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ACTIVITY REPORT

Project-Team DANCE

Dynamics and Control of Networks

IN COLLABORATION WITH: Grenoble Image Parole Signal Automatique (GIPSA)

DOMAIN

Applied Mathematics, Computation and Simulation

THEME

Optimization and control of dynamic systems

Contents

Project-Team DANCE

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Keywords

Computer sciences and digital sciences

A1.2.6. – Sensor networks

A1.2.7. – Cyber-physical systems

A1.2.9. – Social Networks

A1.5. – Complex systems

A6.1.1. – Continuous Modeling (PDE, ODE)

A6.1.3. – Discrete Modeling (multi-agent, people centered)

A6.4. – Automatic control

A8.8. – Network science

Other research topics and application domains

B2.3. – Epidemiology

B6.3.4. – Social Networks

B7. – Transport and logistics

B8.2. – Connected city

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2 Overall objectives

DANCE is a joint research team of Inria Grenoble – Rhône-Alpes and GIPSA-lab, established in February 2021 as the evolution of former team NeCS. The team is bilocated at the Inria center in Montbonnot and at Gipsa-Lab on Saint-Martin-d'Hères campus, both locations being in the Grenoble area.

The team's mission is to advance the field of Automatic Control to meet the challenges of today's hyper-connected society. We perform both fundamental research about control systems theory and network science and applied research in relevant domains such as mobility, transportation, social networks, and epidemics.

Both researchers and general public have become aware that our society and our lives depend on **complex dynamical systems** that can be understood as **networks**. Examples are plentiful and we shall only remind a few: transportation networks allow ourselves to travel, commute, and transport goods; power networks provide our homes and factories with energy; supply chains are the backbone of manufacturing; social networks support our professional and personal relationships; networks of neurons constitute our brains; and ecological networks such as foodwebs sustain our survival.

In stark contrast with this reality and its popular recognition, the mathematical and conceptual tools available to scientists and engineers to understand and manage these systems are lagging behind. We believe that these *complex network systems are first and foremost dynamical systems* and therefore amenable to an Automatic Control approach, since Automatic Control, as a field, is devoted to study dynamics and the ways to monitor and to regulate them. However, the century-old theory of Automatic Control has been developed to study other kinds of mechanical or electrical systems that lack a network structure: inspecting a 1999 landmark book like [50] shows that control theorists did not yet consider networks to be a topic of study as late as 20 years ago. Despite substantial efforts by the research community during the last 15 years, the theory of systems and control has not yet been able to integrate itself with the big advances that have been made in network science. The ambition of this team is to contribute to closing this gap.

The research of the DANCE team encompasses both methodological work and applications in close interdependence since methodological questions are motivated by selected application areas. The dominant one is the broad area of **mobility**. By this term we encompass questions about vehicular and multi-modal transportation, navigation methods for pedestrians in urban and cluttered/noisy environments, and Connected Autonomous Vehicles, namely their cooperative behavior and their effect on the overall transportation system. The team maintains and develops experimental platforms on mobility, including the GTL-Rocade (Grenoble Traffic Lab) [53], [40], GTL-Ville [39], and GTL-Healthmob [38]. A growing application area concerns **social systems**, mainly in relation with the dynamics that take place in online social media: on this topic we collaborate at the national and international levels with researchers from engineering, computer science and social sciences. The mathematical methods developed by the team may also find potential application in other areas that team members are currently exploring: brain networks (by a control perspective on Deep Brain Stimulation), smart buildings (seen as a large-scale systems), networks of oscillators, and biological networks (biochemical and epidemic networks).

From our application scenarios, it appears that the networks that we are interested in share several important features:

- they are inherently dynamical and their evolution can be influenced from the outside;
- their structure (that is, the topology of their interconnections) shapes their global behavior;
- their structure and their composition evolve together with the evolution of their components;
- they are large and therefore require tools that scale well with size;
- their dynamics, structure, and state are known with possibly large uncertainties (even though they may generate big data streams).

Our approach is a **control systems approach**, that begins by identifying suitable state variables, input variables and output variables. To cope with the specific features of complex network systems, we develop new system-theoretic tools for modeling, estimation, and control. Depending on the application and on the modeling methodology, the mathematical models will be differential (or difference) equations on graphs or continuous models such as partial differential equations. In the applications, estimation and control take advantage of the structure of the systems and of their specific, physical, features.

3 Research program

In presenting our research, we shall distinguish five research *Axes*. The first two axes present our theoretical work that develops a broad set of tools for modeling, identification and control of network dynamics. Focusing on the nexus between networks and control systems implies that our methods will blend ideas from network science and control science. The first axis regards methods that define network dynamics by the graph that naturally describes their physical or informational structure; the second axis goes beyond this graph-theoretic representation by using approximations or aggregations to deliver methods that are suitable to large networks. The remaining three Axes present methods that are tailored to our main applications in transportation, in social networks, and in epidemics.

Research Axis 1: Exact Automatic Control methods for networks

Most methods from Automatic Control do not apply well to networks, simply because they were designed for systems that do not have a network structure. Once the presence of network structure is recognized, it has to be accounted for in analysis and design. Firstly, a network structure implies *obstructions to the flow of information* between different parts of the system. A key instrument to take them into account is the deployment of graph-theoretical methods, as we will exemplify below. Secondly but not less importantly, a network structure implies the opportunity (or sometimes the need) to *scale* the network up in size, growing larger and larger networks by the addition of nodes and edges. Sometimes, classical control methods scale poorly in terms of complexity or performance, and therefore need overhaul. This research axis therefore pertains to the development of system-theoretic methods that are based on graph theoretical representations of the system and whose complexity and performance scale well with the size of the network, so that networks with tens or hundreds of nodes can be studied.

Research Axis 2: Approximate methods for large-scale networks

Axis 1 was devoted to the control-theoretic analysis of networks by Graph Theory tools, under the assumption that a complete knowledge of the network is available. These methods are suitable for systems with a relatively small number of nodes (tens or hundreds), like formations of moving robots or sensor networks, but become ineffective for larger networks. Complete knowledge of the network is typically not available, because of the presence of noise, errors in data, links changing in time. Additionally, even if in some cases it is possible to obtain a good approximation of the network structure, the applicability of estimation and control methods is reduced by the limitation of computational resources. In order to address these limitation, this research axis (Axis 2) develops system-theoretic methods that abstract from the detailed network state, by performing operations of aggregation or approximation. These tools are meant to be applied to networks with thousands of nodes.

The remaining three axes develop methods that are directly motivated by the applications: we therefore describe them in the next section.

4 Application domains

Smart Transportation Systems

Smart transportation is the main domain of application for the team. The research topics include cooperative control of Connected and Autonomous Vehicles, pedestrian navigation, vehicular traffic in urban road networks, and multi-modal transportation. The experimental platforms Grenoble Traffic Lab (GTL) and GTL-Ville continuously collect real-time data about traffic in Grenoble. Other data collection campaigns, such as TMD-CAPTIMOVE, have produced datasets about multi-modal transportation.

