



IN PARTNERSHIP WITH:
CNRS

**Université Claude Bernard
(Lyon 1)**

**Ecole normale supérieure de
Lyon**

Activity Report 2014

Team DANTE

Dynamic Networks : Temporal and Structural Capture Approach

IN COLLABORATION WITH: Laboratoire de l'Informatique du Parallélisme (LIP)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Networks and Telecommunications

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Team DANTE

Keywords: Graph Theory, Signal Processing, Stochastic Models, Network Science, Distributed Algorithms

Creation of the Team: 2012 November 01, *updated into Project-Team:* 2015 January 01.

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2. Overall Objectives

2.1. Overall Objectives

The goal of DANTE is to develop **novel models, algorithms and methods to analyse the dynamics of large-scale networks**, (*e.g. social networks, technological networks such as the Web and hyperlinks, Articles and co-citation, email exchanges, economic relations, bacteria/virus propagation in human networks...*). Large datasets describing such networks are nowadays more "accessible" due to the emergence of online activities and new techniques of data collection. These advantages provide us an unprecedented avalanche of large data sets, recording the digital footprints of millions of entities (*e.g. individuals, computers, documents, stocks, etc.*) and their temporal interactions.¹ Such large amount of information allows for easier and more precise traceability of social activities, better observation of the structural and temporal evolution of social/technological/economical networks, the emergence of their localized and cascading failures, and provides information about the general roles of self-organization in an interdisciplinary sense. All these questions represent a major scientific, economic, and social challenge, which has the potential to revolutionize our understanding of the arising socio-technical world of our age.

Our main challenge is to propose **generic methodologies and concepts to develop relevant formal tools to model, analyse the dynamics and evolution of such networks, that is, to formalise the dynamic properties of both structural and temporal interactions of network entities/relations:**

- **Ask** application domains relevant questions, to learn something new about such domains instead of merely playing with powerful computers on huge data sets.
- **Access** and collect data with adapted and efficient tools. This includes a reflexive step on the biases of the data collected and their relations to real activities/application domain.
- **Model** the dynamics of networks by analyzing their structural and temporal properties jointly, inventing original approaches combining graph theory with signal processing. A key point is to capture temporal features in the data, which may reveal meaningful insights on the evolution of the networks.
- **Interpret** the results, make the knowledge robust and useful in order to be able to control, optimise and (re)-act on the network structure itself and on the protocols exchange/interactions in order to obtain a better performance of the global system.

The challenge is to solve a major scientific puzzle, common to several application domains (*e.g., sociology, information technology, epidemiology*) and central in network science: how to understand the causality between the evolution of macro-structures and individuals, at local and global scales?

3. Research Program

3.1. Graph-based signal processing

Participants: Christophe Crespelle, Éric Fleury, Paulo Gonçalves, Márton Karsai, Benjamin Girault.

Evolving networks can be regarded as "out of equilibrium" systems. Indeed, their dynamics is typically characterized by non standard and intricate statistical properties, such as non-stationarity, long range memory effects, intricate space and time correlations.

¹YouTube claims to receive 48 hours of video every minute, Google and Facebook represent major world companies that generate millions of traces on our activities every second. Every day, hundreds of millions of posts are added to the blogosphere, from which information on citizen opinions and their evolutions can be collected.

Analyzing, modeling, and even defining adapted concepts for dynamic graphs is at the heart of DANTE. This is a largely open question that has to be answered by keeping a balance between specificity (solutions triggered by specific data sets) and generality (universal approaches disconnected from social realities). We will tackle this challenge from a graph-based signal processing perspective involving signal analysts and computer scientists, together with experts of the data domain application. One can distinguish two different issues in this challenge, one related to the graph-based organisation of the data and the other to the time dependency that naturally exists in the dynamic graph object. In both cases, a number of contributions can be found in the literature, albeit in different contexts. In our application domain, high-dimensional data "naturally reside" on the vertices of weighted graphs. The emerging field of signal processing on graphs merges algebraic and spectral graph theoretic concepts with computational harmonic analysis to process such signals on graphs [48].

As for the first point, adapting well-founded signal processing techniques to data represented as graphs is an emerging, yet quickly developing field which has already received key contributions. Some of them are very general and delineate ambitious programs aimed at defining universal, generally unsupervised methods for exploring high-dimensional data sets and processing them. This is the case for instance of the « diffusion wavelets » and « diffusion maps » pushed forward at Yale and Duke [33]. Others are more traditionally connected with standard signal processing concepts, in the spirit of elaborating new methodologies via some bridging between networks and time series, see, *e.g.*, ([43] and references therein). Other viewpoints can be found as well, including multi-resolution Markov models [51], Bayesian networks or distributed processing over sensor networks [42]. Such approaches can be particularly successful for handling static graphs and unveiling aspects of their organisation in terms of dependencies between nodes, grouping, etc. Incorporating possible time dependencies within the whole picture calls however for the addition of an extra dimension to the problem "as it would be the case when switching from one image to a video sequence", a situation for which one can imagine to take advantage of the whole body of knowledge attached to non-stationary signal processing [34].

3.2. Theory and Structure of dynamic Networks

Participants: Christophe Crespelle, Éric Fleury, Anthony Busson, Márton Karsai.

Characterization of the dynamics of complex networks. We need to focus on intrinsic properties of evolving/dynamic complex networks. New notions (as opposed to classical static graph properties) have to be introduced: rate of vertices or links appearances or disappearances, the duration of link presences or absences. Moreover, more specific properties related to the dynamics have to be defined and are somehow related to the way to model a dynamic graph.

Through the systematic analysis and characterization of static network representations of many different systems, researchers of several disciplines have unveiled complex topologies and heterogeneous structures, with connectivity patterns statistically characterized by heavy-tails and large fluctuations, scale-free properties and non trivial correlations such as high clustering and hierarchical ordering [45]. A large amount of work has been devoted to the development of new tools for statistical characterisation and modelling of networks, in order to identify their most relevant properties, and to understand which growth mechanisms could lead to these properties. Most of those contributions have focused on static graphs or on dynamic process (*e.g.* diffusion) occurring on static graphs. This has called forth a major effort in developing the methodology to characterize the topology and temporal behavior of complex networks [45], [36], [52], [41], to describe the observed structural and temporal heterogeneities [30], [36], [31], to detect and measure emerging community structures [35], [49], [50], to see how the functionality of networks determines their evolving structure [40], and to determine what kinds of correlations play a role in their dynamics [37], [39], [44].

