

**FY 2019 Application CREST Research Proposal**

Research Area	Computational Foundation: Technology for Computing Revolution for Society 5.
Title of proposed research project	New Concepts and Tools for Designing Dependable Society 5.0 (CODESO) ディペンダブルな Society 5.0 のための新しい設計手法とツール

**Japanese Side**

Name of Research Director	Kohei Suenaga
Affiliated Institution, Section, Title	Kyoto University, Graduate School of Informatics, Associate Professor Researcher ID No. 70633692
Academic Background	2003.03: Graduates from Dept. of Information Science, University of Tokyo 2005.03: Graduates from Master Program in Graduate School of Information Science and Technology, University of Tokyo 2008.03: Graduates from Doctoral Program in Graduate School of Information Science and Technology, University of Tokyo (Ph.D. in Information Science and Technology)
Professional Appointments and Awards (Research Director)	2008.04--2009.03: JSPS Research Fellowship for Young Scientists (PD) 2009.04--2010.03: Researcher in IBM Research Tokyo 2010.04--2011.02: Postdoctoral researcher in University of Lisbon 2011.04--2012.03: JSPS Research Fellowship for Young Scientists (PD) 2012.04--2013.09: Assistant Professor in Hakubi Center for Advanced Research in Kyoto University 2013.10--Current: Associate Professor in Graduate School of Informatics, Kyoto University 2018.04--Current: Guest Associate Professor in National Institute of Informatics
Information of Research Director	URL: <a href="https://researchmap.jp/ksuenaga/">https://researchmap.jp/ksuenaga/</a>
Research Period	[10. 19] – [03. 25]
Total Research Budget	Total Budget: 500,000 thousand yen

**French Side**

Name of Research Director	Thao Dang
Affiliated Institution, Section, Title	CNRS, Laboratory VERIMAG (Grenoble), Research Director (Directrice de recherche)

Academic Background	<p><u>Sept 1997</u>: Engineer degree, École Nationale d'Ingénieurs Electriciens de Grenoble ENSIEG (National Superior School of Electrical Engineers of Grenoble, which now became National Graduate School of Energy, Water, and Environment (ENSE<sup>3</sup>)).</p> <p><u>Oct 2000</u>: PhD in Automatic Control, INPG (Grenoble National Polytechnic Institute), advisors: Oded Maler and Eugene Asarin</p>
Professional Appointments and Awards (Research Director)	<p><u>Jan 2001- Jan 2002</u>: Postdoctoral researcher, University of Pennsylvania (Philadelphia, USA), supervisor Rajeev Alur</p> <p><u>Feb 2002 - Sept 2014</u>: CNRS researcher (chargé de recherche), Laboratory VERIMAG, Grenoble</p> <p><u>Oct 2014 – now</u>: CNRS research director (directrice de recherche), Laboratory VERIMAG, Grenoble</p> <p><b>HSCC 2019 Test-Of-Time Award</b> for the paper “Reachability analysis via face lifting” by Thao Dang and Oded Maler, in HSCC 1998. (<i>“this award recognizes the work published at a Hybrid Systems: Computation and Control (HSCC) conference in 2009 or before, which has proven to be the most visionary and impactful, leading to new directions of research being initiated, or new applications being brought into the hybrid systems research community”</i>)</p> <p><b>ARITH24 2017 Best Paper Award</b> (24th IEEE Symp. on Computer Arithmetic)</p> <p><b>TESTCOM/FATES 2008 Best Paper Award</b> (20th IFIP International Conference on Testing of Software and Communicating Systems TESTCOM 2008 and 8th International Workshop Formal Approaches to Testing of Software FATES 2008)</p>
Information of Research Director	URL: <a href="http://www-verimag.imag.fr/PEOPLE/Thao.Dang">http://www-verimag.imag.fr/PEOPLE/Thao.Dang</a>
Research Period	[10. 19] – [10. 24]
Total Research Budget	Total Budget: 459 k euros

## Research Proposal Overview

### Outline of Research Project

**Background and Objective.** In Society 5.0, the physical space (including people, things, and systems) is connected to the cyber-space, and performant services obtained by Artificial Intelligence (AI) are fed back to physical space. This project focuses on designing information systems in Society 5.0, used for controlling and supervising various devices in such a super-smart society, in particular sensors, robots, and IoT devices. They contain key technologies including artificial intelligence (*e.g.*, deep learning) and real-time technology. Such systems can be modelled as *cyber-physical systems* (CPS) augmented with AI *learning-enabled* components which impose new requirements: higher levels of autonomy and adaptability in uncertain and dynamically changing environments, and more reliable and efficient techniques for processing large amounts of data in real time. Furthermore, dependability becomes more stringent, since AI components are often “unpredictable” (due to a lack of formal framework to provide safety guarantees) and their failures may directly affect people’s lives and fortune. Striking real examples of AI failures include unsafe medical treatment recommendations, and self-driving car accidents.

The existing design approaches are not suitable to respond to these requirements. Indeed, the existing model-based approach which has been successfully used for engineering systems should be enhanced with the data-driven approach, since many networks of objects and phenomena, emerging in Society 5.0, are not amenable to first principle analysis (due to a lack of sufficient understanding of their complex interaction) and discovering their dynamics should rely on data. In addition, using advanced machine learning and data analytics techniques, substantial values can be extracted out of data, obtained in huge quantities via data technology.

The goal of the project is to develop *new concepts and tools for AI-intensive Cyber-Physical Systems* (AI-CPS). Our modelling paradigm combines the model-based (white-box) and data-driven (black-box) approaches, leading to an approach that we call *gray-box*. The black-box approach should rely on behaviors. To see the difference between the data-driven behavior-based approach and the model-based approach, consider an example of monitoring a robot. The model-based approach uses a model to predict its behavior, and the predicted behavior is compared with the robot's actual behavior. A data-driven behavior-based monitor, in contrast, solely observes the actual behavior and detects certain patterns that indicate a fault. The data-driven behavior-based approach thus needs new pertinent concepts to discover and interpret meaningful behavioral patterns. To this end, it is crucial to define distance measures for behaviors as well as for sets of behaviors. Based on these measures, we will develop new techniques to address major steps of the process of designing AI-CPS. By providing an integrated methodology for modeling, testing, verifying, and online monitoring and control for AI-CPS, our project provides foundations to guarantee dependability of “*new computing technology for significant transformation in information processing*” and “*high-efficiency computing technology to link and collaborate with the technology layers including algorithms and architectures*”, an objective of the Computing Foundation CREST Call. Our project also accelerates the achievement of the strategic objectives “*Creating Technology for Computing Revolution for Society 5.0*” from the perspective of dependability. The research will be organized in 5 work packages (WP):

1. WP1 New robustness and performance measures for assessing dependability of AI-CPS
2. WP2 Data-driven modelling
3. WP3 Verification (to provide correctness proofs)
4. WP4 Testing (to quickly detect design bugs on real systems)

5. WP5 Online monitoring and control (to detect potential problems during the system execution and perform recovery actions in real time).

**Mid-period and Final Objectives.** Our objective for the middle of the research project is to achieve theoretical foundations and conceptual algorithms for the problems in the above 5 work packages. Our objective to reach at the end of at the end of the research period is to achieve performant algorithms which are demonstrated on various case studies, such as self-driving systems, smart buildings, and autonomous robots.

**Originality and novelty.** The new robustness and performance measures together with the associated data-driven behavior-based modeling, validation, monitoring and control methods developed in the project will bring formal and semi-formal analysis to AI-intensive cyber-physical-systems, enabling design of dependable Society 5.0. The novelty of our research lies in the use of the behavior-based approach capable of handling complex networks of components in Society 5.0 and the enhancement of this approach using formal methods.

**Research infrastructure and preparation.** The project is led by two Research Directors: Kohei Suenaga (Kyoto university, Kyoto) and Thao Dang (CNRS/VERIMAG, Grenoble). The joint research groups are: Masako Kishida Group (NII, Tokyo), Eugene Asarin Group (IRIF, Univ. of Paris and CNRS, Paris), Benoît Barbot Group (LACL, Univ. Paris-Est Créteil, Paris), and Aneel Tanwani Group (CNRS/LAAS, Toulouse). The researchers of the consortium have complementary competences (computer science, control, information theory) and made substantial contributions in the research domains directly related to the problems of the project.

The development of the new concepts and tools will be built upon the research results achieved by the project members, namely on temporal logic specifications, information-theoretic measures for timed regular languages, program logic, program and hybrid systems verification, cyber-physical systems testing, temporal behavior monitoring, hybrid and sampled-data control systems. Timed systems (automata with clocks) and hybrid systems (automata with differential equations) are mathematical models widely used for embedded and cyber-physical systems. Promising preliminary results for a number of problems are also available.

**Expected impact on the research cooperation between France and Japan.** The researchers on the French and Japanese sides have worked (separately) on some common problems. This project will strengthen the French-Japanese cooperation by making concrete joint contributions to advance a cutting-edge technology domain of mutual interest. This will also create opportunities to discover new common interests and possibilities of future long-term cooperation.

**Added value of the collaboration.** For a number of key problems in the project (such as monitoring, verification and testing) the members have developed different approaches and methods (such as using program logic and synthesis, nonstandard analysis, set-based numerical and algebraic computations, information theory) which can be combined to create new performant and scalable techniques. More importantly, the complementary backgrounds of the members (control theory, computer science, mathematics) is essential to the achievement of the objectives of the project.

**Collaboration framework.** The project will be carried out in close collaborations via regular teleconference meetings, in-person meetings, and inter-group and inter-country visits, in particular of PhD students and postdocs.

**Requested funding.** We request a funding of 459 k euros for the French side and 500,000 thousand yen for the Japanese side. The funding will allow us to recruit postdocs and PhD students.

## Major Achievements of the Research Director (Japanese Side)

### (1) List of principal research papers (within 10 papers)

1. Kensuke Kojima, Minoru Kinoshita, Kohei Suenaga: Generalized homogeneous polynomials for efficient template-based nonlinear invariant synthesis. Theor. Comput. Sci. 747: 33-47 (2018) (Preliminary version appeared in SAS 2016: pp. 278—299)
2. Taro Sekiyama, Kohei Suenaga: Automated Proof Synthesis for the Minimal Propositional Logic with Deep Neural Networks. APLAS 2018: 309-328
3. Akifumi Imanishi, Kohei Suenaga, Atsushi Igarashi: A guess-and-assume approach to loop fusion for program verification. PEPM 2018: 2-14
4. Takamasa Okudono, Yuki Nishida, Kensuke Kojima, Kohei Suenaga, Kengo Kido, Ichiro Hasuo: Sharper and Simpler Nonlinear Interpolants for Program Verification. APLAS 2017: 491-513
5. Masaki Waga, Ichiro Hasuo, Kohei Suenaga: Efficient Online Timed Pattern Matching by Automata-Based Skipping. FORMATS 2017: 224-243
6. Tatsuya Sonobe, Kohei Suenaga, Atsushi Igarashi: Automatic Memory Management Based on Program Transformation Using Ownership. APLAS 2014: 58-77
7. Kohei Suenaga, Hiroyoshi Sekine, Ichiro Hasuo: Hyperstream processing systems: nonstandard modeling of continuous-time signals. POPL 2013: 417-430
8. Ichiro Hasuo, Kohei Suenaga: Exercises in Nonstandard Static Analysis of Hybrid Systems. CAV 2012: 462-478
9. Kohei Suenaga, Ryota Fukuda, Atsushi Igarashi: Type-based safe resource deallocation for shared-memory concurrency. OOPSLA 2012: 1-20
10. Kohei Suenaga, Ichiro Hasuo: Programming with Infinitesimals: A While-Language for Hybrid System Modeling. ICALP (2) 2011: 392-403

### (2) List of principal invited lectures (within 10 lectures)

11. Kohei Suenaga: Automated proof synthesis for propositional logic using deep learning. 5th France-Japan Cybersecurity workshop. April 23rd, 2019.
12. Kohei Suenaga: 超準プログラミング言語を用いたハイブリッドシステムのモデリングと検証 (English title: Modeling and Verification of Hybrid Systems with Nonstandard Programming Languages). 9th Workshop on Interaction between Cryptography, Information Security and Mathematics (CRISMATH 2017), 22 Dec 2017.
13. Kohei Suenaga: そのプログラム、バグってないですか? : 数学を使ってバグを見つけるための形式検証手法 (English title: Isn't that program buggy?—Formal Verification for Detecting Bugs Using Mathematics). IPSJ Kansai Branch Seminar 2016 “Peripheral Technologies of IoT”. Dec 21st, 2016.
14. Kohei Suenaga: 超準解析を用いたハイブリッドシステム検証手法 (English title: Verification of Hybrid Systems with Nonstandard Analysis). Symp. on the Connection between Engineering and Modern Mathematics. December 20th, 2016.
15. Kohei Suenaga: Formal verification of software, continuous, and hybrid systems -- Or: How do we verify our program is correct? Machine Learning Summer School 2015. August 27th, 2015.
16. Kohei Suenaga: Nonstandard Analysis Meets Programming Language Theory. Twelfth International Conference on Computability and Complexity in Analysis (CCA 2015). July 13th, 2015.
17. Kohei Suenaga: Type-Based Safe Resource Deallocation for Shared-Memory Concurrency. Invited Talk at The 30th JSSST Annual Conference. 2013 年 9 月 12 日
18. Kohei Suenaga: 形式検証手法は無限小プログラミングを使えばハイブリッドシステムにもそのまま使える (English title: Application of Formal Verification to Hybrid Systems by Infinitesimal Programming). Future Technology Design (FTD) 2013. September 11th, 2013.
19. Kohei Suenaga: Programming with Infinitesimals -- A WHILE-Language for Hybrid System Modeling. Google Tech Talk. September 5th, 2011.

