DOCTORAL PROGRAM IN INFORMATION TECHNOLOGY

Chair:
Prof. Carlo Fiorini

Introduction

The PhD program in Information Technology (IT) goes back to the year 2001, when the two traditional programs in Automation-Computer Engineering and Electronics-Telecommunications were merged. As such, the unified course covers the research interests in four scientific areas, namely Computer Science and Engineering, Electronics, Systems and Control, and Telecommunications. This broad variety of research activities is completely focused in the ICT area, and perfectly corresponds to the core mission of the Dipartimento di Elettronica e Informazione (DEI). However, pursuant the history of the Department, and following the new trends of the modern society, some cross-related research fields are also encouraged, such as ecology, environmental modelling, operations research, and transportation systems. The PhD program in IT is the largest at the Politecnico in terms of number of students. There are more than 50 first year students and about 150 in total. The students are subject to an examination every year to evaluate the progress achieved in their research and course work.

Topics

The research carried out in the Department (including 35 between computing or experimental laboratories) can be subdivided into 4 main areas:
Computer Science and Engineering (Vice-Coordinator: Prof. Andrea Bonarini): Information systems, Database management, Information design for the web, Methods and applications for interactive multimedia, Embedded systems design and design methodologies, Dependable systems: performance, security and reliability, Autonomous robotics, Artificial intelligence, Computer vision and image analysis, Machine learning, DEpendable Evolvable Pervasive Software Engineering, Compiler Technology, Natural Language Processing and Accessibility.
Electronics (Vice-Coordinator: Prof. Angelo Geraci): Circuits and systems: theory and applications, Single-photon detectors and applications, Radiation detectors and low noise electronics, Electronic circuit design, Electron devices.
Systems and Control (Vice-Coordinator: Prof. Carlo Piccardi): Control systems, Robotics and industrial automation, Optical measurements and laser instrumentation, Dynamics of complex system, Planning and management of environmental systems, Operations research and discrete optimization.
Telecommunications (Vice-Coordinator: Andrea Virgilio Monti Guarnieri): Networking, Applied electromagnetics, Information transmission and radio communications, Optical communications, Wireless and space communications, Remote sensing, Signal processing for multimedia and telecommunications

Industrial collaborations

Due to its intrinsic technological nature, the PhD curriculum is corroborated by many industrial collaborations. About 25% of the total number of scholarships are funded by industry or by international research projects involving industrial partners. In the school vision, the collaboration between university and industry is ideally based on the challenge of turning invention into technological innovation. This amounts to shaping new technology frontiers and to building a fertile atmosphere for a mixture of world-class research at universities and in private companies. This also amounts to creating a common terrain of friendly culture, to size the risk and to believe in strong basic research. The external referee board is composed by members of public and private companies, working in industry and in applied research. The board is in charge of monitoring the activities of the PhD program and giving suggestions for its development. The board meets once a year to point out the new emerging research areas worth to be investigated and to monitor the visibility of the course in the industrial world. In 2008, the PhD "Alumni Association" was started, that organizes a successful yearly scientific and relational event (PHDAEY).

Educational aspects

The teaching organization and subject of the courses reflect the scientific interests of DEI faculties. The curricula include a wide choice of courses (about 30 per year), of different nature. The challenge is to promote interdisciplinary research while offering technical advanced courses that spur innovative and cutting edge research. Therefore, particular attention is devoted to help each student to make the best choice according to an internal regulation scheme.

Internationalization

Every year, thanks to an extra budget offered by the Department, at least 10 courses are delivered by foreign professors. Moreover, the PhD program encourages joint curricula through agreements with foreign institutions. At present we count joint agreements for a Double PhD Program with the Wuhan University, China, that includes collaborative research, lectures, symposia and exchange of researchers, students and information; the cooperation with the Center for Communications and Signal Processing of the New Jersey Institute of Technology aimed at PhD co-tutoring in the area of wireless communication systems; the agreement for a joint Doctorate in Information and Communication Technology between DEI and the TELECOM Paristech (former ERNST), Paris, France; double PhD Program with Drexel University. The PhD program in Information Technology participates in ICO-NEH (International Curriculum Option of Doctoral, e

some activities are organized within the Network of Excellence EURO-NF (Network of the Future) and of ACCM, Austrian Centre of Competence in Mechatronics.
Every year at least 4 fellowships are assigned to foreign students, selected on the basis of their CV and research interest.

Conclusions

It is quite clear that the core mission is to offer an excellent PhD curriculum, through high quality courses, a truly interdisciplinary advanced education, cutting-edge research, and international and industrial collaborations.

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Flavio Gaj (Unicredit Spa)

Prizes and awards

In 2011 the following awards have been obtained by PhD students:

Chorafas Foundation Award: Andrea Abba, Carlo Ferrari

RANK JOINS FOR WEB BASED DATA SOURCES

Adnan Abid

Rank join operators perform a relational join among two or more relations, assign numeric scores to the join results based on the given scoring function and return K join results with the highest scores. The top-K join results are obtained by accessing a subset of data from the input relations, provided these relations provide the tuples in descending order of score. Several rank join operators have been proposed to compute top-K joins with various different settings and assumptions. Classical applications of rank join are concerned with data stored within databases, whereas, very few of them have considered top-K query processing for Web based data sources.

In this thesis, we address the problem of computing top-K join results from Web based data sources. Unlike the data stored in databases, the Web based data sources are characterized by non-negligible response time. This delay in data extraction slows down the execution of classical rank join algorithms, and they take a long time to get top-K joins. In this thesis, we propose score guided rank join algorithms with the following objectives: i) minimize the time to get top-K join results; ii) avoid the access to the data that does not contribute to the top-K join results.

Furthermore, two main join topologies are defined in databases, namely, parallel and pipe joins.
In parallel join topology, data extraction from data sources is independent of one another, and we can extract data in parallel. Instead, in pipe join topology, data extraction of one source depends upon data extracted from another source, hence, data extraction has to be pipe-lined. We present rank join algorithms for both these join topologies which are customized for Web based data sources. We analyse the effectiveness of our proposed rank join algorithms with extensive experimental evaluation with synthetic and real data sets. The results reveal that our propose algorithms minimize the time to get top-K joins, while incurring a few extra data accesses as compared to the optimal number of data accesses.

Most of the rank join operators store the results in an output buffer before reporting them. Because reporting of these results depends upon the score upper bound of all unseen join results. Especially, in the case of Web based data sources there is a large delay between observing and reporting of a join results, as they involve non-negligible response time. Therefore, we augment rank joins with a method to efficiently report a join result as soon as it is observed, with certain probabilistic guarantees to be among the final top-K joins. The experimental analysis of the results shows that on average our proposed probabilistic reporting algorithm reports the join results much earlier than the deterministic algorithms.

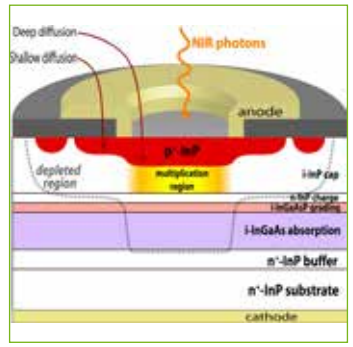
There are several future directions out of this work, for example, incorporating uncertain data for the Web based data sources to process rank joins can be an area to work. Similarly, processing rank joins with data sources for which we do not know chunk size or response time, which will be useful while using parallel and pipe joins in a single complex query plan. Apart from this, provisional reporting for pipe joins is another possible extension to this work. Lastly, computing maximum number of rank joins with a given number of fetches is again an interesting problem that emerges from the work done in this thesis.

InGaAs/InP SINGLE PHOTON AVALANCHE DETECTORS FOR THE NEAR INFRARED RANGE

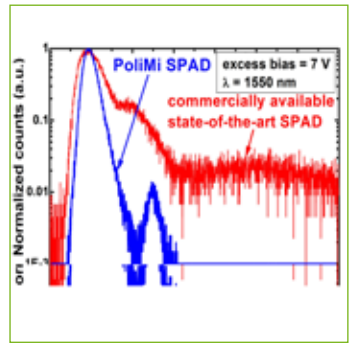
Fabio Acerbi

In the last years, single photon detection has become more and more important when very faint or ultra-fast optical signals must be measured. Advanced applications are found in many fields, such as measurement of fluorescent decays (in physics, chemistry and biology), single molecule detection, characterization of new materials, non-invasive testing of VLSI circuits, single-photon sources characterization, fiber-optics testing, laser-ranging in space and telemetry, quantum cryptography, quantum computing and studies of quantum physics. In order to be able to detect single photons, the sensor must have a very high sensitivity.
Different kinds of single-photon detectors have been developed. Among the others, solid-state detectors have the advantage of high reliability and robustness, and they can be very compact and portable. Single-photon Avalanche Diodes (SPADs) are very sensitive solid-state detectors with high detection efficiency and very sharp time resolution (tens of picoseconds). SPAD made in silicon have very low noise and high efficiency in the visible wavelength range, but they cannot be employed to detect photons in the near-infrared range, due to silicon absorption coefficient. Alternative materials must be explored, such as Germanium or InGaAs.

My Ph.D. research was focused on the study, the design, the fabrication and the characterization of new InGaAs/InP SPADs, for the detection of photons in the near-infrared range, up to 1700nm. This research exploited the collaboration with the Canadian National Research Council (NRC), where the devices were fabricated.
A detailed simulation activity was carried out to obtain the optimal structure for InGaAs/InP SPADs, analyzing the effect of all structural parameters on SPAD performance. Initially, a commercially-available simulator was employed to calculate the electric field inside the device, but it was inadequate to simulate the particular working conditions of SPAD. Thus, a custom "SPAD simulator" was developed, able to simulate the detection efficiency at different wavelength, the dark count rate and afterpulsing, at different temperatures and excess biases. Moreover, another 2D version of the simulator was developed to simulate the dependence of avalanche trigger efficiency on radial position, thus quantifying edge effects.
Thanks to several considerations and analysis on device structure and the simulation results, the new SPAD structure was designed. However, some physical properties of InGaAs and InP were not completely known and the simulation results were based on values reported in literature. Many different SPAD structures were designed with different diffusion masks, in order to experimentally study the effect of diffusion geometries on SPAD performances and to extract the unknown parameters. Moreover, some specific new structures were introduced, with special patterns in the diffusion masks, to improve SPAD performances. The manufacturing processes involved in SPAD production were analyzed in depth and, thanks to the collaboration with NRC, it was possible to slightly adapt it to our specific requirements. The zinc diffusion process was studied by means of several blanket and patterned diffusion tests, at different temperatures and flux rates of precursor gasses. The optimal ranges of diffusion conditions were obtained and employed in SPAD manufacturing.
Moreover, different wafers were grown, with the same doping and thicknesses but with different growth conditions in order to obtain the optimal conditions, giving lower defects concentration, thus the best SPAD performances.
Another important part of the present research activity was the characterization of commercially-available InGaAs/InP SPADs (with state-of-the-art performances).



1. Structure of a planar front-illuminated InGaAs/InP SPAD.



2. Timing response distribution of PoliMi SPADs and commercial available SPADs.

Detection efficiency, dark count rate, afterpulsing, timing jitter and uniformity of electric fields were measured and analyzed, not just to acquire data on their performances, but also to obtain information about behaviors and problems related to their fabrication. The main contributions to dark count rate were identified. Electric field uniformity was characterized with three different methods: bi-dimensional map of detection efficiency, acquisition of infrared emission and bi-dimensional scan of timing jitter. Results confirm that edge effect in commercial SPADs (with high multiplication region thickness) is strong and electric field in the center of active area is lower. This affects also the time resolution of the detector. Moreover, afterpulsing probabilities of different SPADs were measured by means of different methods, obtaining trap concentrations and release time constants.
Then, the PoliMi InGaAs/InP SPADs were produced and characterized. Unfortunately, it was observed that doping of charge layer cannot be controlled with sufficient precision by the fab, thus MOCVD reactor calibrations and other solutions was employed to obtain the designed values. Moreover, a large variation in semiconductor quality from one production batch to another was observed.
The performances of the first runs of PoliMi SPADs were promising. Afterpulsing, which is the main bottleneck of InGaAs/InP SPADs in many applications, is significantly lower in PoliMi SPADs than in commercial SPADs. This allows operating these detectors at higher repetition rates. Moreover, measurements show that the time resolution and the electric field uniformity of PoliMi SPADs are better than commercial SPADs and their time response shows a reduced tail and no second peaks, which demote the time resolution of new generation commercial InGaAs/InP SPADs. Detection efficiency is slightly lower than commercial SPADs (probably due to a lower absorption region thickness) and the dark count rate is comparable at low temperature, but it is higher at room temperature: this is likely due to the InGaAs quality, which must be improved. Moreover, by comparing the dark count rate of two PoliMi SPAD diffused at different temperatures, we observe that diffusion process significantly affect the defects concentration inside multiplication region.

ADVANCED RIDE-BY-WIRE SYSTEMS FOR LIGHT AND ELECTRIC VEHICLES

Giovanni Alli

In this thesis the development of two innovative vehicles for personal transportation will be described.
The first is a micro-vehicle, named Flyboard, which fits the mobility needs in internal wide areas (e.g. Expositions, Airports, Railway stations). Flyboard is basically a platform suspended on 4 wheels (2 driving wheels and 2 pivoting wheels). This vehicle can be driven by balancing the weight on the plantar foot sensors or by using a smartphone as a joystick.
The second vehicle is an electric pedal assisted bicycle (EPAC) that is energetically autonomous, that is the battery has never to be recharged. "Bike+", that is its name, maximize the metabolic efficiency of the cyclist, that is minimize his fatigue, by utilizing the system energy in a smart way. In order to achieve that goal the metabolic efficiency of the human engine has been inspected when a man is pedaling. After that an energy management algorithm has been developed in order to maximize the cyclist's efficiency.
Finally a new concept of multi-vehicle/multi-business vehicle sharing has been designed.
It is based on the "key-less mobility" idea, that is thanks to a smartphone application the user can access all the system services including, for instance, the vehicle ignition command.

TEST AND DIAGNOSIS STRATEGIES FOR DIGITAL DEVICES: METHODOLOGIES AND TOOLS

Luca Amati

This work proposes an adaptive diagnosis technique for complex digital device and system called Automatic Fault Detective. This technique is based on Bayesian Networks, it allows the description of the system at an high level of abstraction to simplify the task of test engineer teams. In this thesis, different directions of research are covered, aiming at an optimization of the cost of a diagnostic process: the identification of minimum cost initial test set for fault detection, an adaptive step-by-step execution sequencing of tests, a robustness analysis of the obtained diagnostic conclusions. The proposed methods are verified on both simulated systems (to prove correctness of results) and implemented on some real industrial case studies.

MODELING OF STATISTICAL VARIABILITY IN NANOSCALE CHARGE-TRAP FLASH MEMORIES

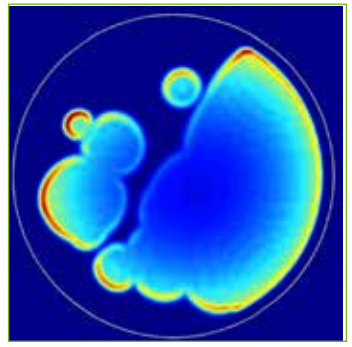
Salvatore Maria Amoroso

The ever growing market of mobile communication and digital consumer electronics has stimulated the rapid development of Flash memory technology. For more than 20 years the conventional floating-gate technology has been able to meet the requirements of higher storage density, higher programming/erasing speed, higher reliability and lower power design through a continuous scaling of the cell size. However, the floating gate technology faces nowadays difficult technical challenges and some physical limitations towards further scaling. The charge-trap memory cell is considered today the most practical evolution of the floating-gate Flash cell, allowing improved reliability and scaling perspectives. However, the discrete nature of the stored charge necessarily gives rise to statistical issues related to the number and position fluctuation of the electrons in the storage-layer, determining a statistical dispersion of the threshold voltage shift after the program operation. This statistical dispersion is expected to be further worsened when considering the additional contribution of atomistic doping to non-uniform substrate inversion, enhancing percolative source-to-drain conduction. Moreover the statistical nature of the process ruling the injection of charge from the substrate into the storage layer, may represent a further important variability source for the program operation of nanoscale charge-trap memory devices, compromising the tightness of the programmed threshold-voltage distribution, as already pointed out for floating-gate devices. Cell scaling increases the impact of these variability sources, as the number of charges (electrons and ionized dopants) decreases shrinking the cell dimensions. This thesis focuses the attention on the statistical variability affecting the reading and programming operations of nanoscale charge-trap memories. Chapter 1 briefly introduces the floating-gate Flash technology, pointing out the main scaling limits for both NAND and NOR architectures. Then the charge-trap technology is presented highlighting its potential benefits in terms of reliability, scaling perspective and technological feasibility. The end of the chapter is devoted to present the major sources of statistical variability for the charge-trap technology.
Chapter 2 gives a thorough overview of the issues related to the resolution of individual discrete charges in 3D drift-diffusion simulations. Three possible approaches to deal with this problem are outlined, the first being the use of charge smearing over a fine mesh, the second being the splitting of the Coulomb potential into short and long range components, and the third being the introduction of quantum corrections for both the electrons and the holes in the solution domain. It will be shown that even the quantum corrections are not enough to remove the artificial charge localization introduced in drift-diffusion simulations dealing with single Coulombic attractive centers and a mobility model correction will be proposed to relieve this artifact from simulation results.
Chapter 3 presents a comprehensive investigation of threshold voltage shift variability in deeply-scaled charge-trap memory cells, considering both atomistic substrate doping and the discrete and localized nature of stored charge in the nitride layer. The first part of the chapter outlines the physics-based 3D TCAD model developed for this study: the statistical dispersion of the thresh- old voltage shift induced by a single localized electron in the nitride is evaluated in presence of non-uniform substrate conduction. The role of 3-D electrostatics and atomistic doping on the results is highlighted, showing the latter as the major spread source. The threshold voltage shift induced by more than one electron in the nitride is then analyzed, showing that for increasing numbers of stored electrons a correlation among single-electron shifts clearly appears. The second part of the chapter is devoted to the scaling trend and the practical impact of these statistical effects on cell operation: for fixed density of trapped charge, the average threshold voltage shift decreases with scaling the cell dimensions as a consequence of fringing fields, not predictable by any 1-D simulation approach. Moreover, the distribution statistical dispersion increases with technology scaling due to a more sensitive percolative substrate conduction in presence of atomistic doping and 3-D electrostatics. The impact of the discrete electron storage in the nitride on random telegraph noise (RTN) in- stabilities is also investigated, showing that despite single cell behavior may be modified, negligible effects result at the statistical level.
Chapter 4 addresses the study of charge-trap memory programming variability. The first part of the chapter presents the physics-based Monte-Carlo model developed to simulate the statistical electron injection process from the substrate to the storage layer: for a correct evaluation of the threshold-voltage dynamics, cell electrostatics and drain current are calculated by means of a 3D TCAD approach in presence of atomistic doping, largely contributing to percolative substrate conduction, and in presence of discrete traps in the storage layer. Results show that the low average programming efficiency commonly en- countered in nanoscale charge-trap memories mainly results from the low impact of locally stored electrons on cell threshold voltage in presence of fringing fields at the cell edges. The second part of the chapter evaluates the impact of the statistical process ruling electron injection on the statistical dispersion of cell threshold voltage during the program operation: it is shown that the discrete electron injection process plays the dominant role in determining the threshold voltage spread, compared to the fluctuation in the number and position of the trapping sites and to the fluctuation of the threshold-voltage shift induced by stored electrons in presence of percolative substrate conduction.
As will be shown in chapter 3, a further burden for the programming ac- curacy is given by RTN instabilities, whose amplitude is enhanced by percolative substrate conduction in presence of atomistic doping5. In particular, the threshold-voltage shift given by single RTN traps was shown to follow an exponential distribution6, with standard deviation proportional to the square root of the channel doping concentration when a uniform doping profile is adopted. These results reveal that channel doping is one of the most important parameters for RTN in MOS devices, opening the possibility for technology optimizations by engineered doping profiles. To this purpose Chapter 5 presents a thorough numerical investigation of the effect of non-uniform doping on random telegraph noise in nanoscale Flash memories, considering both discrete RTN traps and discrete channel dopants. For fixed average threshold voltage, the statistical distribution of the random telegraph noise fluctuation amplitude is studied with non-constant doping concentrations in the length, width or depth direction in the channel, showing that doping increase at the active area edges and retrograde and δ-shape doping appear as the most promising profiles for random telegraph noise suppression.
The conclusions of this work are summarized at the end of the manuscript, outlining what has been accomplished and proposing some future work that can extend and improve the understanding of the effects of variability on the charge-trap memory performances.