Transportation research is currently at a crucial stage: we are facing the emergence of new technologies and systems such as vehicle connectivity, automation, shared-mobility, multimodal navigation and advanced sensing which are rapidly changing mobility and accessibility. This in turn will fundamentally transform how transportation planning and operations should be conducted to enable smart and connected communities. On one hand, this process presents us with a great opportunity to build safer, more efficient, reliable, accessible, and sustainable transportation systems. On the other hand, the uncertainties regarding how such disruptive technologies will evolve pose a number of fundamental challenges. These challenges include: (a) understanding the impacts of connected and automated vehicles on the traffic flow; (b) shifts in travel demand induced by new paradigms in mobility, such as shared mobility; (c) the computational challenges of real-time control strategies for large-scale networks, enabled by emergent technologies; (d) transitioning to predictive and proactive traffic management and control, thus substantially expanding the horizons of transportation network management; (e) the need for identifying different modes of transport used by a certain population. The need to effectively address these challenges provides the opportunity for fundamental advances in transportation and navigation and will be the object of this research axis.

Cyber-Social Systems

Online social networks, such as online blogging platforms and social media, are chief examples of complex systems where social and technological components interact. We can refer to such systems as *Cyber-social networks*: social components are human individuals whose collective behavior produces the overall behavior of the system, whereas technological (or cyber) components are devices or platforms endowed with sensing, computation, and communication capabilities. In these contexts, the interactions between the individuals are mediated and determined by the ubiquitous presence of digital technology. Online social services routinely record behaviors and interactions and exploit this information to constantly optimize themselves for the users, by the ubiquitous presence of recommendation systems. These large data streams can also enhance our understanding of social dynamics. Beyond the analysis power, these tools offer new opportunities to influence the behaviors of the individuals. This influence can be obtained in various ways, including advertising, diffusing sensitive information, or altering the way individuals interact. These evidences open the way to identify ways to "actuate" (in engineering jargon) social systems. Understanding these dynamics in a control systems perspective is thus not only a scientific challenge, but also an urgent need for the society.

Epidemics

The recent COVID-19 pandemics has proved how important is the understanding of network dynamics to mitigate and contain epidemics. The group has taken up this challenge and produced multiple contributions that leverage our expertise about control of networks, social networks, online media, and human mobility. Indeed, our research on network dynamics has long time considered networked epidemic models (such as SIS or SIR) as "academic" examples of application. This perspective includes works about epidemics that we published until 2020 [62, 73]. As soon as the Covid-19 pandemics struck, we realized how our expertise could be useful and we initiated several initiatives which have leveraged a combination of internal expertise (namely about network dynamics, control, and mobility) and external expertise on mathematical epidemiology (from Institut Pasteur and MAMBA Inria team). A network model of epidemics evolution coupled with human mobility in the Grenoble area can be visualized in the interface GTL-Healthmob.

This line of work on epidemics models is gradually being integrated in the other research axes (notably, in transportation research) rather than being developed as a main team priority.

5 Highlights of the year

This year has been marked by several PhD graduations: Maria Castaldo (Disorders of online media), Pierre Gogendeau (Geolocalisation from heterogeneous data), Renato Vizuete (Open multi-agent systems) Ujjwal Pratap (Resilient control in scale-free networks).

5.1 Awards

Renato Vizuete has received the 2022 Outstanding Student Paper Prize by the Networks and Communication Systems Technical Committed of the IEEE Control Systems Society. The prized paper is [63].

Bassel Othman (PhD student, graduated in 2021) has received the 11ème prix de la Chaire Sanef Abertis - Ecole des Ponts ParisTech for his thesis work.

6 New software and platforms

6.1 New software

6.1.1 GTL-Rocade

Name: Grenoble Traffic Lab

Keywords: Road traffic, Traffic data

Functional Description: The Grenoble Traffic Lab (GTL-Rocade) initiative, led by the NeCS team, is a real-time traffic data Center (platform) that collects traffic road infrastructure information in real-time with minimum latency and fast sampling periods. The main elements of the GTL are: a real-time data-base, a show room, and a calibrated micro-simulator of the Grenoble South Ring. Sensed information comes from a dense wireless sensor network deployed on Grenoble South Ring, providing macroscopic traffic signals such as flows, velocities, densities, and magnetic signatures. This sensor network was set in place in collaboration with Inria spin-off Karrus-ITS, local traffic authorities (DIR-CE, CG38, La Metro), and specialized traffic research centers. In addition to real data, the project also uses simulated data, in order to validate models and to test the ramp-metering, the micro-simulator is a commercial software (developed by TSS AIMSUN ©).

URL: `https://gtl.inrialpes.fr`

Contact: Carlos Canudas-de-Wit

Participants: Alain Kibangou, Andres Alberto Ladino Lopez, Anton Andreev, Carlos Canudas-de-Wit, Dominik Pisarski, Enrico Lovisari, Fabio Morbidi, Federica Garin, Hassen Fourati, Iker Bellicot, Maria Laura Delle Monache, Paolo Frasca, Pascal Bellemain, Pietro Grandinetti, Remi Piotaix, Rohit Singhal, Vadim Bertrand

6.1.2 GTL-Ville

Name: Grenoble Traffic Lab - City

Keyword: Traffic data

Functional Description: The GTL-Ville platform is developed within the framework of the ERC Scale-FreeBack project (http://scale-freeback.eu/). Its functions are divided into three axes: 1- Collect traffic data in real time via different sources. We are currently working with three suppliers: TomTom (company) for speed data from Floating Car Data (FCD), La Métro for counting data from existing loops and Karrus (company) to complete the counting data from La Métro via radars deployed since last fall. 2- Estimate traffic indicators with the lowest possible latency using collected data and historical data applied to models developed by PhD students of the ERC project. 3- Visualize raw data and calculated indicators via a web interface (http://gtlville.inrialpes.fr/).

URL: `http://gtlville.inrialpes.fr`

Contact: Carlos Canudas-de-Wit

6.1.3 GTL-Healthmob

Name: GTL-Healthmob

Keywords: Road traffic, Epidemiology

Functional Description: This project, initiated by the DANCE team with support from Scale-freeBack ERC and the Healthy Mobility Inria project, is a demonstrator of epidemics mitigation through efficient mobility control. First, mobility in the Grenoble urban area is captured through origin-destination matrices calibrated thanks to household travel surveys and INSEE data. The mobility is modeled from origins (residences) to destinations (activity-oriented) such as workplaces, schools, hospitals, parks, stores, malls,... This mobility model is coupled with a SIR model. Based on this complex model, the platform lets you visualize different pre-computed simulations using epidemiological and mobility restrictions parameters. This include scenarios optimized to limit the spread and the economic impact of the epidemic. The user can also run a simulation using custom parameters.

URL: http://gtlville.inrialpes.fr/covid-19

Contact: Carlos Canudas-de-Wit

7 New results

7.1 Research Axis 1: Exact Automatic Control Methods for Networks

Participants: H. Fourati, P. Frasca, F. Garin, A. Kibangou, R. Vizuete.

7.1.1 Open Multi-Agent Systems

Open Multi-Agent Systems, also known as Open Networks or Dynamics Networks, are networks whose nodes can exit or enter the network at any time, as opposed to closed networks whose node set is fixed. In practice, this is a relevant question because large networks and populations often evolve with time. Mathematically, the evolution of the node set makes the utilisation of control-theoretic notions, such as stability, delicate. In a first phase, results have been obtained by two approaches. First, we have studied the stability of consensus in an open system under the assumption of having a finite "universe" set of possible nodes, from which the actual nodes of the network are chosen [74]. Second, we have have studied the stability of contractive dynamics in the presence of joining/leaving nodes, essentially by understanding the process of node arrival/departure as a disturbance [56].In the last year, we have concentrated on multi-agent optimization problems in the presence of replacements of the agents, providing several contributions: some preliminary convergence results about random coordinate descent were presented last year in [63] (a full paper is under review), the possibility of packet losses is accounted for in [36] and an analysis based on the notion of regret has been performed in [37]. Future work on OMAS will resort to the approximation methods that are described in Axis 2.