The challenge is now to extend this kind of statistical characterization to dynamical graphs. In other words, links in dynamic networks are temporal events, called contacts, which can be either punctual or last for some period of time. Because of the complexity of this analysis, the temporal dimension of the network is often ignored or only roughly considered. Therefore, fully taking into account the dynamics of the links into a network is a crucial and highly challenging issue.

Another powerful approach to model time-varying graphs is via activity driven network models. In this case, the only assumption relates to the distribution of activity rates of interacting entities. The activity rate is realistically broadly distributed and refers to the probability that an entity becomes active and creates a connection with another entity within a unit time step [47]. Even the generic model is already capable to recover some realistic features of the emerging graph, its main advantage is to provide a general framework to study various types of correlations present in real temporal networks. By synthesizing such correlations (*e.g.* memory effects, preferential attachment, triangular closing mechanisms, ...) from the real data, we are able to extend the general mechanism and build a temporal network model, which shows certain realistic feature in a controlled way. This can be used to study the effect of selected correlations on the evolution of the emerging structure [38] and its co-evolution with ongoing processes like spreading phenomena, synchronisation, evolution of consensus, random walk etc. [38], [46]. This approach allows also to develop control and immunisation strategies by fully considering the temporal nature of the backgrounding network.

3.3. Distributed Algorithms for dynamic networks: regulation, adaptation and interaction

Participants: Thomas Begin, Anthony Busson, Paulo Gonçalves, Isabelle Guérin Lassous.

Dedicated algorithms for dynamic networks. First, the dynamic network object itself trigger original algorithmic questions. It mainly concerns distributed algorithms that should be designed and deployed to efficiently measure the object itself and get an accurate view of its dynamic behavior. Such distributed measure should be "transparent", that is, it should introduce no bias or at least a bias that is controllable and corrigible. Such problem is encountered in all distributed metrology measures / distributed probes: P2P, sensor network, wireless network, QoS routing... This question raises naturally the intrinsic notion of adaptation and control of the dynamic network itself since it appears that autonomous networks and traffic aware routing are becoming crucial.

Communication networks are dynamic networks that potentially undergo high dynamicity. The dynamicity exhibited by these networks results from several factors including, for instance, changes in the topology and varying workload conditions. Although most implemented protocols and existing solutions in the literature can cope with a dynamic behavior, the evolution of their behavior operates identically whatever the actual properties of the dynamicity. For instance, parameters of the routing protocols (*e.g.* hello packets transmission frequency) or routing methods (*e.g.* reactive / proactive) are commonly hold constant regardless of the nodes mobility. Similarly, the algorithms ruling CSMA/CA (*e.g.* size of the contention window) are tuned identically and they do not change according to the actual workload and observed topology.

Dynamicity in computer networks tends to affect a large number of performance parameters (if not all) coming from various layers (*viz.* physical, link, routing and transport). To find out which ones matter the most for our intended purpose, we expect to rely on the tools developed by the two former axes. These quantities should capture and characterize the actual network dynamicity. Our goal is to take advantage of this latter information in order to refine existing protocols, or even to propose new solutions. More precisely, we will attempt to associate "fundamental" changes occurring in the underlying graph of a network (reported through graph-based signal tools) to quantitative performance that are matter of interests for networking applications and the end-users. We expect to rely on available testbeds such as Senslab and FIT to experiment our solutions and ultimately validate our approach.

4. Application Domains

4.1. Life Science & Health

In parallel to the advances in modern medicine, health sciences and public health policy, epidemic models aided by computer simulations and information technologies offer an increasingly important tool for the

understanding of transmission dynamics and of epidemic patterns. The increased computational power and use of Information and Communication Technologies make feasible sophisticated modeling approaches augmented by detailed in vivo data sets, and allow to study a variety of possible scenarios and control strategies, helping and supporting the decision process at the scientific, medical and public health level. The research conducted in the DANTE project finds direct applications in the domain of LSH since modeling approaches crucially depend on our ability to describe the interactions of individuals in the population. In the MOSAR/iBird project we are collaborating with the team of Pr. Didier Guillemot (Inserm/Institut. Pasteur/Université de Versailles). Within the TUBEXPO and ARIBO projects, we are collaborating with Pr. Jean-Christophe Lucet (Professeur des université Paris VII, Praticien hospitalier APHP).

4.2. Network Science / Complex networks

In the last ten years the science of complex networks has been assigned an increasingly relevant role in defining a conceptual framework for the analysis of complex systems. Network science is concerned with graphs that map entities and their interactions to nodes and links. For a long time, this mathematical abstraction has contributed to the understanding of real-world systems in physics, computer science, biology, chemistry, social sciences, and economics. Recently, however, enormous amounts of detailed data, electronically collected and meticulously catalogued, have finally become available for scientific analysis and study. This has led to the discovery that most networks describing real world systems show the presence of complex properties and heterogeneities, which cannot be neglected in their topological and dynamical description. This has called forth a major effort in developing the methodology to characterize the topology and temporal behavior of complex networks, to describe the observed structural and temporal heterogeneities, to detect and measure emerging community structure, to see how the functionality of networks determines their evolving structure, and to determine what kinds of correlations play a role in their dynamics. All these efforts have brought us to a point where the science of complex networks has become advanced enough to help us to disclose the deeper roles of complexity and gain understanding about the behavior of very complicated systems.

In this endeavor the DANTE project targets the study of dynamically evolving networks, concentrating on questions about the evolving structure and dynamical processes taking place on them. During the last year we developed several projects along these lines concerning three major datasets:

- Mobile telephony data: In projects with academic partners and Grandata we performed projects based on two large independent datasets collecting the telephone call and SMS event records for million of anonymized individuals. The datasets record the time and duration of mobile phone interactions and some coarse grained location and demographic data for some users. In addition one of the dataset is coupled with anonymised bank credit information allowing us to study directly the socioeconomic structure of a society and how it determines the communication dynamics and structure of individuals.
- Skype data: Together with Skype Labs/STACC and other academic groups we were leading projects in the subject of social spreading phenomena. These projects were based on observations taken from a temporally detailed description of the evolving social network of (anonymized) Skype users registered between 2003 and 2011. This data contains dates of registration and link creation together with gradual information about their location and service usage dynamics.
- Twitter data: In collaboration with ICAR-ENS Lyon we collected a large dataset about the microblogs and communications of millions of Twitter users in the French Twitter space. This data allows us to follow the spreading of fads/opinions/hashtags/ideas and more importantly linguistic features in online communities. The aim of this collaboration is to set the ground for a quantitative framework studying the evolution of linguistic features and dialects in an social-communication space mediated by online social interactions.