P-N JUNCTION AVALANCHE MODELING FOR HIGH PERFORMANCE SINGLE PHOTON DETECTOR ARRAY

Mattia Assanelli

In recent years we observed a growing interest in using SPADs in various fields of research, ranging from biology to astronomy. In this class of applications Single-photon detectors are employed in conjunction with the time-correlated single photon counting technique (TCSPC) to reconstruct the ultra-fast and ultra-faint optical signals emitted from the object under test. This technique requires single-photon detectors with high photon detection efficiency (PDE) and good timing resolution. SPADs are now the winning technology because not only they provide the typical advantages of solid state devices compared to vacuum tubes, but they also offer higher PDE. Until now, the above mentioned applications, were mainly based on a single TCSPC measurement chain and, as a consequence, they have been relying on scanning when an image of the sample was necessary. In addition, some measurements are not feasible with single-chain systems because concurrent acquisitions are mandatory over multiple channels (e.g. Forster resonance energy transfer (FRET)). For these reasons there is now a strong effort towards the parallelization of such systems. In photon-timing measurements (such as TCSPC), it is critical to detect the arrival time of the incident photons with the smallest attainable jitter. When employing a SPAD detector a suitable current pick-up circuit and a comparator that senses the rising edge of the avalanche current is needed. The first problem to overcome when building a SPAD array is the crosstalk between pixels. In order to avoid the crosstalk, it is necessary to employ high threshold values 100 mV or more) in the avalanche discrimination comparator.
Recent generation SPAD devices have been engineered in order to reduce the Dark Count Rate (DCR) and to make it more sensible to the temperature reduction. However, as a side effect, an increase of the photon-timing jitter dependence on the comparator threshold has been observed. These devices are so unsuitable for timing arrays where high thresholds are mandatory to avoid electrical crosstalk. From this, the importance of understanding the statistical phenomena involved in the avalanche current growth in order to be able to design timing enhanced devices suitable for arrays: with good timing performance at high threshold levels. A complete reassessment of the statistical phenomena involved in photon-timing jitter is mandatory because models tailored on past generation devices do not properly describe the behavior of recent field-engineered devices.



1. Carrier distribution, 700ps after injection, simulated with the 2D avalanche spread simulator. It is worth nothing the secondary injections, due to photon-assisted propagation, which dramatically affect the avalanche propagation.

The attainable photon-timing jitter of a device can be basically ascribed to two contributions: the buildup statistics, which is related to the growth of the first filament of current, and the statistics introduced during the lateral spread of the avalanche current. At the beginning of my PhD work I assessed the contribution of the avalanche buildup statistics to the overall photon-timing jitter. A 1-D Monte Carlo buildup simulator employing both local and non-local impact-ionization models had been developed. From these simulations emerged that the buildup contribution to the overall photon-timing jitter is only appreciable at ultra low thresholds and cannot be considered responsible of the poor photon-timing performance at high threshold levels.
Past studies stated that in thin SPADs the avalanche injection position statistics is the main contribution to photon-timing jitter. As a matter of fact, avalanches experience different growth speeds as a function of the injection position. An avalanche injected in the center of the device will always experience a faster growing current than a border-triggered one. Indeed, in the border-triggered case, when the activated area reaches the border of the device, the current growth pace will slow down because only the front that faces toward the inner part of the device will propagate effectively.
The role of injection position statistics is questioned in recent devices. To address this issue we developed an experimental setup able to characterize the photon-timing jitter as a function of the injection position by means of a laser focused on the device active area. Results not only confirmed that the injection position statistics is not the main contribution to photon-timing jitter, but also evidenced interesting dependencies of the timing performance on the specific resistance of the devices. At that time the main cause of jitter in our devices was not yet identified. Finally these measurements allowed us to devise and validate a figure-of-merit for the photon-timing jitter (PTFOM). This tool has proven to be effective in comparing different SPAD designs for what concerns the photon-timing performances. Therefore, the PTFOM is an important design tool that can serve as guide in developing new device structures. In order to find the cause of the poor timing resolution at high threshold in recent SPAD devices a very simple 2D simulator of the avalanche propagation was then developed. In this simulator the simplicity was privileged with respect to the rigorous physical modeling of the device. The lack of rigorous physical modeling was balanced out employing some fitting parameters. The speed of this simulator was its distinctive feature and allowed us to carry out the fitting procedure in a reasonable time. Thanks to this simulator we could state that the photon-assisted propagation phenomenon is the main cause of jitter in our devices. This phenomenon was always considered negligible in past generation devices. Even if photon-assisted propagation cannot be reduced, thanks to this simulator we found that a device with smaller space charge resistance is less sensitive to this statistical phenomenon. The reduction of the space charge resistance is so mandatory in order to fabricate devices with good photon timing jitter at high thresholds.
The shortcomings of the simple simulator were patched with some fitting parameters. So we developed a more advanced 2D avalanche spread simulator. To date, this is the most advanced SPAD devices simulator present in literature. At its core the avalanche spread is regulated by a diffusion equation. The model includes excess bias dependent current growth time constants. Furthermore both non-local space charge effects and distributed bulk resistance are included. This simulator confirmed the results obtained with the simpler one, this time, without any fitting parameter (at this link http://tinyurl.com/av-prop are reported some animations of the current growing inside the devices obtained with the advanced simulator).
Once assessed the role of the space charge resistance in determining the photon-timing performance of a device we explored various possible ways in order to reduce it and to fabricate timing enhanced devices suitable for arrays. In particular we suggested, for the first time, to employ a P-i-N device as SPAD. We found that this solution would have a dramatic effect in reducing the space charge resistance (and in improving the jitter performance) without affecting the dark count rate.

BOUNDED APPROACHES FOR VERIFICATION OF INFINITE-STATE SYSTEMS

Marcello Maria Bersani

Many verification problems involve checking and synthesis of infinite state systems. In this thesis we study how to solve general verification problems by means of instances of, possibly different, problems of bounded size. Informally, we say that a problem is of bounded size when the object (or solution) which we take into consideration while solving the problem can be defined by a bounded representation with respect to the dimension of the initial problem. In par- ticular, we will face with the satisfiability problem of qualitative specification defined by formulae of linear temporal logic and model-checking problem defined for a specific class of counter systems.
We define the problem of *k*-bounded satisfiability for formulae of LTL(**FO**), which is a language obtained by adding to linear temporal logic (LTL) a first-order language, and we give an encoding in the decidable theory of equality and uninterpreted functions. Moreover, we consider a fragment of this general logic and we show that the satisfiability problem for LTL (with past operators) over arithmetical constraints can be answered by solving a finite amount of instances of *bounded* satisfiability problems when atomic formulae belong to certain suitable fragments of Presburger arithmetic. A formula is boundedly satisfiable when it admits an ultimately periodic model of the form uv^{ω}, where *u* and *v* are finite sequences of *symbolic valuations*. Therefore, for every formula there exists a *completeness bound* c, such that, if there is no ultimately periodic model with $|uv| \leq c$, then the formula is unsatisfiable. In this case, we say that the language has the completeness property. Whenever a fragment of LTL(**FO**) benefits of such a completeness property then *k*-bounded satisfiability can be exploited to solve the satisfiability problem for the language.
Most verification problems on counter systems are known to be undecidable in general; decidability can be retained by considering a more specific prob- lem than the general one which is defined with respect to runs with bounded features. We study model-checking problems on counter systems when the spec- ification languages are LTL-like dialects with arithmetical constraints. Guards characterizing transitions of counter systems are Presburger definable formulae and runs are restricted to reversal-bounded ones. We introduce a generaliza- tion of reversal-boundedness that captures both original Ibarra's notion as well as more recent ones. We show the NexpTIME-completeness of the reversal- bounded model-checking problem and the reversal-bounded reachability prob- lem. We show the effective Presburger definability for reachability sets and for 1sets of configurations for which there is a reversal-bounded run verifying a given temporal formula. Moreover, we show that reversal-bounded model-checking problem can be solved by looking for ultimately periodic runs with bounded length satisfying a given property. Therefore, since we are restricting the anal- ysis to bounded runs, we can exploit a reduction to *k*-bounded satisfiability of a temporal formula encoding the transition relation of a counter systems and the semantics of a given temporal specification over ultimately periodic runs.

SILICON SPAD ARRAYS FOR PARALLEL PHOTON TIMING APPLICATIONS

Corrado Cammi

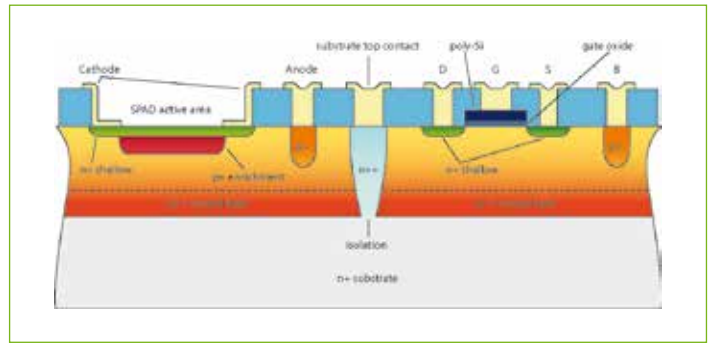
Recent discoveries and evolutions in the medical and biological fields have drastically increased the need for novel analysis and consequently have led to a rising quest of suitable diagnostic instruments. Among these, Time Correlated Single Photon Counting (TCSPC) has reached a considerable importance and a great deal of techniques has been developed based on it, such as: Fluorescence Lifetime Imaging Microscopy (FLIM), optical tomography and Lifetime Förster Resonance Energy Transfer (FRET). In order to satisfy the required specifications, new analytical systems with improved performance have to be developed; particularly the ability to work at high counting rate and to perform multidimensional analysis are of the utmost importance.

Nowadays TCSPC systems can rely on fast and high power lasers and on parallel timing acquisition electronics. However, the development of multi-pixel detectors is still incomplete. Commercially available solutions are mainly based on multi-anode Photo Multiplier Tubes (PMTs, 16 channels) that, however, present some intrinsic drawbacks such as: bulky and fragile structure, high power dissipation, low Photon Detection Efficiency (PDE) and sensibility to electromagnetic disturbances. Consequently the major effort towards multidimensional TCSPC systems is devoted to the implementation of new single-photon detector arrays.

Concerning single channel systems, silicon Single-Photon Avalanche Diodes (SPADs) have nowadays replaced PMTs in many applications. The best-in-literature results have been obtained exploiting custom technologies for their fabrication; starting from intrinsic advantages (ruggedness, integrability, high PDE, low power dissipation, insensitivity to magnetic fields), over the last decade, SPADs have undergone further improvements. In particular, custom SPADs developed by the Politecnico di Milano show a large PDE (50% @550 nm) and further improvements have been recently demonstrated by using a thicker absorption layer, enhancing the PDE peak to 60% at 650 nm, and reaching a value of 40% at 800 nm. Regarding noise, an optimized electric field profile has led both to a reduction in room temperature Dark Counting Rate (DCR) and to a stronger temperature dependence that increases the advantages attainable by cooling the detector. This resulted in large area devices (50 to 100 μm diameter) with a DCR as low as 10 cps when cooled down to -15° C.

Unfortunately, field engineering also introduced a stronger dependence of the photodiode timing jitter on the threshold used for avalanche detection. Therefore, in order to obtain the best timing performance, the avalanche signal is read by a suitable external timing circuit (patented by the Politecnico of Milano) connected to a fast comparator with a low threshold (5-10 mV); although this solution guarantees the best performance in terms of timing jitter (FWHM < 30 ps), this approach is not suitable for parallel systems. The presence of electric couplings between adjacent channels due to the use of multiple Active Quenching Circuits (AQCs), combined with low threshold comparators, leads the parallel timing chains to interfere with each other causing unacceptable electrical crosstalk and preventing low threshold operation. As a consequence, the development of photon timing SPAD arrays relying on the replica of the typical single channel configuration is simply not possible.

The problem has been solved by integrating the timing pick-up circuit close to the detector: in this way, parasitic capacitances are minimized and the filtering action on the current flowing through the device is reduced, enabling the extraction of stronger and steeper signals. The integration of the front-end circuitry close to the device allows to attain remarkable timing performance with a higher threshold hence limiting the electrical crosstalk issue. Capacitance reduction also decreases the number of carriers flowing through the SPAD during avalanche with a significant benefit in terms of afterpulsing probability and optical crosstalk.



1. Cross section of a custom SPAD and of a nMOS fabricated by the same technology.

2. Compact module including the 8x1 photodetection system.

The purpose of this work has been the implementation of the front-end integration solution exploiting custom technology, thus maintaining all the previously described features of the photodetector, in order to enable the fabrication of high performance time-resolved arrays of SPADs. A great effort has been consequently devoted to the integration of MOS transistors (Figure 1), needed to fabricate the timing circuit, since their implementation has required several modifications to the process flow employed for custom SPAD fabrication. The temporal behavior of the novel timing pick-up circuit has been fully investigated, paying particular attention to the effects of its dimensioning on the extraction of the avalanche signal, in order to achieve the best timing performance at high threshold. The pixel is completed by an external AQC made with a standard CMOS technology that allows the system to work at high counting rate, while guaranteeing stable timing performance.

The proposed pixel architecture has been replicated, aiming at the development of a 8x1 array, as required by the European project called PARAFLUO (PARAllel FLUOrescence, 7th framework). A compact module (12 cm x 5 cm x 5 cm), including the whole photodetection system, a custom microlens array and a liquid cooling system, has been finally fabricated (Figure 2).

Characterization measurements underlines that the structure and process dependent SPAD performance, such as DCR and PDE, match the ones obtained with standalone SPAD - without front-end integration - proving the modified process flow to be effective. Finally, the designed system shows remarkable timing performance: in particular, a FWHM of 45 ps, at 1 Mcps, with all pixels working in parallel at the same count rate, has been obtained.

A GEOMETRIC APPROACH TO ANALYSIS AND SYNTHESIS OF ACOUSTIC WAVE FIELDS FOR MULTIMEDIA APPLICATIONS

Antonio Canclini

In this thesis we propose a novel approach to wave field analysis and synthesis based on the geometric description of a sound field. Under the hypothesis of homogeneous medium, wave propagation can be approximated by means of acoustic rays that originate from a point source and spread in all the directions. The interaction with the environment causes the rays to reflect over the obstacles following the geometrical acoustic laws. Contiguous bundle of rays can be represented as acoustic beams that split and branch during the propagation as they encounter reflectors. An acoustic wave field can be seen as the superposition of acoustic beams, each characterized by the origin (source), direction and angular aperture. Due to the projective nature of rays, the most suitable tool for their representation is projective geometry, which gives also a compact and efficient description of more complex acoustic entities such as sources, receivers, reflectors and beams.

As far as the wave field analysis is concerned, projective geometry makes it possible to convert standard acoustic measurements (TOAs, TDOAs, DOAs) into homogeneous quadratic constraints, which all share the same mathematical formulation. This way, through the combination of multiple constraints it is possible to formulate a cost function whose form is equivalent for several estimation problems, ranging from standard ones (e.g. acoustic source localization), to novel ones such as the inference of the geometry of the environment.

As far as the sound field synthesis is concerned, the geometric description of a wave field leads to developing a methodology that aims at reproducing a complex wave field by superimposing elementary beams rendered by means of a loudspeaker array. The knowledge of the map of the environment, which can be estimated in the analysis stage, can be exploited to compensate for the environment hosting the loudspeakers, thus making the rendering system environment-aware. In particular, the reverberations (in terms of early reflections) are seen as determined by a set of image loudspeakers, which are inserted into the model and contribute to the reproduction of the wave field.

This thesis also includes various novel validation methodologies for the proposed techniques. As far as wave field analysis is concerned, we show that it is possible to predict the accuracy of estimation algorithms as a linear mapping between the error on the measurements and the estimation error. As for the sound field synthesis, we propose a methodology for assessing the quality of wave fields reproduced by real loudspeakers. The wave field is sampled over a circle with a pair of rotating microphones and extrapolated by means of the circular harmonic decomposition. The deviation between the extrapolated and the expected wave fields are then evaluated by means of standard (MSE-based) and novel (modal analysis) metrics. In this thesis we also show the results of some simulations and experiments of room compensation and virtual environment rendering.

The solutions proposed in this thesis find potential application in a wide range of fields, including advanced telecommunications (telepresence), immersive gaming, distributed music production, spatial audio at home.

EVOLUTIONARY LEARNING AND SEARCH-BASED CONTENT GENERATION IN COMPUTER GAMES

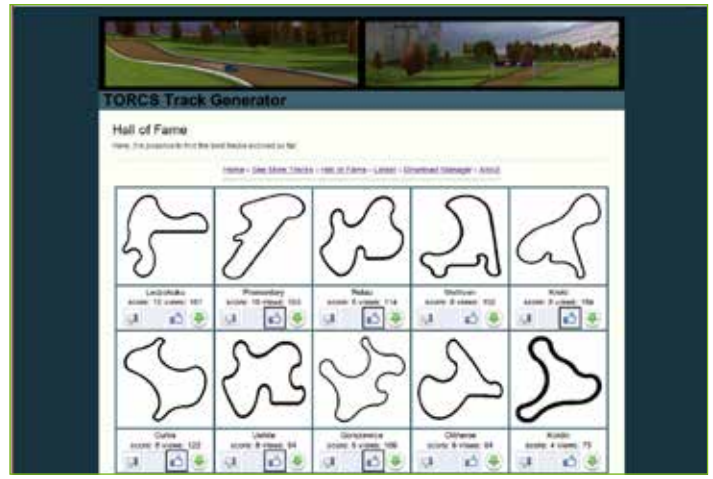
Luigi Cardamone

It has been almost 60 years since 1952, when one of the first videogames, Tennis for two, was played using an oscilloscope. During these years, videogames have been going through a constant and rapid evolution towards realism and playability. Modern computer games feature realistic 3D graphics and sophisticated physics engines which reproduce real or fictional environments with an impressive level of detail. The majority of new titles are multi-player oriented and are played on the internet against or in cooperation with other players.
However, the level of complexity achieved in computer games poses several challenges for developing the Artificial Intelligence (AI) of the non-player characters (NPCs). Usually, the non-player characters present very simple and predictable behaviors. Once the player discovers a weakness in the game AI, this weakness can be exploited indefinitely without any possibility that the behavior will change. In general, modern computer games need an AI which is adaptive and able to show human-like behaviors. The AI should be able to adapt both to new environments (e.g. new maps not available in the original game) and to the player to improve the user's fun or to dynamically balance the challenge. Another problem of the increasing complexity in computer games is related to the game content, e.g., maps, levels, racing tracks available within a game. Game content represents an important element for the game longevity, i.e., the time required to complete the game. Unfortunately, in modern games levels and maps have a huge amount of detail and can require many months of work by several designers to generate the few levels that will be shipped with the game.
In this context, Computational Intelligence might represent an interesting approach for dealing with some of the open problems in computer games. Computational Intelligence is a field of Artificial Intelligence which includes techniques and mathematical models which are inspired by nature, like Evolutionary Algorithms, Neural Networks and Reinforcement Learning. Computational Intelligence has already been applied to computer games in several academic works. The number of scientific publications on this topic is fast growing and the results show that Computational Intelligence can be a valid tool to support the development of computer games. A large number of research works focus on learning behaviors for non-player characters. Almost all the early works in this area focused on board games like Go, Checkers, Backgammon, Chess.