7.1.2 Cyber-Physical Systems: a control-theoretic approach to privacy and security

Cyber-physical systems are composed of many simple components (agents) with interconnections giving rise to a global complex behaviour. One line of research on security of cyber-physical systems models an attack as an unknown input being maliciously injected in the system. We study linear network systems, and we aim at characterizing input and state observability (ISO), namely the conditions under which both the whole network state and the unknown input can be reconstructed from some measured local states. We complement the classical algebraic characterizations with novel structural results, which depend only on the graph of interactions (equivalently, on the zero pattern of the system matrices). More precisely, we consider a structured system, namely a family of linear systems, where the graph of interactions is fixed while the intensities of interactions (edge weights) are free parameters. We obtain two kinds of results:

generic results (also known as structural results), true for almost all interaction weights, and strongly structural results, true for all non-zero interaction weights. Our recent results [32] focus on delay-L left invertibility, namely the possibility to reconstruct the input sequence from the output sequence, with the input being reconstructed up to L time steps before the current output. Delay-L left invertibility assumes that the initial input is known, but when this property is combined with strong observability, then both the input and the state can be reconstructed. Building upon classical results on linear systems theory and on structured systems, a graphical characterization is obtained of the integers L for which a structured system is generically delay-L left invertible.

7.2 Research Axis 2: Approximate methods for large-scale networks

Participants: C. Canudas de Wit, P. Frasca, F. Garin, A. Kibangou, A. Velleret.

7.2.1 Node aggregation and scale-free methods

The task of controlling large-scale networks is very difficult in the first place because of its large dimensionality, making the computation of traditional control algorithms too expensive. In systems of large dimensions, the number of sensors is often much lower than the number of states, which makes it hard to identify the mathematical model of the system and to estimate its state. Similar issues arise regarding the number of actuators. Another difficulty is that the energy needed to control all nodes of the network can grow exponentially with the number of nodes, at least for some network structures [67]. Therefore, in some cases, it can be preferable to *control and estimate some aggregated measure* of the entire network rather than all individual states, since the energy required to control aggregated quantities instead of all network states is much less. Examples of aggregate quantities would be, for instance, the average state of the whole network and its variance, or the average values in different regions of the network.

Therefore, the scale-free approach that is developed in the ERC Scale-FreeBack project is based on the aggregation of the variables that belong to neighboring nodes. The aggregation is done in such a way to construct a scale-free network, where the goal is to control the averaged state and the variance of the hubs, corresponding to regions or groups of nodes, and the control is applied to the boundaries of the hubs. In scale-free dynamic network modelling & analysis, the purpose is to reduce the system network complexity by finding the appropriate level of scale aggregation, while imposing the control and observation model properties required. The ultimate goal has consisted in developing novel control methods for scale-free network systems [16]. The team has applied these novel tools to traffic networks, namely in the GTL-Ville experimental platform.

7.2.2 The continuation method

When considering limit models for large networks, we naturally fall into continuous limits. These limits can take different forms. One way to define continuous limits is to regard, instead of the agent states, their *distribution*. The evolution of the distribution would then be naturally described by a partial differential (PDE) or integro-differential equation. A good approximation implies that control actions can be designed on the continuous system and have guaranteed performance on the original (graph-based) one. By the thesis work of D. Nikitin and a series of papers, we have reached a twofold objective: (1) we have developed a sound and complete theoretical framework for the PDE approximation of large networked ODE systems [15]; and (2) we have applied this framework to multiple applications including swarms of autonomous robots [15], traffic networks [22], and spin-torque oscillators [65] (full paper is to appear).

7.2.3 Graphons

Another promising way to define continuous limits is by the concept of graph function, or *graphon*, which is the limit object of a sequence of dense networks [61, 51]. Conversely, finite graphs can be generated by sampling from the continuous graphon: in this case, the properties of the finite networks can be inferred from the properties of the graphon. Recent works related to the application of graphons include the study of dynamics over networks [58, 60], centrality measures [49], link prediction [75], large population games [66, 52]. Inspired by results on centrality measures [49], we have recently been able to use graphons to define performance *metrics* that quantify system-theoretic properties like stability, controllability, or sensitivity to noise [73]. These metrics can be computed from the graphon at low computational cost and approximate well the system-theoretic properties of the corresponding dynamics on graphs of large-but-finite size. This year, our work has focused on the analysis of the SIS model, through the postdoc work of Aurélien Velleret (an article is in preparation).

7.3 Research Axis 3: Mobility systems and transportation networks

Participants: C. Canudas de Wit, H. Fourati, P. Frasca, F. Garin, A. Kibangou, M. Čičić, M. Rodriguez Vega, U. Pratap, R. Kalaoane, N. Cele, X. Xu, X. Dai, P. Gogendeau, T. Kraemer Sarzi Sartori.

7.3.1 Network-level traffic estimation, prediction and control

Methods for traffic estimation, prediction and control have been widely studied for highway traffic, but need significant advances to extend to urban traffic. Indeed, urban traffic is by nature a network problem, with issues about modeling intersections, and about dealing with the increased complexity. Our contributions have covered both estimation and prediction problems and control design.

Regarding **traffic state estimation** in urban networks, our contributions have dealt with three main sub-problems. First, the optimal sensor location problem was considered. In [69], the location of turning ratio sensors is considered for the dynamic case, under a limited number of available sensors. The second problem considers the estimation of flow and density using heterogeneous sources of information, such as fixed sensors and aggregated vehicle velocities from Floating Car Data (FCD).

In [68], we used FCD speed information directly to better model urban intersections, and [35] incorporates OD-matrix measurements to better estimate turning parameters using a route-based approach. These methods were validated using real data under different scenarios [18]. For the third problem, we consider the estimation of the aggregated density of an urban network. To solve this problem, we propose a method to calculate a virtual representation of the same underlying physical network where each road is divided into a number of cells, such that the estimator for the virtual system converges. We show that the difference between the real and virtual averages is small: these contributions were tested using real data collected in the city of Grenoble via the Grenoble Traffic Lab for urban networks (GTL-Ville) [39].

Regarding **control design**, we have studied control of traffic networks where the actuators can be either traffic lights schedule or variable speed limits. Most recently, we switched our focus from classical traffic performance objectives to suitably-defined performance indexes, so as to study and minimise the fuel consumption and hence the ecological impact of traffic [17]. To estimate the fuel consumption, a macroscopic network traffic model is associated with an artificial neural network calibrated using a microscopic physical energy model and data provided by a microscopic traffic simulator. We find that speed limits directly impact energy consumption and pollutant emissions, as they affect the accelerations and average speeds through the network. We design controllers with variable speed limits and with signalized access control, for improved environmental sustainability and traffic performance both in a synthetic urban area and in the peri-urban area at its boundaries. Controllers are designed with nonlinear model predictive control, in which the traffic evolution and the fuel consumption are predicted with macroscopic models, and then evaluated using the microscopic traffic simulator SUMO and a physical fuel consumption and NOx emission model. The results reveal that in transient phases between different levels of congestion, the variable speed-limit controller is faster to decongest the network, in an energy-efficient way, resulting in an improvement of the environmental sustainability and the traffic performance both in the controlled network, and at its boundary roads.