## Major Achievements of the Research Director (French Side)

### (1) List of principal research papers (within 10 papers)

1. T. Dang, T. Dreossi, E. Fanchon, O. Maler, C. Piazza and A. Rocca. Set-Based Analysis for Biological Modelling. *Automated Reasoning for Systems Biology and Medicine ARSBM*, Computational Biology Series, Springer, 2019.
2. T. Dreossi, T. Dang, and C. Piazza. Reachability computation for polynomial dynamical systems. *Formal Methods in System Design*, 50(1): 1-38 (2017).
3. A. Rocca, V. Magron, and T. Dang. Certified Roundoff Error Bounds using Bernstein Expansions and Sparse Krivine-Stengle Representations. 24th IEEE Symp. on Computer Arithmetic ARITH24, 2017. **Best Paper Award**
4. A. S. Adimoolam, T. Dang, A. Donzé, J. Kapinski, Xiaoqing Jin: Classification and Coverage-Based Falsification for Embedded Control Systems. CAV 2017, pages 483-503, Springer, 2017.
5. T. Dang and T. Nahhal. Coverage-guided test generation for continuous and hybrid systems. *Formal Methods in System Design*, 34(2):183–213, 2009.
6. T. Dang and R. Testylier. Hybridization Domain Construction using Curvature Estimation. *Hybrid Systems: Computation and Control HSCC'2011*, pages 123-132, ACM, 2011.
7. T. Dang and T. Nahhal. Using disparity to enhance test generation for hybrid systems. In *TESTCOM/FATES 2008*, LNCS, pages 54– 69, Springer, 2008. **Best Paper Award**
8. R. Alur, T. Dang, and F. Ivancic. Counter-example guided predicate abstraction of hybrid systems. *Theoretical Computer Science (TCS)*, 354(2):250–271, 2006.
9. E. Asarin, O. Bournez, T. Dang, O. Maler, and A. Pnueli. Effective synthesis of switching controllers for linear systems. *Proceedings of the IEEE*, 88:1011–1025, 2000.
10. T. Dang and O. Maler. Reachability analysis via face lifting. In *Hybrid Systems: Computation and Control HSCC 1998*, LNCS 1386, pages 96–109. Springer-Verlag, 1998. **HSCC 2019 Test-Of-Time Award**

### (2) List of principal invited lectures (within 10 lectures)

11. T. Dang. Invariance and stability verification of hybrid systems. *Methods and Tools for Distributed Hybrid Systems (DHS 2018)*. Paris, France, 4 July 2018.
12. T. Dang. Vaidation of Cyber-Physical Systems: from Formal to Semi-Formal. Halmstad Summer School on Cyber-Physical Systems. June 2018, Halmstad, Sweden.
13. T. Dang. Parameter synthesis for biological systems modelling. 5th Int. Workshop on Synthesis of Complex Parameters. Thessaloniki, Greece. April 2018.
14. T. Dang. Parameter synthesis for biological models. Workshop Verification of Biological Systems. Labex Digicosme Open University, Paris, May 2019.
15. T. Dang. Template Complex Zonotopes: A New Set Representation for Verification of Hybrid Systems. Int. Workshop on Symbolic and Numerical Methods for Reachability Analysis SNR, Vienna, April 2016.
16. T. Dang. Set-based analysis of dynamical systems and their applications. 4th Workshop on Hybrid Autonomous Systems HAS. April 2014.
17. T. Dang. Applying the Hybridization Approach to Biological Models. Workshop Formal Methods for Bioinformatics. Paris, 4 Nov 2011.
18. T. Dang. Reachability techniques for the analysis of dynamical systems models in biology. Toward Systems Biology, Grenoble, 2007.

## Project Description

### 1. Background and Objective

Artificial intelligence (AI) and data sciences are revolutionizing our society toward a super-smart society (Society 5.0). In a super-smart society, information systems contain “key technologies including artificial intelligence (e.g., deep learning)”, and real-time technology. This impacts systems design in two directions. In one direction, new system theory and methods should be invented in order to handle new AI technological developments. In the other direction, systems design can exploit the advances in AI and data sciences to bring large-scale improvements in efficiency, dependability and security to information and control systems. We consider information systems used for controlling and supervising various devices in such a super-smart society, in particular sensors, robots, IoT devices. They can be seen as cyber-physical systems (CPS) with new requirements and features, and their design is faced with new challenges.

First, model-based design has been intensively used CPS and Internet-of-Things (IoT), since this approach exploits computing technology to create complex mathematical models to automatically debug, verify, test and implement into products and services. Such models are built to capture our knowledge of how a system evolves within an environment, using explicit rules and representations. However, many objects and phenomena, emerging in our increasingly networked and computerized society, are not amenable to first principle analysis and discovering their dynamics should rely on data. On the other hand, increasingly affordable computing power and storage nowadays allow obtaining huge quantities of data, and substantial values can be extracted out of data, using machine learning and data analytics techniques. Second, such systems now require higher levels of autonomy and adaptability in uncertain and dynamically changing environments. This is achieved often by using AI technology, therefore the systems we should consider are *learning-enabled*. There are a number of challenges in designing this new generation of information systems. On one hand, AI techniques are “unpredictable” due to a lack of formal framework to provide safety guarantees. On the other hand, classical methods for verifying (such as model-checking) safety critical properties rely on rather fixed models, that is once the system is deployed, its structure and configuration are generally fixed. The existing methods thus face a fundamental problem because the new generation systems with AI components are supposed to learn from experience and interactions with the environment, and adapt and regulate their behavior accordingly. *Real-time* data processing becomes challenging due to large amounts of information.

In an AI-intensive Society 5.0 it is imperative to ensure that its learning-enabled components work correctly because they may directly affect people’s lives and fortune. Striking real examples of AI failures include unsafe medical treatment recommendations, and self-driving car accidents. To respond to the above-mentioned challenges in ensuring dependability of a Society 5.0, we propose *new concepts and tools for AI-intensive cyber-physical systems* (AI-CPS). The modelling paradigm should combine the model-based (white-box) and data-driven (black-box) approaches, leading to an approach that we call *gray-box*. For example, to monitor a robot, the model-based approach uses a model to predict its behavior, and compared it with the robot’s actual behavior. A data-driven behavior-based monitor, in contrast, solely observes the actual behavior and detects certain patterns that indicate a fault. The data-driven behavior-based approach thus needs new pertinent concepts to discover and interpret meaningful behavioral patterns. To this end, it is crucial to define distance measures for behaviors as well as for sets of behaviors. Based on these measures, new validation and control techniques should then be developed.

### 2. Objectives of proposed research project

#### (1) Objective to be achieved in the middle of the research period

We will develop new techniques to address major steps of the process of designing dependable AI-intensive CPS. The research will be organized in 5 work packages:

- WP1 New robustness and performance measures for assessing dependability
- WP2 Data-driven modelling
- WP3 White-box and gray-box verification algorithms for AI-CPS
- WP4 Black-box testing algorithms for AI-CPS

- WP5 Online monitoring and control for enforcing safety and performance constraints

Our mid-period objectives is to achieve theoretical foundations for WP1 and conceptual algorithms for the problems in all the other work packages.

## (2) Objective to be achieved at the end of the research period

Our objectives to reach at the end of the research period is to achieve *performant effective algorithms*, their *efficient implementation* in *software toolboxes*, for

- verification of AI-CPS
- testing by falsification and statistical model-checking of AI-CPS
- synthesis of online monitors and controllers

The toolboxes are evaluated, improved and demonstrated via various case studies, such as self-driving systems, smart buildings, autonomous robots.

## 3. Research Plans and Approach

The work packages will be carried out in parallel, with a collective effort put on the WP1 first, since it lays foundations that can be exploited by the other work packages, which however can start using the preliminary results [EA1, EA4].

### **WP1 (Measures) New robustness and performance measures for assessing and monitoring dependability and safety properties of cyber-physical systems**

Verification, testing, monitoring and control of AI-CPS can only be done with respect to relevant and clearly defined criteria, mostly quantitative. In WP1 we will systematically define such criteria for various situations, starting from clean mathematical foundations, through algorithmic tools and ending with practical application methodology. Our criteria will be mainly based on distances for individual behaviors and on volumes and entropy for sets of behaviors; however, we will compare these techniques with inductive robustness measures and probabilistic criteria. Based on preliminary results for timed systems [EA1, EA4], we will proceed as follows:

1. Distance measures on behaviors: (1a) Identifying relevant distances for various CPS and observations thereof; (1b) Geometric and topological properties of distances; (1c) Comparison of distances to inductive robustness measures.
2. Measuring sets of behaviors: (2a) Epsilon-entropy of sets of behaviors and construction of epsilon-nets; (2b) Simple classification of CPS according to the size of their sets of behaviors.
3. Extending the distance/entropy approach: (3a) to hybrid systems with control/disturbance/state/output; (3b) to systems with machine learning components.
4. Developing methodology of quantitative dependability, safety assessment for AI-CPS: when distance, entropy or probability should be used.

### **WP2 (Modelling) Data-driven modelling**

Our goal is to develop new techniques for extracting information from temporal behavior data (signals, waveforms, sequences), and come up with succinct representation that captures their properties. This data can be obtained by simulating/executing real systems and measuring/observing entities of interest. We will use Signal Temporal Logic (STL) [Donzé&Maler FORMATS10] as formalism for mining properties of dynamical behaviors, inferring classifiers and clustering of such behaviors. STL is a language for specifying properties of signals and time series over logical and real values. It has been used to specify and monitor behaviors of diverse systems such as robots, medical devices (artificial pancreas, anesthesia machine), analog circuits, biochemical models of cellular pathways, and cyber-physical control systems, mostly within the automotive domain. An STL property can be viewed as a classifier of behaviors based on their multi-dimensional dynamic feature, thus being more refined than traditional measures such as steady states or measures based on averages. Using parametric STL, a formula can be used as a feature extractor which reduces the signal into a (low-dimensional) set in the parameter space that can be used for classification and clustering. On the other hand, dynamical systems will also be considered in combination with STL specifications, to capture more accurately dynamical behaviors.

We identify in the following directions: (1) fundamental studies on the quantitative semantics of STL which reflects measures of satisfaction robustness in space and time. This work will be done in interaction with WP1 (Measures); (2) algorithms for learning predicates and parameter space exploration; (3) learning algorithms for STL parametric identification, classification and clustering, (4) extension of methods for data-driven dynamical models for control synthesis; (5) methods for building mixed dynamical system and STL models.



**WP3 (Verification) Verification algorithms using new measures**

Formal verification is a method to check if a system is dependable by mathematical proofs. Formal verification, initially studied in software science, is becoming popular in practical software development due to various easy-to-use tools such as Infer developed by Facebook. We aim at formal verification tailored to the components that constitute Society 5.0. One of the targets of WP3 is to incorporate the existing and the new measures investigated in WP1 in the verification framework. As mathematical models, we will use timed systems (automata with clocks) and hybrid systems (automata with differential equations), widely used for embedded and cyber-physical systems. Concretely, we study the following:

**Model checking of gray-box hybrid systems.** Model-checking is one of the formal verification approaches that establish a property (formal specification) of a system (described by a formal model). Most of existing model-checking methods assume a white-box model that we know its behavior completely. We study the extension of model checking to gray-box models, of which we only have partial knowledge on the behavior.

**Robust model-checking.** We consider model-checking problems with respect to a property satisfaction robustness metric. A robust model-checking algorithm verifies, for example, that all behaviors of a CPS are at a distance greater than epsilon from a set of specified forbidden behaviors.

**Verification of systems with learning-enabled components.** We focus on verifying quality assurance of neural networks (NN): (1) robustness verification of NN that deals with various types of data that are typically obtained from sensor networks; (2) verification of software/hybrid systems with NN components. For (1), we will apply set-based computation to propagate input perturbation effect, using reachability analysis, abstract interpretation and uncertainty propagation techniques [TD2, TD3, TD11, MK10]. For (2), we will investigate the assume-guarantee approach which determines the rules on input/output relations for each component to ensure that the overall system satisfies a global property, by inspiring from input/output stability in control theory [AT2].

**WP4 (Testing) Falsification and Statistical Model-Checking of AI-CPS**

When a system is too complex to be amenable to formal verification, or only an implementation is available, it is validated by testing approaches which treats the system as a black box (that is, we can only observe its response to an input signal). We will focus on sampling-based methods, in the spirit of the Monte Carlo and quasi-Monte Carlo approaches. While the goal of falsification [TD5] is to find a faulty behavior (by minimizing the property satisfaction robustness function), statistical model-checking [BB3] aims at providing statistical correctness guarantees. It is important to measure the quality of an arbitrary sample in evaluating quantitative properties, in terms of error bounds or statistical guarantees. Figures of merit (such as Kolmogorov-Smirnov statistic) will be investigated. The measures developed in WP1 will be used to define suitable robustness metrics. To deal with learning-enabled components, correctness of their generalization will be assessed.

**WP5 (Online Monitoring and Control) Online Monitoring and Control for enforcing Dependability and Performance constraints**

Monitoring a deployed system to detect a potential faulty situation, in which case a supervisory controller should perform corrective actions to avoid disastrous consequences. This activity is paramount for a social infrastructure such as Society 5.0 to function safely and efficiently. A monitoring algorithm needs to efficiently analyze large amounts of various types of data gathered from sensors and processed by computers. The corresponding control actions have to ensure that the resulting behavior satisfies the safety and performance constraints up to an allowed margin. To design such algorithms, we will investigate:

**Robust monitoring.** Such an algorithm decides, whether a behavior observed within an error margin is certainly correct, certainly erroneous, or marginal. We will develop online monitoring algorithms that can deal with such measures.

**Gray-box monitoring by combining formal verification and online monitoring.** Formal verification studied in WP3 and online monitoring in WP5 stand in a trade-off relationship: the former promises high assurance but complete verification is impossible; the latter is flexible but comes with runtime overhead. We will study a framework that enables flexible partition of verification burden to formal verification and online monitoring. This idea is recognized as *gradual typing* in the area of programming language theory [Siek et al., ECOOP'07]; it integrates static typing and dynamic typing in a single language in a flexible way.