5. New Software and Platforms

5.1. Sensor Network Tools: drivers, OS and more

As outcomes of the Equipped FIT IoT-LAB, ANR SensLAB project and the Inria ADT SensTOOLS and SensAS, several softwares (from low level drivers to OSes) were delivered and made available to the research community. The main goal is to lower the cost of developing/deploying a large scale wireless sensor network application. All software are gathered under the IoT-LAB web site: <https://www.iot-lab.info> web page where one can find:

- low C-level drivers to all hardware components;
- ports of the main OS, mainly FreeRTOS, Contiki, TinyOS, Riot, Linux;
- ports and development of higher level library like routing, localization.

IoT-LAB software is licensed under a CeCILL License. IoT-LAB users are welcome to contribute code, papers, tutorials or experiments reports.

5.2. Queueing Systems

Online tool: <http://queueing-systems.ens-lyon.fr>

This tool aims at providing a simple web interface to promote the use of our proposed solutions to numerically solve classical queueing systems. It is a joint project between Thomas Begin (DANTE) and Pr. Brandwajn (UCSC). This tool supported since 2011 attracts each month hundreds of visitors from all around the world. Its current implementation includes the solution to:

- a queue with multiple servers, general arrivals, exponential services and a possibly finite buffer (*i.e.*, $Ph/M/c/N$ -like queue) (refer to [32] for more details);
- a single server queue with Poisson arrivals, general services and a possibly finite buffer (*i.e.*, $M/Ph/1/N$ -like queue);
- a queue with multiple servers, general service times and Poisson arrivals (*i.e.*, $M/Ph/c/N$ -like queue) based on a recent work that was published in 2014 in Performance Evaluation [4]. Associated URL is: <http://queueing-systems.ens-lyon.fr>

6. New Results

6.1. Highlights of the Year

6.1.1. *The Internet of Things: A new equipments of excellence*

Inaugurated last autumn, the very large scale IoT-LAB platform (<https://www.iot-lab.info>) is strengthening the capabilities of the FIT equipment of excellence dedicated to the Internet of Things. Offering a unique wide-ranging collection of equipment, these laboratories are available to both researchers and commercial companies alike.

IoT-LAB is a large-scale experimental platform for communicating objects and networks of sensors. It enables the rapid deployment of experiments and the collection of large amounts of data. It includes over 2700 sensor nodes, distributed over six sites in France, offering a wide range of different processor architectures and radio components. IoT-LAB is available for use on line. It is already used by over 300 users in forty countries, including around ten commercial companies. As of the end of October 2014, some 10 000 experiments had already been carried out.

6.1.2. *Graph-based signal processing*

Our first results towards the definition of a digital framework for signal processing on graphs constitutes an important outcome of DANTE's activity in 2014. Our participation to this emerging discipline was marked with several scientific recognitions: publication in the main DSP conference [14], involvement in the first ANR project focusing on this theme and retained for funding (2015-2019), we are in charge of the organisation of a Special Session dedicated to "Methodologies for signal processing on graphs" at Eusipco conference (2015).

6.1.3. Complex contagion process

Diffusion of innovation can be interpreted as a social spreading phenomena governed by the impact of media and social interactions. Although these mechanisms have been identified by quantitative theories, their role and relative importance are not entirely understood, since empirical verification has so far been hindered by the lack of appropriate data. Here we analyse a dataset recording the spreading dynamics of the world's largest Voice over Internet Protocol service to empirically support the assumptions behind models of social contagion. We show that the rate of spontaneous service adoption is constant, the probability of adoption via social influence is linearly proportional to the fraction of adopting neighbors, and the rate of service termination is time-invariant and independent of the behavior of peers. By implementing the detected diffusion mechanisms into a dynamical agent-based model, we are able to emulate the adoption dynamics of the service in several countries worldwide. This approach enables us to make medium-term predictions of service adoption and disclose dependencies between the dynamics of innovation spreading and the socioeconomic development of a country. This work was recently published in the *Journal of the Royal Society Interface*.

6.2. Diffusion and dynamic of complex networks

Participants: Márton Karsai [correspondant], Éric Fleury, Christophe Crespelle.

Time varying networks and the weakness of strong ties We analyse a mobile call dataset and find a simple statistical law that characterizes the temporal evolution of users' egocentric networks. We encode this observation in a reinforcement process defining a time-varying network model that exhibits the emergence of strong and weak ties. We study the effect of time-varying and heterogeneous interactions on the classic rumor spreading model in both synthetic, and real-world networks. We observe that strong ties severely inhibit information diffusion by confining the spreading process among agents with recurrent communication patterns. This provides the counterintuitive evidence that strong ties may have a negative role in the spreading of information across networks.

Complex contagion process in spreading of online innovation [8]. Here we analyse a dataset recording the spreading dynamics of the world's largest Voice over Internet Protocol service to empirically support the assumptions behind models of social contagion. We show that the rate of spontaneous service adoption is constant, the probability of adoption via social influence is linearly proportional to the fraction of adopting neighbors, and the rate of service termination is time-invariant and independent of the behavior of peers. By implementing the detected diffusion mechanisms into a dynamical agent-based model, we are able to emulate the adoption dynamics of the service in several countries worldwide. This approach enables us to make medium-term predictions of service adoption and disclose dependencies between the dynamics of innovation spreading and the socio-economic development of a country.

The role of endogenous and exogenous mechanisms in the formation of R&D networks [10]. Here we propose a general modeling framework that includes both endogenous and exogenous mechanisms of link formations in networks with tunable relative importance. The model contains additional ingredients derived from empirical observations, such as the heterogeneous propensity to form alliances and the presence of circles of influence, i.e. clusters of firms in the network. We test our model against the Thomson Reuters SDC Platinum dataset, one of the most complete datasets available nowadays, listing cross-country R&D alliances from 1984 to 2009. Interestingly, by fitting only three macroscopic properties of the network, this framework is able to reproduce a number of microscopic measures characterizing the network topology, including the distributions of degree, local clustering, path length and component size, and the emergence of network clusters. Furthermore, by estimating the link probabilities towards newcomers and established firms from the available data, we find that endogenous mechanisms are predominant over the exogenous ones in the network formation. This quantifies the importance of existing network structures in selecting partners for R&D alliances.