2D traffic models. Macroscopic traffic models use classical fluid dynamics equations to describe car flow on a stretch of road where vehicles are treated as infinitesimal particles and we look at the evolution of their density. The basic evolution equation, which corresponds to mass conservation, expresses the conservation of the number of vehicles. Models that tried to extend this idea to traffic flow on road networks have not been successful in representing correctly traffic dynamics on networks. In fact, state-of-the-art traffic assignment models integrate traffic dynamics based on first-order nonlinear partial differential equation (PDE) models such as the Lighthill-Whitham-Richards (LWR) model, but they have some limitations in terms of their scalability and computation time due to the complexity of the underlying assignment problem. In our perspective, it is fundamental for traffic control, understanding the network effects and design network models that capture how the various traffic streams interact and evolve throughout the network. We have addressed the problem of describing correctly traffic flow dynamics on networks by using new concepts as 2D models and micro-macro models on networks, in relation with the research undertaken in Axis 2. The second generation came out this year through the thesis work of L. Tumash and the key publication [22], as well as novel control techniques for boundary control [21].

7.3.2 Heterogeneity and autonomy in traffic

After 70 years of research, traffic flows of homogeneous vehicles are fairly well understood. More elusive is the understanding of heterogeneous traffic flows. As of today, a novel and peculiar sort of heterogeneity is appearing in traffic: the presence of automated (possibly autonomous) and connected vehicles (CAVs). Their appearance has motivated us to assess their impact on traffic and explore their potential as means for estimation and for control. Indeed until recently, traffic control infrastructures, such as ramp metering systems and variable speed limits, have been considered to be the essential tools for all traffic estimation and control goals, for instance mitigation of fluctuations in traffic flow . Today, instead, the advances in automation have brought the idea of exploiting CAVs for traffic control purposes.

In 2018, the first experimental result has finally been showed in [70]: using the same ring setup of [71], one of the HVs was replaced with an AV, so as to obtain a mixed traffic scenario with a single AV. Such a ring setup approximates a scenario in which AVs are sparsely and periodically introduced in the traffic. Starting from this practical evidence of the possibility of controlling traffic flow via a limited number of autonomous vehicles, our team has developed the rigorous analysis of these experiments. Our approach has been to assess the effects, and potential improvements, of autonomous vehicles in terms of system-theoretic properties of the collective vehicle dynamics, such as of *stability and string stability* [59]. In [12] we performed an analysis of stability and safety for strings of vehicles that are described by a realistic nonlinear model (the Optimal Velocity Model).

Further results have been obtained about the coordination of CAVs with unreliable communication [7].

For this research, we have exploited tools that pertain to Axis 1, where the vehicles constitute the nodes of a network of interactions.

7.3.3 Electromobility

The simultaneous proliferation of electric vehicles (EVs) and intermittent renewable energy sources promises to expedite decarbonization of two sectors with highest emissions. As the transportation and power systems grow ever more coupled, modelling the traffic and energy flows in a joint manner is becoming increasingly important. Such models need to capture the transport and evolution of energy stored in EV batteries as they travel through the road network, as well as the flows of energy between the power and the transportation systems at charging stations [27].

To tackle these problems, we proposed a macroscopic electromobility model - Coupled Traffic, Energy and Charging (CTEC) model in [28]. This model augments the LWR macroscopic traffic model with an inhomogeneous advection equation, describing the evolution of vehicles' State of Charge (SoC), and is completed by a model of the charging station dynamics. Based on this model, a simple control law was designed to exemplify how controlling EV charging can potentially help the power grid by reducing peak demands.

Furthermore, it is important to understand the impact that EVs will have inside urban traffic networks, which relates to the usual mobility patterns of people. To tackle this, [27] introduces a new model depicting EVs mobility and the evolution of their State-of-Charge (SoC) in urban traffic networks. The model couples the vehicles' mobility described by a set of dynamic equations over a graph capturing the

Origin-Destination motion derived from the model introduced in [64], [48], with the energy consumption associated with the EVs mobility patterns.

7.3.4 Multimodal mobility & pedestrian navigation

Mobility is currently evolving in urban scenarios and multimodality today is the key to more efficient transportation. In order to analyze the ecological impact of the various transportation modes, it is important to be able to detect the mode used by the commuter and the rule used to switch from one mode to another. The ultimate goal is to suggest smarter itineraries to commuters. To this purpose, detection and classification of activities in human mobility from one's principal residence to one's destination (for example, place of work, place of entertainment, etc.) is an important study to carry out. We aim to identify, with high precision, the nature of the transportation modes used during the day (walking, cycling, public transportation, car, etc.) as well as transitions from one mode to another. To reach this goal, our studies involve inertial and attitude modules, embedded in most inertial units, connected watches and smartphones. These technological tools constitute truly innovative and promising instrumentation for non-invasive automatic information capture. In [20] we have devised machine learning approaches for transportation mode detection (bus, tramway, walking, bike, kick scooter), by using features extracted from IMUs (Inertial Magnetic Units). The location of sensors on the body is crucial in order to get accurate results.

Detection of transportation mode. During the internship of X. Xu we have developed a hybrid classification technique to classify ride hailing transportation mode with buses by using acceloremeter data. Data was collected in the cities of Durban and Johannesburg, South Africa, by using inertial measurement units of the Captimove platform. Participants were equipped with two sensors (one in the trouser pocket and the one in the chest). Data were used to train a hybrid model combining a supervised classifier and a K-NN.

Public transportation quality of service analysis using machine learning tools. Efficiency of a public transportation system is usually evaluated through recurrent feedback from users. In the PhD thesis works of N. Cele and R. Kalaoane, various questionnaires have been collected in Kwadeka, a township of the city of Durban, and in Braamfontein, Johannesburg. The purpose is to build new tools for analyzing the quality of service in public transportation. For the Kwadabeka case, which is an economically and socially disadvantaged area, the focus was on identification of the key factors affecting the satisfaction of commuters. We first built a perceived quality of service metric in a logistic regression form. After defining the notion of key factors in the context of our study, we demonstrated how detecting analytically those key factors. Our results show that affordability, accessibility and waiting time are the key factors influencing the perceived quality of service. For Brammfontein case, we first study the issue of incomplete questionnaires. A machine learning approach to predict qualitative missing data by carefully designing the features to train the model was considered. Precisely, instead of using rating scores of attributes, we have introduced and showed that qualitative score occurrence (or frequency) and its normalized form allows getting good results. Reconstructed data are then used to design a satisfaction-dissatisfaction matrix (SDM) which informs policy makers and operators on attributes of the transportation system to be maintained or improved. The method is evaluated through data collected from users of minibus taxis, the main transportation mode in Braamfontein, Johannesburg (South Africa) and in many developing countries. The obtained SDM reveals that if certain attributes (e.g. safety, timetable,speed etc.) are improved and others (e.g. affordability, availability and access to stops) are maintained, the minibus taxis industry could become an important contributor to a viable public transport system. On the other hand, the results guides policy makers on the important aspects of minibus taxis that are fundamental to improve the satisfaction level in terms of quality of service provision.

7.3.5 Data fusion for navigation

Our activities on data fusion for navigation have been multifold, spanning filtering methods, applications of deep learning, noise compensation and applications that range from mobility to marine biology.