**Control of information systems.** The information from sensors is not only used for monitoring, but looking from the perspective of controlled dynamical systems, our objectives also include the design of control actions that influence the behaviors. We will formulate the performance constraints in terms of acceptable upper bounds on the deviation of the observed behaviors from the desired behavior using a distance measure. Several approaches are possible to design or control a system from temporal logic specification for a given performance constraint. In contrast to more conventional Boolean semantics, we will investigate approaches with quantitative semantics, such as STL [Bakhirkin & Basset TACAS19]. The choice is not only motivated by the need to alleviate the computational burden that comes with exact partition-based verification methods, but also seem more conducive for designing control actions which depend on the behaviors observed with uncertainty (due to time- or space-sampled measurements). In this regard, we will investigate whether our results on control strategies for designing sampled-data [AT2, AT3, AT8, MK1, MK4] and quantized [AT9, MK2] controllers are compatible with validation algorithms using quantitative semantics [EA3, TD5, KS5].

#### 4. Originality and novelty of the proposed research and comparison to current state of similar studies

Concerning data-driven modelling, SINDy (sparse identification of nonlinear dynamics) or DMD (dynamic mode decomposition, to build linear models) are among the most popular techniques. For information systems we consider, an appropriate modelling formalism should permit: (1) rigorous analysis, (2) efficient model revision to account for new data, (3) ability to explain how the system works or does not work. High dimensionality and nonlinearity are bottlenecks that hinder effective use of formal methods for complex dynamical systems with differential equations/inclusions mixed with mode switching. The STL formalism could be seen as an abstraction that retains key spatial temporal patterns of the behaviors of such dynamical systems. Monitoring and testing algorithms for STL can handle a large number of variables. Using STL therefore provides a good trade-off between model expressiveness and computation effectiveness. New techniques for constructing mixed dynamical system and STL models will also increase the scope of data-driven modelling.

Behavior-based systems<sup>1</sup>, where each behavior is represented by a component, have been used successfully in robotics to design autonomous robots which, based on information from sensors, can capture the environment to react in situations that were not explicitly defined. A network of interacting behaviors leads to emergent behaviors not directly explainable by the individual behaviors. This poses conceptual and practical challenges for the behavior-based approaches. To reason about compound behaviors of the overall system, quantifying sets of behaviors and the relationship between behaviors and data is a crucial prerequisite. The new *distance measures* and *information theoretic quantities* together with the associated *verification and testing methods* developed in WP3 and WP4 will lead to an approach for formal and semi-formal analysis of behavior-based systems and enable its applications to AI-CPS.

Concerning *online monitoring and control* in WP5, the existing approaches for monitoring and control under correctness constraints use temporal logics with Boolean semantics. As a result, partitions required for checking a given LTL or CTL specification requires partition-based abstractions, which cannot be carried out for systems of large size. In our project, the use of STL specifications allows us to check correctness quantitatively and it has the potential of overcoming the computational burden associated with current methods. The recent work carried out by the project members [EA1, EA3, Bakhirkin & Basset TACAS19] paves the way for exploring such methods for online monitoring and control design methods. Moreover, the outcome of the project will enhance the class of control-theoretic problems which can be addressed in combination with temporal logic specifications using quantitative semantics.

All in all, the results of the project will constitute a foundational step towards a *formal behavior-based design approach* for AI-intensive CPS systems in Society 5.0.

#### 5. Research infrastructure and preparation

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<sup>1</sup> (the development of which is rooted in the subsumption architecture advocated by R. Brook in the 80s)

**Backgrounds and achievements of the project members.**

**Kohei Suenaga (Research Director on the Japanese side)** is an expert in program and hybrid system verification. He led a JST PRESTO project “Formal methods for hybrid systems based on the theory of nonstandard programming languages” (2015--2018), which led to the publications and patents on program and hybrid systems verification [KS1, KS3-7, KS-P-1, KS-P-(3-8)]. He also led JSPS Grant-in-Aid for Scientific Research project “Formal verification of hybrid systems based on infinitesimal programming” (2012--2015). Before that, he established the foundation and the implementation of nonstandard programming languages [KS10, KS11, KS13], which is a programming language extended with a constant that denotes an infinitesimal number; this language is used to model and verify hybrid systems. He is also interested in implementing research via industrial collaboration; he collaborated with TOYOTA (2014-2016) and is working as a scientific advisor in four startup companies (PatentField, LegalForce, DaiLambda, and SenseTime Japan).

**Thao Dang (Research Director on the French side)** is an expert in hybrid systems verification and testing. She was the coordinator of two ANR projects: MALTHY (Algebraic methods for model-checking of real-time and hybrid systems) 2014-2018, VAL-AMS (High-Confidence Validation of Analog and Mixed Signal Systems), an industrial project funded by Toyota (USA), since 2013 till today, on Model-based Testing of Automotive Control Systems, a project funded by BOSCH (Germany) on Testing of Embedded Systems in 2015-2016, a project funded by UTRC (United Technologies Research Center, Ireland) on Validation of CPS in 2016. She was a Principal Investigator (for VERIMAG) in the ANR project COMPACS (Computation-Aware Control Design and Implementation), 2014-2017. Thao Dang contributed pioneering results on hybrid systems reachability computation and verification [TD40]. More recently, she has led novel research in high-confidence semi-formal hybrid systems testing [cite] and application to CPS (see FORM 6F).

**Masako Kishida (Lead of Japanese Joint Group 1)** is a control theorist and has experience in analysis and design of a wide variety of control systems from tissue engineering to controls over networks. In particular, she has many publications on analysis of uncertain systems, including reachability analysis and its applications to controls along with event- and self-triggered controls, and system analysis that takes the structures of uncertainties into account. She is currently participating in JST ERATO project, Metamathematics for Systems Design, where she collaborates with computer scientists on control of hybrid systems.

**Eugene Asarin (Lead of French Joint Group 1)** is an expert in hybrid and timed systems. His works on theory and practice of verification of hybrid systems [EA9, TD19, EA7, EA6] strongly impacted this domain since its early years. More recently, he led a novel research work combining information theory and verification [EA4, EA1] and coordinated the project ANR-11-BS02-004 EQINOCS (Entropy and Quantity of INformation in mOdel of Computational Systems) in 2011-2015. He also worked on specification of timed patterns, timed pattern-matching and monitoring [EA3, EA8].

**Benoît Barbot (Lead of French Joint Group 2)** His main interests are the analysis of probabilistic discrete and continuous time models as well as developing tools to support this analysis. He is the main developer of Cosmos (<http://cosmos.lacl.fr>), a Statistical Model Checker for the Hybrid Automata Stochastic Logic.

**Aneel Tanwani (Lead of French Joint Group 3)** is an expert in studying problems related to control design and performance analysis of controlled dynamical systems. He is the coordinator of JCJC project ANR-17-CE40-0019-01, titled ConVan (Control of Constrained Interconnected Systems Using Variational Analysis). His research interests broadly include stability analysis of switched and hybrid systems [AT7], control under limited information [AT1, AT2, AT3, AT8], observation of switched systems [AT5, AT6], stochastic systems [AT2, AT3], game theory [AT4], and set-valued analysis [AT9].

**Nicolas Basset (Associate Professor in the French Research Director's Group)** is an expert in uniform sampling of behaviors of timed systems. He won ICALP 2013 Best Student Paper Award for the paper *Maximal Entropy Measure for Timed Automata*, and FORMATS 2018 Best Paper Award for the paper *Distance on timed words and applications*, the results of which can be readily used for WP2-5. He obtained in 2018 a CNRS PEPS JCJC grant for the project Verenah on verification and learning for hybrid systems. He is currently the Principal Investigator (for VERIMAG) of the Plan-Cancer INSERM project MoDyLAM in which the role of VERIMAG is to explore the application of STL to biological modelling.

**Promising preliminary results** obtained by the project members include: reachability analysis of nonlinear systems [TD3, TD39, TD38] abstract interpretation using complex-valued zonotopic domains [TD2, TD4] coverage guided hybrid systems testing (Thao), input signal generation for falsification of black-box CPS [BB1], uniform generation of traces of timed automata [BB4], distances measures [EA1], statistical model-checking

[BB3], temporal specification monitoring [EA3, KS5], Uncertainty propagation [MK10] monitoring and data mining of temporal behaviors using (extensions of) STL [Bakhirkin & Basset TACAS19].

## 6. Future Prospect of Research

This project will result in an integrated methodology for modeling, testing, verifying, controlling, and monitoring AI-CPS. We believe that our result will lead to a new research area of development of methodology for AI-CPS that includes the viewpoints of, for example, requirement mining and business operations. We also envisage that our technical core of gray-box systems testing and verification will lead to a new industry of dependable systems design. Currently, developing a dependable system does not earn direct revenue for industry because it incurs a cost to product development. With our gray-box systems testing and verification methods, users can test the products that they use without complete knowledge about their internal behavior; which enables product auditing with formal methods to be a good business area. Once such methods are employed by product users, formal methods will become a commodity for system developers. For this scenario to be realistic, we need to strategically leverage intellectual properties. We plan to build a patent portfolio in such a way that we can lead this social trend in the industry after this project ends. This technological trend will lead to Society 5.0 to be a reliable social infrastructure. Making a social infrastructure dependable is, we believe, a great contribution to society.

## 7. Specific for collaboration

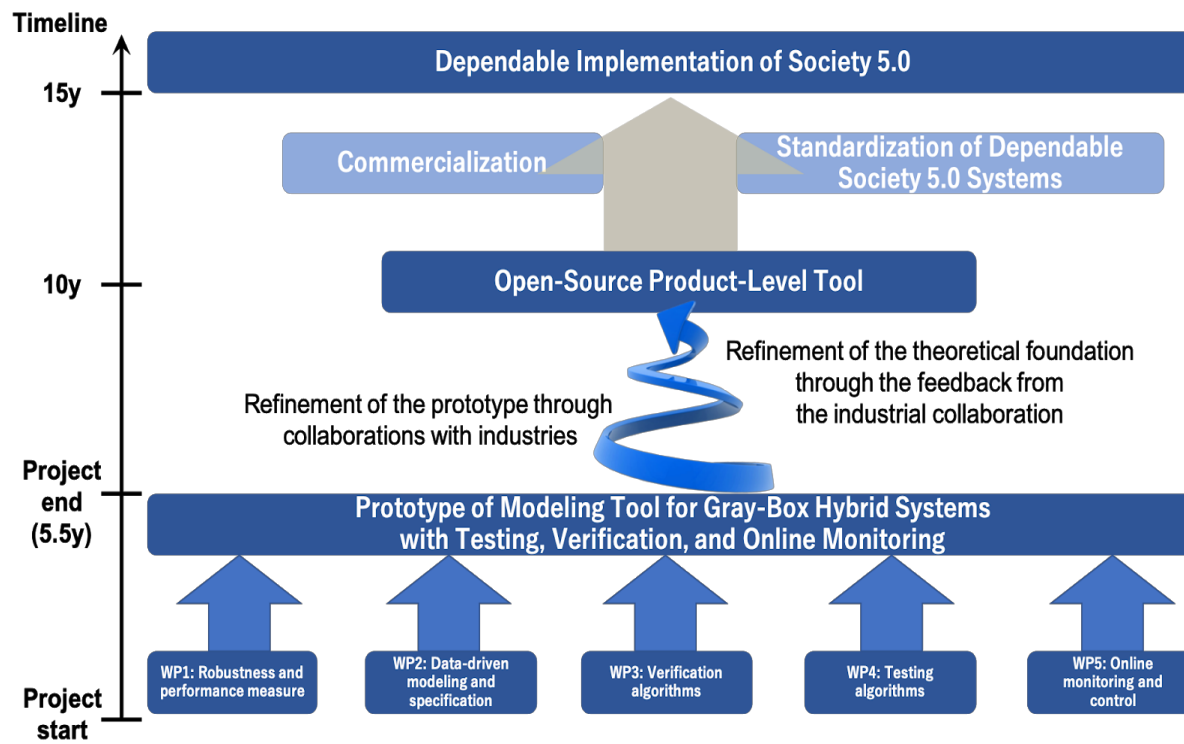
**Group participation and responsibility in the work packages.** All the work packages (WP) will be investigated by at least 4 groups on both the French and Japanese sides (see the following table). Each group is the leader or a co-leader of a work package. The groups of two Research Directors will participate in every work package, to coordinate the collaborations between the groups.

	Suenaga group	Kishida group	Dang group	Asarin group	Barbot group	Tanwani group
WP1 (Measures)	✓	✓	✓	Lead		✓
WP2 (Data-driven Modelling)	✓	✓	Lead		✓	
WP3 (Verification)	Lead	✓	✓	✓		
WP4 (Testing)	✓		✓		Lead	
WP5 (Online Monitoring and Control)	✓	co-Lead	✓	✓	✓	co-Lead

**Collaboration framework.** We plan to organize research meetings between two sides via teleconferences once every 2 or 3 weeks, and inter-group visits by the members (in particular PhD students and postdocs). Two in-person meetings will be organized in France and in Japan, in the middle and at the end of the project.

**Expected impact on the research cooperation between France and Japan.** The researchers on the French and Japanese sides have worked (separately) on common problems. This project will strengthen the French-Japanese cooperation by making joint contributions to advance a cutting-edge technology domain of mutual interest. This will also create opportunities to discover new common interests and possibilities of future long-term cooperation.

**Added value of the collaboration.** For a number of key problems in the project (such as monitoring, verification and testing) the members have developed different approaches (such as using program logic and synthesis, nonstandard analysis, set-based numerical and algebraic computations, information theory) which can now be combined to create new performant and scalable techniques. More importantly, the complementary backgrounds of the members (control theory, computer science, mathematics) is essential to the achievement of the project objectives. The postdocs and PhD students in the project will visit the groups of the other side. We believe that these visits, by which they can experience a different research culture at an early stage of their academic career, will be a great opportunity for them to learn how to create international collaborations, and more specifically to exploit and combine the strength of the French and Japanese research.