1. One of the racing tracks generated with the proposed approach.

More recently, the application domain has broadened to include many game types: arcade games, first person shooters, racing games, real time strategies. Overall, many games have been used and a variety of techniques have been investigated: evolutionary computation, fuzzy logic, neural networks and reinforcement learning. However, very few works focus on (i) on-line learning, i.e., a learning process that is performed in-game; (ii) transfer learning, i.e., a set of techniques for exploiting the knowledge of a source domain to facilitate learning in a target domain. Computational intelligence for game content generation, is a more recent research topic and some of the early examples were only published as recently as 2006. Thus, many research directions are still open or explored by only a few works, such as, for example, first person shooters. Among the others, an interesting research direction is the generation of personalized game content which uses the feedback of the user to generate content which can maximize his/her preferences.
In my thesis, I focus on the application of Computational Intelligence to computer games. In particular I focus on Evolutionary Algorithms and Neural Networks. I take into account two main topics in the design of computer games: the development of non-player characters and the generation of game content. In the first part I investigate different learning paradigms which can support the development of non-player characters. In particular I examine (i) off-line learning, a learning process applied out-of-game to generate strong and competitive non-player characters with a static behavior; (ii) on-line learning, a learning process applied in-game to generate non-player characters which can evolve over time by learning new behaviors from scratch or by adapting an existing one; (iii) transfer learning, a set of techniques for transferring behaviors across different games, by exploiting the knowledge of a source domain in order to accelerate the learning in a target domain. The proposed approaches are tested using a state-of-the-art open source car racing simulator. The results show that the approaches presented in my thesis are promising for supporting the development of sophisticated non-player characters.
In the second part of my thesis, I examine search-based procedural content generation to automatically generate content in different game types. I investigate two key aspects: the representation of the game content and the fitness function. In particular I consider two types of fitness functions: (i) theory-driven fitness function, which comes from a theoretical study of the problem and aims to generate content which presents some interesting characteristics like variety and diversity; (ii) user-driven fitness function, which aims to generate personalized game content that maximizes user preferences. The second type of fitness was investigated using an Interactive Genetic Algorithm, i.e., an interactive system in which the user directly scores the proposed game content.
The approaches presented in the thesis were tested in several games, which involve completely different representations of the game content. In particular, the proposed approaches were applied to generate racing tracks for a racing game, maps for a First Person Shooters and levels for a platform game. The empirical results and the feedback received from the user study show that the proposed approaches are able to generate game content with a good potential for interesting game-play.

1. One of the best maps generated for a First Person Shooter using the proposed approach.



3. Screenshot of the Interactive Genetic Algorithms for evolving racing tracks.

STABILITY CONTROL SYSTEMS FOR TILTING VEHICLES

Pierpaolo De Filippi

Summary

Motorcycle dynamics control is one of the most interesting applications of control system theory. Dealing with motorcycle dynamics, in fact, is more complex than it is for four-wheeled vehicles, as the dynamics are coupled due to the large roll angle that a motorcycle can achieve. This is one of the reasons that caused a lagging in the design of electronic control systems for two-wheeled vehicles. Moreover, there are also cultural and economic factors: in fact, many riders believe that they do not need any help riding their bikes and that active control systems alter the riding experience. Finally, as the market of two-wheeled vehicles is smaller than the four-wheeled one, the amount of investments on R&D is limited and thus the control strategies must have the simplest possible architecture and a reduced sensor layout in order to reduce production costs.
Furthermore, the packaging constraints of the actuators are more stringent than those for four-wheeled vehicles and higher static and dynamic performance requirements are requested to the actuators. The recent technological advances in actuators which have led to semi-active steering dampers and suspensions, drive and brake-by-wire systems have radically changed the starting point of control systems design. In recent times, motorcycle manufactures have been working on production version of traction control systems, ABS and slow-adaptive control of steering dampers. This thesis has been developed within this interesting and evolving context, with the aim of providing a thorough analysis of semi-active and active control systems to enhance the stability of two-wheeled vehicles and proposing innovative solutions, which are both effective from the application viewpoint and theoretically sound from a methodological perspective. To the best of the author's knowledge, this is one of the first attempts to devise industrially amenable electronic control systems for two-wheeled vehicles.
The Thesis is organized into three different parts. After an introductory chapter which describes the modes of vibrations typical of two-wheeled vehicles, the first part of the thesis presents an overview on the actuators and sensors that can be used to control the stability of two-wheeled vehicles. The second and third part of the thesis will focus on presenting original solutions to the design of semi-active and active control strategies: the second part is devoted to the design of algorithms to control a semi-active steering damper and semi-active suspensions, while the third part is devoted to the design of an active control system that restores the stability of the vehicle acting on the front and rear braking torque and rear traction torque.

Main Contributions

The main contributions of this thesis can be summarized as follows:

- The problem of forward speed estimation in two-wheeled vehicles is solved by means of an extended Kalman filter. In the open scientific literature only simple signal-based solutions to this problem exist which do not guarantee a good estimate while cornering. It is shown that combined use of a nonlinear model derived on straight-running and a time-varying longitudinal friction coefficient of the road allows us to get a reliable estimation of the forward speed.
- A new control approach named Mix R-SH/R-GH algorithm is proposed for the control of a semi-active steering damper. A switching control law that allows to better damp some critical modes of the vehicle is derived. This strategy turns out to be very powerful and flexible as it uses an off-the-shelf steering damper and a reduced number of sensors. Some preliminary experimental results obtained on a prototype motorcycle assess the industrial suitability of the proposed control strategy.
- An original online steering angle estimation algorithm for two-wheeled vehicles is studied, which is the enabling step to move toward an industrial implementation of the proposed control strategies for the semi-active steering damper. The estimation method is based on a sensor configuration which may be suitable for industrial purposes. The validity of the proposed approach is first assessed in simulation and then also on an instrumented test motorbike.
- A new algorithm is proposed to control semi-active suspensions for stability enhancement. To the best of the Author's knowledge, semi-active suspensions have been employed only to improve comfort and handling in two- and four-wheeled vehicles. The proposed control strategy, named Stability algorithm, aims at improving the stability of the motorcycle by acting on the force delivered by the front and rear semiactive dampers. To this end, the controlled variable is the roll rate of the vehicle. The proposed control strategy is scheduled on the roll angle and it is fed by the roll rate and by the same signals used by the common comfort-oriented control strategies.
- To the best of the Author's knowledge, the first attempt to devise an electronic stability control (ESC) for two-wheeled vehicles is discussed. In four-wheeled vehicles, ESC is now part of most commercial cars. For two-wheeled vehicles, the design of such a control system is an open problem, and it constitutes a challenging task due to the complexity of two-wheeled vehicles dynamics and to the strong interaction between the vehicle and the rider. An innovative control architecture, named Full-authority with time-varying saturation (FA-SAT) which allows us to enhance the active safety while guaranteeing a good riding feeling is proposed. The control variables are the front and rear wheel braking torque and the rear wheel traction torque, while the regulated variables are the roll rate, to increase the stability of the vehicle, and the longitudinal acceleration, to guarantee the riding feeling. An activation and deactivation control logic is also devised, which constitutes a very important step towards the implementation on a real motorcycle.

Open Issues and Topics of Future Research

Even though all the topics covered in this thesis have been extensively analyzed and tested, yet there are some open issues to be explored in future research. Moreover, some of the findings of the performed research suggest future directions which seem to be worth further investigation. First of all, as up to now only the control strategy discussed in Chapter 4 has been tested on a real vehicle, in the next future the attention will be focused on experimentally testing the other proposed control algorithms. This phase will most probably unveil some new issues to be considered and some adjustments or slight modifications of these control strategies will be needed to optimize their performance and their implementation on vehicle ECUs. As far as active control of two-wheeled vehicles is concerned, this thesis represents the first attempts in this direction and many problems are still open. First of all, a formal proof of the closed-loop system stability is an open issue. In order to tackle this problem, appropriate models of the vehicle dynamics of interest should be derived. The currently available models, namely multi-body models or simple analytical models, are either too complex to be employed for control design purposes or fail to model the lateral dynamics. To move on a real test vehicle it will be necessary to test and validate the proposed control strategy on a physical simulator, in order to evaluate the interaction between different riders and the control system in a safe manner. Finally, in the future a motorbike will be equipped with front and rear active brakes and an electronic control body. In medium/long term, an interesting research path can be anticipated. The approach followed in this thesis, in fact, consists of an independent design of the different chassis subsystems. However, to gain maximum safety, comfort and performance at the same time, an integrated design needs to be considered.

TWO-PARAMETER BIFURCATIONS IN SMOOTH AND PIECEWISE-SMOOTH DYNAMICAL SYSTEMS: NEW THEORETICAL RESULTS AND APPLICATIONS

Fabio Della Rossa

Nonlinear systems of ODEs depending on parameters are ubiquitous in all fields of science. The discussion of the impact of parameters on the asymptotic behavior of the dynamical system is typically the major concern. This discussion requires the determination of the so-called bifurcations, namely the parameter combinations at which some degeneracies create a structural change in the dynamics of the system. The computation of the bifurcations can be rarely performed analytically, so that one must rely upon numerical techniques. The aim of this thesis is to improve the available techniques and their software implementations and to extend them to cases which have not yet been covered: particular relevance is given to bifurcations (in smooth and non smooth systems) concerning multiple degeneracies, the so-called codimension-2 bifurcaiton points. Those points assume a strategic importance in the bifurcation analysis, since more bifurcation curves depart from them, so that they become the organizing centers of the bifurcation diagrams. Most of the identified theoretical results are implemented in MatCont, a standard software used for the bifurcation analysis, and are applied to various significant problems in engineering, biology and sociology.

DESIGN AND ANALYSIS OF SEMI-ACTIVE SYSTEMS FOR VEHICLES

Diego Delvecchio

This Thesis deals with the analysis and the design of control systems of semi-active suspensions for ground vehicles. In particular the Thesis discusses the following topics:

- Analysis and modeling of semi-active actuators. A protocol for the characterization and non-linear models of semi-active dampers are proposed.

- A new comfort-oriented control strategy based on the half car model is presented to compensate the limitations of the state-of-art algorithm designed for quarter-car representation of the vehicle.

- A new handling-oriented control strategy has been developed to maximize the efficiency of the transmission of force between the tire and the ground.

- The application of the model reference control technique to semi-active dampers is discussed. In particular, the description of an industrial application of such control approach is illustrated.

- A simulation study of the influence of suspension systems on the out-of-plane dynamics of a motorcycle is deeply analyzed. Furthermore, a novel control strategy which aims at increasing the stability of the motorcycle during critical maneuvers is designed.

- For industrial application of semi-active suspensions system, information regarding the vertical dynamics of the vehicle is required to be as much robust and cost effective as possible. Observers based on Kalman-filtering technique for estimation of suspension stroke speed and tire deflection with different sensors layouts are designed and analyzed. Finally, a sensor reduction in a 4-wheels vehicle equipped with semi-active suspensions is presented.

- In the last Chapter an innovative architecture of suspension, the dual stage suspension system, is presented and analyzed. Such system is able to approximate the behavior of a reactive system in which both the damping and the stiffness coefficients can be modulated.

QUALITY DRIVEN MODEL TRANSFORMATIONS FOR FEEDBACK PROVISIONING

Mauro Luigi Drago

Verifying that a software system has certain non-functional properties is a primary concern in many engineering fields. Although several model-driven approaches exist to predict the quality attributes of a system from design models, they still lack the proper level of automation envisioned by Model Driven Software Development. In particular, when a potential issue concerning the non-functional properties is discovered in system models, the identification of a solution is still entirely up to the engineer and to his/her experience. Automation for the interpretation of the analysis results, for the identification of the potential quality-related issues, and for the identification of the possible solutions and design alternatives is mandatory for the successful application of Model Driven Engineering techniques in the current development practice.

This problem, known in literature with the term *feedback provisioning*, is the problem on which our research concentrates. In this thesis we present QVT-Rational, our multi-modeling and programmable framework to automate the detection-solution loop characteristic of feedback provisioning. QVT-Rational proposes the adoption of quality-driven model transformations to specify how alternative system variants exhibiting certain quality properties can be automatically generated and proposed as feedback to the engineer. Our framework represents a valid improvement in the process of designing for quality. It provides a language to define the non-functional properties of interest for a particular engineering domain, a language to specify requirements about them, a convenient mechanism to integrate existing analysis tool-chains in order to predict quality, and provides an engine to automatically explore the solution space and identify valid system alternatives.

DIRECT DATA-DRIVEN CONTROL SYSTEM DESIGN: THEORY AND APPLICATIONS

Simone Formentin

In many industrial applications, a mathematical description of the plant is not available or the modeling study is too expensive and time-consuming.
Data-driven methods overcome these problems, allowing the control system designer to quickly select the best model of the process in a specific class, in order to use it for controller tuning purpose. Nevertheless, in classical system-identification procedures, it is difficult to find a model, which is both simple and reliable. Moreover, detecting which dynamics is relevant for the final control objective is not a simple task.
In the so-called "direct" data-driven methodologies, a controller is directly selected from data, without need to identify a model of the system. In this way, process dynamics are automatically considered relevant or not, depending only on their weight on the final control index. Moreover, if only "non-iterative" techniques are considered, this approach has the additional nice feature that the experimental effort is the same required by the classical approach, where a model is identified from data and the controller is designed based on the resulting model.
So far, the largest part of the research in this topic has been limited to linear time-invariant plants and classical reference tracking control schemes, whereas only few preliminary studies focused on nonlinear plants or on different topologies for signal routing. This fact represents a strong limiting factor when such methods have to be applied on a real-world system.
In this work, existing direct data-driven design methods are extended to a larger class of industrially relevant problems, including control of time-delay systems, cascade schemes, multivariable plants and some critical nonlinear issues like linear parameter-varying dynamics and feed-forward linearization. Specifically, each theoretical development is accompanied by a thorough discussion on the implementation issues, so as to make the final extended method ready-to-use for the interested user.
In this thesis, the statistical efficiency of non-iterative methods is also analyzed and improved via optimal input design. This study shows that the input signal of the controller identification experiment can be analytically selected for optimizing the final control criterion and that the optimal spectrum has the same structure for all the considered methods.
Finally, some real-world engineering applications are dealt with to prove the effectiveness of the extended methods. Specifically, engine and vehicle dynamics problems, like air-path control in diesel engines and braking control in two-wheeled vehicles, are selected as benchmark applications for their complex dynamics and their practical interest.

A REFERENCE MODEL AND A RUN-TIME SUPPORT FOR PERVASIVE ADAPTIVE SYSTEMS

Marco Funaro

Computing facilities are an essential part of the fabric of our society, and an ever-increasing number of computing devices is deployed within the environment in which we live. The vision of pervasive computing is becoming real. To exploit the opportunities offered by pervasiveness, we need to revisit the classic software development methods to meet new requirements: (i) pervasive applications should be able to dynamically configure themselves, also benefiting from third-party functionalities discovered at run time and, (ii) pervasive applications should be aware of, and resilient to, environmental changes. In this thesis we focused on the software architecture, with the goal of facilitating both the development and the run-time adaptation of pervasive applications. More specifically, we advocated for the adoption of the REST architectural style to deal with pervasive environment issues. Indeed, we believe that, although REST has been introduced by observing and analyzing the structure of the Internet, its field of applicability is not restricted to it. Following this belief, we created a new architectural style, called P-REST, that is derived by REST by taking into account the inherent instability of pervasive environments. Specifically, we augmented REST with asynchronous and event-based communication, we parted with the classical client-server interactions and adopted a peer to peer coordination model, and we implemented distributed facilities like the naming service and the discovery service.
In this context, the challenge was providing a middleware support allowing applications to have minimal assumptions about the environment while being able to dynamically adapt to the surroundings. Specifically, the middleware was meant to assist applications in (i) discovering the different functionalities offered in the pervasive environment and benefiting from them, and (ii) enabling easy and effective reactions to the environmental changes. To this extent, the PRIME (P-rest Run-tIME) middleware enforces the P-REST style to design, build and maintain pervasive applications. A PRIME application is composed of computational entities that comply with P-REST style and that we (following the REST nomenclature) called resources. To coordinate such resources and obtain complex behaviors, we devised a coordination language called PaCE (Prime Coordination languagE). Two were the requirements that drove us in the PaCE design. First, we needed a simple and high-level language with an imperatively-flavoured syntax that could result intuitive for most developers; second, we wanted to make the underlying distribution and asynchronicity as seamless as possible. To meet such requirements, we were inspired by data-flow languages to make distribution and asynchronicity implicit. The data-flow semantics was coupled with an imperative syntax. PaCE scripts can resort to remote resources to achieve their goal but they are also allowed to use local functions written both in Java and Scala programming languages. The execution of PaCE scripts was entrusted to an interpreter. We choose an interpreter over a compiler because we wanted to manipulate PaCE scripts at run time. Specifically, the PaCE interpreter exposes the APIs to change variable bindings at run time. As a last step, we built a case study to evaluate both the complexity of the development process for a real-world system and the performance of PRIME. Performance revealed compatible with modern smart-phones while, thanks to the P-REST abstractions and to PaCE, the development of resources and their coordination scripts resulted simple and intuitive.

MODELING EMOTIONAL INTERACTION IN AFFECTIVE COMPUTING EXPERIMENTS: A STUDY ON AFFECT RECOGNITION IN VIDEOGAMES

Maurizio Garbarino

This thesis presents a reference model and some computational methods for the automatic detection of affective states of people interacting with artificial systems. The model can be successfully adopted to analyze and compare many Affective Computing studies evaluating similarities and differences among proposed approaches. When we first approached Affective Computing and started reviewing the literature, we noted that the same problem was being approached from different points of view. While the main question — to automatically recognize emotions — was shared among various studies, a wide range of dissimilar experiments was conducted. These heterogeneous approaches, however, were sharing some key aspect of Emotion Detection problem in Affecting Computing. Nevertheless, without a well-defined model, it was difficult to deeply understand which aspects (variables) were the most relevant, and how they were related to each other. This lack of a common model motivated us to formalize the problem. Sharing a general model helps to better approach and analyze the problem (e.g., what can we infer from the model? What are we underestimating?), and to systematically verify hypotheses (e.g., is the inference we are making correct? Should we consider a different relationship among variables?). This lead to an improvement of the formalization of the problem toward a valid, agreed, and effective formulation.

We introduce a machine-centered model that characterizes the interaction between a subject and a machine as well as the affective state of the subject. The model is general enough to represent many different experimental protocols as well as more practical scenarios proposed by both the Psychophysiology and the Affective Computing communities. The model considers 5 variables: emotional state, ground truth, stimulus, acquired multimodal measurements, and the set of non-modeled variables. Then, it describes relationships between variables, highlighting the critical aspects to consider while designing an affective computing experiment. Finally, we have introduced some considerations about time dependency of variables and extended the model with a dynamic perspective. To complete the model, we discuss some methodological issues related to Emotion Detection. An agreed methodology should provide the guidelines to follow in the realm of formal use and evaluation of the model. In fact, we propose a methodology aimed at guiding the use of the model to design experiments, data acquisition, data preprocessing (e.g., artifact removal, data normalization and feature extraction), data analysis and validation (e.g., how to get a correct estimation). Guidelines are provided for the selection of stimuli and questionnaires, to control the possible sources of noise and their influences of the measurements. The methodology describes data, the acquisition procedure, and takes into account the devices that are currently available. It goes through the feature extraction phase that requires artifacts to be removed from signals. Then, it considers the data analysis phase, which includes data normalization, dimensionality reduction, and model estimation. Finally, it presents the validation phase that, by means of cross–validation technique, allows the estimation of reliable models.