BiLSTM Network-Based Extended Kalman Filter for Magnetic Field Gradient Aided Indoor Navigation. We proposed an innovative method to estimate the velocity of a moving body [25]. This is achieved using solely raw data from a triad of low-cost inertial sensors, i.e. accelerometer and gyroscope, as well as a determined arrangement of magnetometer array. The proposed approachcombines a magnetic field gradient-basedExtended Kalman Filter (EKF), with a Bidirectional Long Short-Term Memory (BiLSTM) network. This is to better estimate the velocity, especially when the magnetic field disturbances are low, which causes other magnetic field-based methods to be inaccurate. The proposed method also makes it possible to well update the velocity regardless of sensor location, without any heavy computation or complex tuning, as the case for the Zero-Velocity Update Technique (ZUPT). The performance of the proposed approach is demonstrated through real experiments data using a Magneto-Inertial Tachymeter (MIT). The obtained results show the efficiency of the velocity estimation and possibly position, for different sensor placements and trajectory scenarios.

Assessment of radiation effects on attitude estimation processing for autonomous things. We investigate and assesse neutron radiation effects on attitude estimation (AE) processing, typically embedded in inertial navigation systems (INSs) and upcoming autonomous things [14]. Findings highlight the importance of radiation-induced critical failures that can upset the on-board AE processing and consequently the inertial navigation. Radiation tests and analyses were conducted by considering as on-board AE processing the execution of classical AE algorithm on multi-core computer hardware exposed to 14-MeV neutron and thermal neutron radiation. Three computing strategies and different case-study scenarios were tested and compared. Results suggest that the contribution of radiation-induced soft errors to be mitigated on the embedded AE processing is essentially related to single-event functional interrupts (SEFIs) that can lead the inertial navigation to critical failures.

Effectiveness of Attitude Estimation Processing Approaches in Tolerating Radiation Soft Errors. We investigate and compare the neutron induced soft-error tolerance effectiveness of four classical attitudeestimation (AE) processing approaches that are typically embedded in inertial navigation systems of autonomous things [33]. Resultsof 14-MeV and thermal neutron radiation testing campaignsindicate that the four case-study AE approaches – implementedwithout protection mechanisms – can be critically perturbed bysingle event upsets (SEUs), recovering themselves after a few seconds whether sensors' measurements are continuously provided.Although a few SEU-induced mismatches were observed in theresults of the case-study AE approaches, compared with anothertype of processing approach based on neural network algorithms,the AE algorithms presented a signifcantly higher effectivenessin tolerating SEUs.

Dynamic Grid-based Q-learning for Noise Covariance Adaptation in EKF and its Application in Navigation. The process and measurement noise covariance matrices significantly impact the Extended Kalman Filter (EKF) performance and are often hand-tuned in practice, which usually entails a tedious task. Q-learning, a well-known method in reinforcement learning, has been applied recently to better adapt the noise covariance matrices for the EKF, thanks to its simplicity and capability in handling uncertain environments. Typically, some heuristics are involved in designing the Q-learning-based EKF (QLEKF), such as tuning grid size and covariance matrices values of each state, which inevitably degrades the estimation performance when the heuristics are not suitable. We propose a dynamic grid-based Q-learning EKF (DG-QLEKF) to overcome that drawback, which brings two novelties, an updated ϵ-greedy algorithm and a dynamic grid strategy [29]. The proposed algorithm and strategy can thoroughly exploit arbitrary search scope and find appropriate values of noise covariance matrices. The effectiveness of DGQLEKF, applied in navigation for attitude and bias estimation, is validated through the Monte Carlo method and real flight data from an unmanned aerial vehicle. The DG-QLEKF leads to much more improved state estimation than the QLEKF and traditional EKF.

Q-Learning-Based Noise Covariance Adaptation in Kalman Filter for MARG Sensors Attitude Estimation. The attitude estimation of a rigid body by magnetic, angular rate, and gravity (MARG) sensors is a research subject for a large variety of engineering applications. A standard solution for building up the observer is usually based on the Kalman filter and its different extensions for versatility and practical implementation. However, the performance of these observers has long suffered from the inaccurate process and measurement noise covariance matrices, which in turn entails tedious parameter turning procedures. To overcome the laborious noise covariance matrices regulation, we propose a Q-learning-based approach to autonomously adapt the values of process and measurement noise covariance matrices [30]. The Q-learning method establishes a reinforcement learning mechanism that forces the noise covariance matrices pair with the least difference between predictions and measurements of output to be found in a predetermined candidate set of noise covariance matrices. The effectiveness of the Q-learning approach, applied to Extended Kalman filter-based attitude estimation, is validated through the Monte Carlo method that uses real flight data on an unmanned aerial vehicle.

Dead-reckoning configurations analysis for marine turtle context in a controlled environment. In the past few years, dead-reckoning (DR) has been frequently used to estimate the trajectory of marine animals at a fine temporal scale using bio-logger devices. The precision of the swim sequence trajectory estimation depends on various accumulated errors from external forces, sensors and computation. Trajectory accuracy is hard to estimate due to the difficulty of collecting precisely-known underwater positions. We aim at estimating this accuracy at a fine temporal scale using a reference system for positioning. This work focuses on how each sensor frequency and algorithm used for the DR affect trajectory accuracy and the global power consumption of the bio-logger [13]. We develop a dual GPS Real Time Kinematic (RTK) system offering us reference trajectories with 2 cm accuracy on position and 1.6○ on heading. The DR algorithms use 3-axis Inertial Measurement Unit (IMU), depth and speed sensor data for orientation and speed determination. For the experimental tests, the GPS module and the bio-logger are attached to a swimmer doing breaststroke imitating turtle movement for different swim sequences between 15 and 40 minutes. Power consumption of the electronics is measured during laboratory tests. Results show that using an adapted speed sensor and correcting for marine current, even roughly, provide us with the best gain in accuracy. The use of the gyroscope or high-frequency sampling of sensors does not increase the accuracy of the trajectory reconstruction to a level that would be critical for slow moving marine animal applications.

7.3.6 Human mobility and epidemics

Reducing human mobility is a very effective non-pharmaceutical intervention to reduce epidemics spread, and lockdowns have been effectively used in various countries in 2020. However, it is clear that mobility reductions have heavy economic and social effects. In our team, we have focused on understanding the interplay of human mobility and epidemics spread at the urban level. Our model [64] is based on an urban mobility model describing daily mobility between homes and destinations such as schools, workplaces, shopping and leisure, coupled with SIR epidemics evolution at each node of the mobility network. Mobility restrictions can be easily described in this model, either by reducing capacity of some destinations, or by reducing opening hours. An optimization problem can then be devised, to maximise economic activity (a suitably weighted average of mobility towards various categories of destinations) under the constraint that epidemics spread remains low enough to avoid saturation of ICU beds in hospitals. The model and the optimization problem were initially proposed in [64], considering an academic example. The model has then be extended and implemented to a city-level model that realistically reconstructs mobility in the Grenoble area [48, 42]. As a result, the web interface GTL-Healthmob is a platform which can be used to simulate different scenarios of mobility (with or without restrictions of capacity and of opening hours) and visualise their effects on epidemic spread in the Grenoble area, see [38] for a thorough description. The complexity of the non-convex optimization problem has then been tackled, with tools from monotonic optimization and a receding-horizon approach [42].

7.4 Research Axis 4: Social dynamics and Cyber-social networks

Participants: P. Frasca, M. Castaldo, N. Bouarour.

7.4.1 Opinion dynamics and social influence

Models of social influence are much studied in network science to understand the dynamics of opinions and beliefs. The team activity in this field has been focused on the following issue [57]. Social influence, through phenomena of imitation and peer pressure, tends to favour the agreement of opinions and beliefs: nevertheless, disagreement persists in social groups. How can we explain the persistence of disagreement? Our research has rigorously studied multiple mathematical models that aim to understand the persistence of disagreement. The most recent results regard the effects of limited confidence between peers [55], which can explain the formation of opinion groups. Studying these dynamics has required to solve delicate mathematical questions related to switching, nonsmooth and hybrid dynamical systems [54], [31].