We plan to deliver a prototype of our methods at the end of this project. After this project, we plan to refine this prototype into a product-level design tool for systems design of Society 5.0 components. To this end, we seek collaboration with industrial partners. By applying our tool to their problems, we refine our tool and theoretical foundations. We expect that we can release an open-source product-level tool 10 years after the project start. We leverage the released tool to develop a dependable implementation of Society 5.0.

## Project Organization and Research Schedule

### 1. Project Organization

#### Japanese Side

Group Name	Name of Research Director/ Lead Joint Researcher	Affiliation and Title	Research Item
Suenaga Group	Kohei Suenaga	Kyoto University Associate Professor	New Concepts and Tools for Designing Dependable Society 5.0 <b>WP3</b> Verification
Kishida Group	Masako Kishida	National Institute of Informatics Associate Professor	<b>WP5</b> Online Monitoring and Control

#### French Side

Group Name	Name of Research Director/ Lead Joint Researcher	Affiliation and Title	Research Item
Dang Group	Thao Dang	CNRS, Laboratory VERIMAG, Grenoble Research Director	New Concepts and Tools for Designing Dependable Society 5.0 <b>WP2</b> Data-driven Modelling
Barbot Group	Benoît Barbot	Université Paris-Est Créteil Associate Professor	<b>WP4</b> Testing
Asarin Group	Eugene Asarin	IRIF - University of Paris and CNRS Professor	<b>WP1</b> Measures
Tanwani Group	Aneel Tanwani	Associate Researcher (CRCN), CNRS, Laboratory of Architecture and Analysis of Systems (LAAS), Toulouse.	<b>WP5</b> Online Monitoring and Control

## 2. Research Schedule

Research Subjects	2019 Fiscal year (6 months)	2020 Fiscal Year	2021 Fiscal Year	2022 Fiscal Year	2023 Fiscal Year	2024 Fiscal Year (12months)
<b>1. WP1 (Measures)</b>						
• Distance measures on behaviors (Asarin group, Dang group)						
• Measuring sets of behaviors (Asarin group, Dang group)						
• Extending the distance/entropy approach (Asarin group, Dang group, Kishida group, Tanwani group)						
• Developing methodology (Asarin group, Dang group, Kishida group, Tanwani group)						
<b>2. WP3 (Date-driven modelling)</b>						
• STL quantitative semantics studies (Dang group, Asarin group)						
• Learning predicates and parameter space exploration (Dang group, Barbot group)						
• parametric STL classification and clustering (Dang group, Asarin group)						
• extension of methods for data-driven dynamical models for control synthesis (Dang group, Kishida group)						
• methods for building mixed dynamical system and STL models (Dang group, Kishida group)						
<b>3. WP3 (Verification)</b>						
• Model checking algorithms for gray-box hybrid systems (Suenaga group, Kishida group, Dang Group)						
• Robust model checking (Suenaga group, Kishida group, Asarin group)						
• Verification of systems with learning-enabled components (Suenaga group, Kishida group, Dang group)						
<b>4. WP4 (Testing)</b>						
• development of a lightweight efficient prototype for sampling timed signals for existing measures (Barbot group, Dang group)						
• theoretical guarantees of the quasi-Monte Carlo approach (Barbot group, Dang group, Asarin group)						
• learning approaches using uniform sampling of signals (Barbot group, Dang group, Suenaga group)						

3. WP5 (Online Monitoring and Control)													
• Robust monitoring (Kishida group, Asarin group, Dang group)													
• Grey-box monitoring (Tanwani group, Suenaga group, Dang group)													
• Control of information systems (Kishida group, Tanwani group, Dang group, Asarin group)													



## Research Project Organization 1 (Japanese Side)

(Research Members at Research Director's Group)

*For Form4-1J, describe in less than two A4-size sheets (no exceptions). If this instruction is not followed, the research proposal might not be accepted.*

### Research Director's Group

Research Director	Research Institution	Title	2019FY effort (%)
Kohei Suenaga	Kyoto University	Associate Professor	30
Research Participants	Affiliation (Omit if the same as above)	Title	
Three postdoctoral researchers to be hired		Postdoctoral researcher	
Three PhD students to be hired		PhD student	

### ○ Research Items and Overview

#### ▪ Title of Research Project :

New Concepts and Tools for Designing Dependable Society 5.0

#### ▪ Research Subjects in Charge

As the research director, we will lead and participate in the entire project; we will lead WP3 (Verification).

#### ▪ Overview

We here describe the plans on WP3, which we lead in this project. We plan to assign one postdoc and one Ph.D. student to each topic.

- **Model checking algorithms for gray-box hybrid systems.** We adapt the existing hybrid-system model-checking techniques to gray-box systems. We first work on the model-checking algorithm based on *property-directed reachability* (PDR), which is known to work efficiently to software model checking. PDR [Bradley VMCAI'11] is a variant of software/hardware model checking algorithms that tries to prove the safety of the given system by an iterative refinements of approximations of reachable states. In the previous JST PRESTO project led by Suenaga, he extended PDR to hybrid systems, which is called *HybridPDR*. Suenaga has implemented a semi-automated verifier that conducts verification using the hints given by humans.

We plan to adapt HybridPDR to gray-box hybrid systems. We plan to combine HybridPDR with online model learning. HybridPDR executes the given model several times during verification to generate

counterexamples. From these execution traces, we can use these traces as data to learn the invisible part of the model. By assuming that the internal behavior of the model can be described by, for example, a Markov Decision Process (MDP), then we can estimate the likelihood of a concrete model. By iteratively refining the learned MDP in addition to the iteration conducted by HybridPDR, we can verify a gray-box system with certain estimated model.

We will first formalize this idea and prove its soundness relative to the feasibility of the assumption that the internal behavior can be described by an MDP. Then, we implement a prototype of this approach and confirm its effectiveness using some benchmarks.

- **Robust model-checking.** For this topic, we will first adapt existing robust model-checking techniques (e.g., [Clarke et al. ATVA'11, Fainekos et al. FORMATS'06]) to the gray-box setting. We will combine statistical model checking developed by Barbot group [BB7, BB3] and model learning mentioned above. We will formalize the algorithm and investigate its property and also implement it to validate its effectiveness. This will be carried out in interaction with WP4 (Testing).
- **Verification of systems with learning-enabled components.** As stated in the project description, our primary focus is the verification of neural networks (NN). Currently, although testing and verification techniques of NN for image-recognition tasks are well studied, verification of NNs for other tasks is less studied. In Society 5.0, NN are expected to process various types of data and to be applied also to the tasks other than image recognition. In collaboration with an industry partner (see Section “Research infrastructure and preparation” in Form 3), Suenaga has categorically surveyed testing and verification techniques for image-recognition NN and is trying to enhance them with formal verification. We plan to transfer these techniques to NN that are typically used in Society 5.0 such as sensor data processing and natural language processing.

#### • Role in the entire research project

We leverage our expertise in programming language theory and program verification to contribute to the entire project. We will be leading WP3 (Verification); our work in WP3 will result in a set of methods that ensure the correctness of systems in high degree of confidence using mathematics. Through the collaboration with the other members working on testing and monitoring, we make our methods practically more useful.

## Research Project Organization 2 (Japanese Side)

(Research Members at the Joint Research Group)

- *This form is prepared in less than two A4-size sheets (no exceptions) for each joint research group. If this instruction is not followed, the research proposal might not be accepted).*

### Joint Research Group (1)

Lead Joint Researcher	Joint Research Institution	Title	2019FY Effort (%)
Masako Kishida	National Institute of Informatics	Associate Professor	20
Research Participants	Affiliation (Omit if the same as above)	Title	
3 researchers to be hired	National Institute of Informatics	Post-doctoral researcher	
3 Ph.D. students to be hired	National Institute of Informatics	Ph.D. student	

### ○ Research Items and Overview

#### ▪ Title of Research Item of the Joint Research Group :

WP5 (Online Monitoring and Control)

#### ▪ Research Subjects in Charge

Kishida group will co-lead WP5 (Online Monitoring and Control). We will also work on control-related problems that appear in the following work projects; WP1 (Measures), WP2 (Data-driven modelling) and WP3 (Verification).

#### ▪ Overview

An ultimate goal of this research group is to develop control algorithms that guarantee the dependability of the system subject to uncertainties using the data-driven models along with the real-time data processing.

#### WP1 (Measures)

We will propose measures to assess the robustness and performance of hybrid control systems subject interval and/or probabilistic uncertainties arising from such as modeling error and disturbances. This measure will be utilized in WP2, in particular to the construct STL model from data being processed.

#### WP2 (Data-driven Modelling)

We will develop data-driven modelling algorithms such that the constructed model and data, subject to uncertainties, are within a given distance with respect to the measures developed in WP1. In particular, we aim at expressing the effects of control inputs to the dynamical system in addition to its autonomous behavior. We also investigate the problem of building mixed dynamical system and STL models. The resulting models will be time-varying and capture slowly time-varying dynamics of the system as well as drastic mode changes to detect failures of some components. Our work on WP1 and WP2 will be carried out concurrently.

WP3 (Verification)

Using the model developed in WP2, we develop robust model-checking algorithm. For this, we perform reachability analysis based on the knowledge of uncertainties and analyze the safety region of the control input that satisfies the safety constraint subject to uncertainties.

WP5 (Monitoring and Control)

Monitoring and control approach will be developed in interaction with WP1, WP2 and WP3, to make use of the new measures and modelling and verification methods. Using dynamically changing models, we develop control algorithms so as to enforce safety and performance constraints as well as possible control constraints subject to dynamically changing environment. This will be achieved by preparing several control strategies in advance and then switching between the strategies based on the monitoring results. Another problem is to optimize the monitor by minimizing the number of sensors and/or the frequency of the data collections.

**• Role in the entire research project and necessity**

Data-driven models intrinsically contain uncertainties. The lead joint researcher has control-theoretic background with a focus on uncertain dynamical systems. Many of her work has been focused on the uncertainty analysis problems [MK5-MK8] and its applications to reachability and control problems [MK1, MK4, MK9, MK10]. Her other work includes the problems of stability-guaranteeing control and optimizations [MK1-MK3]. Such knowledge and experiences will be utilized throughout the project, especially in WP5.

The main role of this group is to develop algorithms that detect faults and then compute suitable control actions to achieve desired behavior of dynamical systems based on online-learning in WP5.

This research group will collaboratively work with other groups that participate in WP1, WP2, and WP3, in each WP respectively, for the development of various tools, and lead all other groups jointly with Tanwani group to achieve the project's final goal in WP5.

## Research Project Organization 1 (French Side)

(Research Members at Research Director's Group)

### Research Director's Group

Research Director	Research Institution	Title	2019FY effort (%)
Thao Dang	CNRS (French National Center for Scientific Research), Laboratory VERIMAG	Research Director	60%
Research Participants	Affiliation (Omit if the same as above)	Title	
Nicolas Basset	Université Grenoble Alpes, Laboratory VERIMAG	Associate professor	
Olivier Lebeltel	CNRS (French National Center for Scientific Research), Laboratory VERIMAG	Research engineer	
Akshay Mambakam	Université Grenoble Alpes, Laboratory VERIMAG	PhD student	
1 PhD student to be recruited			

### ○ Research Items and Overview

#### ▪ Title of Research Project :

New Concepts and tools for Designing Dependable Society 5.0

#### ▪ Research Subjects in Charge

All the work packages, namely WP1 (Measures), WP2 (Data-driven modelling), WP3 (Verification), WP4 (Testing), WP5 (Online monitoring and control)

#### ▪ Overview

WP2 (Data-driven modelling) The group will lead this work package. We will first work on the STL semantics problems. The current quantitative semantics is not appropriate for a number of situations when predicates involve more than one signal. Considering all the involved signals allows more accurate evaluation of robustness of satisfaction, but requires computing the Hausdorff distance between unions of polyhedra. The problem of learning predicates from temporal data will be considered in parallel, together with the problem of efficiently exploring the parameter space. The existing work often uses predicates specifying simple bounds on signal values. We will investigate more complex predicates using segmented regression. Once the fundamental ingredients for capturing accurately temporal-spatial patterns by STL, we will develop learning algorithms for STL parametric identification, behaviors classification and clustering. This work will be carried out in the context of the PhD thesis of Akshay Mambakam who will join the group in September 2019.

On the other hand, the group will join force with Kishida group to study how to combine STL and dynamical system models. The first question to address is: what is the maximal level of detail STL specifications can provide and in case it is not sufficient to distinguish two behaviors leading to different outcomes, more accurate modelling formalisms, such as dynamical systems, should be used. Within this work package, Kishida group will extend data-driven dynamical systems modelling to the control setting. With her group, we will develop methods for building mixed dynamical system and STL models.

For WP1 (Measures), we will continue to collaborate with Asarin group to develop new measures for timed and hybrid behaviors, and to extend the methodology for control systems.

For WP3 (Verification), we will work two problems: gray-box model-checking and verification of CPS with AI components. For the first problem, we will investigate how to use the sampling-based testing approach to handle the black-box subsystems and compose the result with traditional model-checking of white-box subsystems. We will collaborate with Suegana group on this topic. A sampling-based technique specialized for gray-box model-checking will be developed. This work will be carried out in interaction with the WP3 (Testing). For verification of AI-CPS, we will first focus on verification of neural networks (NN), in particular their generalization to new data. We will investigate the set-based computation approach to assess correctness and performance of their generalization. Efficient set representations, key to the success of this approach, will be investigated, starting with complex-valued zonotopes [TD2, TD5, TD9] which can efficiently capture contraction, stability and robustness properties. Another problem is verification of CPS with NN in closed loop, where NN are used to implement some complex control function (to avoid performing online optimization). Assume-guarantee rules similar to input-output stability conditions [AT2] from control theory will be derived.