After the formal definition of the model and the methodological discussion, we present our case study whose original purpose is to advance the knowledge about Affect Detection in video games. In particular, we are interested in investigating whether physiological measurements could discriminate the player's preference between different video game experiences. The cognitive task in the experiment concerns playing a car racing simulation video game. During a session, each participant played a set of 7 races versus one computer driver, which was the only opponent. The only difference between races was the skill level of the opponent, set to provide 3 different game experiences: the first variant was against a relatively weak opponent, the second variant was against a challenging opponent, the last variant was against a strong opponent. The opponent skill has been changed among races considering that this has a high potential impact on player emotional state and that it could be easily adapted in a real-time affective loop to control the enjoyment level of the player.

A number of critical issues needed to be addressed during the design of the experiment. We studied whether physiological response could provide a more robust and interesting insight, since classical metrics, such as in-game performance, are not necessarily a good estimate of the preference for a generic player. The answer to this question is an important aspect for the development of an adaptive video game able to offer different game experiences according to the preferences inferred from the player's physiological status. In principle, different players have different preferences, given their experience, their mood, the emotions they feel, and many other factors. If we could identify the player's preference on-line, we might adapt the game to match it.
The physiological signals involved were Blood Volume Pulse, Galvanic Skin Response, Electrocardiogram, Respiration, and Skin Temperature. To have a comparison with non physiology-related data, we also collected a number of in game metrics regarding position and movements of the cars, brake/steering commands, etc.

Different analyses have been performed: from preference learning approach, to the canonical classification approach using k-NN and 3 classes of enjoyment. A comparison of performances between physiological features and in-game features showed that the latter could better predict the user reported preference. However, a deeper analysis showed that in-game features were more correlated to the task than to the preference itself. This result has been obtained thanks to a novel approach, derived from our model, that exploits the correlation between stimuli, emotion, and ground truth. When classes of preferences are unbalanced, the proposed method helps to find the features that result more correlated to the reported preference. This result has been obtained thanks to a novel approach, derived from our model, which exploits the correlation between Stimuli, Emotion, and Ground Truth. When classes of preferences are unbalanced, the proposed method helps to find such features that result more correlated to the reported preference.

In conclusion, the key contributions of this work are the proposal of a well-defined model, the discussion of main methodological issues, and the design and analysis of a real world experiment of affect detection from physiological signals based on a car racing game. The reference model of affect interaction, together with the methodology, can be used to evaluate similarities and differences among different approaches proposed in literature. The model supports the process of understanding and framing results and proposals, to help the development of a more scientific approach and organization in the area. Moreover, it can help experimental designers to formally define hypotheses and interactions between different aspects of a given proposal. The complete model adds a dynamical perspective to the Stimuli-Emotion-Measurements system taking into account their relationships over time. This model can be a reference point for future experiments in Affective Computing. With this tool, researchers can clearly put in evidence relationships between different key aspects while designing their experiments.

CRYOGENIC ELECTRONIC CIRCUITS OPERATING AT 1 KELVIN FOR CHARACTERIZATION OF QUANTUM DEVICES

Filippo Guagliardo

In this PhD thesis we develop several circuits for measurement on quantum dots for quantum computing. The main application is to use the spin of a trapped electron inside a quantum dot, as a bit in a conventional computer; enjoying the advantages to use a quantum magnitude. The measurements are done by measuring the current flowing into or near a quantum dot thought a transimpedance amplifier which allow a perfect control of voltage on the device under test (DUT). First we described the design, realization and characterization of a complete system based on several transimpedance amplifier working at room temperature, each optimized for a particular measurement; they have resolution from 20fA to 1nA and bandwidth from 12Hz to 60kHz; there is also a low offset stage that allows measurements with voltage across quantum dot in 10μV range.
The performances of this room temperature system are limited by input parasitic capacitance due to the long wire which connect the sample to electronics. In fact to study the properties on quantum dot, without being affected by thermal effect, the sample has to be cooled at 300m Kelvin and placed in magnetic field up to 12T. These conditions were reached via a cryostat from cryogenics which permits a electrical control and sensing of the DUT only via wires of about 3-4 meters longitude. The parasitic capacitance associated with them is about 1nF and limit both the resolution and the bandwidth of transimpedance. The only way to reduce the input capacitance is insert into cryostat the detection electronics by miniaturizing it in a integrated chip. But this circuits should be able to work to the temperature present inside the cryostat, in particular we identify a good amplifier holder at 20cm far from sample in which the temperature can reach up to 1 Kelvin. We choose a cmos technology from AMS 0.35μm, as bipolar technology does not reach temperature below 80 Kelvin. The simulation models associated with technology does not are available for temperature below 250 Kelvin, so we proceeded with the characterization of the technology at liquid helium temperature 4 Kelvin. We characterize integrated resistors, their value almost double when going from 300 Kelvin to 4 Kelvin and they has a non linear effect if the width of them is below 10μm. We tested also integrated capacitors which maintain almost the same value from 300 Kelvin up to 4 Kelvin. Finally we tested also transistor, high conductive transistor does not work at 4 Kelvin due to freeze-out effects: a huge kink effect and hysteresis behavior appear on mosfet's characteristic, making the devices unusable as transistor. On the other hand Pmos transistor with $W/L \leq 71$ and Nmos transistor with $W/L \leq 35$ still have a good transistor characteristic at 4 Kelvin. We extracted from them higher threshold voltages and also higher mobility respect room temperature; in Nmos at 4K still remains a small kink effect at high drain to source voltage. We notice that mobility and threshold voltages are different for different W/L. So it's not possible to extract mobility and threshold voltage valid for the technology at 4 Kelvin.
We developed a transimpedance amplifier, using a operational amplifier divided into two stages. A first stage at cryogenic temperature which is composed by only one transistor, so with a known mobility overtaking the geometry dependence.
The second stage is a room temperature operation amplifier, it raises the dc gain of whole opamp. We use a cryogenic feedback resistor to enjoy the reduction of thermal noise. We measure a 1.3pARMS resolution over 10kHz bandwidth with a 150μW of power consumption at 4K. But the single transistor front-end have high offset voltage 1.3V which may be corrected but his variations may affect the measurement on quantum dots. To overtake this effect we design a whole integrated cryogenic transimpedance amplifier to reduce the input offset voltage. With a differential amplifier input stage the offset voltage can be reduced up to mV range. We decide to use only one Pmos 50μm x 0.7μm and one Nmos 50μm x 1.4μm and synthesizing a whole transimpedance amplifier by combine this two mosfet. In this way it is possible also to simulate the circuit at 4K, using a simple model and the parameter extracted during characterization.
The measurements confirm the simulated result, we realized a transimpedance amplifier which has a current resolution 2.8pARMS over 30kHz bandwidth; a voltage offset is 0.2mV which permit very low bias voltage measurements on quantum dot. The entire circuit is on a silicon chip with dimension 1200μm x 560μm and it's supplied on ±1.5V with 5mA of supply current; this characteristic make him ideal devices to be attached inside the cryostat. It also does not require others special component at room temperature just voltage supply and acquisition system. The robust design has permitted to obtain a transimpedance working from 300K to 4K.
The cryogenic transimpedance amplifier has also provided with a current output with current gain G=1000 independent from temperature, based on coupling between integrated resistors. Finally we designed realized and tested a full cryogenic system with bandwidth 100kHz and 40pARMS resolution, multi-channel variable gain, using a non-trivial opamp structure to improve the bandwidth without affecting the stability.
Our systems is used in laboratory MDM IMM of the "Centro nazionale delle ricerche" a research institute in Milano.

EFFICIENT DETERMINISTIC ALGORITHMS FOR FINDING OPTIMAL CYCLE BASES IN UNDIRECTED GRAPHS

Claudio Iuliano

Given a simple undirected graph G, a (generalized) cycle corresponds to a subgraph in which every node has an even number of incident edges. All cycles of a graph form a vector space over GF(2), the so-called cycle space, and a basis of this space, i.e., a cycle basis, provides a compact representation of the cyclic structure of G.
In a variety of applications, e.g., analysis of electrical circuits, network design, periodic event scheduling, computational biology and organic chemistry, we are given a graph G with a nonnegative weight assigned to each edge and we are interested in finding a minimum cycle basis, i.e., a cycle basis of minimum total weight, where the weight of a basis (cycle) is defined as the sum of the weights of its cycles (edges).
The main goal of the thesis is to devise efficient deterministic algorithms for the minimum cycle basis problem. Our interest is to improve on the best worst-case complexity as well as on the actual performance over an extensive range of instances.
We start by analysing the main deterministic algorithms proposed in the literature and by pointing out the respective strength and weakness.
A unified computational framework is proposed and used for a detailed comparative study. Based on this analysis, we adopt the general strategy of generating a set of candidate cycles from which a minimum cycle basis is extracted by a linear independence test.
We introduce the concept of isometric cycle that gives rise to a very compact set of candidate cycles. We provide a full characterization of this set and describe an efficient procedure for generating it. We also investigate further reduction of the number of candidate cycles, but we show that the set of isometric cycles achieves the best tradeoff between the size of the set of candidate cycles and the related generation time.
By restricting attention to the set of isometric cycles we propose two efficient deterministic algorithms.
First, we devise an independence test exploiting the characterization of isometric cycles and using a bit packing technique. The overall resulting O(m^2 n / log n) algorithm turns out to be the best one from the worst-case complexity point of view.
Then, we propose an independence test whose adaptive choices aim at avoiding unnecessary operations, which leads to a very efficient Adaptive Isometric Cycles Extraction algorithm (AICE).
Computational results show that AICE outperforms the previous algorithms by one or two order of magnitude on medium-size instances and allows to obtain an optimal solution also for large-size instances in a reasonable time.
We also investigate two variants of the minimum cycle basis problem with additional structural constraints that are of interest in some applications, such as the analysis of electrical circuits and network design.
In the first variant, a nonnegative length is assigned to each edge and we look for a minimum cycle basis with cycles of bounded length, i.e., such that the length of each cycle does not exceed a given constant. We prove that the general problem is NP-hard and we devise a simple fully polynomial-time approximation scheme (FPTAS). We show that the special case where all edges have equal length is polynomially solvable and the algorithm that we propose has the same worst-case complexity as the one for the unconstrained minimum cycle basis problem.
In the second variant, a nonnegative bound is assigned to each edge and we wish to find a cycle basis with limited edge overlap, i.e., such that each edge belongs to a number of cycles of the basis not greater than its prescribed bound. We prove that it is NP-complete to decide whether such a cycle basis exists and we propose a constructive heuristic aiming at minimizing the maximum bound violation, i.e., the excess for each edge of the number of cycles containing it over its bound.

SOCIAL PRODUCTION OF KNOWLEDGE BY ONLINE COMMUNITIES

David Laniado

In recent years a new paradigm has emerged on the Web, characterized by the massive participation of users in the production of content. The results present the typical advantages of a bottom up process: information tends to cover the most various topics, keeping up to date and reflecting the point of view of the users, giving prominence to the most popular ideas but representing also the long tail of diverse views. On the downside, social Web applications suffer for a lack of organization; the absence of a single coherent point of view, in conjunction with scarcely structured content, makes it harder to retrieve and organize information.
The Semantic Web offers standards and tools for the representation of knowledge in structured format, but most online communities appear as still far and often reluctant to the adoption of these solutions, which can hardly deal with the simple and quick interfaces that characterize Web 2.0 applications, and with the messy heterogeneous data created by many different-minded users.
This work presents an investigation on how the new bottom up paradigm based on the participation of large masses of users on the Web can deal with production and organization of knowledge on a large scale.

As a first case study we choose Twitter, the most popular microblogging system, and we focus on hashtags, a convention adopted by users to face information fragmentation: adding a hash at the beginning of a word, this is turned into a tag. Hashtags are potentially very useful to aggregate content and conversations around a topic, a community or a thread of conversation, and their function is similar to that of URIs in the Semantic Web. To identify the hashtags which show the desirable characteristics of strong identifiers, we represent them as virtual documents and we propose some metrics based on information retrieval. We introduce the notion of *nontag*, as the word corresponding to a hashtag after removing the hash character, and we compare the usage of each tag with its corresponding nontag. We compute entropy of tags and we study the evolution of their usage over time. We look at the various ways in which hashtags are used, and show through evaluation that our metrics can be applied to detect hashtags that represent real world entities.
Then we focus on social bookmarking systems, that leverage the very little effort of assigning quick keywords to resources, to build collective classifications of large quantities of data. Tags are just arbitrary sequences of characters freely chosen by users, which are not explicitly associated to a specific meaning. This freedom together with the simplicity of the user interfaces has done the success of this kind of systems. However, the absence of any kind of explicit semantics represents a strong limitation for information organization and retrieval. To address this issue we propose an algorithm to disambiguate tags according to their context of usage, and to map them onto WordNet concepts; we use WordNet noun hierarchy to present a taxonomy of related tags, improving the users' navigation experience.
Beyond the basic level of identifiers, and the hierarchy among tags, we inspect the problems related to the lack of semantics in a broader sense. In traditional tagging systems, a tagging action consists just in the association of a label to a resource; there is no place for specifying anything about the kind of tag, the kind of communicative action performed, or the relation intercurring between the label and the tagged resource. This simplicity of the interfaces makes the users' vocabulary excessively poor in many cases, and limits the effectiveness of annotation retrieval. The third contribution of this thesis is the proposal of a vocabulary for tagging based on RDF named graphs. In the NiceTag ontology we represent a tag as the relation between a resource and a sign, with the possibility of typing all of these elements, including the relationship and the act of tagging itself, and we provide primitives for the description of different kinds of tagging actions as communication acts.
The second part of the thesis is focused on the collaborative encyclopedia Wikipedia, which is the largest example of collaboration on the Web, and as such covers a special interest for the study of social dynamics in online production communities. All content in Wikipedia is organized around articles, whose titles serve the function of identifiers; the analogy with Semantic Web URIs is straightforward.
To organize content, in Wikipedia there is also a category structure, which is collaboratively managed by the users. This hierarchy has been widely exploited for the construction of formal ontologies and knowledge bases; to this end, researchers have inspected the large and incoherent graph of Wikipedia categories looking for proper subsumption relations between classes and subclasses, and discarding the other ones. As an alternative approach, here we aim at making sense of all the associations established by the community, to assign Wikipedia articles to general topics. The naive approach of associating with a category all the articles transitively assigned to it shows to be pretty good for some well delimited categories, but impracticable in most cases due to the extreme tangledness of the graph and to the conspicuous presence of inconsistencies. To deal with the entire graph we propose and evaluate two methods, based on the shortest path between a page and a topic in the category graph, and on the probability of reaching each topic following a random path from a given article.
To study patterns of collaboration in Wikipedia, the first challenge which we face is attributing the production of single units of content to their "real" authors. To address this issue, we present a method to individuate the authors of a wiki page as the editors who provided most of its accepted content, according to a metric of *edit longevity*. While previous works failed to study the network of collaborations in a wiki scaling up to the size of Wikipedia in a major language, by selecting the main contributors of each article we manage to represent a whole wiki as a co-authorship network, scaling up to the size of the English Wikipedia.
We also focus on discussion pages associated to articles. We extract and analyze the structure of the discussions according to different criteria; to estimate contentiousness, we count the number of chains of consecutive replies between pairs of users, while as a compact and robust indicator of depth we introduce the h-index of a discussion tree.
On the other hand, we are able to study the network of explicit communications that accompany the collaborative redaction of content in Wikipedia, and to compare patterns of discussion about articles with personal conversations.
With these two complementary approaches of studying the article content authors and the discussion structure, we are able to characterize structural units of content in a wiki along two different dimensions, corresponding to implicit and explicit coordination dynamics. Representing the networks of interactions over the whole wiki, we can study structure and dynamics of its community; in particular, we focus on assortativity measures to quantify the tendency of users to interact with similar or dissimilar users. In all networks we find evidence of the strong interaction between users in the core and in the periphery of the community, which we point out as a characterizing feature of Wikipedia. We rely on different sociometric criteria to identify the most influential users and to analyze their role.
Aggregating units of content according to semantic criteria, we characterize the sub-communities active around particular topics and areas of interest, and we find evidence of significant differences in collaboration patterns over diverse semantic areas.

AN INNOVATIVE CMOS ASIC FOR A VERY WIDE DYNAMIC-RANGE RADIATION MONITOR READOUT IN SPACE APPLICATIONS

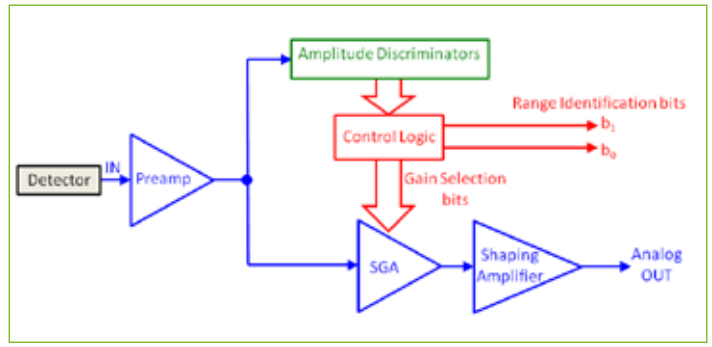
Daniele Macera

The work has consisted in the study, design and test of an innovative front-end ASIC for the semiconductor radiation detectors of a very wide dynamic-range Radiation Monitor (RM) for space satellites. Such system is intended to implement the ΔE *vs* E technique for discriminating both energy and type of the particles hitting the satellite during its mission, which is useful to get not only a knowledge about the radiations characterizing the space environment under study but also an estimation of the level of damage of the equipment aboard the satellites itself.
The RM provides a multi-channel detection scheme constituted by a couple of silicon strip detectors consisting of 4 strips each and a cubic CsI(Tl) scintillator crystal with six square silicon photodiodes placed in correspondence of its faces. In the ambit of this PhD thesis, however, work has been focused on the design of the single-channel version of the front-end electronics for photodiodes.
The most critical requirement for the developed front-end consisted in its ability to process input charge signals from 25 k to 100 M elementary positive charges (holes), for an overall input dynamics of 1:4000. Other major requirements were (see Table 1) a detector capacitance of 300 pF, an Equivalent Noise Charge < 3 k electrons r.m.s. with a maximum detector leakage current of 50 nA, a maximum event-rate of 50 kHz and a DC power consumption < 5 mW/channel.

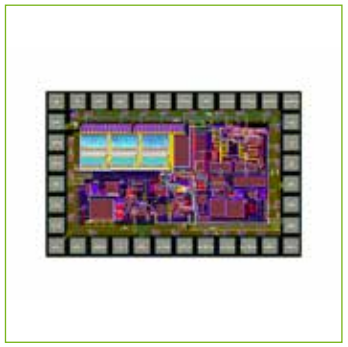
Collected charge type	holes
Input charge range	25 k – 100 M electrons
Shaping time	3 µs
Detector capacitance	300 pF
Equivalent Noise Charge	< 3 k electrons r.m.s.
Max Detector Leakage Current	50 nA
Max Event Rate	50 kHz
Max Power Consumption	5 mW/channel

Table 1. Specifications table of the front-end ASIC for photodiodes.