Another line of research focuses on methods and algorithms to effectively influence opinions. Most methods are graph-theoretical in nature and are based on on looking for the most influential nodes [8]. The setup is the following: We suppose that one strategic agent must identify k target nodes in the network in order to maximally spread its preferred opinion. In the literature, this problem is cast as the maximization of a set function and, leveraging on the submodular property, is solved in a greedy manner by solving k+ separate single targeting problems. Our main contribution is to exploit the underlying graph structure to build more refined heuristics for dense and sparse graphs.

7.4.2 Attention dynamics in social media

According to some popular narrative, social media are plagued by issues like the viral diffusion of *fake news* and the formation of *filter bubbles*, that is situations in which an Internet user encounters only information and opinions that conform to and reinforce his/her own beliefs. Our research makes the hypothesis that these phenomena are a natural byproduct of the very nature of online social networks, which make interactions highly dynamical and introduce unprecedented effects of *feedback* and scale through the action of algorithms that measure, personalize, and monetize an individual's online experience [72]. Our research more precisely concentrates on what we can call "trending bubbles": digital media and their algorithms concentrate the public debate, drawing a disproportionate amount of attention on a few items and then away from them in a very short time. These effects derive from the tendency to emphasize novelty and timeliness in terms of identifying unprecedented surges of activity. Concretely, this line of research aims at identifying the concentration and scattering of media attention through a parsimonious mathematical model that captures the time evolution of collective behaviors. We have already developed a mathematical model for the attention dynamics [9] and we are currently testing the predictions of the model on data sets collected with our partners at CIS, Paris, to record the fruition of contents on selected YouTube channels and on Twitter. We are also looking for similar dynamics of attention in other situations where large numbers of individuals interact: relevant instances of such collective dynamics are large-scale scientific collaborations like the PolyMath project that we study in [11].

7.4.3 Feedback in recommendation systems

In online platforms, recommender systems are responsible for directing users to relevant contents. In order to enhance the users engagement, recommender systems adapt their output to the reactions of the users, who are in turn affected by the recommended contents. This reciprocal influence creates a feedback loop that is the focus of our work. Our main result so far has been a tractable analytical model of a user that interacts with an online news aggregator [19]. Creating this model has required three delicate steps:

1. defining the model of the user (who assimilates the received information with a confirmation bias);
2. defining the model of the recommender (that proposes items with the goal of maximizing the number of user's clicks);
3. specifying their interconnection, that is, the information that they exchange.

This model is able to analytically underline the feedback loop between the evolution of the users opinion and the personalised recommendation of contents, and yields qualitative predictions that support the concerns about potential long-term effects on the consumption of contents by users. Ongoing work is addressing the experimental validation of these results.

8 Bilateral contracts and grants with industry

Participants: H. Fourati, C. Canudas de Wit.

TMI-V "Tachymètre Magnéto-Inertiel couplé Vision)." Co-PI: H. Fourati (2018-2022).

Abstract: The objective of the TMI-V project is the indoor localization without infrastructure, by developing an autonomous, precise, robust solution with no prior knowledge of the environment integrated in equipment worn on the upper body to be used in virtual reality and augmented reality applications. An array of magnetometers and inertial sensors will be used. The project is ongoing, in collaboration with SysNav company.

FAUCON "Fusion AUtonome de Capteurs Optroniques-électromagnétiques-inertiels pour la navigation du système de combat aérien future - Partie A: Navigation et Géolocalisation par Vision" in collaboration with the companies "Safran Electronique & Défense" and "Thales AVS", funded by the "Direction Générale de l'Armement (DGA)", 2021-2022. Contact: H. Fourati

Abstract: During this project, it will be a question of proposing new techniques and new perspectives based on vision data and on inertial measurements of high quality (like that which can be found on high-performance sensors, with a performance class better than 1 Nautical/hour for example). More specifically, it is therefore a question of identifying the candidate architectures of Navigation and Geolocation systems by vision coupled with inertial, making it possible to meet the emerging performance needs of future platforms. The work will include a bibliographic study, as well as a model (for example Matlab) without depriving themselves of the most audacious and innovative solutions.

OpNet IFPEN-INRIA, "Optimal urban mobility network design for sustainable space sharing between vehicles and soft transport modes" (2022-2025)
Abstract: This project aims to find the optimal topological structure of a road network that can be modeled in several layers, each representing a mode of transport. The primary objective of this network is to optimize the mobility of people in urban areas in terms of environmental impacts and exposure to pollutant concentrations. In practice, the optimization variables considered are the location and size (or capacity) of new roads, the change in traffic direction, new public transport lines, the location of new cycle paths, the sizing low emission zones (or arcs of the road graph with restricted access), etc. To achieve this objective of topological optimization of the mobility network, an important part of the thesis will have to be devoted to the analysis of mobility data. Indeed, the different graph structures that can be explored in this thesis and which are often transformations of the original road graph according to mathematical laws, require a calibration of the parameters which will be made from real mobility data. Learning techniques will therefore be used to extract useful information from the various sources of mobility data, among which an important role will be played by the mobility data available at IFPEN, in particular Geco air and Geovelo data.

9 Partnerships and cooperations

9.1 International initiatives

9.1.1 Participation in other International Programs

PHC (Partenariat Hubert Curien)

PercepTrans

Participants: Kibangou Alain, Fourati Hassen.

Title: Merging perception and quantitative measurements to assess quality of service in public transportation using machine learning techniques

Partner Institutions
- University of Johannesburg, South Africa

Date/Duration: Jan 2021-Dec 2023

Additionnal info/keywords: Public transportation; Machine learning; user perpection.

9.2 International research visitors

9.2.1 Visits of international scientists

Walter MUSAKWA

Status Researcher

Institution of origin: University of Johannesburg

Country: South Africa

Dates: July 4-14; Nov. 7-16.

Context of the visit: Exchanges within the PercepTrans project framework

Mobility program/type of mobility: research stay

Retsepile KALAOANE

Status PhD student

Institution of origin: University of Johannesburg

Country: South Africa

Dates: July 4-31; Nov. 7-Dec. 3.

Context of the visit: Exchanges within the PercepTrans project framework

Mobility program/type of mobility: research stay

9.2.2 Visits to international teams

Research stays abroad

Kibangou Alain

Visited institution: University of Johannesburg

Country: South Africa

Dates: April 14-29; Oct. 19-30

Context of the visit: Exchanges within the PercepTrans project framework.

Mobility program/type of mobility: research stay, lecture

9.3 European Initiatives

Scale-FreeBack ERC Advanced Grant (2016–2022). PI: C. Canudas de Wit.

Abstract: The overall aim of Scale-FreeBack is to develop holistic scale-free control methods of controlling complex network systems in the widest sense, and to set the foundations for a new control theory dealing with complex physical networks with an arbitrary size. Scale-FreeBack envisions devising a complete, coherent design approach ensuring the scalability of the whole chain (modelling, observation, and control). It is also expected to find specific breakthrough solutions to the problems involved in managing and monitoring large-scale road traffic networks. Field tests and other realistic simulations to validate the theory will be performed using the equipment available at the Grenoble Traffic Lab center and a microscopic traffic simulator replicating the full complexity of the Grenoble urban network. See also: scale-freeback.eu

9.4 National initiatives

HANDY (Hybrid and Networked Dynamical Systems). ANR PRC (2019-2023). Co-PI: P. Frasca.

