruitment and supervision of students at Master-level at DS4H and Polytech Nice. Every semester, we work with 5-6 students.

11.3.2 Others science outreach relevant activities

- In 2025, Marie-Agnès Peraldi-Frati participated to the dedicated programme "1 scientifique, 1 classe, Chiche!", targeted at Junior High School audience, and meant to encourage young people, girls in particular, to consider scientific studies and careers. We animated, jointly with their traditional teacher, a robotic challenge addressed to 13 years old students in a nearby school.
- Robert de Simone, Luigi Liquori, Pavlo Tokariev, and Irman Faqrizal attended the Synchron Open Seminar in Aussois during the last week of November, and gave presentations there on their ongoing research.
- Nicolas Ferry and Gérald Rocher participated to the organization of the DYNABIC Hackathon in Nice (January 2025) were 100 participants were provided with the DYNABIC tools and hands on exercices.
- Nicolas Ferry organized the second DYNABIC-Day in Sophia Antipolis as a dissemination event toward academics and industrials. Gerald Rocher was one of the presenter at the event.

12 Scientific production

12.1 Major publications

[1] C. André, J. Deantoni, F. Mallet and R. De Simone. 'The Time Model of Logical Clocks available in the OMG MARTE profile'. In: *Synthesis of Embedded Software: Frameworks and Methodologies for Correctness by Construction*. Ed. by S. K. Shukla and J.-P. Talpin. Chapter 7. Springer Science+Business Media, LLC 2010, July 2010, p. 28. URL: https://hal.inria.fr/inria-00495664 (cit. on p. 7).

[2] Y. Bao, M. Chen, Q. Zhu, T. Wei, F. Mallet and T. Zhou. 'Quantitative Performance Evaluation of Uncertainty-Aware Hybrid AADL Designs Using Statistical Model Checking'. In: *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems* 36.12 (Dec. 2017), pp. 1989–2002. DOI: 10.1109/TCAD.2017.2681076. URL: https://hal.inria.fr/hal-01644285 (cit. on p. 8).

[3] T. Carle, D. Potop-Butucaru, Y. Sorel and D. Lesens. 'From Dataflow Specification to Multiprocessor Partitioned Time-triggered Real-time Implementation *'. In: *Leibniz Transactions on Embedded Systems* (Nov. 2015). DOI: 10.4230/LITES-v002-i002-a001. URL: https://hal.inria.fr/hal-01263994 (cit. on p. 8).

[4] L. Henrio, E. Madelaine and M. Zhang. 'A Theory for the Composition of Concurrent Processes'. In: *36th International Conference on Formal Techniques for Distributed Objects, Components, and Systems (FORTE)*. Ed. by E. Albert and I. Lanese. Vol. LNCS-9688. Formal Techniques for Distributed Objects, Components, and Systems. Heraklion, Greece, 2016, pp. 175–194. DOI: 10.1007/978-3-319-39570-8_12. URL: https://hal.inria.fr/hal-01432917 (cit. on p. 8).

[5] F. Honsell, L. Liquori, P. Maksimovic and I. Scagnetto. 'LLFP : A Logical Framework for modeling External Evidence, Side Conditions, and Proof Irrelevance using Monads'. In: *Logical Methods in Computer Science*. Special Issue in honor of Pierre Louis Curien (23rd Feb. 2017). URL: https://hal.inria.fr/hal-01146059 (cit. on p. 21).

[6] F. Honsell, L. Liquori, C. Stolze and I. Scagnetto. 'The Delta-framework'. In: 38th IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science, (FSTTCS) 2018. Vol. 122. 38th IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science, FSTTCS. Ahmedabad, India, 2018, 37:1–37:21. DOI: 10.4230/LIPIcs.FSTTCS.2018.37. URL: https://hal.archives-ouvertes.fr/hal-01701934 (cit. on p. 21).

[7] F. Jebali and D. P. Butucaru. 'Ensuring Consistency between Cycle-Accurate and Instruction Set Simulators'. In: *18th International Conference on Application of Concurrency to System Design, ACSD 2018, Bratislava, Slovakia, June 25-29, 2018*. 2018, pp. 105–114. DOI: 10.1109/ACSD.2018.00019. URL: https://doi.ieeecomputersociety.org/10.1109/ACSD.2018.00019 (cit. on p. 8).

[8] L. Liquori and C. Stolze. 'The Delta-calculus: syntax and types'. In: FSCD 2019 - 4th International Conference on Formal Structures for Computation and Deduction. Dortmund, Germany, 2019. DOI: 10.1007/978-3-030-44411-2_6. URL: https://hal.archives-ouvertes.fr/hal-01963662 (cit. on p. 9).