Controlling Contagion Processes in Time-Varying Networks [9]. In this project we derive an analytical framework for the study of control strategies specifically devised for time-varying networks. We consider the removal/immunization of individual nodes according to their activity in the network and develop a block variable mean-field approach that allows the derivation of the equations describing the evolution of the contagion process concurrently to the network dynamic. We derive the critical immunization threshold and assess the effectiveness of the control strategies. Finally, we validate the theoretical picture by simulating numerically the information spreading process and control strategies in both synthetic networks and a large-scale, real-world mobile telephone call dataset.

Data-driven spreading for the detection of weak ties [24]. In this work we propose a new method to infer the strength of social ties by using new data-driven simulation techniques. We qualify links by the importance they play during the propagation of information in the social structure. We apply data-driven spreading processes combined with a river-basin algorithmic method to identify links, which are the responsible to bring the information to large number of nodes. We investigate the correlations of the new importance measure with other conventional characteristics and identify their best combination through a percolation analysis to sophisticate further the assignment of social tie strengths. Finally we explore the role of the identified high importance links in control of globally spreading processes through data-driven SIR model simulations. These results point out that the size of infected population can be reduced considerably by weakening interactions through ties with high importance but zero overlap compared to strategies based on dyadic communications.

Dynamic Contact Network Analysis in Hospital Wards [18]. We analyse a huge and very precise trace of contact data collected during 6 months on the entire population of a rehabilitation hospital. We investigate the graph structure of the average daily contact network. Our main results are to unveil striking properties of this structure in the considered hospital, and to present a methodology that can be used for analyzing any dynamic complex network where nodes are classified into groups.

6.3. Performance analysis and networks protocols

Participants: Anthony Busson [correspondant], Thomas Begin, Isabelle Guérin Lassous.

Modeling and optimization of CSMA/CA in VANET [7]. We propose a simple theoretical model to compute the maximum spatial reuse feasible in a VANET. We focus on the ad hoc mode of the IEEE 802.11p standard. Our model offers simple and closed-form formulas on the maximum number of simultaneous transmitters, and on the distribution of the distance between them. It leads to an accurate upper bound on the maximum capacity. In order to validate our approach, results from the analytical models are compared to simulations performed with the network simulator NS-3. We take into account different traffic distributions (traffic of vehicles), and study the impact of this traffic on capacity. An application of this work is the parameterization of the CSMA/CA mechanism.

Fast and accurate approximate performance analysis of multi-server facilities [4]. Systems with multiple servers are common in many areas and their correct dimensioning is in general a difficult problem under realistic assumptions on the pattern of user arrivals and service time distribution. We present an approximate solution for the underlying $Ph/Ph/c/N$ queueing model. Our approximation decomposes the solution of the $Ph/Ph/c/N$ queue into solutions of simpler $M/Ph/c/N$ and $Ph/M/c/N$ queues. To further mitigate dimensionality issues, for larger numbers of servers and/or service time phases, we use a reduced state approximation to solve the $M/Ph/c/N$ queue. The proposed approach is conceptually simple, easy to implement and produces generally accurate results for the mean number in the system, as well as the loss probability. Typical relative errors for these two quantities are below 5%. A very significant speed advantage compared to the numerical solution of the full $Ph/Ph/c/N$ queue can be gained as the number of phases representing the arrival process and/or the number of servers increases.

Interference and throughput in spectrum sensing cognitive radio networks using point processes .

Spectrum sensing is vital for secondary unlicensed nodes to coexist and avoid interference with

the primary licensed users in cognitive wireless networks. In this paper, we develop models for bounding interference levels from secondary network to the primary nodes within a spectrum sensing framework. Instead of classical stochastic approaches where Poisson point processes are used to model transmitters, we consider a more practical model which takes into account the medium access control regulations and where the secondary Poisson process is judiciously thinned in two phases to avoid interference with the secondary as well as the primary nodes. The resulting process will be a modified version of the Matérn point process. For this model, we obtain bounds for the complementary cumulative distribution function of interference and present simulation results which show the developed analytical bounds are quite tight. Moreover, we use these bounds to find the operation regions of the secondary network such that the interference constraint is satisfied on receiving primary nodes. We then obtain theoretical results on the primary and secondary throughputs and find the throughput limits under the interference constraint.

Modeling of IEEE 802.11 Multi-hop Wireless Chains with Hidden Nodes [11]. We follow up an existing modeling framework to analytically evaluate the performance of multi-hop flows along a wireless chain of four nodes. The proposed model accounts for a non-perfect physical layer, handles the hidden node problem, and is applicable under workload conditions ranging from flow(s) with low intensity to flow(s) causing the network to saturate. Its solution is easily and quickly obtained and delivers estimates for the expected throughput and for the datagram loss probability of the chain with a good accuracy.

Anticipation of ETX Metric to manage Mobility in Ad Hoc Wireless Networks [19]. When a node is moving in a wireless network, the routing metrics associated to its wireless links may reflect link quality degradations and help the routing process to adapt its routes. Unfortunately, an important delay between the metric estimation and its inclusion in the routing process makes this approach inefficient. In this paper, we introduce an algorithm that predicts metric values a few seconds in advance, in order to compensate the delay involved by the link quality measurement and their dissemination by the routing protocol. We consider classical metrics, in particular ETX (Expected Transmission Count) and ETT (Expected Transmission Time), but we combine their computations to our prediction algorithm. Extensive simulations show the route enhancement as the Packet Delivery Ratio (PDR) is close to 1 in presence of mobility.

6.4. Graphs & Signal Processing

Participants: Paulo Gonçalves [correspondant], Éric Fleury, Christophe Crespelle.