Abstract: Networked dynamical systems are ubiquitous in current and emerging technologies. From energy grids, fleets of connected autonomous vehicles to online social networks, the same scenario arises in each case: dynamical units interact locally to achieve a global behavior. When considering a networked system as a whole, very often continuous-time dynamics are affected by instantaneous changes, called jumps, leading to so-called hybrid dynamical systems. Hybrid phenomena thus play an essential role in these control applications, and call upon the development of novel adapted tools for stability and performance analysis and control design. In this context, the aim of HANDY project is to provide methodological control-oriented tools for realistic networked models, which account for hybrid phenomena. The project brings together researchers from LAAS in Toulouse, CRAN in Nancy, GIPSA in Grenoble and LSS in Gif-sur-Yvette, with expertise in various domains of automatic control, ranging from geometric control and optimization, switched systems, hybrid dynamics, nonlinear control, and multi-agent systems. See also: projects.laas.fr/handy

DOOM (Systems-theory for the Disorders Of OnlineMedia). 80 PRIME grant from CNRS MITI (2019–2022). PI: P. Frasca.

Abstract: Online social media have a key role in contemporary society and the debates that take place on them are known to shape political and societal trends. For this reason, pathological phenomena like the formation of "filter bubbles" and the viral propagation of "fake news" are observed with concern. The scientific assumption of this proposal is that these information disorders are direct consequences of the inherent nature of these communication media, and more specifically of the collective dynamics of attention thereby. In order to capture these dynamics, this proposal advocates the mathematical modelling of the interplay between the medium (algorithmic component) and the users (human component). The resulting dynamics shall be explored by a system-theoretic approach, using notions such as feedback and stability. This quantitative and rigorous approach will not only unlock fundamental insights but also deliver suggestions on suitable policies to manage the media. See also: cis.cnrs.fr/doom

Vaccination strategies for epidemics on finite and infinite networks. MODCOV19 2021 post-doc grant from CNRS (2022). PIs: Pierre-André Zitt (Université Gustave Eiffel, LAMA), Jean-François Delmas (Ecole des Ponts ParisTech, CERMICS), Paolo Frasca and Federica Garin.

Abstract: The Covid-19 pandemics has shown to which extent epidemics may be a global issue, with the virus propagating on a social network that arguably contains the whole world population, something like 8 billion nodes. Propagation models do exist and massive simulations can be performed, but are not easy to deploy on such a large scale and in presence of large uncertainties. Hence, analytical insights based on sound mathematical approximations of large networks are valuable and have the potential to lead to policy recommendations. This project proposes to push forward the theory of infinite-dimensional epidemic models by building upon recent advances on the approximation of large networks by graphons. Graphons are continuous approximations of realistic families of graphs and therefore excellent models to describe large networks: indeed, analysis and design results that are obtained on graphons have guaranteed implications for large networks.

9.5 Regional initiatives

ON-ROUTE Initiative de Recherche Grenoble Alpes (IRGA). PI: A. Kibangou (2021-2024). Co-PI: P. Frasca

Abstract: Nowadays, millions of users regularly seek routing advice from Online Routing Applications (ORAs) like Waze, Google Maps and TomTom. Their adoption is so pervasive that ORAs have the potential to influence the patterns of congestion in traffic networks and the modal split in multimodal transportation networks. Online routing can be seen as an example of "social feedback" from the users, where information is collectively gathered from and used to influence back a complex dynamical system, whose evolution depends on the users' choices. Online routing is in general formulated as a multicriteria optimization problem which is solved by the ORA to satisfy the user utilities, while the transportation network manager aims at optimizing some overall measure of the efficiency of the network. To fulfill its purpose, the network manager (at the level of a city, for instance, or at larger scale) has the possibility to intervene through multiple control actions (such as variable speed limits, ramp metering, access control, traffic lights) and by setting regulatory policies for the ORAs activities. It is therefore crucial for the network manager to understand the dynamics induced by ORAs in order to take adequate control actions and set effective regulatory policies. Unlike most existing projects and works, which mainly study the problem from the service providers' points of view in order to generate smart routing or parking recommendations, we adopt the point of view of the transportation network manager that seeks to optimize the overall system. This project therefore aims at (i) analyzing the effect of online routing on transportation network congestion; and (ii) introducing mitigation strategies against the adverse effects of ORAs through control actions (variable speed limits, ramp metering, access control, traffic lights) and regulatory policies (frequency of routing recommendations).

10 Dissemination

Participants: C. Canudas de Wit, H. Fourati, P. Frasca, F. Garin, A. Kibangou.

10.1 Promoting scientific activities

10.1.1 Scientific events: selection

H. Fourati has been

- Member of the Conference Editorial Board of the IEEE Control Systems Society (CDC and ACC), 2021-present.
- Member of the Conference Editorial Board of the IEEE robotics and automation society (RAS), with main task of coordinating reviews of regular papers submitted to the Society sponsored conference: the IEEE international conference on robotics and automation (ICRA), 2023.

F. Garin has been Associate Editor in the following editorial board:

- "European Control Association (EUCA) Conference Editorial Board" (ECC) since 2017

10.1.2 Journal

C. Canudas de Wit has been

- Senior Editor of the Asian Journal of Control AJC

- Senior Editor of IEEE Transactions on Control of Networks Systems IEEE-TCNS
- Editorial Advisory Board of Transportation Research part C

H. Fourati has been

- Associate editor at IEEE Transactions on Automation Science and Engineering (TASE).
- Associate editor at IEEE sensors journal (SJ).

P. Frasca has served in the editorial boards of

- Automatica, Associate Editor (2021–2024)
- Asian Journal of Control (Wiley), Associate Editor (2017–2022)

F. Garin has been

- Associate Editor in the editorial board of IEEE Control Systems Letters, since Dec. 2021

A. Kibangou has been

- Associate Editor in the editorial board of IEEE Transactions on Control of Networks Systems IEEE-TCNS since Jan. 2022

10.1.3 Invited talks

Alain Kibangou gave a public lecture titled 'Opportunities and Challenges of flexible mobility in modern cities' on April 20, 2022 at University of Johannesburg (South Africa). Paolo Frasca has given talks on "The closed loop between opinion formation and personalised recommendations" at the Workshop on Stochastic modeling and complex networks: application to the dynamics of opinions in social networks (Avignon, October 2022) and at the Laboratoire Jacques-Louis Lions, Paris Sorbonne (November 25, 2022).

10.1.4 Leadership within the scientific community

SAGIP C. Canudas-de-Wit has been member of the 'Conseil d'Administration' of SAGIP, the French Society of Automatic Control and Industrial Engineering (2019-2022)
CNU H. Fourati is an elected member of CNU61 (Conseil National des Universités, Génie informatique, Automatique et Traitement du Signal), since 2015. The CNU61 committee oversees promotions of university lecturers all over France.
GdR MACS P. Frasca is member of the steering committee of the GdR MACS, a body that is funded by CNRS and coordinates national activities in Automatic Control in France, 2019–2023
IEEE and IFAC C. Canudas de Wit is Fellow of the IEEE and of the IFAC (International Federation of Automatic Control), both since 2016. P. Frasca is Senior member of the IEEE since 2018. Team members participate to the following technical committees of IEEE Control Systems Society and of the IFAC: IEEE-CSS Technical Committee "Networks and Communications Systems" (P. Frasca and F. Garin); IFAC Technical Committee 1.5 on Networked Systems (P. Frasca and C. Canudas de Wit); IFAC Technical Committee 2.5 on Robust Control (P. Frasca); IFAC Technical Committee 7.1 Automotive Control (C. Canudas de Wit); IFAC Technical Committee 7.4 Transportation systems (C. Canudas de Wit); IFAC TC 9.2. Systems and Control for Societal Impact (P. Frasca).