For WP4 (Testing), based on our preliminary results on generating signals satisfying temporal constraints for CPS testing [BB1], we and Barbot group will study quantitative guarantees that a set of behaviors provide about the system correctness. To this end, we will first study Kolmogorov-Smirnov (KS) statistic which can be used as figure of merit of a sample of behaviors, with respect to assessing the set of all possible behaviors. Effective use of KS statistic requires handling sets of points in high dimensions.

Testing can be readily applied to AI-CPS, since in most practical cases, NN are too large and complex to come up with effective sampling strategy for the overall system. To address this issue, using a compositional approach, we derive an abstraction of the input/output relation. Using a set of input behaviors with the same output (obtained from data) we can cluster them into (small) subsets, for which set-based verification can be performed to check if all the input signals in each subset indeed produce the same output. An input/output robustness measure will allow approximating exhaustive verification by a finite  $\varepsilon$ -net of input signals, developed in WP1.

For WP4 (Online Monitoring and Control), the group will first work on an online STL monitoring algorithm and study a conceptual monitoring framework suitable for different robustness measures.

### • Role in the entire research project

The group will participate in and coordinate all the work packages. This task is facilitated by the established collaborations between the group and other members of the project. More importantly, the competences in hybrid systems, timed systems and information theory of the group and their preliminary results, in particular, [TD27, TD2, BB1, EA1] will allow the group to contribute to many problems of the project.

## Research Project Organization 2 (French Side)

(Research Members at the Joint Research Group)

### Joint Research Group (1)

Lead Joint Researcher	Joint Research Institution	Title	2019FY Effort (%)
Eugene Asarin	IRIF – Université de Paris and CNRS	Professor	40%
Research Participants	Affiliation (Omit if the same as above)	Title	
Aldric Degorre		Associate professor	
Peter Habermehl		Associate professor	
Amaury Pouly		CRCN	
Mahsa Shirmohammadi		CRCN	
1 PhD student to be recruited		PhD student	

#### ○ Research Items and Overview

##### ▪ Title of Research Item of the Joint Research Group :

WP1 (Measures)

##### ▪ Research Subjects in Charge

Asarin group will work on problems that appear in the following work packages:

- WP1 (Measures)
- WP3 (Verification)
- WP5 (Monitoring and Control)

##### ▪ Overview

We will lead the WP on performance and correctness measures relevant for CPS and ML-enabled systems, to be used in the rest of the project. As the first step we will find distances between behaviors corresponding to various multi-component systems and observation scenarios. At the foundational level, we will explore geometrical properties of the distances (in particular ensure their compactness, which is a necessary condition for computational tractability, and provide efficient-nets to be used in WP4 for testing). We will formalize and explore distance-based quantitative model-checking and monitoring, providing relevant quantitative criteria of robust correctness. Based on distances we will introduce quantitative measures for sets of behaviors of CPS (variants of entropy), taking into account control and disturbance. An important challenge here is to find fast

algorithms to approximate entropy. Finally, we will compare various criteria in quantitative verification (Maler&Donze's inductive robustness, our distance-based robustness, probabilistic and cost-based approaches, our entropy approach), and come up with methodological recommendations for the choice of relevant performance and correctness measures.

In WP3 and WP5 we will adapt our metrics found in WP1 to concrete needs of robust verification, monitoring and control by developing and implementing algorithms and tools in collaboration with Suenaga, Kishida and Dang Groups. We will also explore novel approaches to invariant search and reachability analysis for verification and control of continuous and hybrid systems.

▪ **Role in the entire research project and necessity**

Asarin's group will share its strong expertise in fundamental informatics with other participants. The group's approaches to quantitative assessment of correctness, robustness and performance will be instrumental for all the other project and provide verification criteria and methodology for WP3, mathematical tools for testing and statistical model-checking for WP4 and behavior quality criteria for WP5.



**Joint Research Group (2)**

Lead Joint Researcher	Joint Research Institution	Title	2019FY Effort (%)
Benoît Barbot	LACL, Université Paris-Est, Créteil	Associate professor	40%
Research Participants	Affiliation (Omit if the same as above)	Title	
1 researcher (to be recruited)		Postdoctoral researcher	

○ **Research Items and Overview**▪ **Title of Research Item of the Joint Research Group :**

WP4 (Testing)

▪ **Research Subjects in Charge**

WP2 (Data-driven modelling), WP4 (Testing), WP5 (Online Monitoring and Control)

▪ **Overview**

The group leads WP3 (Testing). Quantitative properties of black-box AI-CPS can be expressed by averaging some function defined on the set of input signals (for instance, to express the probability that a signal leads to incorrect behaviors) or robustness of property satisfaction. We will focus on sampling-based methods and algorithms, in the spirit of the Monte Carlo and quasi-Monte Carlo approaches. Maximizing the chance of finding faulty behaviors can be achieved by sampling uniformly [BB4] over a measure of the input signal space (two sets of same-measure are sampled with the same probability).

- The first task will be the development of a lightweight efficient prototype for sampling time signal for different kind of measure. Following progress in WP1 new measure will be added to the prototype.
- The second task will be to improve theoretical guarantee of the quasi-Monte Carlo approach using knowledge on the shape of signal space i.e. for timed word we assume the shape as a polytope.
- The third task will be to investigate and to implement learning approaches using uniform sampling of signals.

The first task will start at the beginning of the project and yield a first version of the prototype which will be improved with the progress of other tasks and work packages. The second and third task are independent and will start once a working preliminary prototype is finished.

▪ **Role in the entire research project and necessity**

2019 (CREST)

We will continue the collaboration with Dang group on the generation of temporal signals. The third task will be carried out in collaboration with Suenaga group on model learning to deal with gray-box model-checking in WP3 (Verification), and to various learning algorithms in WP2 (Data-driven modelling) and WP5 (Online Monitoring and Control). The group have strong competences in statistical model-checking and applications to industrial models such as Simulink [BB3, BB6, BB7].

**Joint Research Group (3)**

<b>Lead Joint Researcher</b>	<b>Joint Research Institution</b>	<b>Title</b>	<b>2019FY Effort (%)</b>
Aneel Tanwani	LAAS -- CNRS, Toulouse	CRCN	30
<b>Research Participants</b>	<b>Affiliation</b> (Omit if the same as above)	<b>Title</b>	
1 researcher (to be recruited)		Postdoctoral researcher	

○ **Research Items and Overview**▪ **Title of Research Item of the Joint Research Group :**

WP3 (Online monitoring and control)

▪ **Research Subjects in Charge**

WP1(Measures) and WP5 (Online monitoring and control)

▪ **Overview**

One of the central objects of this research project is to use formal methods for designing control policies which ensure dependable functioning of the information systems that across in Society 5.0. For WP5, which we co-lead with Kishida group, we want to design such controllers under various information constraints associated with the observed behaviors. Using the framework of finite-state transition machines, the problem is to design the control inputs which yield correctness with respect to a temporal logic specification in an online setting. The challenge lies in integrating new results in formal methods for online monitoring, to achieve desired control performance. Our group will also collaborate with the other groups participating in WP1 to develop new measures to hybrid control systems.

▪ **Role in the entire research project and necessity**

The lead researcher at LAAS, partnering in this project, comes from a control-theoretic background. His recent publications deal with stability analysis and control under sampled-data measurements [AT1, AT2, AT3, AT8], designing control to maintain state-trajectories within prescribed sets [AT9], and using tools from the theory of automata to answer decidability of structural properties like observability of dynamical systems [AT5]. The research team at LAAS will work in close collaboration with the other partners to develop an understanding of the tools developed in WP1 and WP3, and will contribute essentially to the development of control design algorithms in WP5, for which a proper control-theoretic background is really essential.



## Research Budget (Japanese side)

### 1. Research Budget Plan in Item (Entire Team on Japanese side)

	<b>1<sup>st</sup> Year</b> 2019.10 ~ 2020.3	<b>2<sup>nd</sup> Year</b> 2020.4 ~ 2021.3	<b>3<sup>rd</sup> Year</b> 2021.4 ~ 2022.3	<b>4<sup>th</sup> Year</b> 2022.4 ~ 2023.3	<b>5<sup>th</sup> Year</b> 2023.4 ~ 2024.3	<b>Final Year</b> 2024.4~ 2025.3	<b>Total</b> (Thousand yen)
<b>Equipment</b>	7,000	0	0	7,000	0	0	14,000
<b>Materials/ Consumables</b>	2,100	2,100	2,100	2,100	2,100	2,100	12,600
<b>Travel</b>	12,600	25,200	25,200	25,200	25,200	25,200	138,600
<b>Personnel and Services (Number of Researchers)</b>	30,000 (6)	60,000 (6)	60,000 (6)	60,000 (6)	60,000 (6)	60,000 (6)	330,000
<b>Other</b>	800	800	800	800	800	800	4,800
<b>Total</b> (Thousand yen)	52,500	88,100	88,100	95,100	88,100	88,100	500,000

### Note

## 2. Research Budget plan by group on Japanese side

	<b>1<sup>st</sup> Year</b> 2019.10 ~ 2020.3	<b>2<sup>nd</sup> Year</b> 2020.4 ~ 2021.3	<b>3<sup>rd</sup> Year</b> 2021.4 ~ 2022.3	<b>4<sup>th</sup> Year</b> 2022.4 ~ 2023.3	<b>5<sup>th</sup> Year</b> 2023.4 ~ 2024.3	<b>Final Year</b> 2024.4 ~ 2025.3	<b>Total</b> (Thousand yen)
<b>Research Director's Group Suenaga</b> (Kyoto University)	<b>26,300</b>	<b>44,100</b>	<b>44,100</b>	<b>47,600</b>	<b>44,100</b>	<b>44,100</b>	<b>250,300</b>
<b>Joint Research Group1 Kishida</b> (National Institute of Informatics)	<b>26,200</b>	<b>44,00</b>	<b>44,000</b>	<b>47,500</b>	<b>44,000</b>	<b>44,000</b>	<b>249,700</b>
<b>Total</b> (Thousand yen)	<b>52,500</b>	<b>88,100</b>	<b>88,100</b>	<b>95,100</b>	<b>88,100</b>	<b>88,100</b>	<b>500,000</b>

List of major equipment costing 10 million yen or more (item, estimated cost)

Not applicable

## Research Budget (French side)

## 1. Research Budget Plan in Item (Entire Team on French side)

	1 <sup>st</sup> Year ( - )	2 <sup>nd</sup> Year ( - )	3 <sup>rd</sup> Year ( - )	4 <sup>th</sup> Year ( - )	5 <sup>th</sup> Year ( - )	Final Year ( - )	Requested funding (Thousand Euro)	Full Cost (Thousa nd Euro)
<b>Personnel costs</b>	257	288	323	260	186		294	1314
<b>Materials/ Consumables</b>	2.5	4	4	2.5	2.5		15.5	15.5
<b>Building and land costs</b>								0
<b>Provision of services</b>	1.5	1.5	1.5	1.5	2.5		8.5	8.5
<b>General costs</b>	20.72	24.36	30.28	26.28	39.36		141	141
<b>Total</b> (Thousand Euro)	281.72	317.86	358.78	290.28	230.36		459	1479

## 2. Research Budget Plan in Item (Dang Group (Research Director's Group))

	1 <sup>st</sup> Year ( - )	2 <sup>nd</sup> Year ( - )	3 <sup>rd</sup> Year ( - )	4 <sup>th</sup> Year ( - )	5 <sup>th</sup> Year ( - )	Final Year ( - )	Requested funding (Thousand Euro)	Full Cost (Thousa nd Euro)
<b>Personnel costs</b>	111	144	144	114	73		99	586
<b>Materials/ Consumables</b>	1.5	1.5	0.5	0.5	0.5		4.5	4,5
<b>Building and land costs</b>								
<b>Provision of services</b>	0.5	0.5	0.5	0.5	0.5		2.5	2.5
<b>General costs</b>	7.72	10.36	10.28	10.28	17,36		56	56
<b>Total</b> (Thousand Euro)	120.72	156.36	155.28	125.28	91.36		162	649

**Note** The Research Director's group will organize a workshop about the results of the projects and related topics. We plan to spend 10 k euros to invite two speakers and to cover organization fees. Thhis cost is reflected in the general costs.