In order to process signals belonging to the required dynamics we have subdivided the whole dynamic range into smaller sub-ranges, each one covering a single decade. In particular, we have defined a Very Low Range from 25 kel to 100 kel, a Low Range from 100 kel to 1 Mel, a Middle Range from 1 Mel to 10 Mel and a High Range from 10 Mel to 100 Mel. A very simplified blocks schematic of the designed system is shown in Figure 1.
When the Preamplifier receives a charge from the detector it produces a signal which is analyzed by a set of Amplitude Discriminators that recognize the sub-range it belongs to. This information is delivered to a Control Logic which, by means of a Selectable Gain Amplifier, sets in real-time the gain of the channel such that the signals of each sub-range can use the whole voltage swing provided at Shaping Amplifier output. A couple of Range Identification Bits is also generated by the Control Logic such to provide the information about the recognized sub-range. This is mandatory in order that the back-end electronics used for sampling the Shaping Amplifier output signal be able to uniquely interpret what the received charge is.
The implementation of the described technique requires the front-end ASIC to be time-variant and so the first phase of the work consisted in a theoretical study aimed to analytically calculate its frequency-domain weight function for simulating noise performance. The results have been very good and so we have proceeded with the design of the complete channel and with the realization of two ASIC prototypes: one containing only the front-end analog section (A-Prototype) and the other containing the complete fully-functional channel.
The experimental tests have been successfully carried out by testing both prototypes with input signals between 340 k and 100 M elementary charges, providing very good results in terms of functionality, noise (a Signal-to-Noise Ratio between 106 and 750 has been measured in the High Range) and non-linearity (< 2.8% in the High Range) despite the time-variant mode of operation. The DC power consumption resulted to be 4 mW/channel.
Some unexpected issues also emerged from the test phase, but they have been carefully investigated and solved in a new design phase which has led to a new ASIC prototype (Figure 2) which is currently under characterization.



1. Simplified blocks schematic of the designed front-end for photodiodes – single channel version. The different colors identify different ASIC sections: analog (blue), digital (red) and mixed-signal (green).



2. Layout of the new photodiodes front-end ASIC prototype – single channel version.

PERFORMANCE AND LIMITATIONS OF CHARGE-TRAP STORAGE FOR NON-VOLATILE MEMORY TECHNOLOGIES

Alessandro Maconi

Semiconductor non-volatile memories have gained in the last decade an explosive success, thanks to the ever increasing market demand for portable consumer products requiring permanent data storage, such as digital cameras, MP3 players, removable cards, USB sticks, mobile phones, and, lately, solid state drives (SSD). The Flash technology, allowing high-density, small volume, and low-power devices, demonstrated the possibility to fulfill the requirements for these new applications to be developed. In particular, the NAND and the NOR Flash architectures represent today the winning solution for data and code storage, respectively.
Floating-Gate (FG) Flash memories have been able so far to satisfy the market requirements, especially for the portable equipments, and to become the mainstream non-volatile memory (NVM) technology. The increase of the integration density and the concurrent reduction of the producing cost are the basis of the growth of the storage semiconductor industry, as they allow not only to offer better memories at lower price, but also to open new market possibilities. Projecting into the next decade, though, there are several problems that must be faced to further scale the FG concept: problems like Stress Induced Leakage Current (SILC) and Random Telegraph Noise (RTN) or cell-to-cell parasitic interference are increasing their importance as the dimensions of the cells become smaller.
For these reasons alternative technologies have been presented in the past years, and they can be divided in two main categories: evolutionary technologies and new storing concepts. The former ones are still based on a MOS-like transistor where the threshold voltage (VT) of the cell is changed by injecting and trapping charge in the gate oxide; instead the latter ones completely change the approach to store information putting it, for example in the resistive state of the cell.
One of the most promising technologies in the first category seems to be the charge trap (CT) concept, where the polysilicon FG is replaced with a layer an insulator material with a high density of defects that act as traps where to store the charge injected from the substrate. In the thesis CT technology is fully analyzed, explaining how it can solve some of the problems of the Flash cells, and presenting the different possibilities, such as planar SONOS (Silicon-Oxide-Nitride-Oxide- Silicon) and TANOS (TaN-Alumina-Nitride-Oxide-Silicon), or 3D architectures, briefly discussing advantages and drawbacks of the different approaches.
However, the feasibility of a high-density non-volatile memory technology based on CT storage has not been clearly demonstrated so far: aim of the thesis is to investigate the performance and limitations of CT storage for future non-volatile technologies.
The first part of the thesis is dedicated to the analysis of planar CT memories: first a simple analytical model for the program operation of these devices is presented, allowing to explain some of the fundamental differences between the FG and the CT memories. This analytical model is then extended to a more accurate numerical one, in order to address some of the peculiarities that cannot be described by the former.
The obtained model is able to reproduce program and erase transients, and is tested against experimental data on SONOS devices.
In order to understand the differences between the SONOS and TANOS memories, the impact of the introduction alumina layer in TANOS devices is discussed, starting from experimental evidences that show trapping even in this layer, that is usually considered as an ideal insulator. Program, erase and retention transients on TANOS devices were not correctly reproduced by only considering trapping in the silicon nitride layer; integrating the extracted properties in the numerical model allowed instead to correctly reproduce these experimental results.
In the FG Flash, the Incremental Step Pulse Programming (ISPP) represents a mandatory programming scheme for multi-level deca-nanometer NAND Flash memories, as it allows to obtain very narrow threshold voltage distributions. With this algorithm, accurate placement of cell VT by Fowler-Nordheim tunneling is achieved by applying short pulses of equal duration and increasing amplitude to the gate, keeping the channel grounded. In the case of FG devices, a constant increase of the pulse amplitude gives the possibility to reach a stationary condition where the VT variation per step equals the increase of the gate voltage: this can be exploited to tighten the VT distribution by means of verify operations after each programming pulse.
Different results are, instead, reported for nitride-based memories, displaying a VT variation per step that is usually lower than the increase of the gate voltage. A comprehensive understanding of this behavior and of its impact on device performance represents a mandatory issue for the development of multi-level SONOS and TANOS memories. The experimental analysis has been made on large area SONOS capacitors and allowed to better understand the physical differences between these devices and the FG Flash, mainly highlighting and explaining the decrease in the trapping efficiency, due to the decrease of the free traps in the storage layer; the experimental characterization has then been extended to TANOS large area capacitors, pointing out that the role of the alumina layer is not negligible, as predicted by the previous analysis.
Afterwards, with the help of a 3D model, simulations of the ISPP on ultra-scaled deca-nanometer devices is presented, revealing a further decrease of the programming efficiency, that is caused by the fringing field that reduces the impact of the single trapped electron on the VT shift.
The second part of the thesis is instead dedicated to the modeling of cylindrical CT memories: in order to overcome some of the problems arising in planar devices, such as the erase/retention trade-off, and allowing to exploit the third dimension, vertical cylindrical devices have recently been proposed.
A physics-based analytical model is presented, solving the Poisson equation in cylindrical coordinates to obtain the electrostatic solution and study the curvature effect impact on the electric field in the gate stack; a modification of the well-known Fowler-Nordheim formula is then proposed for tunneling through cylindrical dielectric layers, in order to study the transient dynamics. The model is then tuned against experimental data, and a parametric analysis of the gate-all-around CT cells is presented, trying to understand the fundamental dependencies of the program, erase and retention transients on the geometrical parameters of the device.
In these vertical structures the nitride layer cannot be easily cut at the borders of each cell, and this can lead to worse retention transients. In order to understand the impact of this effect, an experimental characterization has been performed on planar cells whose nitride layer is not cut above the active area but extends in one direction. By comparing the retention transients on such cells with the ones obtained on capacitors with a self aligned storage layer, the impact of the lateral charge migration can be highlighted: while at room temperature the effect is negligible, at 150°C the retention transients on the cell display a faster loss with respect to the ones on the capacitor.
A 2D simulator has then been developed in order to quantitatively model the retention transients and to tune the diffusion parameters. This model has then been straightforwardly extended to simulate retention on vertical cylindrical devices, allowing to carry on simulations on these structures and testing also the disturbs to neighboring cells and impact of the lateral migrated charge on the string resistance, showing a non negligible impact of the lateral diffusion even at 85°C, and thus limiting the working temperature of the devices.

CONTROL BASED DESIGN OF COMPUTING SYSTEMS

Martina Maggio

In the domain of computing systems, two trends nowadays appear evident. One is a steadily increasing complexity of architectures and applications, the other is an attempt to make systems as "self adaptive" as possible, in order to have them maintain certain levels of performance and/or reliability in the presence of varying environmental conditions.

The two trends above are of course intertwined. More powerful hardware leads designers to devise more advanced functionalities, which in turn increases the overall complexity. On the other hand, more complex systems can be in a larger number of conditions, and present to the outside world a more articulated interface, so that making them capable of adapt themselves is more and more difficult.

In the last years, much interest can also be observed for the use of control-related methods to control computing systems, in a view to cast the mentioned quest for adaptation in the natural framework of feedback control.

This work attempts in some sense to start synchronising all the developments above, by fostering the use of the systems and control theory also in the design of computing systems. In the author's opinion this is a viable means to to counteract a dangerous tendency, i.e. -- crudely speaking -- that toward a "computer community" designing more and more complex objects without any notion of dynamics and control, and a "control community" attempting to model said systems with correspondingly more and more complex formalisms.

To break such destabilising a feedback loop, the remark is initially made -- to the best of the author's knowledge for the first time in so explicit a manner -- that the main problem is that, when a feedback loop is closed around a computing system that is already fully designed and functional, the controlled object includes some "core physical phenomenon", that normally is quite simple, plus a number of programming superstructures that were designed and introduced with little if any knowledge of dynamics. As a consequence of that, the suggestion is here made and motivated to use the systems theory as a common language and design framework, aiming specifically at concentrating the modelling effort on the mentioned core phenomenon, so that anything to control it emerge naturally as the implementation of a controller model in the system-theoretical sense.

With this innovative approach, it is shown that not only many relevant computing system functionalities can be viewed as feedback controllers in nature, but also that adopting that point of view allows for often surprisingly simple solutions, that can be implemented into existing systems and also provide innovative guidelines to streamline the design of future ones.

In fact, in order to take the challenge of bridging the gap between the two communities, the overall problem of computing system control was endowed with a taxonomy, the problem classes of which were reduced to their core and structured to be comprehensible by both sides. This meant defining problem classes' characteristics so that an appropriate control strategy could be envisaged and, at the same time, the computing system re-design that was needed to achieve the correct functionalities emerged. Looking at the taxonomy from a computer scientists' perspective, one can identify the class to which any particular problem belongs to, and therefore choose the appropriate technique to treat it, based on sound control-theoretical considerations. On the other hand, looking at the taxonomy with a control-oriented viewpoint, one can identify the "core physics" of the problem, thus model all and only the relevant part of the phenomenon, thus in turn figure out and apply the simplest and most effective technique to control it.

The taxonomy classifies problems in four types, along two axes. The first axis divides problems in those that can be viewed as set point following ones, and that are better formulated as functional minimisation ones. The other axis accounts for the presence or the absence of modelling uncertainty. In this dissertation, two classes of problems (out of the four defined) were addressed, namely the set point following ones. For the treated cases, a practical example is shown as a representative problem for the whole class but generalisation is also envisaged. The other problems were not treated here due to time limitations and are deferred to future research.

The operating system task scheduling was chosen as the case study for the first class of problems, where model uncertainties can be neglected. A general framework was proposed, to analyse and assess scheduling policies from a control-theoretical perspective, i.e., by means of dynamic systems and control properties. Within this framework, two different policies were presented and validated by means of simulations, the I+P and the I+PI schedulers. The latter one was also implemented in a kernel to be run on a microcontroller and tests were conducted on the architecture to validate the approach and gather results to be compared with classical scheduling algorithms. It can be concluded that the proposed approach yields advantages both in terms of interpretability of the involved quantities and from a practical (computer science benchmark-oriented) standpoint. More advanced techniques were also proposed, i.e., model predictive control, and their advantages (in terms of achievable results) and drawbacks (in terms of additional complexity) were evidenced.

The operating system application control through resource allocation was treated as a representative example for the second class of problems, where model uncertainties cannot be neglected. In this case, adaptive control was shown to be necessary. For the mentioned problem, a methodology was developed, that from the analysis of sensors and actuators could lead to the control synthesis. Since the literature does not offer comparable results on the same problem, also heuristic and machine learning techniques were considered, comparing them with classical, adaptive and model predictive control. In this case, adaptive and model predictive control yields advantages with respect to the mentioned solutions.

During this work the author and her advisor were able to interact with a variety of different people and discuss a vast corpus of computing system problems. Some work is ongoing on the third class of problems, for which a representative example was found in (web) services composition. Generalising from the expertise gained so far, it is possible to conclude that the proposed approach for design and control of computing systems yielded some advantages, whenever it was applied, spanning from the (sole, but crucial) simplification of the problem to the design of novel and beneficial solutions.

ON THE GEOMETRY OF OPTIMIZATION BASED ON THE EXPONENTIAL FAMILY RELAXATION

Luigi Malagò

In this thesis, we present a geometric perspective on the study of meta-heuristics in optimization that belong to the paradigm of Model-based Search (MBS). We describe a geometric framework for the study of the behavior of model-based algorithms, based on notions of Information Geometry (IG). In particular, we focus on the optimization of pseudo-Boolean functions, i.e., real-valued functions defined over a vector of binary variables, in the black-box context when the analytic formula of the function to be minimized is unknown. The algorithms that belong to MBS introduce a statistical model over the original search space associated to the optimization problem, and exploit it, in order to guide the search for the optimum towards regions that with higher probability could include the global optimum. Such paradigm can be applied in both the discrete and the continuous domain, and it provides a unifying view over many algorithms and techniques in different communities, in particular in Evolutionary Computation (EC), and in Stochastic Optimization (SO), as well as other approaches in optimization, such as the Method of Moments (MoM), and Linear Programming (LP) and Semi-definite Programming (SDP) relaxations, among the others. In order to study the behavior of model-based algorithms, we introduce the optimization problem of the stochastic relaxation, i.e., the minimization of the expected value of the original function with respect to a density in a given statistical model. The stochastic relaxation is a function defined over a statistical model for the original search space, and its variables are the parameters that identify a density in the model. By solving the new optimization problem, and by sampling its solution, we can obtain points that are feasible for the original problem, and under some conditions, correspond to global optima. At different extents, MBS algorithms search for the optimum of a function by minimizing the stochastic relaxation, often with iterative approaches that generate a sequence of densities in the statistical model. Such sequences can be produced in different ways, for instance by following the direction of the gradient of the stochastic relaxation, as in gradient descent algorithms; by employing techniques based on selection of the sample, estimation of the correlations, and then sampling, as in Estimation of Distribution Algorithms (EDAs); or by estimating and sampling a probabilistic model of the function to be minimized, as in the Distribution Estimation using Markov Random Fields (DEUM) framework, a relatively new family of algorithms in EC. In our research, we focus on statistical models that belong to the exponential family of probability distributions, a class of statistical models well known and used in statistics, which includes many common distributions, both in the continuous and in the discrete case. We introduce a geometric framework, based on IG, for the study of the exponential family, which allows us to describe properties of the model and of the stochastic relaxation, independently of the specific parametrization. Such approach provides a unifying perspective on different techniques and heuristics in MBS, and allows the comparison of algorithms that at first sight appear different and incomparable. The theoretical analysis we develop in the thesis focus on the characterization of the tangent space at each point of the exponential family, in order to the study the direction of maximum decrement of the stochastic relaxation, and on the description of the topological closure of the exponential family, to identify limits of sequences of densities in the model. In particular, we derive the formula for the natural gradient of the stochastic relaxation, that is, the gradient evaluated with respect to the Fisher information metric. Differently from the regular gradient with respect to the natural parameters of the exponential family, the natural gradient has the intrinsic property of being invariant with respect to the parametrization for the model, and is known to suffer less from premature convergence in case of large plateaus. For these reasons, the natural gradient identifies a better candidate direction for gradient descent algorithms in MBS compared to the regular gradient. Moreover, the geometrical framework we introduce allows to compare gradient-based methods and function modeling techniques, where probabilities of a point in the search space are estimated according to the value of the function. Indeed, under some hypotheses, we show how a step in the direction of the gradient is equivalent to an estimation of a distribution where probabilities are proportional to the value of the function. This provides a new perspective on the behavior of many existing algorithms in the MBS literature, in particular in the DEUM framework. In a single generation approach, an EDA learns a model for the variables of the function and estimates the parameters of a distribution from a subset of the initial sample only once. Then, the estimated distribution is sampled, in order to look for the minimum of the function. In such a scenario, the probability of a model-based algorithm to consistently identify the global optimum of a function, strongly depends on the ability to correctly identify the relevant interactions that appear among the variables of the function. Our analysis proves how the landscape of the stochastic relaxation of a given function depends on the choice of the statistical model, and how the presence of local minima is determined by some missing interactions among the sufficient statistics of the exponential family. Follows that, in black-box contexts, model selection is crucial in order to identify the relevant interactions among the variables of a function, and thus obtain a good model for the stochastic relaxation. For this reason, many model-based algorithms rely on efficient model selection techniques from statistics and machine learning, able to estimate statistical models in the high-dimensional setting. In the thesis, we see how model selection in MBS can be formalized as a sparse linear regression problem, which in turn, under some assumptions, corresponds to an estimation of the gradient of the function evaluated with respect to the uniform distribution. We exploit such relationship between gradient estimation and linear regression, and we present a novel algorithm for model selection based on ℓ_1-norm penalization. In this thesis we focus on gradient descent techniques, based on the natural gradient, and we present efficient algorithms in the Stochastic Natural Gradient Descent (SNGD) framework able to find the global minimum of well known benchmarks in pseudo-Boolean optimization. Due to the properties of the exponential family we estimate the natural gradient by evaluating empirical covariances, and as a consequence of the robustness of natural gradient, we show how SNGD requires a sample of smaller size, and thus a reduced number of functions evaluations, compared to other techniques in EC. In the last part of the thesis, we present an alternative approach to model selection in MBS, which we called Function Composition Algorithm (FCA). The idea is that of applying a transformation to the original variables in the function to obtain a new set of variables, by the choice of a proper one-to-one mapping. Next, a low dimensional statistical model is employed in the new space, and once the population has been transformed, estimation and sampling are performed as in a regular EDA. The choice of the model corresponds implicitly to the choice of a different model in the original space, which in turn depends on the specific transformation among the variables. By iteratively choosing different transformations, estimating a distribution and sampling, we identify a sequence of densities each belonging to a low dimensional exponential family, able to capture higher order interactions among the variables. All algorithms we propose in the thesis have been evaluated with respect to a set of benchmarks of increasing difficulty, and their performance have been compared with other algorithms in the literature of MBS, and in particular EDAs. This thesis provides contributes at different levels. In particular, it goes into the direction of linking theory and practice in MBS, by introducing a theoretical framework based on a geometric perspective for a rigorous analysis of different model-based algorithms. The theoretical analysis not only provides a novel and unifying perspective on the subject, but also it serves as a motivation for the proposal and definition of new and efficient algorithms for black-box pseudo-Boolean optimization.