10.1.5 Scientific expertise

Alain Kibangou served as reviewer for the ERC StG call. Paolo Frasca served as reviewer for the ERC CoG call.
C. Canudas de Wit has been HCERES expert for the evaluation of the LITIS research laboratory, 2022.
Hassen Fourati has been member of 5th Kimura best paper award selection committee for nomination of best paper published in 2021 at Asian journal of control (AJC).

C. Canudas de Wit has been chair of the selection committer for the IFAC-High Impact Paper 2022 prize.

10.1.6 Research administration

Inria Carlos Canudas de Wit has been member of the 'Commission de Evaluation'.
Inria Grenoble Several team members have been involved in committees at Inria Grenoble Rhône-Alpes. C. Canudas de Wit is a member of the COST-Inria-RA (Conseil d'Orientation Scientifique et Technologique, Inria Rhône-Alpes), since 2017. F. Garin has been president (since July 2019) of 'Comité des Emplois Scientifiques' (post-docs and 'délégations'). H. Fourati has been a member of 'Commission de développement technologique' (research engineers), since 2022.
GIPSA-lab F. Garin is 'responsable du pôle automatique et diagnostic' (chair of the Automatic Control and Diagnostics division) at GIPSA-lab, since Jan 2020. A. Kibangou is an elected member of 'Conseil de laboratoire' of GIPSA-lab, since Jan 2020.
Persyval-lab F. Garin has been member of the research committee of PERSYVAL-Lab LabEx as co-leader of the research axis on cyber-physical systems (since 2019).
UGA A. Kibangou is in his second term as an elected member of "Conseil du pôle MSTIC" at Univ. Grenoble Alpes. He has been member of this council since 2016. H. Fourati is member of "Conseil documentaire" of University Grenoble Alpes representing the discipline "Sciences and technologies", 2020-2023.

10.2 Teaching - Supervision - Juries

10.2.1 Teaching

H. Fourati gives each year around 250h of lectures and labs on average for first and second year students at the electrical engineering department (GEII) of IUT1, and third year students of bachelor's degree at Univ. Grenoble Alpes. The courses include Mathematics, logics, networks and automatic control. He also teaches for the MARS master of the University of Grenoble.
P. Frasca has lectured about Intelligent Transportation Systems & Coordination of Autonomous Vehicles in the Master Autonomous and Robotics Systems (MARS) of the University of Grenoble (8h in 2022).
F. Garin gives each year a class 'Distributed Algorithms and Network Systems', 13.5h, M2, Univ. Grenoble Alpes.
A. Kibangou gives each year 250h of lectures and labs on average for first and second year students at the electrical engineering department (GEII) of IUT1 at Univ. Grenoble Alpes. The courses include Control theory and Mathematics. He is director of studies for the second year of the BUT program (Bachelor Universitaire de Technologie) and responsible of Control theory teaching.

10.2.2 Supervision

- PhD: Maria Castaldo, Attention dynamics on YouTube: conceptual models, temporal analysis of engagement metrics, fake views, Univ. Grenoble Alpes, Nov. 2022, co-advised by P. Frasca and Tommaso Venturini and Floriana Gargiulo (Centre Internet et Société, CNRS)
- PhD: Pierre Gogendeau, Système multi-capteurs embarqué pour la géolocation d'animaux marins, Univ. Montpellier, from Sept. 2019, Nov. 2022, co-advised by Serge Bernard (LIRMM Montpellier), Sylvain Bonhommeau (IFREMER) and H. Fourati
- PhD: Renato Vizuete, Contributions to open multi-agent systems: consensus, optimization and epidemics, Univ. Paris-Saclay, Sept. 2022, co-advised by Elena Panteley and P. Frasca
- PhD: Ujjwal Pratap, Estimation and control for resilience in large-scale network systems, Univ. Grenoble Alpes, Sept. 2022, co-advised by C. Canudas de Wit, F. Garin, and H. Sandberg (KTH Stockholm).
- PhD in progress: Ghadeer Shaaban, Magneto-visual-inertial navigation with invariance and learning: Improving estimation in benign cases and under attacks, from October 2022, co-advised by A. Kibangou, H. Fourati and C. Prieur
- PhD in progress: Tommaso Toso, Online Routing Recommendations in Multimodal Transportation Networks, from October 2021, co-advised by A. Kibangou and P. Frasca.

- PhD in progress: Retsepile Kalaoane, Quality of service in public transportation: case analysis of Braamfontein, Johannesburg, from November 2021, co-advised by A. Kibangou, T. Gumbo, W. Musakwa and I. Musonda (Univ. of Johannesburg).
- PhD in progress: Nomfundo Cele, Perception of Quality of Service on public transportation in developing countries, from November 2020, co-advised by A. Kibangou and W. Musakwa (Univ. of Johannesburg).
- PhD in progress: Nassim Bouarour, User behavior and recommendation systems, from Oct. 2020, co-advised by Sihem Amer-Yahia (LIG Grenoble), Idir Benouaret (LIG Grenoble) and P. Frasca.
- PhD in progress: Tarso Kraemer Sarzi Sartori, Mitigation of radiation effects on the attitude estimation processing of autonomous things, from Oct. 2020, co-advised by R. Possamai Bastos (TIMA Grenoble) and H. Fourati.

10.2.3 Juries

P. Frasca has been member of the following Ph.D. defense committees:

- Carmela Bernardo. *Convergence analysis of heterogeneous opinion dynamics with bounded confidence and stubbornness*. University of Sannio, Benevento, Italy. Ph.D. advisor: Francesco Vasca, *External referee*, 2022
- Zohreh Sanai. *Coordination of Open Multi-Agent Systems*. University of Cagliari, Italy. PhD advisors: Carla Seatzu and Mauro Franceschelli. January 2022

F. Garin has been member of the following Ph.D. defense committees:

- Bikash Adhikari, Univ. Lorraine, Nancy, July 2022
- Renato Vizuete, Univ. Paris-Saclay, Sept. 2022

A. Kibangou has been member of the following Ph.D. defense committees:

- Antoine Lebon, Univ. Toulon, Toulon, July 2022 (Reviewer)
- Maria Castaldo, Univ. Grenoble Alpes, Grenoble, Nov. 2022
- Roza Cherfi, Univ. Grenoble Alpes, Grenoble, Dec. 2022

F. Garin has been member of the recruiting committee for a MCf (assistant professor) position, sect. 61, at École Centrale Lille.

11 Scientific production

11.1 Major publications

[1] V. Giammarino, S. Baldi, P. Frasca and M. L. Delle Monache. 'Traffic Flow on a Ring With a Single Autonomous Vehicle: An Interconnected Stability Perspective'. In: *IEEE Transactions on Intelligent Transportation Systems* 22.8 (Aug. 2021), pp. 4998–5008. DOI: 10.1109/TITS.2020.2985680. URL: https://hal.inria.fr/hal-03011895.

[2] M. U. B. Niazi, C. Canudas de Wit and A. Kibangou. 'Average State Estimation in Large-scale Clustered Network Systems'. In: *IEEE Transactions on Control of Network Systems* 7.4 (Dec. 2020), pp. 1736–1745. DOI: 10.1109/TCNS.2020.2999304. URL: https://hal.archives-ouvertes.fr/hal-02524982.

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