**3. Research Budget Plan in Item (Asarin Group (Joint Research Group 1))**

	<b>1<sup>st</sup> Year</b>	<b>2<sup>nd</sup> Year</b>	<b>3<sup>rd</sup> Year</b>	<b>4<sup>th</sup> Year</b>	<b>5<sup>th</sup> Year</b>	<b>Final Year</b>	<b>Requested funding (Thousand Euro)</b>	<b>Full Cost (Thousand Euro)</b>
<b>Personnel costs</b>	61	94	94	94	61		99	404
<b>Materials/ Consumables</b>		1,5	2,5				4	4
<b>Building and land costs</b>								
<b>Provision of services</b>								
<b>General costs</b>	5	6	10	8	10		39	39
<b>Total (Thousand Euro)</b>	55,4	56,9	99,5	96	57,4		142	447

**4. Research Budget Plan in Item (Barbot Group (Joint Research Group 2))**

	<b>1<sup>st</sup> Year ( - )</b>	<b>2<sup>nd</sup> Year ( - )</b>	<b>3<sup>rd</sup> Year ( - )</b>	<b>4<sup>th</sup> Year ( - )</b>	<b>5<sup>th</sup> Year ( - )</b>	<b>Final Year ( - )</b>	<b>Requested funding (Thousand Euro)</b>	<b>Full Cost (Thousand Euro)</b>
<b>Personnel costs</b>	73	25	12	26	26		48	201
<b>Materials/ Consumables</b>	1	0,5	0	1	1		3.5	3.5
<b>Building and land costs</b>								
<b>Provision of services</b>	0,5	0,5	0,5	0,5	1		3	3
<b>General costs (Travel)</b>	5	4	5	4	5		23	23
<b>Total (Thousand Euro)</b>	79	30	17.5	31	43		77.5	230.5



### 5. Research Budget Plan in Item (Tanwani Group (Joint Research Group 3))

	<b>1<sup>st</sup> Year</b> ( - )	<b>2<sup>nd</sup> Year</b> ( - )	<b>3<sup>rd</sup> Year</b> ( - )	<b>4<sup>th</sup> Year</b> ( - )	<b>5<sup>th</sup> Year</b> ( - )	<b>Final Year</b> ( - )	<b>Requested funding</b> (Thousand Euro)	<b>Full Cost</b> (Thousand Euro)
<b>Personnel costs</b>	12	25	73	26	26		48	201
<b>Materials/ Consumables</b>		0.5	1	1	1		3.5	3.5
<b>Building and land costs</b>								
<b>Provision of services</b>	0.5	0.5	0.5	0.5	1		3	3
<b>General costs (Travel)</b>	3	4	5	4	7		23	23
<b>Total</b> (Thousand Euro)	15.5	30	79	31	45		78.5	230.5

## List of Achievements/Ex-Post Evaluation Results (Japanese side)

### (Research Director: Kohei Suenaga)

[author notation in English papers by the research director: Kohei Suenaga or K. Suenaga]

#### 1. Principal papers, books, and other publications related to this research proposal

–within 20 achievements

1. [KS1] Kensuke Kojima, Minoru Kinoshita, Kohei Suenaga: Generalized homogeneous polynomials for efficient template-based nonlinear invariant synthesis. Theor. Comput. Sci. 747: 33-47 (2018)
2. [KS2] Taro Sekiyama, Kohei Suenaga: Automated Proof Synthesis for the Minimal Propositional Logic with Deep Neural Networks. APLAS 2018: 309-328
3. [KS3] Akifumi Imanishi, Kohei Suenaga, Atsushi Igarashi: A guess-and-assume approach to loop fusion for program verification. PEPM 2018: 2-14
4. [KS4] Takamasa Okudono, Yuki Nishida, Kensuke Kojima, Kohei Suenaga, Kengo Kido, Ichiro Hasuo: Sharper and Simpler Nonlinear Interpolants for Program Verification. APLAS 2017: 491-513
5. [KS5] Masaki Waga, Ichiro Hasuo, Kohei Suenaga: Efficient Online Timed Pattern Matching by Automata-Based Skipping. FORMATS 2017: 224-243
6. [KS6] Hirofumi Nakamura, Kensuke Kojima, Kohei Suenaga and Atsushi Igarashi: A Nonstandard Functional Programming Language. APLAS 2017: 514-533.
7. [KS7] Kensuke Kojima, Minoru Kinoshita, Kohei Suenaga: Generalized Homogeneous Polynomials for Efficient Template-Based Nonlinear Invariant Synthesis. SAS 2016: 278-299.
8. [KS8] Tatsuya Sonobe, Kohei Suenaga, Atsushi Igarashi: Automatic Memory Management Based on Program Transformation Using Ownership. APLAS 2014: 58-77
9. [KS9] Takumi Akazaki, Ichiro Hasuo, Kohei Suenaga: Input Synthesis for Sampled Data Systems by Program Logic. Proc. of the 4th Workshop on Hybrid Autonomous Systems (HAS 2014) 22-39.
10. [KS10] Kohei Suenaga, Hiroyoshi Sekine, Ichiro Hasuo: Hyperstream processing systems: nonstandard modeling of continuous-time signals. POPL 2013: 417-430
11. [KS11] Ichiro Hasuo, Kohei Suenaga: Exercises in Nonstandard Static Analysis of Hybrid Systems. CAV 2012: 462-478
12. [KS12] Kohei Suenaga, Ryota Fukuda, Atsushi Igarashi: Type-based safe resource deallocation for shared-memory concurrency. OOPSLA 2012: 1-20
13. [KS13] Kohei Suenaga, Ichiro Hasuo: Programming with Infinitesimals: A While-Language for Hybrid System Modeling. ICALP (2) 2011: 392-403
14. [KS14] Kohei Suenaga: Type-Based Deadlock-Freedom Verification for Non-Block-Structured Lock Primitives and Mutable References. APLAS 2008: 155-170.
15. [KS15] Eri Iimura, Naoki Kobayashi, Kohei Suenaga: Identifying Deadlock Errors by Type Error Slicing. Transaction of PRO 1(2) 71-84. 2008.
16. [KS16] Kohei Suenaga, Naoki Kobayashi: Type-Based Analysis of Deadlock for a Concurrent Calculus with Interrupts. ESOP 2007: 490-504.

17. [KS17] Naoki Kobayashi, Kohei Suenaga, Lucian Wischik: Resource Usage Analysis for the  $\pi$ -Calculus. Logical Methods in Computer Science 2(3). 2006.
18. [KS18] Naoki Kobayashi, Kohei Suenaga, Lucian Wischik: Resource Usage Analysis for the  $\pi$ -Calculus. VMCAI 2006: 298-312.
19. [KS19] Kohei Suenaga, Naoki Kobayashi, Akinori Yonezawa: Extension of Type-Based Approach to Generation of Stream-Processing Programs by Automatic Insertion of Buffering Primitives. LOPSTR 2005: 98-114.
20. [KS20] Koichi Kodama, Kohei Suenaga, Naoki Kobayashi: Translation of Tree-Processing Programs into Stream-Processing Programs Based on Ordered Linear Type. APLAS 2004: 41-56.

## 2. Research papers/publications other than the above –within 20 achievements

21. [KS21] Ryosuke Sato, Kohei Suenaga, Naoki Kobayashi: Ordered Types for Stream Processing of Tree-Structured Data. JIP 19 74-87. 2011. **Outstanding Paper Award.**
22. [KS22] Kohei Suenaga, Naoki Kobayashi: Fractional ownerships for safe memory deallocation. APLAS 2009: 128-143.
23. [KS23] Koichi Kodama, Kohei Suenaga, Naoki Kobayashi: Translation of tree-processing programs into stream-processing programs based on ordered linear type. Journal of Functional Programming 18(3) 333-371. 2008.
24. [KS24] Kohei Suenaga, Yutaka Oiwa, Eijiro Sumii, Akinori Yonezawa: The Interface Definition Language for Fail-Safe C. ISSS 2003: 192-208.

## 3. Retrospective evaluation of research themes that the research applicant represented in other systems of competitive research funds

Not applicable.

## List of Achievements/Ex-Post Evaluation Results (French Side)

**Research Director: Thao Dang**

**[author notation in English papers by the research director: T. Dang or Thao Dang]**

### 1. Principal papers, books, and other publications related to this research proposal

**–within 20 achievements**

1. [TD1] M. Al Khatib, A. Girard, and T. Dang. Timing Contracts for Multi-core Embedded Control Systems. Chapter in Control subject to Computational and Communication Constraints: current challenges, LNCIS 475, Springer, 2018.
2. [TD2] A. S. Adimoolam and T. Dang. Augmented Complex Zonotopes for Computing Invariants of Affine Hybrid Systems. Chapter in Control subject to Computational and Communication Constraints: current challenges, LNCIS 475, Springer, 2018.
3. [TD3] T. Dreossi, T. Dang, and C. Piazza. Reachability computation for polynomial dynamical systems. *Formal Methods in System Design*, 50(1): 1-38, 2017.
4. [TD4] A. Rocca, V. Magron, and T. Dang. Certified Roundoff Error Bounds using Bernstein Expansions and Sparse Krivine-Stengle Representations. ARITH24 (24th IEEE Symp on Computer Arithmetic), 2017. **Best Paper Award**
5. [TD5] A. S. Adimoolam, T. Dang, A. Donzé, J. Kapinski, X. Jin: Classification and Coverage-Based Falsification for Embedded Control Systems. CAV 2017, pages 483-503, Springer, 2017.
6. [TD6] M. Al Khatib, A. Girard, and Thao Dang. Stability verification and timing contract synthesis for linear impulsive systems using reachability analysis. *Nonlinear Analysis: Hybrid Systems*, 50(1): 211-226, Elsevier, 2017.
7. [TD7] M. Al Khatib, A. Girard, and Thao Dang. Self-triggered control for sampled-data systems using reachability analysis. IFAC World Congress, Toulouse, France, 2017.
8. [TD8] M. Al Khatib, A. Girard, and T. Dang. Scheduling of Embedded Controllers Under Timing Contracts. HSCC 2017, ACM, pages 131-140, 2017.
9. [TD9] A. S. Adimoolam and T. Dang. Template complex zonotopes for stability and invariant verification. ACC 2017, Seattle, USA, 2017.
10. [TD10] T. Dang and T. Dreossi. Temporal Specification Testing of Hybrid Systems CASE 2017 13th Conference on Automation Science and Engineering, IEEE, 2017.
11. [TD11] A. S. Adimoolam and T. Dang. Augmented Complex Zonotopes for Computing Invariants of Affine Hybrid Systems. FORMATS 2017, LNCS, pages 97-115, Springer, 2017.
12. [TD12] T. Dreossi, T. Dang, and Carla Piazza Parallelotope Bundles for Polynomial Reachability. HSCC 2016, pages 297-306, ACM, 2016.
13. [TD13] T. Dang, A. Donzé, J. Kapinski, J. Deshmukh, and X. Jin. Efficient Guiding Strategies for Testing of Temporal Properties of Hybrid Systems. NASA Formal Methods NFM 2015, Pasadena, CA, April 2015.

14. [TD14] T. Dang, T. Dreossi, C. Piazza. Parameter Synthesis Through Temporal Logic Specifications. 20th International Symposium on Formal Methods FM 2015, LNCS 9109, pp 213-230, 2015.
15. [TD15] T. Dang and N. Shalev. Test Coverage Estimation Using Threshold Accepting. Proceedings of 12th International Symposium Automated Technology for Verification and Analysis ATVA 2014, LNCS 8837, pages 115-128, Sydney, November 3-7, 2014.
16. [TD16] T. Dreossi and T. Dang. Parameter Synthesis for Polynomial Biological Models. 17th Int Conference Hybrid Systems: Computation and Control HSCC 2014, ACM, April 2014.
17. [TD17] T. Dang and I. Mitchell. Proceedings of the 15th ACM International Conference Hybrid Systems: Computation and Control HSCC 2012. Beijing, China, April 17-19, 2012. ACM, 2012.
18. [TD18] R. Testylier and T. Dang. NLTOOLBOX: A Library for Reachability Computation of Nonlinear Dynamical Systems. 11th International Symposium Automated Technology for Verification and Analysis ATVA 2013, LNCS, pages 469-473, 2013.
19. [TD19] T. Dang and R. Testylier. Reachability analysis for polynomial dynamical systems using the Bernstein expansion. *Reliable Computing Journal*, Special issue: Bernstein Polynomials in Reliable Computing, ISSN 1573-1340, Dec 2012.
20. [TD20] T. Dang and T. M. Gawlitza. Discretizing Affine Hybrid Automata with Uncertainty. 9th International Symposium Automated Technology for Verification and Analysis ATVA 2011, LNCS 6996, pages 473-481, Springer, 2011.

## 2. Research papers/publications other than the above -within 20 achievements

21. [TD21] T. Dang, T. Dreossi, E. Fanchon, O. Maler, C. Piazza and A. Rocca. Set-Based Analysis for Biological Modelling. *Automated Reasoning for Systems Biology and Medicine ARSBM*, Computational Biology Series, Springer, 2019.
22. [TD22] T. Dang, A. ElDin Mady, B. Menouer, R. Kumar, and M. Moulin. Validation of Industrial CyberPhysical Systems: an application to HVAC systems. International conference Complex Systems Design and Management (CSDM), Springer, 2016..
23. [TD23] T. Dreossi and T. Dang. Parameter Synthesis for Polynomial Biological Models. 17th Int Conference Hybrid Systems: Computation and Control HSCC 2014, ACM, April 2014.
24. [TD24] T. Dang, B. Jeannet, and R. Testylier. Verification of embedded control programs. Proc. European Control Conference ECC 2013, Zurich, July 2013.
25. [TD25] T. Dang, C. Le Guernic, and O. Maler. Computing reachable states for nonlinear biological models. *Theoretical Computer Science*, 2011.
26. [TD26] G. Frehse, C. Le Guernic, A. Donzé, S. Cotton, R. Ray, O. Lebeltel, R. Ripado, A. Girard, T. Dang, and O. Maler: SpaceEx: Scalable Verification of Hybrid Systems. CAV 2011, LNCS 6806, pages 379–395, Springer, 2011.
27. [TD27] T. Dang. Model-based Testing of Hybrid Systems. Chapter in Model-Based Testing for Embedded Systems, CRC Press, 2011.
28. [TD28] T. Dang and R. Testylier. Hybridization Domain Construction using Curvature Estimation. Hybrid Systems: Computation and Control HSCC'2011, pages 123-132, ACM, 2011.
29. [TD29] S. Tripakis and T. Dang. Modeling, Verification and Testing using Times and Hybrid Automata. Chapter in Model-based Design of Heterogeneous Systems, CRC Press, 2009.