[9] F. Mallet and R. De Simone. 'Correctness issues on MARTE/CCSL constraints'. In: *Science of Computer Programming* 106 (Aug. 2015), pp. 78–92. DOI: 10.1016/j.scico.2015.03.001. URL: https://hal.inria.fr/hal-01257978 (cit. on p. 7).

[10] J.-V. Millo and R. De Simone. 'Periodic scheduling of marked graphs using balanced binary words'. In: *Theoretical Computer Science* 458.2 (Nov. 2012), pp. 113–130. DOI: 10.1016/j.tcs.2012.08.012. URL: https://hal.inria.fr/hal-00764076 (cit. on p. 7).

[11] D. Potop-Butucaru, R. De Simone and J.-P. Talpin. 'Synchronous hypothesis and polychronous languages'. In: *Embedded Systems Design and Verification*. Ed. by R. Zurawski. CRC Press, 2009, pp. 6-1–6–27. DOI: 10.1201/9781439807637.ch6. URL: https://hal.inria.fr/hal-00788473 (cit. on p. 7).

[12] C. Stolze and L. Liquori. 'A Type Checker for a Logical Framework with Union and Intersection Types'. In: FSCD 2020 - 5th International Conference on Formal Structures for Computation and Deduction. Paris, France, 2020. DOI: 10.4230/LIPIcs.FSCD.2020. URL: https://hal.archives-ouvertes.fr/hal-02573605 (cit. on p. 9).

[13] M. E. Vara Larsen, J. Deantoni, B. Combemale and F. Mallet. 'A Model-Driven Based Environment for Automatic Model Coordination'. In: Models 2015 demo and posters. Models 2015 demo and posters. Ottawa, Canada, 1st Oct. 2015. URL: https://inria.hal.science/hal-01198744.

[14] M. Zhang, F. Dai and F. Mallet. 'Periodic scheduling for MARTE/CCSL: Theory and practice'. In: *Science of Computer Programming* 154 (Mar. 2018), pp. 42–60. DOI: 10.1016/j.scico.2017.08.015. URL: https://hal.inria.fr/hal-01670450 (cit. on p. 8).

12.2 Publications of the year

International journals

[15] J. Deantoni, P. Muñoz, C. Gomes, C. Verbrugge, R. Mittal, R. Heinrich, S. Bellis and A. Vallecillo. 'Quantifying and combining uncertainty for improving the behavior of Digital Twin Systems'. In: *Automatisierungstechnik* 73.2 (3rd Feb. 2025), pp. 81–99. DOI: 10.48550/arXiv.2402.10535. URL: https://hal.science/hal-04467401 (cit. on pp. 16, 18).

International peer-reviewed conferences

[16] B. Combemale, P. Vicat-Blanc, A. Blouin, H. Bril El Haouzi, J.-M. Bruel, J. Deantoni, T. Duval, S. Gérard and J.-M. Jézéquel. 'Engineering Digital Twins: A Research Roadmap'. In: *Proceedings of the 2nd International Conference on Engineering Digital Twins (EDTconf 2025)*. EDTconf 2025 - 2nd International Conference on Engineering Digital Twins. Grand Rapids, Michigan, United States, 2025, pp. 1–7. URL: https://inria.hal.science/hal-05223776 (cit. on p. 16).

[17] L. Hogie. 'How Digital Twins Can Improve the Design of Distributed Computing Frameworks'. In: *IEEE Xplore*. FMEC 2025 - 10th International Conference on Fog and Mobile Edge Computing. Vol. 33. 10th International Conference on Fog and Mobile Edge Computing (FMEC). Tampa (Florida), United States: IEEE, July 2025, pp. 244–247. DOI: 10.1109/FMEC65595.2025.11119372. URL: https://hal.science/hal-05285529 (cit. on p. 17).

[18] A. R. Ndouna, M. Frappier and F. Mallet. 'A Modular Orthogonal Integration of Operational and Prescriptive Timing Requirements using TASTD ⋆'. In: *28th Brazilian Symposium, SBMF 2025, Recife, Brazil, December 3–5, 2025, Proceedings*. SBMF 2025 - 28th Brazilian Symposium on Formal Methods. Vol. LNCS-16363. 28th Brazilian Symposium, SBMF 2025, Recife, Brazil, December 3–5, 2025, Proceedings. Recife, Brazil: Springer, 2025. DOI: 10.1007/978-3-032-12086-1_2. URL: https://inria.hal.science/hal-05433530 (cit. on p. 16).