GAME THEORETIC MODELS FOR RESOURCE SHARING IN WIRELESS NETWORKS

Ilaria Malanchini

In the last years, wireless communications have been characterized by an impressive growth of standards and technologies, and, as a result, the increasing demand in wireless spectrum has shown that current policies for the use of the available "resources" are inadequate. Furthermore, the rapid proliferation of wireless access networks and the evolution of the end–user terminal are increasing the opportunities for a mobile user to connect anytime and anywhere and, differently from the past when wireless connectivity was monopolized by a single operator/technology, the overprovisioning of access networks nowadays allows mobile users to choose among multiple access opportunities on the base of availability, cost and/or quality, eventually achieving a seamless, ubiquitous, and pervasive connectivity experience. At the same time, the increasing demand in wireless spectrum has shown that new, more flexible spectrum management schemes are necessary to improve the efficiency in spectrum usage. Within this field, recent advancements in the field of software–defined radios allow the development of spectrum–agile devices that can be programmed to operate on a wide spectrum range and tuned to any frequency band in that range with negligible delay. Resulting cognitive radios are able to sense a wide spectrum range, dynamically classifying spectrum blocks for data communications, and "intelligently" selecting the best spectrum opportunity.
To reach the ambitious goal of providing seamless and pervasive connectivity to end users, however, many technical challenges still have to be addressed in different fields, e.g., on the network side, signaling architectures are required to effectively support user's mobility among multiple networks and to manage the radio resource allocation process, on the user side, effective techniques are required to discover and classify the multiple connectivity opportunities based on quality parameters (actual throughput, access delay, wireless interference level) to steer eventually the dynamic selection of the best connectivity opportunity. In a nutshell, all the opportunities introduced by the technological advances have considerably increased the degrees of freedom offered to the end users, but they have also increased complexity and heterogeneity in the network design and management.
In fact, end users can now seamlessly select the "best" wireless access network to connect to (problem of network selection), being even allowed to exploit the available spectrum, taking decisions that are based on the current availability of different spectrum opportunities (problem of spectrum sharing). These two scenarios are inherently characterized by some sort of competitive dynamics among the users, which may compete to get access to the best network and/or to the best spectrum portion. To this extent, a deeper understanding and prediction of such dynamics is central to quantitatively characterize the potentials of future wireless networks.
This work aims at shedding light on the performance modeling of radio resource sharing/ allocation situations. Since, in general, the quality of service perceived by a system (e.g., user, network) strictly depends on the behavior of the other entities, and the involved interactions are mainly competitive, this work introduces a frame- work based on non–cooperative game theoretic tools to characterize radio resource sharing/allocation. Non–cooperative game theory is suitable in distributed networks, where control and management are inherently decentralized.
In detail, we propose non–cooperative game theoretic models for network selection and spectrum sharing by considering different scenarios where both users and networks take part in the game.
First, we consider the case in which many users have to make decisions on which wireless access point to connect to.
In this scenario, the quality perceived by the users mainly depends on the number of other users, i.e., congestion, choosing the very same accessing opportunity. We provide several congestion games both in wireless and mesh networks. We then consider the case in which also networks take part into the competition. In this context, we consider two–stage games where networks make decisions on how to use the available resources, and users react to this selecting the network that maximizes their satisfaction.
Then, we refer to the problem of spectrum sharing, where users directly compete for portions of the available spectrum. Also this problem can be modeled as a congestion game. Furthermore, we also assume a time–varying availability of the spectrum, and we introduce a repeated game. Finally, we provide a more complex model where the users utility function is based on the Shannon rate.
The aim of this second part is to provide a better representation of the satisfaction perceived by the users, i.e., in terms of achievable throughput. Due to the complexity of the game, we first provide a complete analytical study of the two–user case. Then, we extend the analysis to the N–user case. First, we analyze the game through simulations. Then, inspired by the obtained results, we introduce stochastic geometry in the analysis of the spectrum game. Namely, we first provide a stochastic characterization of the two–player game, assuming that nodes are placed at random over a disk. Then, we leverage the analysis to give an asymptotic expression for the coupling probability in a game where the transmitter positions form a (low density) Poisson process, which may be interpreted as the fraction of players essentially playing a two–player game. Finally, using a directed–influence–graph approach, we show how we can study the N–player game and predict the performance in large networks.

COMBINING EXPRESSIVENESS AND EFFICIENCY IN A COMPLEX EVENT PROCESSING MIDDLEWARE

Alessandro Margara

Several complex systems operate by observing a set of primitive events that happen in the external environments, interpreting and combining them to identify higher level composite events, and finally sending the notifications about these events to the components in charge of reacting to them, thus determining the overall system's behavior.
Examples of systems that operate this way are sensor networks for environmental monitoring, financial applications, fraud detection tools, and RFID-based inventory management. More in general, the information system of every complex company can and should be organized around an event-based core that realizes a sort of nervous system to guide and control the operation of the other sub-systems.
The task of identifying composite events from primitive ones is performed by the Complex Event Processing (CEP) Engine. It operates by interpreting a set of event definition rules that describe how composite events are defined from primitive ones. The CEP engine is usually part of a CEP system or middleware which also handles the communication with local and remote clients.
To capture all the requirements of the aforementioned applications, a CEP engine has to face several challenges. First, it has to provide a suitable language for rule specification, explicitly tailored to model complex temporal relationships that join together primitive events in composite ones. Second, it has to implement efficient processing algorithms, to detect composite events and deliver notifications to interested parties with the lowest possible delay. Finally, it has to support distributed scenarios, in which the communication parties may be deployed over a wide geographical area.
This thesis first proposes a modelling framework to compare and analyze not only existing CEP systems, but all the systems developed with the aim of processing continuous flows of information according to predeployed processing rules. This allows us to identify the main advantages and limitations of existing approaches, by looking at a wide range of proposals. Moreover, our modelling framework draws a common ground for comparing efforts coming from different research communities, with different background, expertise, and vocabulary. We believe that our work can bridge the gap between different worlds, promoting the communication and reducing the effort required to compare and merge the results produced so far.

Moving from the issues identified while analyzing existing works, we introduce T-Rex, a new CEP system explicitly designed to combine expressiveness and efficiency. In particular, we first present TESLA, the new event definition language used by T-Rex. TESLA is explicitly designed to model in an easy and natural way the complex relationships that join primitive events and the actions required to aggregate them to obtain composite events.
Then we discuss in details the implementation of T-Rex, studied to efficiently process TESLA rules. First of all we focus on the problem of matching, i.e., selecting relevant (primitive) events based on their content, which is one of the fundamental actions present in every event-based system. We propose a novel matching algorithm explicitly designed to take advantage of parallel hardware, including modern Graphical Processing Units (GPUs). This is the first solution that analyzed the adoption of parallel hardware to speed up matching and our evaluation shows impressive results with respect to existing sequential solutions.
Afterward, we focus on complete TESLA rules, and we discuss and compare two different processing algorithms that take two opposite approaches to process incoming events. A comparison with existing products shows the effectiveness of both our proposals and the differences among them.
Independently from the adopted algorithm, T-Rex leverages the presence of multiple processing cores to efficiently evaluate different rules in parallel. To further reduce the time required to handle the most complex rules, i.e., those involving a large number of primitive events, we present and evaluate a third algorithm to process TESLA rules on GPUs.
Our contribution goes beyond the implementation of T-Rex, indeed this is the first work that describes in details how CEP can leverage off-the-shelf parallel hardware: multi-core CPUs and GPUs. Since our analysis is organized around the basic language constructs provided by TESLA, but also present in most of existing CEP languages, our work represents an important contribution to determine how CEP can take advantage of currently available parallel hardware architectures and which processing algorithms are best suited to exploit their processing power.
The last aspect examined by this thesis is how to take advantage of the availability of multiple processing nodes, distributing the processing load over different machines, to better support large-scale distributed scenarios, reducing the delay required to receive results, or the occupation of network resources. To this extent, we present and compare different solutions for a distributed T-Rex, extracting the advantages and limitations of each of them. They include the protocols to organize available nodes into an overlay network, to partition and distribute event definition rules, and to cooperatively handle event processing and delivery.

ADVANCED TECHNIQUES FOR FLEXIBLE DATABASE QUERIES

Mirjana Mazuran

In this thesis we will tackle the problem of Big Data Analytics by focusing on how to extract synopsis from it, that is find recurring patterns in the data. We will show how these patterns can be used to get the gist out of data, that is, to represent in a succinct way the data's most frequent properties. These properties are in their turn a valuable source of knowledge that gives an idea of what "goes on" inside the data. They can be used as a compact representation of data as well as a basis for making efficient decisions. Moreover, we will see how the use of aggregates is decisive in Big Data because it allows for better analysis of data itself. The introduction of aggregates broadens the range of applications of Big Data Analytics.

The first aim of the thesis is to propose novel applications of data mining techniques to provide advanced database functionalities. In particular we focus on extracting frequent information from a dataset in order to use it for query answering, that is allowing users to query the frequent patterns rather than the data. We consider such patterns as intensional information because they represent a dataset in terms of a set of properties rather than in terms of the data (which is called extensional information). Intuitively, intensional information is a summary of the data contained in the document. Our goal is to propose a methodology for the XML scenario that uses association rules to represent intensional knowledge and provides an automatic strategy for translating user queries over the original dataset to queries over the mined association rules. In fact, intensional knowledge provides (often hidden) information about the actual data contained in the database. Such information is particularly valuable when the original documents are not available or reachable anymore or when the user prefers to obtain a synthetic, possibly faster but partial, answer. Moreover, frequent patterns can provide initial knowledge about vast datasets and help the refinement of more specific investigation. Several issues are tackled to achieve our goal. First of all, while data mining techniques are mostly supported in relational databases, XML databases still lack appropriate ways to extract intensional knowledge. In particular, there is no agreed upon definition of association rule in the XML context. In fact, inthe literature, the extraction of association rules from XML documents is done by first translating the document into relational format and then applying well established algorithms. However, in such a way the information about the structure of the data in the XML document is lost and to take it into account, a native definition of association rule for XML is required. Therefore, one of the aims of this work is the definition of a method for extracting, storing and using structure-preserving XML-association rules. A second problem, once we are able to represent intensional knowledge in both the relational and XML context, concerns the automatic translation of user queries formulated over the original dataset into queries over the XML association rules.

From the XML tree-based scenario we take a step further into analyzing a similar but more complex representation, that is, graph-based data. We present DatalogFS, an extension of Datalog that allows to introduce more flexibility into the querying process by using count-based aggregates. Our approach allows users to write queries in terms of programs in DatalogFS, which are considered synopsis of expanded Datalog programs. We provide a rewriting of DatalogFS programs into Datalog and a semantics that allows us to keep the simple and elegant least-fixpoint semantics of Datalog and all of its optimizations, such as the differential fixpoint and magic sets. Our approach provides a way of efficiently querying massive graph-based datasets using count-based aggregates. This feature introduces more flexibility into the querying process because it allows a better analysis of data. In fact, aggregates are one of the most commonly used features in the support of massive analytics and web mining. The introduction of aggregates in Datalog broadens the range of its applications. We will show how this new feature is suitable to support flexible queries in massive databases containing web-based data, social network data and so on. In particular, we will see how to write DatalogFS programs that implement Apriori and PageRank, making our proposal helpful in the process of analyzing both relational and web-based data. Moreover, we will also focus on the application of DatalogFS programs for the analysis of data coming from social networks. For example, using the Markov Chains and Diffusion Models we will show how DatalogFS can be efficiently used to analyze the role of retweets in the Twitter network.

GEOPHYSICAL INVERSION FOR HYDROCARBON RESERVOIR CHARACTERIZATION

Fabio Marco Miotti

The reservoir characterization is a delicate and challenging activity which provides the description of a reservoir model that incorporates all the characteristics related to its ability to store hydrocarbons and also to produce them. The problem of reservoir characterization is of significant economic nature to the oil companies, since the capability of estimating the oil and gas saturations allows to reduce the costly drilling of un-productive reservoir. The reservoir characterization can be performed by using various exploration techniques such as: seismic, electromagnetic sounding and well log data, depending on the peculiarity of the sediment lithology, and the cost of the exploration campaign. The present study faces the problem of the reservoir characterization through an original formulation of the inverse problem. The thesis is structured into two parts since two different geophysical exploration techniques are employed in the characterization of the subsurface media.
First, I study the petrophysical properties of the reservoir in-situ, through the integration of heterogeneous well log data for improving the estimation of the petrophysical properties of the reservoir. On this framework I formulate the joint inversion of well log data, p-velocity, electrical conductivity and density, for estimating porosity, water, oil and gas saturation. This approach allows recovering complementary information for improving the estimation of the petrophysical model, exploiting the strengths of each different geophysical data types. The analyses involves the joint inversion of experimental constitutive equations, also called rock physic models, which represent a proper link between the rock parameters and the geophysical measurements.
I firstly investigate the rock parameter observability through a visual analysis of the constitutive equations. Then I explain that the existence of a common set of rock properties, (cross-properties), that influence different geophysical measurements, makes it possible to reduce the ambiguities of the interpretation. The rock cross-property concept represents the kernel of the inversion algorithm that I propose to estimate the petrophysical model of the reservoir. I formulate a Bayesian joint inversion procedure starting from the well known nonlinear relation $d=g(m)$, where well log measurements represent the input data while the fluid saturation levels and porosity represent the model parameters. Prior to perform the model estimation it is furnished a sensitivity analysis of the model parameters based on the analysis of the Jacobian matrix through the Singular Value Decomposition technique (SVD). Finally I show that the iterative joint inversion procedure is able to control the conditioning problem, to efficiently take into account input data and model uncertainty, and to provide a confidence interval for the solution. Moreover, the inverse analysis offers a clear view of the regularization effect due to the setting of the model covariance matrix. Finally, the inversion procedure is validated on a real well log dataset. Results obtained highlight the importance of integrating heterogeneous dataset, in a systematic Bayesian joint inversion procedure, for improving the characterization of the reservoir.
The second part of the study aims to characterize the reservoir by formulating the inverse problem of Controlled Source Electromagnetic (CSEM) data for 2.5D geometry.
The CSEMmethod is an emerging offshore geophysical technique which employs the electromagnetic remote-sensing technology, based on the induction principle. Since that CSEM data are sensitive to the variations of the electrical resistivity of the subsurface media I focus on the characterization of the reservoir in terms of electrical resistivity. I firstly investigate the electromagnetic propagation into the subsurface medium in order to comprehend the peculiarity of the technique in terms of resolution, data sensitivity and system noise. The parameterization of the CSEM system entails the discretization of the subseafloor through the introduction of a regular grid. This straightforward approach consists of defining the electrical macroregions needed to cover the entire subsurface medium. The problem formulation is based on the nonlinear relation $d=g(m)$, where the input data are represented by the electromagnetic components *Ex, Ez, Hy* in magnitude and phase, while the model parameters consist of the set of the electrical resistivity values which are associated to the macroregions. Since electric and magnetic fields have a wide dynamic range, regularization strategies have been applied on data input for reducing the ill conditioning of the problem. The driving forward model consists of an ad-hoc electromagnetic simulator based on the Finite Element Method (FEM). As in the previous part, the inversion procedure is based on the Bayesian approach.
The sensitivity analysis is performed through the SVD decomposition of the Jacobian matrix. The inversion procedure is then tested on a realistic synthetic scenario in order to investigate the robustness of the algorithm. The iterative inversion algorithm provides the estimation of the model with a measure of the uncertainty associated to their parameters. Results show how the use of the Bayesian inversion can be applied to CSEM data in order to characterize the reservoir in terms of electrical resistivity allowing the discrimination of oil form water. To notice the novelty represented by the FEM forward involved in the inversion of the CSEM data.
The entire study presents useful applications for performing the characterization of the subsurface media through the Bayesian inversion of well log and CSEM data. Finally, in this study is explained how to analyse the multi-dimensional residuals, with a one-dimensional 'distance' functional, in order to depict their topology and to appreciate visually the effect of the regularization.

ELECTRICAL CHARACTERIZATION AND PHYSICAL MODELING OF UNIPOLAR/BIPOLAR RESISTIVE SWITCHING MATERIALS

Federico Nardi

In recent years the technology has marked the deepest changes in our lives and culture. The impressive development of new electronic devices is by far the fastest progress that human kind has ever experienced. The continuous demand of new portable, low-cost, low-power devices has forced a huge effort in R&D, pushing the limits of the current technology. The demand of memory supports represents an excellent example of such rush toward the limits of our technology. Flash memory, representing the main stream memory technology, experienced an impressive development being, at the time of writing, at the 25 nm node. The foresee of the intrinsic limit of Flash scalability, is also driving a tremendous amount of research in completely new memory technologies. This research is yielding to an exciting activity directed to a deeper physical understanding and, at the same time, to a fast technology development.
This Doctoral Dissertation has been focused on Nickel Oxide-based and Hafnium Oxide-based Resistive-switching RAM (RRAM). The work describes working principles, physical/ numerical modeling, reliability issues and innovative memory structures of RRAM technology. Experimental characterization has been a crucial step in this task, being the starting point of physical understanding and thus modeling.
The working principle of RRAM is based on the capability of the material to switch reversibly between two different resistance values. The build-up of a thin conductive filament is responsible of the low resistance that characterizes the so-called set state. There are several experimental evidences that support this hypothesis, but still the actual nature of the conductive filament is unknown. By the use of particular program algorithm we characterized carefully both set and reset states, showing in particular that there is a continuous transition between the set state, that is characterized by a metallic conduction, to the reset state that is, on the contrary, semiconductor-like with a certain activation energy for conduction. This change in resistance can be related to a modulation of defect doping and a consequent shift in the Fermi level. Thanks to this characterization we were able to extract an important microscopic parameter, namely the effective diameter of the conductive filament.
Starting from electrical characterization on NiO (unipolar) RRAM we developed physical models for the set (formation) and the reset (rupture) of conductive filaments, and their dependence on filament size/resistance. A Joule heating thermal model for reset accounts for the reset voltage and current as a function of filament size, taking into account size-dependent heat conduction mechanisms and size-dependent diffusion/ oxidation effects. Set transition is modeled by threshold switching while the resistance-dependent set voltage and current are well reproduced by a change in doping concentration and activation energy.
The unipolar reset switching model was extended to the case of HfO (bipolar) RRAM by considering field driven ion migration. The physical comprehension of these switching mechanisms lead us to evidence a universal unipolar/bipolar reset model with negligible dependence on materials.
Physical-based numerical models for reset and retention of unipolar/ bipolar RRAM have been presented. These models have been validated on electrical characterization results and can be used for numerical simulations of programming, reliability and scaling predictions.
For the first time we demonstrated complementary switching in single stack nonpolar-RRAM devices, based on simulations and DC/pulsed experiments in symmetric HfO-based RRAM. The introduction of this new operation mode, which intrinsically solves the sneak-path problem in cross-bar arrays, seems to be very promising for the development of future high-density memory.
Finally, complementary switching allowed us to explain the coexistence of unipolar and bipolar through vertical ion displacement by field-driven migration and electromigration/ diffusion.
Reset current reduction has been accessed by the control of the dimension of the conductive filament. This can be done limiting the current drained by the cell during its growth, by mean of an integrated MOSFET. We characterized 1T1R structures, showing that there is a linear relationship between the current compliance imposed by the MOSFET during set, and the reset current. By the use of CAFM techniques we were able to direct manipulate single conductive filaments showing reset currents below 1 μA.
These results are in line with the expected dependence on the size of the conductive filament thus supporting area scaling as a powerful method for program power reduction which is crucial for device scaling itself. In particular, since unipolar-RRAM may be utilized in cross-point array with dedicated selector diode, reset scaling is necessary to assure that the integrated diode may carry sufficient current.
We statistically studied data retention issues, showing that the time to failure for the set state (the reset state is on the contrary stable) depends on temperature with an Arrhenius-like behavior, and on the initial resistance, i.e. the diameter of the conductive filament and the activation energy. As can be qualitatively expected the failure time decreases for increasing resistances. This fact in turn yield to an intrinsic trade-off between retention time and reset current, since the lower is the resistance, the higher is the current drained by the cell during reset.
Power reduction was addressed in in unipolar RRAMs by the use of pulsed program operation. Minimum reset current requires controlled set to avoid overshoot effects. Set-reset instability and set due to threshold switching in semiconductor-like conductive filament affect both DC and pulsed reset and appear as main issues in preventing low-current, stable and fast reset. This issue may be suppressed by careful set algorithms or material engineering aimed at obtaining metallic-like filaments with sufficiently high resistance.
To better assess reliability issues, we showed data and discussed RTN affecting the reset state. We developed a simple model based on trapping/ detrapping of a single localized state that is able to reproduce data of relative resistance fluctuation as a function of the resistance. RTN however may hardly cause read mistakes or other issues.
The last part of this thesis was instead dedicated to the description of the synthesis and characterization of a novel device, based on the self-assembly of Ni-NiO core-shell nanowires. The assembly of complex architectures, starting from simple nanometric building blocks, possesses strong potentials since it may lead to the production of large arrays without lithographic limits. Here we demonstrated the working principle of a NiO RRAM constituted by the two NWs in a cross-bar structure. The contact point of the two NWs has in fact a Ni/NiO/Ni stack. For the first time we showed resistive switching at the crosspoint of two nanowires. Set and reset parameters were shown to be compatible with typical values for planar structures. The missing encapsulation of these devices are probably responsible for their low endurance, that was evidenced during the characterization. Eventually we showed that better endurance can be achieved with hybrid devices made by a single core-shell NW, crossed by an EBL deposited metal strip.