30. [TD30] T. Dang and T. Nahhal. Coverage-guided test generation for continuous and hybrid systems. *Formal Methods in System Design*, 34(2):183–213, 2009.
31. [TD31] T. Dang and D. Salinas. Image computation for polynomial dynamical systems using the Bernstein expansion. In Ahmed Bouajjani and Oded Maler, editors, *Computer Aided Verification CAV 2009*, LNCS 5643, pages 219–232. Springer, 2009.
32. [TD32] T. Dang and T. Nahhal. Using disparity to enhance test generation for hybrid systems. In *TESTCOM/FATES 2008*, LNCS, pages 54– 69, Springer, 2008. **Best Paper Award**
33. [TD33] T. Dang, A. Donzé, O. Maler, and N. Shalev. Sensitive state-space exploration. In *Conference on Decision and Control CDC 2009*, Cancun, Mexico, pages 4049–4054, 2008.
34. [TD34] S. Sankaranarayanan, T. Dang, and F. Ivancic. Symbolic model checking of hybrid systems using template polyhedra. In *Tools and Algorithms for the Construction and Analysis of Systems TACAS 2008*, LNCS. Springer-Verlag, 2008.
35. [TD35] E. Asarin, T. Dang, and A. Girard. Hybridization methods for the analysis of nonlinear systems. *Acta Informatica*, 43(7):451–476, 2007.
36. [TD36] R. Alur, T. Dang, and F. Ivancic. Counter-example guided predicate abstraction of hybrid systems. *Theoretical Computer Science*, 354(2):250–271, 2006.
37. [TD37] R. Alur, T. Dang, and F. Ivancic. Reachability analysis of hybrid systems via predicate abstraction. *ACM Transactions on Embedded Computing Systems (TECS)*, 5(1):152–199, 2006.
38. [TD38] E. Asarin, O. Bournez, T. Dang, O. Maler, and A. Pnueli. Effective synthesis of switching controllers for linear systems. *Proceedings of the IEEE*, 88:1011–1025, 2000.
39. [TD39] E. Asarin, O. Bournez, T. Dang, and O. Maler. Approximate reachability analysis of piecewise-linear dynamical systems. In B. Krogh and N. Lynch, editors, *Hybrid Systems: Computation and Control HSCC 2000*, LNCS 1790, pages 20–31. Springer-Verlag, 2000.
40. [TD40] T. Dang and O. Maler. Reachability analysis via face lifting. In *Hybrid Systems: Computation and Control HSCC 1998*, LNCS 1386, pp 96–109. Springer-Verlag, 1998. **HSCC 2019 Test-Of-Time Award**

### 3. Retrospective evaluation of research themes that the research applicant represented in other systems of competitive research funds

Not applicable

## List of Achievements (Lead Joint Researcher(s)) (Japanese side)

### ○ Joint Research Group 1

**Lead Joint Researcher: Masako Kishida (National Institute of Informatics)**

**[author notation in English papers: M. Kishida or Masako Kishida]**

### **List of Achievements (Lead Joint Researcher 1) \*within 10 achievements**

1. [MK1] **M. Kishida**, "Event-triggered control with self-triggered sampling for discrete-time uncertain systems," *IEEE Transactions on Automatic Control*, vol.64, pp.1273-1279, 2019
2. [MK2] **M. Kishida**, "Encrypted control system with quantizer," *IET Control Theory & Applications*, vol.13, pp.146-151, 2019
3. [MK3] M. Ogura, **M. Kishida**, K. Hayashi, J. Lam, "Resource allocation for robust stabilization of Foschini-Miljanic algorithm," *Proc. of American Control Conference*, Philadelphia, PA 2019 (to appear)
4. [MK4] **M. Kishida**, M. Barforooshan, and M. Nagahara, "Maximum hands-off control for discrete-time linear systems subject to polytopic uncertainties," *Proc. of IFAC Workshop on Distributed Estimation and Control in Networked Systems*, Groningen, Netherlands, IFAC-PapersOnLine, vol. 51, no. 23, pp. 355-360, 2018
5. [MK5] **M. Kishida**, "On problems involving eigenvalues for uncertain matrices by structured singular values," *IEEE Transactions on Automatic Control*, vol.62, pp.6657-6663, 2017
6. [MK6] **M. Kishida**, "Approaches to determining a box consistent parameter set for polytopic output constraints on linear fractional models using structured singular values," *IEEE Transactions on Automatic Control*, vol. 62, pp. 1417-1423, 2017
7. [MK7] **M. Kishida**, "On computations of variance, covariance and correlation for interval data," *Mechanical Systems and Signal Processing*, vol. 84, pp. 462-468, 2017
8. [MK8] **M. Kishida** and R. D. Braatz, "On the analysis of the eigenvalues of uncertain matrices by  $\mu$  and  $v$ : Applications to bifurcation avoidance and convergence rates," *IEEE Transactions on Automatic Control*, vol.61, pp.748-753, 2016
9. [MK9] **M. Kishida** and R. D. Braatz, "Quality-by-design by skewed spherical structured singular value," *IET Control Theory & Applications*, vol.9, pp. 2202 -2210, 2015
10. [MK10] **M. Kishida**, P. Rumschinski, R. Findeisen and R. D. Braatz, "Efficient polynomial-time outer bounds on state trajectories for uncertain polynomial systems using skewed structured singular values," *IEEE Transactions on Automatic Control*, vol.59, pp.3063-3068, 2014

## List of Achievements (Lead Joint Researcher(s)) (French side)

### ○ Joint Research Group 1

**Lead Joint Researcher: Eugene Asarin (IRIF, Université of Paris and CNRS)**

**[author notation in English papers: E. Asarin or Eugene Asarin]**

1. [EA1] E. Asarin, N. Basset, A. Degorre: **Distance on timed words and applications**, FORMATS 2018, LNCS 11022, p. 199-214, 2018. **Best Paper Award**
2. [EA2] E. Asarin, J. Cervelle, A. Degorre, C. Dima, F. Horn, V. Kozyakin, **Entropy Games and Matrix Multiplication Games**. STACS 2016, LIPICS vol. 47, 2016.
3. [EA3] D. Ulus, Th. Ferrère, E. Asarin, O. Maler: **Timed Pattern Matching**. FORMATS 2014: 222-236, 2014.
4. [EA4] E. Asarin, N. Basset, A. Degorre, **Entropy of timed regular languages**, *Information and Computation*, **241**, 142-176, 2015.
5. [EA5] E. Asarin, **Measuring Information in Timed Languages**, Invited lecture, *LATA 2012*.
6. [EA6] E. Asarin, V. Mysore, A. Pnueli, G. Schneider, **Low dimensional hybrid systems - decidable, undecidable, don't know**, *Information and Computation*, **211**, pp 138-159, 2012.
7. [EA7] E. Asarin, G. Pace, G. Schneider, S. Yovine, **Algorithmic Analysis of Polygonal Hybrid Systems, Parts I and II**, *Theoretical Computer Science*, **379**:1-2, 231-265, 2007.
8. [EA8] E. Asarin, P. Caspi, O. Maler, **Timed Regular Expressions**, *Journal of the ACM* **49**, No.2, 172-206, 2002.
9. [EA9] E. Asarin, O. Bournez, T. Dang, O. Maler, A. Pnueli, **Effective Synthesis of Switching Controllers for Linear Systems**, *Proceedings of the IEEE* **88**, No. 7, 1011-1025, 2000.
10. [EA10] E. Asarin, O. Maler, A. Pnueli, **Reachability analysis of dynamical systems having piecewise-constant derivatives**, *Theoretical Computer Science* **138**, 35-65, 1995.

### ○ Joint Research Group 2

**Lead Joint Researcher: Benoît Barbot (LACL, Université Paris-Est Créteil)**

**[author notation in English papers: B. Barbot or Benoît Barbot]**

1. [BB1] B. Barbot, B. Basset T. Dang. **Generation of Signals under Temporal Constraints for CPS Testing**. In *Proceedings of NASA Formal Methods NFM 2019*, LNCS, Springer, 2019.
2. [BB2] P. Ballarini, B. Barbot, N. Vasselin. **Performance modelling of access control mechanisms for local and vehicular wireless networks**. In *Proceedings of the 12th EAI International Conference on Performance Evaluation Methodologies and Tools, VALUETOOLS 2019*, pages 111-118. ACM, 2019.



3. [BB3] B. Barbot, B. Bérard, Y. Duploux and S. Haddad. **Integrating Simulink Models into the Model Checker Cosmos**. In *Proceedings of the 39th International Conference on Applications and Theory of Petri Nets (PETRI NETS'18)*, pages 363-373, Bratislava, Slovakia, June 2018, LNCS. Springer.
4. [BB4] B. Barbot, N. Basset, M. Beunardeau and M. Kwiatkowska. **Uniform Sampling for Timed Automata with Application to Language Inclusion Measurement**. In *QEST'16*, volume 9826 of *Lecture Notes in Computer Science*, pages 175-190. Springer, 2016. 2016.
5. [BB5] B. Barbot, M. Kwiatkowska, A. Mereacre and N. Paoletti. **Building Power Consumption Models from Executable Timed I/O Automata Specifications**. In *Hybrid Systems: Control and Computation HSCC'16*, pages 195-204. ACM, 2016. 2016.
6. [BB6] B. Barbot and M. Kwiatkowska. **On Quantitative Modelling and Verification of DNA Walker Circuits Using Stochastic Petri Nets**. In *ICATPN'15*, LNCS 9115, pages 1-32. Springer, 2015.
7. [BB7] B. Barbot, S. Haddad and C. Picaronny. **Coupling and Importance Sampling for Statistical Model Checking**. In *TACAS'12*, LNCS 7214, pages 331-346. Springer, 2012.
8. [BB8] B. Barbot, T. Chen, T. Han, J.-P. Katoen and A. Mereacre. **Efficient CTMC model checking of linear real-time objectives**. In *TACAS'11*, LNCS 6605, pages 128-142. Springer, 2011.

### ○ Joint Research Group 3

**Lead Joint Researcher: Aneel Tanwani (LAAS--CNRS, Toulouse)**

**[author notation in English papers : A. Tanwani or Aneel Tanwani]**

1. [AT1] Associate Editor: *IFAC J. Automatica*, and *IEEE Control Systems Society Conference* Editorial Board.
2. [AT2] G.-X. Zhang and A. Tanwani. **ISS Lyapunov functions for cascade switched systems and sampled-data control**. *IFAC J. Automatica*, vol. 105: 216--227, 2019.
3. [AT3] A. Tanwani, D. Chatterjee, and D. Liberzon. **Stabilization of deterministic control systems under random sampling: Overview and recent developments**. Chapter 6 in *Uncertainty in Complex Networked Systems*, edited by T. Basar, pages: 209-246, Springer Nature, 2018.
4. [AT4] A. Tanwani and Q. Zhu. **Feedback Nash equilibrium for Markov jump games under differential-algebraic constraints with application to robust control**. In *Proc. IEEE Conf. Decision and Control*, pages: 5664-5669, 2018. Also **shortlisted (1 of 3) for "Best paper by a young scholar"** at *International Symposium on Dynamic Games (ISDG)*, Grenoble, July 2018.
5. [AT5] A. Tanwani, B. Brogliato and C. Prieur. **Well-Posedness and Output Regulation for Implicit Time-Varying Evolution Variational Inequalities**. *SIAM Journal on Control and Optimization* 56 (2), 751-781, 2018.
6. [AT6] A. Tanwani, R. Jungers, and M. Heemels. **Observability of discrete-time linear systems with communication protocols and dropouts**. In *Proc. IEEE Conf. Decision and Control*, pages: 4194-4199, 2018.

7. [AT7] M. Della Rossa, A. Tanwani and L. Zaccarian. **Max-Min Lyapunov Functions for Switched Systems and Related Differential Inclusions**. To appear in *IFAC J. Automatica*, 2019. Conference version: *IEEE Conf. Decision and Control*, 2018.
8. [AT8] A. Tanwani and A.R. Teel. **Stabilization with event-driven controllers over a digital communication channel with random transmissions**. In *Proc. IEEE Conf. Decision and Control*, pages: 6063-6068, 2017.
9. [AT9] A. Tanwani, C. Prieur and M. Fiacchini. **Observer-based feedback stabilization of linear systems with event-triggered sampling and dynamic quantization**. *Systems & Control Letters*, 94: 46-56, 2016.
10. [AT10] A. Tanwani, H. Shim and D. Liberzon. **Observability for switched linear systems: Characterization and observer design**. *IEEE Transactions on Automatic Control*, 58 (4): 891-904, 2013.

## Patent list (Research Director and Lead Joint Researcher(s)) (Japanese Side)

### Major Patents

*List important patent applications of recent years that are related to this proposal. Do not exceed one page.*

#### 1. Research Director (Kohei Suenaga (Kyoto University))

- [KS-P-1] International patent application: Kohei Suenaga, Akifumi Imanishi, Atsushi Igarashi: プログラム検証装置、プログラム検証方法、プログラム検証のためのコンピュータプログラム、プログラム変換器、プログラム変換方法、プログラム変換のためのコンピュータプログラム、プログラム製造方法、及び検証用プログラム. PCT/JP2018/044029.
- [KS-P-2] US patent: Hisashi Miyashita, Hiroaki Nakamura, Kohei Suenaga: Information management system, method and program. US8766980
- [KS-P-3] Disclosed Japanese patent application: Ichiro Hasuo, Takumi Akazaki, Kohei Suenaga: 制御入力値生成装置、制御入力値生成方法、および、プログラム. 特開 2015-194917.
- [KS-P-4] Disclosed Japanese patent application: Kohei Suenaga, Minoru Kinoshita, Kensuke Kojima. 不変条件生成装置、コンピュータプログラム、不変条件生成方法、プログラムコード製造方法. 特開 2017-138677.
- [KS-P-5]: Disclosed Japanese patent application: Kohei Suenaga, Minoru Kinoshita, Kensuke Kojima. 不変条件生成装置、コンピュータプログラム、不変条件生成方法、プログラムコード製造方法. 特開 2017-138679.
- [KS-P-6] International patent application: Minoru Kinoshita, Kensuke Kojima, Kohei Suenaga. 不変条件生成装置、コンピュータプログラム、不変条件生成方法、プログラムコード製造方法. PCT/JP2017/003295
- [KS-P-7] Japanese patent application: Ichiro Hasuo, Takamasa Okudono, Kengo Kido, Kohei Suenaga, Kensuke Kojima, Yuki Nishida: 自動証明装置、及びプログラム. 特願 2017-137949.
- [KS-P-8] Japanese patent application: Kohei Suenaga, Akifumi Imanishi, Atsushi Igarashi: プログラム検証装置、プログラム検証方法、プログラム検証のためのコンピュータプログラム、プログラム変換器、プログラム変換方法、プログラム変換のためのコンピュータプログラム、プログラム製造方法、及び検証用プログラム. 特願 2017-246154.
- [KS-P-9] Japanese Patent: Hiroaki Nakamura, Hisashi Miyashita, Kohei Suenaga: 情報管理システム、方法及びプログラム. 特許第 5431261 号.
- [KS-P-10] Japanese Patent: Kohei Suenaga, Ichiro Hasuo: ハイブリッドシステムの検証方法、検証装置、及び検証コンピュータプログラム、並びに、ハイブリッドシステムのモデル変換方法、変換装置、及び変換コンピュータプログラム. 特許 5843230.