6.4.1. Signal Processing on Graphs

Semi-Supervised Learning for Graph to Signal Mapping: a Graph Signal Wiener Filter Interpretation [14]. We investigate a graph to signal mapping with the objective of analyzing intricate structural properties of graphs with tools borrowed from signal processing. We successfully use a graph-based semi-supervised learning approach to map nodes of a graph to signal amplitudes such that the resulting time series is smooth and the procedure efficient and scalable. Theoretical analysis of this method reveals that it essentially amounts to a linear graph-shift-invariant filter with the a priori knowledge put into the training set as input. Further analysis shows that we can interpret this filter as a Wiener filter on graphs. We finally build upon this interpretation to improve our results.

6.4.2. Graphs

(Nearly-)tight bounds on the contiguity and linearity of cographs [6]. In this paper we show that the contiguity and linearity of cographs on n vertices are both $O(\log n)$. Moreover, we show that this bound is tight for contiguity as there exists a family of cographs on n vertices whose contiguity is $\Omega(\log n)$. We also provide an $\Omega(\log n / \log \log n)$ lower bound on the maximum linearity of cographs on n vertices. As a by-product of our proofs, we obtain a min-max theorem, which is worth of interest in itself, stating equality between the rank of a tree and the minimum height of one of its path partitions.

6.4.3. Signal processing

Analysis of intrapartum foetal heart rate (FHR), enabling early detection of foetal acidosis to prevent asphyxia and labour adverse outcomes, remains a challenging signal processing task. In this direction, we carried out a series of works to characterize the fetal heart rate variability with specific attributes able to discriminate between healthy fetuses and fetuses presenting a risk of brain injury. Last year, we investigated two different approaches:

Nearest-Neighbor based Wavelet Entropy Rate Measures for Intrapartum Fetal Heart Rate Variability [23].

Firstly, we showed that a k-nearest neighbor procedure yields estimates for entropy rates that are robust and well-suited to FHR variability. Secondly, we experimentally proved that entropy rates measured on multiresolution wavelet coefficients permit to improve classification performance.

Impacts of labour first and second stages on Hurst parameter based intrapartum FHR analysis [22]. In this study, we proposed to quantify the FHR temporal dynamics with a Hurst exponent estimated within a wavelet framework. Analyses performed over a large (3049 records) and well documented database revealed that the evolution of the Hurst exponent during delivery, is significantly different for healthy fetuses and for acidotic fetuses.

6.5. Complex network metrology

Participant: Christophe Crespelle.

Measuring the Degree Distribution of Routers in the Core Internet [15]. Most current models of the internet rely on knowledge of the degree distribution of its core routers, which plays a key role for simulation purposes. In practice, this distribution is usually observed directly on maps known to be partial, biased and erroneous. This raises serious concerns on the true knowledge one may have of this key property. Here, we design an original measurement approach targeting reliable estimation of the degree distribution of core routers, without resorting to any map. It consists in sampling random core routers and precisely estimate their degree thanks to probes sent from many distributed monitors. We run and assess a large-scale measurement following this approach, carefully controlling and correcting bias and errors encountered in practice. The estimate we obtain is much more reliable than previous knowledge, and it shows that the true degree distribution is very different from all current assumptions.

Measuring Routing Tables in the Internet [21]. The most basic function of an Internet router is to decide, for a given packet, which of its interfaces it will use to forward it to its next hop. To do so, routers maintain a routing table, in which they look up for a prefix of the destination address. The routing table associates an interface of the router to this prefix, and this interface is used to forward the packet. We explore here a new measurement method based upon distributed UDP probing to estimate this routing table for Internet routers.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

7.1.1. HiKoB

Participant: Éric Fleury.

A bilateral contract has been signed between the DANTE Inria team and HiKoB to formalise their collaboration in the context of the Equipex FIT (Futur Internet of Things) FIT is one of 52 winning projects in the Equipex research grant program. It will set up a competitive and innovative experimental facility that brings France to the forefront of Future Internet research. FIT benefits from 5.8 euros million grant from the French government Running from 22.02.11 – 31.12.2019. The main ambition is to create a first-class facility to promote experimentally driven research and to facilitate the emergence of the Internet of the future.

7.1.2. Orange R&D

Participant: Isabelle Guérin Lassous.

A contract has been signed between Inria and France Télécom for the PhD supervision of Laurent Reynaud. The PhD thesis subject concerns mobility strategies for fault resilience and energy conservation in wireless networks.

7.1.3. GranDATA

Participants: Márton Karsai [correspondant], Éric Fleury.

Founded in 2012, Grandata is a Palo Alto-based company that leverages advanced research in Human Dynamics (the application of “big data” to social relationships and human behavior) to identify market trends and predict customer actions. Leading telecom and financial services firms are using Grandata’s Social Universe product to transform “big data” into impressive business results.

The DANTE team and Grandata started to collaborate in 2014 on the analysis of large datasets provided by the company. The aim of the collaboration is to gain better understanding about the dynamical patterns of human interactions, mobility, and the socio-economic structure of the society. As a part of this collaboration Carlos Sarraute (Grandata - R&D Director) visited the Dante team on November and Yannick Leo (DANTE - PhD student) visited Grandata office in Buenos Aires in 2014 December.

7.1.4. STACC, Skype/Microsoft Labs

Participant: Márton Karsai [correspondant].

The Software Technology and Applications Competence Centre (STACC) is a research and development centre conducting high-priority applied research in the field of data mining and software and services engineering. Together with Skype/Microsoft Labs, STACC maintains a long lasting research collaboration with Márton Karsai (DANTE) on the modeling the adoption dynamics of online services.

7.2. Inria Alcatel-Lucent Bell Labs joint laboratory

Participants: Isabelle Guérin Lassous, Paulo Gonçalves, Thomas Begin, Éric Fleury [correspondant].

The main scientific objectives of the collaboration within the framework Inria Alcatel-Lucent Bell Labs joint laboratory is focused on network science:

- to design efficient tools for measuring specific properties of large scale complex networks and their dynamics;
- to propose accurate graph and dynamics models (*e.g.*, generators of random graph fulfilling measured properties);
- to use this knowledge with an algorithmic perspectives, for instance, for improving the QoS of routing schemes, the speed of information spreading, the selection of a target audience for advertisements, etc.

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. IXXI

8.1.1.1. *Linguistic usage and social networks: agent based models and direct observation of verbal interactions. (ULMMA)*

Participants: Éric Fleury, Márton Karsai.

8.1.1.2. *A sociolinguistics of Twitter : social links and linguistics variation*

Participants: Éric Fleury, Márton Karsai.