[19] P. Nguyen, H. Song, R. Dautov, N. Ferry, A. Rego, E. Rios, E. Iturbe, V. Valdes, A. R. Cavalli and W. Mallouli. 'Knowledge Systematization for Security Orchestration in CPS and IoT Systems'. In: *IEEE Xplore*. CSR 2025 - IEEE International Conference on Cyber Security and Resilience. 2025 IEEE International Conference on Cyber Security and Resilience (CSR). Chania, Greece: IEEE, 4th Aug. 2025, pp. 672–678. DOI: 10.1109/CSR64739.2025.11130008. URL: https://hal.science/hal-05285485 (cit. on p. 18).

[20] B. da Silva Oliveira, N. Ferry and J. Deantoni. 'DemIstifyCPS: A Domain-Specific Language for Influence Modeling in Cyber-Physical Systems'. In: MODELSWARD 2026 - 14th International Conference on Model-Driven Engineering and Software Development. Marbella, Spain, 7th Mar. 2026. URL: https://inria.hal.science/hal-05432195 (cit. on p. 17).

[21] P. Tokariev, I. Faqrizal and J. Deantoni. 'Understandable Timing Analysis of Service-Oriented Architecture Components in Software-Defined Vehicle'. In: *Communications in Computer and Information Science. CCIS*. 20th International Conference on Information and Communication Technologies in Education, Research, and Industrial Applications (ICTERI-2025). Proceedings of the 20th Int. Conf. on Information and Communication Technologies in Education, Research, and Industrial Applications (ICTERI-2025) CCIS-2359. Nice, France, 1st Sept. 2025. URL: https://inria.hal.science/hal-05224373 (cit. on p. 18).

[22] Y. Zhang, F. Mallet, M. Zhang and Z. Liu. 'LTLc/CCSL: a Polychronous Temporal Logic'. In: *Presentation as Journal first - following a publication at FAOCS*. ICFEM 2025 - 26th International Conference on Formal Engineering Methods. 26th International Conference on Formal Engineering Methods, ICFEM. HangZhou, Zhejiang, China, 10th Nov. 2025. URL: https://inria.hal.science/hal-05389619 (cit. on p. 16).

Conferences without proceedings

[23] L. Liquori. 'Pandesys : Asynchronous Contact Tracing : ETSI Standard TS 103 757'. In: AI TrustAlert – Intelligenza Artificiale per la Sanità Pubblica: risultati, prospettive e sfide future. Turin (IT), Italy, 30th Oct. 2025. URL: https://hal.science/hal-05410950 (cit. on p. 19).

[24] C. Stolze, L. Liquori and M. Mendler. 'Synpatick: Coherence and Determinacy with Priorities and Clocks'. In: Synchron 2025 - 32th International Open Workshop on Synchronous Programming. Aussois, France, 24th Nov. 2025. URL: https://inria.hal.science/hal-05459053 (cit. on p. 21).

[25] Z. Yao, E. de Maria and R. de Simone. 'Probabilistic Modeling of Spiking Neural Networks with Contract-Based Verification'. In: UCNC 2025 - 22th International Conference on Unconventional Computation and Natural Computation. LNCS. Nice, France, 16th June 2025. URL: https://inria.hal.science/hal-05416855 (cit. on p. 17).

Reports & preprints

[26] B. Dundua, F. Honsell, T. Kutsia, M. Lenisa and L. Liquori. *Towards Fuzzy Constructive Type Theories*. Inria & Université Cote d'Azur, CNRS, I3S, Sophia Antipolis, France, 1st Dec. 2025. URL: https://inria.hal.science/hal-05436632 (cit. on p. 21).

[27] K. Guha, M. Kazolea, L. Liquori, A. Nebot and D. da Silva. *CoPubli: a minimal software pipeline to extract, browse and geolocalise HAL coauthors*. 1st Dec. 2025. URL: https://inria.hal.science/hal-05436705 (cit. on pp. 15, 20).

Other scientific publications

[28] L. Liquori. *oneM2M Executive Viewpoint series: interview Luigi Liquori (Inria): We are extending pandemic-era, virus tracking concepts to military drone scenarios in the context of federated IoT systems*. Dec. 2025. URL: https://inria.hal.science/hal-05459016 (cit. on p. 19).

[29] E. Perais. 'Improving the Asynchronous Contact Tracing (ACT) platform'. ESIGELEC - IRSEEM, 3rd Nov. 2025. URL: https://inria.hal.science/hal-05459022 (cit. on p. 19).

[30] M. Puura. 'Program Recognition using Graph Neural Networks'. Sophia Antipolis: Université Côte d'Azur, France, 9th Sept. 2025, p. 33. URL: https://inria.hal.science/hal-05295727 (cit. on p. 21).

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