SAFETY AND PERFORMANCE SLIP CONTROL DESIGN FOR TILTING VEHICLES

Giulio Panzani

Summary
The control of vehicle longitudinal dynamics - constituted by braking and traction control - has been one of the first topics that have been the successful employment of system control theory applied in the automotive areas. However, the diffusion of electronic control system in two-wheeled vehicles has started with several decades of delay, if compared to four-wheeled vehicle vehicles. There are several reasons that motivate this lag. Firstly, it is unquestionable that, especially in the Western countries, two-wheeled market is little compared to the four-wheeled one: investment in developing advanced electronic systems have been thus less available. Moreover, two-wheeled dynamics are substantially different from four-wheeled ones; front or rear wheel lift from the ground, for example, but above all the static instability of these vehicles are phenomena that are completely absent in the traditional cars. Unfortunately these events are potentially dangerous for the driver, and their dynamic complexity has slowed down the technical progress in this field. The growth of traffic, especially in the big urban areas, has induced motorcycle companies to develop safety-oriented electronic systems to encounter the request of the everyday drivers. An important contribution in the development of such systems is also coming by the racing community: in the last years, many moto-GP teams have been successfully employing traction control systems and other electronic control systems to push two-wheeled vehicle performances further. Actually, this motivation has become fundamental in the two-wheeled vehicle market: electronic devices are always exhibited to the public as performances-oriented rather than safety-oriented systems. Nevertheless, it is clear how performance and safety are tightly bounded in two wheeled-vehicle, thus actually both aims are pursued in the development of such control systems. This Thesis has been developed in this challenging and interesting and evolving context with the aim of providing a thorough analysis of the issues involved in designing longitudinal control systems for road vehicles.
The goal of this work is to provide analysis and solutions to the several problems that are encountered, showing their effectiveness from the application viewpoint but even their theoretically interest from a methodological perspective.

This Thesis is divided in three parts:

1. Motorcycle dynamics
2. Longitudinal control in two-wheeled vehicles
3. Actuation and estimation issues in two-wheeled vehicles

In the first part the motorcycle dynamics are inquired: detailed modeling is discussed and the vehicle dynamic is studied. This part has first of all to introduce the reader to the topics and the problems that longitudinal dynamics involves, by analyzing characteristics and criticality of two-wheeled vehicle longitudinal dynamics. The second part describes the high-level control layer of longitudinal dynamic control, with particular focus on the development of an advanced, state of art traction control system for two wheeled vehicles. Finally, in the third part, estimation and actuation problems which arise in the longitudinal control context are discussed.

Main Contributions

The main contributions of this Thesis can be summarized as follows:

- Longitudinal dynamic modeling and analysis, oriented to the development of longitudinal control systems applied to two-wheeled vehicles. To the best of the author's knowledge, no analytic model of the in plane motorcycle dynamics, that account for suspension, longitudinal, wheel slip and transmission dynamic are present in literature. The availability of comprehensive although treatable analytic models proves useful for future research and application in traction and braking control and estimation problems.
- Advanced and original traction control, wheelie control and launch control systems. The proposed, experimentally validated, traction control system prevents rear wheel slippage without impeding performances through an advanced slip target generation. The wheelie control system prevents the lift of the front wheel of the vehicle, allowing to achieve the maximum performances through a longitudinal acceleration control. The launch control system simplifies the zero speed vehicle acceleration (called launch maneuver) allowing the driver to concentrate only on the clutch release, since engine is controlled in order to keep an adequate rotational speed.
- An experimentally validated electronic throttle control. The proposed controller represents one of the first applications of electronic throttle control to motorbikes. In particular, the control oriented dynamic identification, that allows to easily tune a high bandwidth position regulator, and the control law adaptive extension are the main innovative contributions.
- The rear wheel slip estimation, oriented to traction control with the analysis of the external disturbances that makes difficult the estimate of this quantity. Moreover the detailed signal processing procedure, based on Kalman filtering techniques and on advanced adaptive notch filters proves practically effective. Beside practical interest, the theoretical analysis bring original contributions to the estimation method proposed.
- An innovative methodology to estimate wheelie in two-wheeled vehicle. The proposed method is based on fault detection techniques and proves effective in detecting wheelie during standard but even in track vehicle usage.
- The analysis of the principal measurement axes in vehicle roll angle estimation. The aim of the analysis proposed is to identify which are the inertial measurements (accelerations and angular rates) that are strongly related to the lean angle and that can be used to estimate it in a urban path.
- The problem of forward speed estimation in two-wheeled vehicles is solved by means of an extended Kalman filter. It is shown that combined use of a nonlinear model derived on straight-running and a time-varying longitudinal friction coefficient of the road allows us to get a reliable estimation of the forward speed.

Open Issues and Topics of Future Research

In the development of traction control system, there are several issues that can be tackled to improve the performance of such systems. Dealing with the Traction Control, an interesting research path could be the design of more advanced regulators, for example with variable structure can be exploited to give an important improvement to closed loop performances. Even though strongly related with the considered phenomenon, the vehicle pitch angle is not exploited in Wheelie control; its usage could be significantly improve closed loop performances, and opening several new control solution for this problem. In this perspective, the first step is to inquire estimation techniques for this variable that actually is not an available signal, with the nowadays standard vehicle equipment. Launch control future research could combine the engine control with an electronically controlled clutch release, that nowadays is not possible since typically clutch can be controlled only by the driver. The most interesting open research path, deals with the braking control of motorcycle. Although being the dual problem of traction control (meaning that some solution adopted for this problem can be easily translated from a field to the other), it shows peculiarities that requires ad hoc solutions and studies.

ASSESSING AND OPTIMIZING THE OPERATION OF THE HOABINH RESERVOIR IN VIETNAM BY MULTI-OBJECTIVE OPTIMAL CONTROL TECHNIQUES

Xuan Quach

The purpose of this study was to investigate the operation of the Hoabinh reservoir in the Red River Basin of Vietnam, and assess the room for its improvement by application of system analysis and optimal control techniques. The study aimed at establishing a foundation for further research on inter-reservoir regulation of the Basin. Finally, this study provided a testing ground for developing and comparing different reservoir optimization methods.

Chapter 1 and 2 provide a general and mathematical description of the socio-economic and physical system of the Red River Basin, including the three main objectives of hydropower production, flood control, and water supply. Conceptual and data-driven modeling tools were used to this purpose.

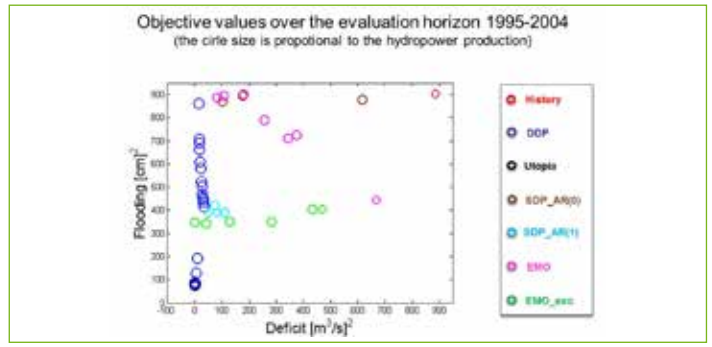
In Chapter 3, the potential of the current infrastructure was assessed by application of Deterministic Dynamic Programming, which provides the upper bound of system performance under the ideal assumption of perfect information about future inflows to the system. Results proved that, in fact, there exists a large room for improvement of the historical regulation, although the existing storage capacity is not fully adequate for flood control.

In Chapter 4 and 5 several different optimal control methods were applied to design new operating policies, including the standard Stochastic Dynamic Programming and Implicit Stochastic Optimization, and a novel method that combines Evolutionary Multi-Objective optimization and Artificial Neural Networks.

Results of this work showed that there are a lot of operating policies that prove Pareto-dominant over the historical one, that is, they can improve all three objectives simultaneously. However, while the improvement is rather significant with respect to hydropower production and water supply, it is much more limited in terms of flood control. To overcome this limitation, the value of hydrometeorological information for anticipatory management was explored by a novel Input Variable Selection technique combined with Evolutionary Multi-Objective optimization (EMO).

Figure 1 shows different operating policies found by different optimization methods on the objective space. The horizontal axis represents the objective value of water deficit ($[m^3/s]^2$), the vertical axis represents the objective value of flood exceedence ($[cm]^2$), and the objective value of hydropower production is shown by the size of the cirle. In general, the results of EMO are comparable to those of SDP. For both methods, using additional information or increasing the model complexity significantly improve the performances of reservoir optimization. However, while in SDP the use of more and more sophisticated models for the upstream catchments is subject to the limits imposed by the so called curses of modelling and of complexity (all the input variables of the decision rule must be regarded as state variables, i.e. modeled by state transition functions, and the computing time increases exponentially with the number of state variables), in the EMO approach any exogenous information can be potentially included in the decision rule at low modeling and computing costs (no further model identification is needed because historical time series are directly used in the optimization; computing time stays almost the same). And it is seen that the policies found by EMO using exogenous information are closet to the Utopia point.

The last Chapter of the thesis compares the results obtained by the different optimization techniques in terms of their effectiveness and significance to the Hoabinh water management. With the proposed operating policy it is



1.

estimated that the maximum flood level of the 1996 flood will reduces from 12.22 m to 11.90 m, the water deficit will be only 7 Mm^3/year compared to 66 Mm^3/year of the history, the annual energy production increases from 7.82 TWh to about 8 TWh, corresponding to a saving of about USD 9 million per year, given that the import price of electicity from China is about 0.051 USD/kWh.

The thesis also discusses the limits of the study and topics for future research. Since, in the Red River Basin there are several other reservoirs and some new more under construction, optimizing the Hoabinh operation may constitute a preliminary exercise for future research on the coordinate management of this multi-reservoir network. If future research will enlarge the system domain to cover the whole inter-reservoir system and consider a larger number of objectives, the EMO approach appears to be the most promising because of its relative simplicity of application to problems with many objectives and high dimensional system.

ELECTRONICAL INSTRUMENTATION FOR IMPEDANCE MEASUREMENT ON BIOSAMPLES

Angelo Rottigni

In the last years electronical systems entered with great importance in the measurement of biological quantities, granting access to information from electrical cellular characteristics: it is in fact possible to measure capacitance or conductance that are dependent on the health state of cells and can be used to perform drug testing. In addition, lab-on-a-chip systems are attracting a growing attention for the possibility of parallelization and portability of bio- logical assays, but they require sensitive and compact electronic measurement systems to be developed, in order to realize instruments that can be utilized also by people outside a biological laboratory, reaching what is called point- of-care diagnostic.

To support on-chip electrobiological measurements, during this research, the development of highly sensitive, economical and compact instruments to detect impedance of biological samples has been explored. A first part of the research dealt with discrete systems development, with the focus of obtaining high sensitivity, while keeping the system compact, low-cost and low-power. These constraints have been considered while designing an handheld impedance based cell counter, that has been used to replace fluorescence-based detection in a dielectrophoretic separation experiment. The need for increased flexibility and compactness, then, lead to the design of a fully integrated chip for impedance measurement with two phases lock-in to obtain magnitude and phase information about the impedance. The challenges in this kind of design are to obtain good performances even with standard, low-voltage and low-cost technology; the design techniques used to solve them are presented in this work. Finally a new circuital topology has been explored to increase the impedance measurement bandwidth over the usual range of operational-amplifier based transimpedance amplifiers. Exploiting modulation and demodulation, together with feedback we can achieve bandwidth bigger than 100MHz with good linearity.

A LANGUAGE-LEVEL APPROACH TO SELF-ADAPTIVE SOFTWARE

Guido Salvaneschi

Over the last few years, self-adaptive software became increasingly important to design complex systems which require less human intervention and to manage devices, such as smartphones, which are naturally subject to context changes. Traditional approaches to self-adaptation encompass software architectures, middleware and design patterns. In this research we explore the use of ad-hoc programming language abstractions to support self-adaptive software.

The importance of this research field is mainly due to a gradual change in the landscape of computer science. Two phenomena can be recognized as the key factors of this change: the increasing complexity of computing systems and the introduction of new electronic devices, tightly coupled with the surrounding environment.
In the course of years, software systems complexity has been growing, increasing the effort and the cost of management and maintenance. As a result, avoiding human intervention and ensuring continuous operations in changing conditions has become a primary issue. This motivated the research on systems capable of managing themselves autonomously, with minimal intervention time and with resource savings. The practical impact of this studies convinced companies to invest considerable effort in this vision. For example, IBM proposed Autonomic Computing, an initiative to reduce the barrier to further system growing, leveraging autonomous decisions and self optimization.
On the other hand, a great variety of new devices has become very popular, such as smartphones, netbooks, palmtop computers and tablets. Portable devices have in common a tight interaction with the environment in which they operate. For example, they are connected to different data sources, such as WiFi, Bluetooth or 3G connections, they can collect information from sensors, such as the GPS or the accelerometer and they can interact with sensor networks and other electronic systems. Since these devices are immersed in a the changing environment, software executing on them must adapt to the external circumstances to maintain effective. For example, they must with variations in network bandwidth, battery power, presence of connectivity and changing reachability of services and hosts. Self-adaptation becomes fundamental to deal with this variability and to guarantee high levels of reliability.

From a software engineering perspective, the design and the implementation of context-adaptable applications is challenging for several reasons. Since adaptation must be performed at run time, the implementation mechanism must support dynamic activation of behavioral variations. Behavioral variations must be properly modularized. This increases maintainability and makes easier to add new variations. Context-specific behaviors typically crosscut the main modularization directions of the application. Behavioral variations can be designed to respond to potentially unpredictable environmental conditions, so dynamic combination is needed. Some combinations of behavioral variations must be avoided. For example the adaptation to the "online" and to the "offline" conditions should not coexist. Since variations combine dynamically, it should be enforced that prohibited combinations do not arise at run time. Supporting unforeseen adaptation is required. For example, it should be possible to remotely provide the required behavioral variations to the application nodes incapable of properly adapt to the current conditions. Finally, the proposed solutions should be integrated with existing tools and methodologies.

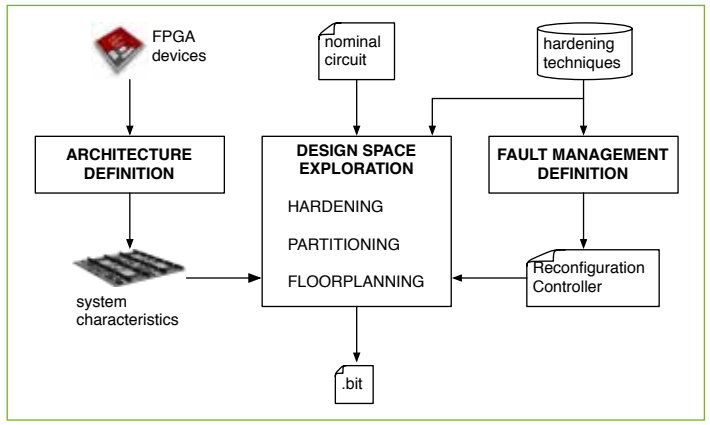
The problem of properly supporting the development of self-adaptive software has been faced with a variety of solutions leveraging reconfigurable architectures, component-based design, middleware and design patterns. Other approaches tackled the problem at the programming language level. Language-level approaches are of special interest because they push the adaptation down to the elementary components of software, allowing for extremely fine-grain adaptability. Previous approaches have been focusing on computational reflection, aspect-oriented programming (AOP) to enforce separation of concerns in adaptable systems at development time and dynamic aspect-oriented programming (DAOP) to support run-time adaptation.
Starting from the pioneering work of Costanza and Hirschfeld, COP emerged as a promising paradigm for developing applications whose behavior can automatically adapt to changes of the context in which the application is embedded and running. COP provides specific language-level abstractions to define and activate behavioral variations that allow the application to dynamically adapt to changes in the execution context.
Thanks to the abstract notion of context assumed by COP, all the conditions to which self-adapting software must respond (e.g. bandwidth availability, presence of wifi or data connection, battery level, current system workload) can be expressed as context. The COP paradigm provides an additional dimension to standard programming techniques to dynamically switch among the behaviors associated with each context. Therefore not only it allows to design context-aware applications for some restricted idea of environmental context but is effective in general to support the development of self-adaptive software. In addition to this, COP provides means to dynamically combine different behaviors when all the associated contexts are active at the same time and properly modularize the code for each behavior.

The first chapters of the thesis include a comprehensive analysis of the existing implementation techniques for self-adaptive software. Since the focus of this work is on language-level solutions, we increase the details of the analysis while moving from architecture-level solutions to ad-hoc language paradigms. The highest level of detail is devoted to COP languages. Following a different approach from the one adopted in literature so far, we compare COP approaches in the perspective of a software engineer committed to the design of a self-adaptive system. A final analysis effort is devoted to the study of the adaptation features in existing mainstream languages. We setup a conceptual framework which is capable of describing all the significant aspects of language-level adaptation including COP approaches. This work completes the background for the dissertation, discussing the use of traditional languages for the implementation of self-adaptive systems.
In the second part of the thesis we address several issues in the field of context-oriented programming for self-adaptive systems. A first effort addresses the issue of the integration with the tool ecosystem which usually supports the development process. In fact, many current COP languages come as ad-hoc compilers which hardly fit in the existing toolchain and easily break the compatibility with tools like IDEs, debuggers, performance profiles and test coverage analyzers. With JavaCtx we propose a lightweight approach to COP which leverages coding conventions to introduce COP in Java and tries to minimize the impact on the development process and the tool usability. With ContextErlang, a COP extension to the Erlang language, we introduce new programming model for contextual applications. This programming model allows to address the issue of asynchronous context provisioning by integrating COP abstractions with the actor concurrency model. Moreover, through dynamic variations loading, ContextErlang also supports unforeseen adaptation. COP is promising to implement autonomic applications, while current approaches mainly involve libraries, middleware and architectural solutions. We propose a conceptual framework which integrates COP and the MAPE-K autonomic loop on which autonomic applications are shaped. We validate our work with an adaptable web application capable of reacting to the bandwidth availability of the application server.

A RELIABILITY-AWARE DESIGN METHODOLOGY FOR EMBEDDED SYSTEMS ON MULTI-FPGA PLATFORMS

Chiara Sandionigi

This PhD thesis proposes a methodology for the design of reliable embedded systems on multi-FPGA platforms. The objective is the exploitation of commercial SRAM-based FPGAs in mission-critical scenarios. Embedded systems and applications for space missions, where maintenance and system's lifetime are critical aspects, constitute the driving application scenario of the thesis, that has been partially supported by European Space Agency.