**Patent list (Research Director and Lead Joint Researcher(s)) (French Side)****Major Patents**

*List important patent applications of recent years that are related to this proposal. Do not exceed one page.*

**1. Research Director (Thao Dang (VERIMAG/UGA))**

US Patent "Coverage guided technique for bug finding in control systems and software"

**Patent number:** 9798652.

**Date of Patent:** October 24, 2017.

**Assignees:** TOYOTA MOTOR ENGINEERING & MANUFACTURING NORTH AMERICA, INC., UNIVERSITY JOSEPH FOURIER. **Inventors:** James P. Kapinski, Jyotirmoy V. Deshmukh, Xiaoqing Jin, Thao Dang, Tommaso Dreossi

### Information on Other Supports (Japanese Side)

Research Director: **Kohei Suenaga (Kyoto University)**

No.	Program	Status	Title of Project (Name of Principal investigator)	Research Period	Role (Principal Investigator or co-Principal Investigator)	Research Fund Received (1) Allocated Budget (For entire period) (2) FY 2019 (planned) (3) FY 2018 (planned) (4) FY 2017  (Thousand yen/unit)	2019 FY Effort (%)
-	CREST	Submitted	New Concepts and Tools for Designing Dependable Society 5.0 (CODESO) (Kohei Suenaga and Thao Dang)	2019.10 — 2024.03	Principal Investigator	(1) 250,300 (2) 26,300 (3) Not applicable (4) Not applicable	30
(1)	基盤研究 (B)	Awarded	圏論と数理論理学によるものづくりサポート—ソフトウェア科学のシステム工学への移転 (Ichiro Hasuo)	2015.04 — 2019.03	Joint researcher	(1) 4,550 (2) 1,544 (3) 1,400 (4) 1,400	10
(2)	基盤研究 (B)	Awarded	IoT システムのための形式検証手法の深化 (Kohei Suenaga)	2019.04 — 2023.03	Principal investigator	(1) 4,044 (2) 2,044 (3) Not applicable (4) Not applicable	20

(3)	挑 戦 的 研 究 (萌 芽)	Submitted	数学の自動化を推進す るための機械学習を用 いた定理自動証明手法 (Kohei Suenaga)	2019.04 — 2021.03	Principal investigator	(1) 3,000  (2) 500 (3) Not applicable  (4) Not applicable	20
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## [Notes]

- A proposal that was once adopted may be revoked if an entry differs from reality.
- We may ask for application and plan documents submitted to other systems when a proposal reaches the interview stage.
- Enter this proposed CREST theme first, followed by other research themes in a descending order of the amount of research funds (for the whole period) the applicant receives.
- Add rows if needed.

**Lead Joint Researcher (1) : Masako Kishida (National Institute of Informatics)**

No.	Program	Status	Title of Project (Name of Principal investigator)	Research Period	Role (Principal Investigator or co- Principal Investigator)	Research Fund Received (1) Allocated Budget (For entire period) (2) FY 2019 (planned) (3) FY 2018 (planned) (4) FY 2017  ( Thousand yen/unit)	2019 FY Effort (%)
-	CREST	Submitted		2019.10 — 2025.3	Co-Principal Investigator	(1) (2) (3)	20
(1)	MEXT Quantum Leap Flagship Program	Awarded	Architecture and applications for small to large scale quantum computation (Kae Nemoto)	2018.10 — 2028.3	Co-Principal Investigator	(1)9,015 (2)1,000 (3)1,000 (4) 15	5

## **Protection of Human Rights and Compliance with Laws and Regulations (Japanese Side)**

It is confirmed that laws and guidelines to be complied with have been understood and drawn up for this research plan. Furthermore, we confirm that laws and guidelines will be complied with in implementing this plan.

(Examples of laws and guidelines to be followed)

- “Guidelines for handling dishonest conduct in research activities” (decision by Minister of Education, Culture, Sports, Science and Technology, August 26, 2014, including succeeding revisions)
  
- “Guidelines for management and audit of public research fund by research organizations (criteria for implementation), put in effect on February 18, 2007”/revision decided by the Minister of Education, Culture, Sports, Science and Technology, including succeeding revisions”
  
- Concerning control for trade security (dealing with technology leaks to overseas parties), foreign exchange and foreign exchange law, laws, ministerial ordinances, and official notices set out by ministries to prevent the results of advanced research from being passed to those who are suspected to conduct activities including applications for military purposes, such as those who develop weapons for mass destruction or terrorist groups
  
- Laws of related countries when conducting research overseas (including taking out biological resources) or joint research with an overseas research organization
  
- As for research in life science, laws, ministerial ordinances, and ethical guidelines set out by ministries for life ethics and security

*(Enter a check mark in when checked)*



Above Checked

(by Research Director on Japanese side)

## Other Special Remarks

*In Form 11J, Provide an overall description of other special remarks in less than two A4-size sheets (no exceptions). If this instruction is not followed, the research proposal might not be accepted).*

### Conflict of interest between the applicant and evaluators

- (1) Conflict of interest between the research applicant (research director) and evaluators (research supervisor, research area advisor)

**【Example】** Clearly show to which conditions conflict of interest shall apply, if yes.

**Conflict of interest between the research applicant and the research supervisor: yes**

The research applicant conducted joint research with the research supervisor on ○○project (1997-2000). It comes under condition (f) for conflict of interest stipulated in 5.1.2(2).

**Conflict of interest between the research applicant and the research area advisor(s): yes**

Research area advisor with conflict of interest: (The Advisor's Name)

The research applicant is conducting joint research with the advisor in \*\* project.

It comes under conditions (c) for conflict of interest stipulated for 5.1.2(2).

- (2) Conflict of interest between the lead joint researcher and the research supervisor

**【Example】** Clearly show to which conditions conflict of interest shall apply, if yes.

**Conflict of interest between the lead joint researcher and the research supervisor:**

Lead Joint Researcher (1)- (Name): No

Lead Joint Researcher (2)- (Name): Yes

Reason: He/She is conducting joint research with the research supervisor in \*\* project.

It comes under conditions (c) for conflict of interest stipulated for 5.1.2(2).

### (Only for those relevant) The reason why lead joint researcher at overseas research organization will join the proposed research

- (1) Necessity for the lead joint researcher at overseas research organization to join, the internal rule for security exports control

The present research proposal requires experts on modeling, testing, verification, and monitoring of IoT systems modeled as hybrid systems. This area is extensively studied by researchers in France. The French-side team of the present proposal consists of the top-level researchers among them. The collaboration of the Japanese-side team, which consists of experts on program verification and control theory, and the French-side team is, we believe, essential to conduct the project effectively.

The organization that Kohei Suenaga (Kyoto University) belongs to designates the security measures for security exports control. The following webpage explain this security measure: <https://www.kyoto-u.ac.jp/en/research/research-compliance-ethics/security-export-control.html>



(2) Contact person responsible for research contracts at the overseas research organization

*Enter name, affiliation, e-mail address, and telephone number.*

Maria Dewailly

Université Grenoble Alpes, Grenoble, France

dgdriv-proposals@univ-grenoble-alpes.fr

+33 4 76 51 46 89

**(Only for those relevant) Special notes for efforts by a research director**

**The other special remarks: Reasons for the application, Differences from the previous application (in case of applications that have been made to the research area two times or more), Change of research institute affiliation, other special notes**

Suenaga plans to conduct research during 2019.10 -- 2020.03 in Arizona State University (ASU) with Prof. Georgios Fainekos. This is a sabbatical visit permitted by Kyoto University; Suenaga remains to be an associate professor in Kyoto University. Suenaga will investigate the topics of this project during this visit. Postdocs and PhD students will be supervised remotely; they may also visit ASU during his visit. Masako Kishida will also supervise them.

**Awards**

1. Kaori Shiojiri, Katsura Koishi, Kohei Suenaga, Takayuki Muranushi, Keisuke Fujii: The third medium ‘scent’ that follows visual and auditory senses. Award of Excellence in Kyoto University Interdisciplinary Research Idea Contest. September 30th, 2013.
2. Ryosuke Sato, Kohei Suenaga, and Naoki Kobayashi: Ordered types for stream processing of tree-structured data. Journal of Information Processing Outstanding Paper Award. March 26th, 2012. Information Processing Society of Japan.
3. Kohei Suenaga: Programming with Infinitesimals: A WHILE-Language for Hybrid System Modeling. Best Presentation Award in the 14th Workshop on Programming and Programming Languages. March 10th, 2012.
4. Kohei Suenaga: Type-Based Deadlock-Freedom Verification for Non-Block-Structured Lock Primitives and Mutable References. Best Presentation Award in the 11th Workshop on Programming and Programming Languages. March 11th, 2009.
5. Kohei Suenaga: Type-Based Analysis of Deadlock for a Concurrent Calculus with Interrupts. Best Presentation Award in the 9th Workshop on Programming and Programming Languages. March 10th, 2007.



**Proposal Preparation Checklist (mainly for Japanese side)****※This checklist should be deleted in submission※**

Check	Reference Material	Check
Have you completed e-Rad researcher registration? (Lead Joint researchers as well)	Chapter 10	<input type="checkbox"/>
Have you completed the educational program on research integrity?	Section 8.1	<input type="checkbox"/>
Conflict of interests with the Research Supervisor*	Section 5.1.1	
A The research project applicant is a relative of the Research Supervisor.		No <input type="checkbox"/>
B The research project applicant and the Research Supervisor are both affiliated with the same smallest organizational unit (e.g. same research lab) of a university, national or other national government-funded research and experiment institution. Or, the research project applicant and the Research Supervisor are affiliated with the same company.		No <input type="checkbox"/>
C The research project applicant and the Research Supervisor are presently working in close cooperation on the same joint research project. Or, have done so within the past five years. (Existence of close cooperation will be judged by the facts that, for example, the research project applicant and the Research Supervisor are working together on the same research project, are performing different parts of the same research project, or are co-authors of a research paper. If you have any questions, please contact JST)		No <input type="checkbox"/>
D The research project applicant and the Research Supervisor had been in a close teacher-student relationship for a total of more than 10 years (not necessarily continuous), or had been in a direct employer-employee relationship. "Close teacher-student relationship" means cases in which the research project applicant and the Research Supervisor were affiliated with the same research lab, and cases in which the Research Supervisor, though affiliated with a different organization, essentially functioned as a research advisor for the research project applicant.		No <input type="checkbox"/>

\*When it is unclear whether any of the above conditions apply, please download and fill the Inquiry Form via the following URL: <http://www.jst.go.jp/kisoken/boshuu/teian/en/top/koubo.html>  
Please send it via email to [rp-info@jst.go.jp](mailto:rp-info@jst.go.jp).

○ **Deadline for Submission**

Immediately before the deadline, e-Rad may suffer high system burden. As a result, the application may take a long time, and troubles, including the failure to complete the application, may occur. Try to complete the application well in advance.

○ **Forms**

Check the proposal documents for possible omissions before submission. A proposal application may not be accepted if relevant forms have been filled out incorrectly.

	Item	Main Check Point	Check Column
	Input of general information on the applicant to e-Rad	All necessary information is provided. File sizes should not exceed 3MB in total in PDF format.	<input type="checkbox"/>
Form 1	Cover of research proposal documents	All necessary information is provided. Information is matched with e-Rad data. The form 1 is within one page when converted PDF	<input type="checkbox"/>
Form 2-1	Research Proposal Overview	When converted to PDF format, the form 2-1 is no more than two pages long?	<input type="checkbox"/>
Form 2-2	Major Achievements of the Research Director	The form 2-2 is within one page when converted PDF	<input type="checkbox"/>
Form 3-1	Project Description	The form 3-1 is within six pages when converted PDF.	<input type="checkbox"/>
Form 3-1 Annex	The research roadmap for development and social implementation toward society 5.0 (for applicants of Computational Foundation only)	The form 3-1 Annex is within one page when converted PDF.	<input type="checkbox"/>
Form 3-2	Project Organization and Research Schedule	The form 3-2 is within two pages when converted PDF.	<input type="checkbox"/>

## 2019 (CREST)

Form 4-1	Research Project Organization 1 (within two pages)	All necessary information is given (Particularly, effort is provided). the form 4-1 is within two pages when converted PDF.	<input type="checkbox"/>
Form 4-2	Research Project Organization 2 (within two pages for each group)	All necessary information is given. The form 4-2 is within two pages for each collaborative group when converted PDF.	<input type="checkbox"/>
Form 5	Research Budget	Total Sum is matched with the research budget given in Form 1.	<input type="checkbox"/>
Form 6	List of Achievements (Research Director) / Ex-Post Evaluation Results (Research Director)	The number of principal achievements listed is no more than 20. The number of the other achievements listed is also no more than 20.	<input type="checkbox"/>
Form 7	List of Achievements (Lead Joint Researcher(s))	The number of achievements listed is no more than 10 for each lead joint researcher.	<input type="checkbox"/>
Form 8	List of Patents (Research Director & Lead Joint Researcher)	The Form 8 is around one page.	<input type="checkbox"/>
Form 9	Information on Other Supports	All necessary information is given.	<input type="checkbox"/>
Form 10	Protection of Human Rights and Compliance with Laws and Regulations	The column is already checked.	<input type="checkbox"/>
Form 11	Other Special Remarks	The form 11 is within two pages when converted PDF.	<input type="checkbox"/>