8.2. National Initiatives

8.2.1. ANR

8.2.1.1. *Equipex FIT (Futur Internet of Things)*

Participant: Éric Fleury.

FIT is one of 52 winning projects in the Equipex research grant program. It will set up a competitive and innovative experimental facility that brings France to the forefront of Future Internet research. FIT benefits from 5.8€ million grant from the French government Running from 22.02.11 – 31.12.2019. The main ambition is to create a first-class facility to promote experimentally driven research and to facilitate the emergence of the Internet of the future.

8.2.1.2. *ANR INFRA DISCO (DIstributed SDN COntrollers for rich and elastic network services)*

Participants: Thomas Begin [correspondant], Anthony Busson, Isabelle Guérin Lassous.

The DANTE team will explore the way SDN (Software Designed Network) can change network monitoring, control, urbanisation and abstract description of network resources for the optimisation of services. More specifically, the team will address the issues regarding the positioning of SDN controllers within the network, and the implementation of an admission control that can manage IP traffic prioritization.

8.2.1.3. *ANR REFLEXION (REsilient and FLEXible Infrastructure for Open Networking)*

Participants: Thomas Begin [correspondant], Anthony Busson, Isabelle Guérin Lassous.

The DANTE team will work on the monitoring of NFV proposing passive and light-weight metrology tools. They will then investigate the modeling of low-level resources consumptions and finally propose methods to dynamically allocate these resources taking into account performance constraints.

8.2.1.4. *ANR CONTINT CODDDE*

Participants: Éric Fleury [correspondant], Christophe Crespelle, Márton Karsai.

It is a collaborative project between the ComplexNetwork team at LIP6/UPMC; Linkfluence and Inria Dante. The CODDDE project aims at studying critical research issues in the field of real-world complex networks study:

- How do these networks evolve over time?
- How does information spread on these networks?
- How can we detect and predict anomalies in these networks?

In order to answer these questions, an essential feature of complex networks will be exploited: the existence of a community structure among nodes of these networks. Complex networks are indeed composed of densely connected groups of that are loosely connected between themselves.

The CODDDE project will therefore propose new community detection algorithms to reflect complex networks evolution, in particular with regards to diffusion phenomena and anomaly detection.

These algorithms and methodology will be applied and validated on a real-world online social network consisting of more than 10 000 blogs and French media collected since 2009 on a daily basis (the dataset comprises all published articles and the links between these articles).

8.2.1.5. *ANR RESCUE*

Participants: Thomas Begin, Isabelle Guérin Lassous [correspondant].

In the RESCUE project, we investigate both the underlying mechanisms and the deployment of a substitution network composed of a fleet of dirigible wireless mobile routers. Unlike many projects and other scientific works that consider mobility as a drawback, in RESCUE we use the controlled mobility of the substitution network to help the base network reduce contention or to create an alternative network in case of failure. The advantages of an on-the-fly substitution network are manifold: Reusability and cost reduction; Deployability; Adaptability.

The RESCUE project addresses both the theoretical and the practical aspects of the deployment of a substitution network. From a theoretical point of view, we will propose a two-tiered architecture including the base network and the substitution network. This architecture will describe the deployment procedures of the mobile routing devices, the communication stack, the protocols, and the services. The design of this architecture will take into account some constraints such as quality of service and energy consumption (since mobile devices are autonomous), as we want the substitution network to provide more than a best effort service. From a practical point of view, we will provide a proof of concept, the architecture linked to this concept, and the necessary tools (*e.g.*, traffic monitoring, protocols) to validate the concept and mechanisms of on-the-fly substitution networks. At last but not least, we will validate the proposed system both in laboratory testbeds and in a real-usage scenario.

8.2.1.6. ANR FETUSES

Participant: Paulo Gonçalves.

The goals of this ANR project consist in the development of statistical signal processing tools dedicated to per partum fetal heart rate characterization and acidosis detection, and are organized as follows: *(i)* construction of a large dataset of per partum fetal heart rate recordings, which is well documented and of significant clinical value; *(ii)* Developments of adaptive (*e.g.* data driven) algorithms to separate data into trend (deceleration induced by contractions) and fluctuation (cardiac variability) components; *(iii)* Developments of algorithms to characterize the non stationary and multifractal properties of per partum fetal heart rate ; *(iv)* Acidosis detection and assessment using the large datasets; *(v)* Algorithm implementation for performing tests in real clinical situations. ANR is a joint project between DANTE, the Physics Lab of ENS de Lyon (SiSyPhe team) and the *Hôpital Femme-Mère-Enfant* of Bron (Lyon). Fetuses started in january 2012 and will end in june 2015.

8.3. European Initiatives

8.3.1. Collaborations with Major European Organizations

University of Namur: Department of Mathematics/Naxys (Belgium). Collaboration with Renaud Lambiotte on dynamical processes on dynamical networks and communities detections.

Aalto University: Department of Biomedical Engineering and Computational Science (Finland). Collaboration with Jari Saramaki on modeling temporal networks and community like modular structure

Central European University (Hungary). Collaboration with János Kertész on modeling complex contagion phenomena.

ISI Foundation (Italy). Collaboration with Laetitia Gauvin on multiplex networks and transportation systems

UPC (Spain): Department of Telematic Engineering. Collaboration with Monica Aguilar Igartua and Luis J. de la Cruz Llopis on vehicular and community networks.

University of Bergen: Institute of Computer Science (Norway). Collaboration with Pinar Heggernes on graph editing problems for analysis and modeling of complex networks.

Ecole Polytechnique Fédérale de Lausanne (Switzerland). Collaboration with Pierre Vandergheynst on Graph Signal Processing

8.4. International Initiatives

8.4.1. Inria International Partners

8.4.1.1. Declared Inria International Partners

- Taiwan, ACADEMIA SINICA & IIIS. Signature of a MoU in the framework of IoT-LAB.

8.4.2. Participation in other International Programs

8.4.2.1. STIC AMSUD

- Understanding and predicting human demanded COntent and mObiLity (UCOOL). To define solutions for the identification and modeling of correlations between the user mobility – describing changes in the user positioning and the current environment he/she is in – and the traffic demand he/she generates. Partners are: LNNC Brasil, Facultad de Ingeniería, Universidad de Buenos Aires (FI/UBA), Universidad Tecnica Federico Santa Maria (USM) Chile,

8.5. International Research Visitors

8.5.1. Visits of International Scientists

8.5.1.1. Invited professors

Ha Duong PHAN (invited professor of ENS Lyon and UCBL)

Date: March 2014 - April 2014

Institution: Institute of Mathematics of the Vietnam Academy of Science and Technology (Vietnam).

Alexandre BRANDWAJN (Invited Inria Researcher Program)

Date: September 29, 2014 - October 29, 2014

Institution: University of California, Santa Cruz (USA).

8.5.1.2. Invited researchers

Laetita Gauvin

Date: one week each month, February 2014 - December 2014

Institution: ISI Foundation (Italy)

Tommaso Panini (PhD Student)

Date: from Oct 2014 until Jan 2014

Institution: Collegio Carlo Alberto (Italy)

Andres Marcelo Vazquez Rodasi (PhD Student)

Date: from un 2014 until Sep 2014

Institution: UPC (Spain)

8.5.1.3. Internships

Karathanos Christos

Date: Apr 2014 - Jul 2014

Institution: Université Nationale Capodistrienne d'Athènes (Greece)

8.5.2. Visits to International Teams

8.5.2.1. Research stays abroad

- Thomas Begin, 2 weeks in Spring 2014, University of California Santa Cruz, Jack Baskin School of Engineering, USA.
- Christophe Crespelle, 1 week in December 2014, Institute of Computer Science of the University of Bergen, Norway.

- Christophe Crespelle is in CNRS delegation for 1 year (2014-2015) at the Institute of Mathematics, Vietnam Academy of Science and Technology, Hanoi.
- Christophe Crespelle, 2 months in June-July 2014, Vietnam Institute for Advanced Study in Mathematics (VIASM), Hanoi.
- Christophe Crespelle, 2 months in January-February 2014, Institute of Mathematics, Vietnam Academy of Science and Technology, Hanoi.
- Márton Karsai, 2 times 2 weeks in March and July 2014, Department of Biomedical Engineering and Computational Science, Aalto University, Finland
- Márton Karsai, 1 week June 2014, ISI Foundation Torino, Italy
- Márton Karsai, 1 week December 2014, Central European University, Hungary

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific events organisation

9.1.1.1. General chair, scientific chair

- Márton Karsai was organiser of the Computational Social Science, ECCS 2014 satellite.

9.1.2. Scientific events selection

9.1.2.1. Chair of conference program committee

- Paulo Gonçalves is officer of the local liaison board of EURASIP
- Anthony Busson was TPC (Technical Program Chair) of ISNCC 2014
- Isabelle Guérin Lassous was Program co-Chair of ACM International Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks (PE-WASUN 2014)

9.1.2.2. Member of the conference program committee

- Paulo Gonçalves is PC member of IWCMC - TRAC 2014.
- Christophe Crespelle is PC member of AlgoTel 2014
- Éric Fleury is PC member of Networking 2014
- Éric Fleury is PC member of NetSciCom 2014
- Isabelle Guérin Lassous is PC member of MSWiM 2014, IPDPS 2014, ICC 2014, Globecom 2014 and MedHocNet 2014.
- Márton Karsai is PC member of CSS ECCS'14

9.1.2.3. Invited talks

- Márton Karsai was invited lecturer at RESCOM Summer School - (May 2014, Furiani, Corsica, France)
- Márton Karsai was invited speaker at TNetSphys'14 - NetSci'14 Symposium (June 2014, University of California, Berkeley, CA, USA)
- Márton Karsai was invited speaker at Complex Networks and Dynamics - ICCSA'14 Satellite meeting (June 2014, Le Havre, France)
- Márton Karsai was invited speaker at Institute of Research and Development (October 2014, Bondy, Paris, France)
- Paulo Gonçalves was invited keynote speaker at the international conference CLOSER 2014.

9.1.3. Journal

9.1.3.1. Member of the editorial board

- Isabelle Guérin Lassous is a member of the editorial board of: Computer Communications (Elsevier), Ad Hoc Networks (Elsevier) and Discrete Mathematics & Theoretical Computer Science.

9.1.3.2. Reviewer

- Márton Karsai was acting as reviewer in Physical Review X, EPJ Data Science, New Journal of Physics, PLoS ONE, Transactions on Network Science and Engineering, Nature Scientific Reports, Physica Scripta, Network Science, Europhysics Letters
- P. Gonçalves was reviewer for *IEEE Signal Processing* (transactions on, letters), *EURASIP J. on Advances in Signal Processing*.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

9.2.1.1. Teaching by *Éric Fleury*

Éric Fleury is Professor at the Computer Science department of ENS de Lyon and holds a Inria chair.

Master : CR15 - Complex Networks, 18H, M2, ENS de Lyon, France

Licence/Master : Alter-disciplinary course, Complexe network: an interdisciplinary approche 6H, L3, M1, M2, ENS de Lyon, France

9.2.1.2. Teaching by *Thomas Begin*

Licence : "Networks", 18h, Bachelor (L3), University Lyon 1, France

Master : "Networking", 63h, Master (M1), University Lyon 1, France

Master : "Advanced Networks", 50h, Master (M2), University Lyon 1, France

Master : "Computer Networks", 12h, Master (M1), ENS de Lyon, France

9.2.1.3. Teaching by *Christophe Crespelle*

Master : "Introduction to Graph Algorithms", 21h, Master (1st year), Institute of Mathematics Hanoi, Vietnam

Licence : "Combinatorial Optimization", 12h, Bachelor (4th year), Vietnam National University of Hanoi, Vietnam

Master : "Introduction to Graph Algorithms", 30h, Master (1st year), Institute of Mathematics Hanoi, Vietnam

9.2.1.4. Teaching by *Isabelle Guérin Lassous*

Professor at Université Claude Bernard Lyon 1 in the Computer Science since 2006. She lectures at the University.

Master : "Networking", 20h, Master (M1), University Lyon 1, France

Master : "QoS and Multimedia Networks", 30h, Master (M2), University Lyon 1, France

Master : "Wireless Networks", 15h, Master (M2), University Lyon 1, France

Master : "Introduction to Networking", 30h, Master (M2), University Lyon 1, France

9.2.1.5. Teaching by *Márton Karsai*

Márton Karsai is an Assistant Professor at ENS Lyon in the Computer Science Department since 2013 and holds a Inria Chair. He is the co-responsible for the Complex Networks Master 2 program. His lectures in 2014:

Master : CR15 - Complex Networks, 18H, M2, ENS de Lyon, France

Master : Dynamical Processes on Networks, 4H, M2, ENS de Lyon, France

Master : Modelling Social Systems, 6H, M2, ENS de Lyon, France

Licence/Master : Alter-disciplinary course, Complexe network: an interdisciplinary approach 4H, L3, M1, M2, ENS de Lyon,

9.2.1.6. Teaching by Paulo Gonçalves

Postgraduate level: Course (theory and practice) on Signal Processing (80 hours Eq. TD), CPE Lyon, France.

9.2.2. Supervision

9.2.2.1. Defended

Shubhabrata Roy, A Complete Framework for Modelling Workload Volatility of a VoD System: a Perspective to Probabilistic Management, Université de Lyon, June 2014, P. Gonçalves and T. Begin

9.2.2.2. In Progress

- Thiago Abreu, Modeling and performance analysis of IEEE 802.11-based chain networks, Université de Lyon, defense scheduled on Mars 2015, I. Guérin-Lassous and T. Begin
- Lucie Martinet, Dynamic contact networks and diffusion process, Oct 2011, E. Fleury and C. Crespelle
- Benjamin Girault, Signal processing on graph, Oct 2012, E. Fleury and P. Gonçalves
- Matteo Morini, New tools for understanding the dynamics of social networks, Oct 2013, E. Fleury, P. Jensen and M. Karsai
- Yannick Leo, Diffusion process and community structure in complex networks, Oct 2013, E. Fleury, C. Crespelle, and M. Karsai
- Huu Nghi Nguyen, Admission control and controllers allocation for SDN networks, Sept 2014, I. Guérin Lassous, A. Busson and T. Begin
- Mohammed Amer, Optimisation and planning of Wi-Fi based networks: SDN paradigm, Nov 2014, I. Guérin Lassous, A. Busson
- Elie Rotenberg, An approach for a reliable estimation of the properties of the Internet topology, September 2010, Matthieu Latapy and Christophe Crespelle
- Laurent Reynaud, Optimized mobility strategies for interference tolerance and energie saving in wireless networks, Oct 2013, . Guérin Lassous

9.2.3. Juries

Eric Fleury was member of the PhD examination board of: Nicolas Tremblay, Daniel Bernades.

Eric Fleury was member of the HdR examination board of: Michael Hauspie, Pierre Borgnat.

Anthony Busson was reviewer and member of the PhD examination board of: Sebastien Faye, Salim Allal.

Christophe Crespelle was member of the PhD examination board of Pham Van Trung, Vietnam Academy of Science and Technology.

Isabelle Guérin Lassous was member of the PhD examination board of: Jordan Augé (reviewer)

Isabelle Guérin Lassous was member of the HdR examination board of: Nadjib Achir (reviewer), Hervé Rivano, Tara Ali Yahya (reviewer), Marco Fiore.

Paulo Gonçalves was reviewer and member of the PhD examination board of Sergey Kirgizov.

9.3. Popularization

- Interview of E. Fleury for X:ENIUS on arte TV: *Big data : opportunity or curse ?* (<http://www.arte.tv/guide/fr/051094-020/x-enius>)
- Interview of M. Karsai for Campus Channel TV: *Master 2 program of Complex Networks* (<https://www.youtube.com/watch?v=k7I1m1NCbTU>)

9.4. Institutional commitment

- Éric Fleury is Vice-Chairman of the Inria Grenoble Rhône Alpes projects committee
- Éric Fleury is member of the Inria Evaluation Committee and member of the board.
- Éric Fleury is member of the junior research position (CR2) jury at Inria Sophia
- Éric Fleury is member of the research (CR1) jury at Inria Sophia
- Éric Fleury is member of the Starting Research Position and Advanced Research position jury
- Paulo Gonçalves is scientific correspondent of the International Relations for Inria Grenoble - Rhône-Alpes
- Paulo Gonçalves is member of the *Comité de Développement Technologique* of Inria Grenoble - Rhône-Alpes
- Isabelle Guérin Lassous is member of the researcher support commission of the Inria Grenoble Rhône Alpes

9.5. Collective Responsibilities outside Inria

- Éric Fleury is Co-chair of the Networking group ResCom of the CNRS GDR ASR. He is also a member of the scientific committee of the GDR ASR.
- Éric Fleury is in the in the Executive Committee of the IXXI – Rhône-Alpes Complex Systems Institute.
- Éric Fleury has been an expert for the Fund for Scientific Research - FNRS.
- Paulo Gonçalves is scientific correspondent of the International Relations for the Computer Science Department at ENS Lyon.
- Isabelle Guérin Lassous is member of the CNRS National Committee for section 06 (Computer Science).
- Isabelle Guérin Lassous was the chair of the AERES expert committee of CALMIP.
- Christophe Crespelle is member of the Council of the LIP laboratory.
- Christophe Crespelle is member of the steering committee of the IXXI – Rhône-Alpes Complex Systems Institute.
- Christophe Crespelle was expert for Nafosted (National funding agency for research in Vietnam) in Computer Science in 2014.
- Thomas Begin is an elected member of the Council of the LIP laboratory.
- Thomas Begin is an elected member of the Advisory Committee for the department Computer Science for University Lyon 1.
- Márton Karsai is the co-responsible of the Complex Networks Master 2 program at ENS Lyon.

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

- [1] S. ROY. *A Complete Framework for Modelling Workload Volatility of VoD System - a Perspective to Probabilistic Management*, Ecole normale supérieure de Lyon - ENS LYON, June 2014, <https://tel.archives-ouvertes.fr/tel-01061418>

Articles in International Peer-Reviewed Journals

- [2] G. BIRGAND, C. AZEVEDO COSTE, G. TOUPET, R. PISSARD-GIBOLLET, B. GRANDBASTIEN, E. FLEURY, J.-C. LUCET. *Attitude and infectious risk in the operating room - The ARIBO study protocol*, in "BMJ Open", January 2014, vol. 4, n^o 1, 8 p. [DOI : 10.1136/BMJOPEN-2013-004274], <http://hal-lirmm.ccsd.cnrs.fr/lirmm-00916840>
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