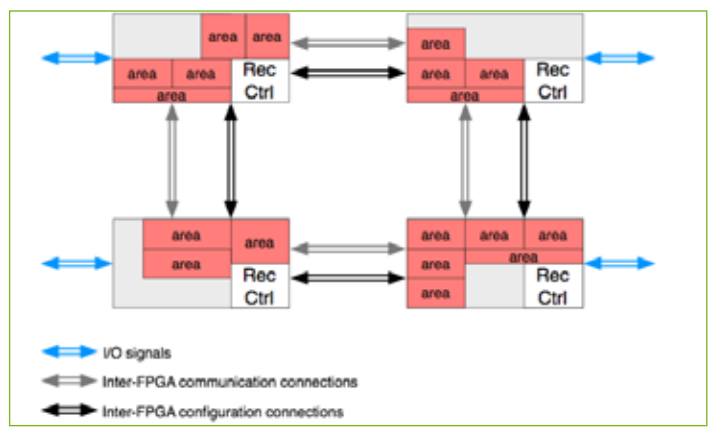


1. Reliability-aware design methodology.

The idea is to achieve fault tolerance by exploiting the reconfigurable properties of the devices. We identify two categories of faults based on the possibility to recover from them by reconfiguration; *recoverable* and *non-recoverable* faults. Recoverable faults can be mitigated by reconfiguring the system, and possibly only the faulty sub-system portion, with the same configuration used before fault occurrence. Non-recoverable faults permanently compromise part or all of the device, such that further use of the corrupted portion of the device must be avoided and the logic hosted must be moved in a different location.

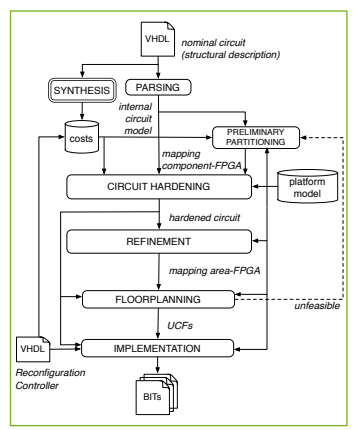
The proposed reliability-aware methodology realizes autonomous fault tolerant systems implemented on multi-FPGA platforms. While some aspects can be taken from previous solutions available in literature, several open issues for the proposed methodology exist and have been investigated. As shown in Figure 1, the methodology is composed of three main activities, each of them tackling one of the identified relevant issues; i) *architecture definition*, establishing how to exploit the available SRAM-based FPGAs to build the autonomous fault tolerant system, ii) *design space exploration*, devoted to the hardening of the nominal circuit and its distribution on the multi-FPGA platform, and iii) *fault management definition*, identifying how to classify the faults and cope with their occurrence.

The proposed autonomous fault tolerant system is hosted on a platform with multiple SRAM-based FPGAs connected to each other in a mesh topology. Each FPGA hosts i) a hardened portion of the entire circuit, organized in *independently recoverable areas* that autonomously detect, mask/tolerate, and signal the occurrence of a fault, and ii) a *Reconfiguration Controller*, that is the engine in charge of monitoring the error signals to trigger, when needed, the reconfiguration of the faulty part of the circuit. An overview of the system architecture is shown in Figure 2.
Rather than making each FPGA an independent fault tolerant sub-system, able to locally detect and recover from faults, we have envisioned a distributed solution, where the Reconfiguration Controller hosted on an FPGA is in charge of reconfiguring the areas hosted on a neighbor FPGA. Fault detection and tolerance techniques, e.g., by means of spatial redundancy, are used to identify the occurrence of the fault and to localize the corrupted portion of the FPGA, the independently recoverable area. Each area generates error signals, monitored by a Reconfiguration Controller hosted on the neighbor FPGA. Reliability requirements are expressed for the Reconfiguration Controller also, in case a fault occurs in the area hosting it, and such that no undesired and/or erroneous reconfigurations take place. Therefore, the module has been designed to be able to autonomously detect the occurrence of a fault and to mitigate its effects while waiting for recovery handled by another controller hosted onto another FPGA.



2. System's architecture.

Indeed, in designing the autonomous fault tolerant system, we are not just pursuing a working solution, rather the approach identifies the solution offering the most convenient trade-off with respect to the designer's selected metrics. Thus, the design space exploration is the core of the proposed methodology. The resulting design flow for the implementation of a hardened system onto the multi-FPGA platform is reported in Figure 3.
The input of the design flow is the structural description of the system to be implemented, described in terms of interconnected components. The flow consists of three main steps, each one performing an exploration of the possible alternatives; i) *hardening*, that selects and applies fault detection/tolerance techniques, ii) *partitioning*, that distributes the obtained reliable circuit among the available FPGAs, and iii) *floorplanning*, that positions each sub-circuit within the related device. When a feasible solution is identified, the implementation phase integrates the Reconfiguration Controllers, one for each FPGA, with the reliable circuit, building the proposed overall reliable system. The obtained system can continue working even if faults occur, thus increasing both reliability and lifetime.



3. Design flow.

A SOFT APPROACH FOR QoS-AWARE SERVICE ADAPTATION

Seyed Hossein Siadat

The performance of Service-Based Applications (SBAs) is relies upon providing a Service Level Agreement (SLA). SLA is a mutually agreed contract between a service provider and consumer that describes non-functional properties of web services. However, QoS parameters are often changing due to dynamic and volatile service environment. In such environment, Web Services need to be able to adapt dynamically trying to respect the SLA. Changes are required to be captured, evaluated and proper actions need to be taken accordingly. Therefore, adaptation and evolution of Web services are of great importance in order to guarantee the quality of service (QoS) defined in a contract. We intend to address the following key issues.

- **Quality of Service Management**. An SBA has some very non-linear characteristics from the QoS perspective. However, current approaches mostly use precise methods for QoS property description and quality measurement. This means that QoS parameters are defined using crisp values and their evaluation is based on precise measurement of defined ranges in the contract. Therefore, any deviation from quality ranges is considered a violation, albeit minor, and thus an adaptation action (mostly service substitution) takes place regardless to its consequences. Moreover, partial satisfaction of QoS parameters cannot be supported by applying precise methods. However, applying precise methods are not suitable for all circumstances due to uncertainty issues. For example, large number of QoS parameters and unclear relation between parameters makes it difficult and complex to formulate an analytical optimization model for QoS management in SBAs.

- **Selecting Service Adaptation Strategies.** Depending on the adaptation triggers, there exist a set of adaptation strategies. However, selection of the most suitable adaptation strategies is a complex task due to the multiple criteria involved in the process of decision making. For example different recovery/adaptation actions have different time and computation complexity. Impact and scope of change should also be considered as adaptation requirements. Moreover, adaptation cost needs to be taken into account for economical reason. Therefore, understanding the adaptation triggers that may produce a faulty situation and adaptation requirements is necessary to make an appropriate decision for adaptation and it has to be done with a special care. We argue what is missing here is an appropriate decision making process for selecting adaptation strategies that takes into consideration different adaptation requirements.

Soft computing is an alternative when the above problems occur by providing inexact solutions for computationally-hard tasks and relaxing parameters. Applying a soft computing approach is beneficial for defining QoS description and measuring quality parameters in order to compute the overall QoS. Inference methods are used when the input-output relation can be expressed in the form of if-then rules. Fuzzy logic is used in this category and describes the system behavior by using simple rules. In general, fuzzy logic is particularly suitable among other techniques in dealing with uncertainty and using imprecise parameters. The definition of quality parameters such as dependability, security and reputation has a high degree of unclarity and ambiguity that makes it difficult to define them in a precise approach using crisp values. Furthermore, mapping such quality parameters to the overall QoS is difficult to be defined using mathematical expression. In this context, linguistic variables can be used to define QoS parameters. The main contribution of this thesis is twofold as follows:

- **Quality factor analysis for adaptation requirements** is aimed to evaluate state of overall QoS as adaptation requirement that triggers adaptation strategies. Various quality parameters are given as inputs into a QoS assessment engine which is a Fuzzy Inference System (FIS) that works based on if-then fuzzy rules. The output of the FIS shows the overall degree of QoS.

- **Decision making for adaptation strategies** that has two stages. The first stage is when we consider QoS as the only adaptation requirement. The output of the FIS, the overall QoS, is taken as adaptation requirement. An algorithm evaluates which adaptation strategy to take regarding to the predefined threshold degree for QoS satisfaction. In the second stage, we consider more adaptation requirements for decision making between alternatives adaptation strategies. A decision making engine that is a FIS system is placed in the architecture for selecting adaptation strategies. The engine uses the overall degree of QoS received from the QoS assessment engine together with other adaptation factors, such as cost of service substitution and importance of QoS, to infer a decision for adaptation strategy selection. Information about adaptation requirements are kept in an adaptation rule base. The output of the engine, after defuzzification, represents priorities of adaptation strategies that need to be taken.

We briefly explain the specific contributions of the thesis as follows:

Flexible Fuzzy QoS Specification for Service Adaptation. We propose a flexible approach to deal with QoS parameters formulated within given value ranges in a contract. We applied a fuzzy approach to define quality parameters so that their degree of satisfaction could be estimated. For that purpose, we introduced satisfaction functions by means of fuzzy membership functions. Specifically, we propose an algorithm for selecting adaptation strategies that works based on satisfaction levels.

Contracting Issues and QoS Compatibility. The approach addresses contracting issues and the problem of negotiating an agreement on SLAs. The approach presents formal definitions for the formation and evolution of contracts based on subtyping relation. For that purpose, we extend standard WS-Policy by value ranges and propose some functionality to work with those ranges which are necessary to perform flexible evolution of services. In particular, we apply Allen's Interval Algebra (AIA) to specify ordering and inclusion relations between QoS parameters and their value ranges.

Adaptive Evaluation of QoS. We propose a fuzzy adaptive system based on learning techniques that can adjust the membership functions initially defined by experts. Adaptive Neuro Fuzzy Inference System (ANFIS) is used to tune QoS parameters adaptively according to a given data set. The difference between predicted and desired QoS is minimized during the learning process. The trained FIS can be used in decision making process for QoS-aware adaptation. The main aim of the study is to address how service providers can model appropriate membership functions for quality parameters to predict overall QoS in SBAs. Experimental results demonstrate the ability of the proposed approach in finding relationship between the quality variables and predicting the overall QoS values.

Selection of Adaptation Strategies. We propose a service adaptation technique that uses fuzzy logic and particularly we use a hierarchical approach to avoid the rule-explosion issue. Two fuzzy inference engines are used, one for calculating and analyzing the aggregated QoS and another one for the decision making of adaptation strategies. In the analyzing step, quality parameters (i.e. response time, availability, reputation, and security) defined by linguistic variable are mapped to aggregated QoS. In the adaptation step, adaptation requirements (i.e. QoS, importance, and cost) are mapped to one of the three adaptation actions (nothing, negotiation, and substitution). The main contribution of the evaluation is a comparison of a fuzzy to a non-fuzzy approach. The comparison counts the number of substitutions and shows that the fuzzy-approach results in fewer substitutions. Taking into account different adaptation requirements, the fuzzy-based approach has been used for trade-off analysis.

ARCHITECTURES, METHODS AND ALGORITHMS TO CONTROL SWITCHING IN OPTICAL NETWORKS

Domenico Siracusa

Internet traffic has been growing quickly for many years and it is expected to follow this trend in the future as well. The services offered by providers, and in particular Carrier Ethernet services, require not only a huge amount of bandwidth, but also a more flexible access to bandwidth that the traditional transport networks, based on circuit-switching, can hardly provide. An important question is whether the migration to packet switching is cost effective. In addition, network performance should be improved while energy consumption and network complexity should be reduced. This objective can be achieved by using optics instead of electronics in all the network elements, whenever possible. In this context, future interconnection subsystems for switches and routers must overcome the physical limitations of current electronic backplanes in order to achieve an aggregate bandwidth much greater than today's. Furthermore, once the transport network is designed and the nodes are deployed, it is necessary to define a multi-domain end-to-end control structure that allows different technologies and domains to inter-work efficiently. Based on this rationale, the main goal of this thesis work is to investigate (*i*) planning *methods* to design a high-capacity Carrier Ethernet multi-layer transport network, (*ii*) Optical Interconnection (OI) *architectures* to improve the performance of the deployed nodes and (*iii*) *architectures* exploiting different *algorithms* to provide these nodes with end-to-end Quality of Service (QoS) capabilities.

The first outcome of the thesis is to provide both a single-layer and a multi-layer design of a Carrier Ethernet based network. The proposed design solutions aim at minimizing the Capital Expenditure of the network. In the single layer design a set of fundamental parameters to evaluate the pros and cons of migrating from legacy circuit-switched technologies to innovative packet-switched ones are identified and presented. In the multi-layer design of a packet-switched CE network both the electronic and the physical layer impairments are jointly taken into account. Two different procedures are proposed to optimize the network resources deployment. As second outcome of the thesis three OI architectures are presented and analyzed. For each of the proposed architectures a preliminary study to assess the impact of the physical layer impairments on the fabrics is carried out. The performance of the investigated OI architectures is evaluated in terms of scalability (maximum achievable throughput) and in terms of power consumption. The first architecture is based on the Arrayed Waveguide Grating (AWG) devices. The design procedure of the devices and the evaluation of the crosstalk impairment are detailed. Moreover, two crosstalk reduction techniques are presented and their impact on the performance of the architecture is studied. The second proposed OI architecture is based on a structure composed by fixed Micro Ring Resonators (MRRs). The design of the structure components and the optimization of the MRRs parameters are presented. The third architecture is hybrid since its building blocks are both fixed and tunable MRRs. Finally, the third main contribution of the thesis is the definition of a control plane solution based on the cooperation between the Path Computation Element (PCE) architecture and the proposed Domain Sequence Protocol (DSP). Different schemes to provide QoS are presented and their effectiveness is evaluated by means of simulations.

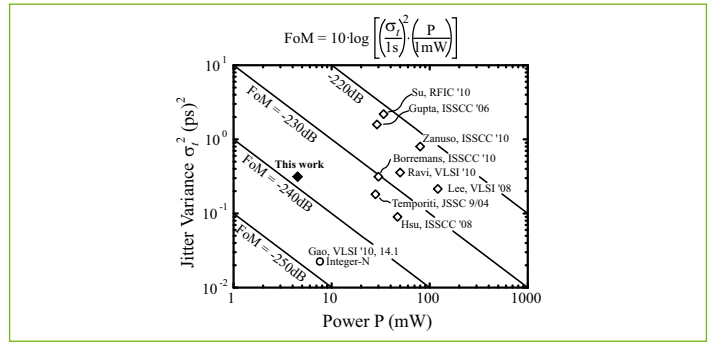
LOW-POWER LOW-JITTER FRACTIONAL-N FREQUENCY SYNTHESIZER USING BANG BANG PHASE DETECTION

Davide Tasca

The advent of ultra-scaled CMOS technologies is leading to the digital imple- mentation of critical subsystems, which traditionally belonged to the realm of analog circuits. This process is sustained by CMOS device scaling which offers both high-performance digital signal processing at very low cost and better device matching for non-minimum-size devices. As an example, the trade-offs among resolution, conversion rate and power dissipation in analog- to-digital and digital-to-analog converters (ADCs and DACs) improve with device scaling. Digitization not only entails the clear advantages of repeata- bility and portability to new scaled processes, but it also paves the way to the extensive application of powerful techniques for correcting the vari- able analog impairments. The frequency synthesizer, conventionally used for coherent demodulation/modulation in wireless transceivers, is one of the building blocks most involved in this evolution. A wealth of literature has been devoted to this topic, since the first digital phase-locked loop (PLL) for those applications was presented in 2004, less than one decade ago. The interest in this class of circuits is expected to increase with the introduction of fourth-generation high-data-rate communication standards, in particular LTE or WiMAX, that require wideband radios with high signal-to-noise ra- tio and may demand a local oscillator with integral phase noise lower than –35 dB. This requirement is sometimes expressed by means of the absolute jitter that is, roughly speaking, the RMS value of the difference between the zero-crossing instants of the PLL output with respect to an ideal noiseless clock. As an example, at 3.6 GHz the specification of integral noise less than –35 dB translates into a jitter lower than 790 fs_{rms} stringent requirement poses limitations to both tolerable phase noise and spurs level. The im- provement of noise and spurs performance always costs an increase in power dissipation; therefore, an important challenge is designing a high-efficiency frequency synthesizer, which in other words has low jitter at low power. A figure-of-merit (FoM), which can characterize a frequency synthesizer in terms of this jitter-power trade-off as the product of the jitter variance σ^t_2 and the power consumption P expressed in milliwatts.

$$\mathrm{FoM} = 10 \cdot \log\left[\left(\frac{\sigma_t}{1\ \mathrm{sec}}\right)^2 \cdot \left(\frac{P}{1\ \mathrm{mW}}\right)\right]$$

State-of-the-art analog and digital fractional-N synthesizers are limited to a FoM of about –233 dB. This value becomes higher when in-band fractional spurs are taken into account. By comparing those values to the best FoM of –251 dB obtained for an integer-N synthesizer, we can realize how large is the efficiency gap still existing between integer-N and fractional-N synthesiz- ers. The main goal of the present work is to reduce this gap and to design a fractional-N digital synthesizer with a FoM closer to the one of the best integer-N synthesizer, but with finer frequency resolution (below 100 Hz). A digital PLL can be directly derived from the fractional-N analog PLL. In this topology, the quantization noise is subtracted from the output of the time-to-digital converter (TDC), acting as a phase detector (PD). This cancellation technique has been also applied to analog PLLs, but the digital version al- lows easy and accurate implementation of this algorithm. The jitter-power trade-off, in this circuit, is mainly set by the TDC, which is analogous to an ADC. The TDC finite resolution may represent the ultimate limit to the PLL in-band noise, but more often, it causes concentrated fractional spurs. As an example, a TDC having 1 ps resolution and employed in a 3.6 GHz PLL with a 40MHz reference clock should produce a –120 dB/Hz in-band noise at the



1. Layout of the new photodiodes front-end ASIC prototype – single channel version.

output, under the assumption of uniform distribution of the TDC quantization noise. In fact, this figure has not been achieved in digital PLLs yet. The problem is that the finite resolution of TDCs gives rise to spurious tones in PLLs. Such tones typically fall within the PLL bandwidth, when a near-integer channel must be synthesized, and substantially increase the output jitter. This justifies the current research effort in realizing TDCs with sub-picosecond res- olution for these applications. In addition to res- olution, the design of TDCs for digital PLLs must focus on the linearity of its characteristic, since nonlinearity is another source of fractional spur gen- eration. All TDCs based on flash conversion trades resolution and linearity against power dissipation. The companion digital topology typically referred as "phase-domain" all-digital PLL (ADPLL) presents similar issues and the same jitter-power trade-off. Several attempts have been done in recent lit- erature to increase TDC resolution at low power. Improvements have been obtained by employing the subranging approach by exploiting the metastabil- ity phenomenon for time amplification. However, this approach complicates the design and makes performance sensitive to voltage supply. Other works have faced the other important issue in TDCs, i.e. the linearity, by shuf- fling randomly the TDC elements. In practice, all high-performance TDCs dissipate a large part of the whole power budget, worsening the jitter-power trade-off and complicating greatly the synthesizer design. In this work, a different approach is proposed, which consists in adopting a single-bit TDC as phase detector. With respect to the standard structure of a digital PLL, a high-resolution controllable delay, i.e. a digital-to-time converter (DTC), is used in place of a high-resolution TDC. This choice leads to easier design and better jitter-power compromise. Compared to a TDC based on a delay line with flip-flops, a DTC is obtained by using a delay line or a delay-varying element. The elimination of flip-flops leads to lower power consumption and lower nonlinearity, since the latter is mainly caused by the mismatches in the delay elements and not by the additional mismatches contributed by the flip-flops.

Single-bit (also called bang-bang or lead-lag) PDs are employed in specific applications of PLLs, such as clock and data recovery (CDR), and they have recently drawn new interest in the field of frequency synthesis. This thesis introduces a fractional-N PLL based on a single-bit TDC, achiev- ing an integrated jitter of 560 fs_{rms} (from 3 kHz to 30 MHz) at 4.5 mW power consumption, even in the worst-case of fractional spur falling within the PLL bandwidth. A prototype circuit, realized in 65 nm CMOS technol- ogy, synthesizes frequencies between 2.9 GHz and 4.05 GHz with 70 Hz of frequency resolution. These performances lead to a Figure-of-Merit (calcu- lated as the product of jitter and power) of –238.3 dB, that represents the state-of-the-art for digital fractional-N PLLs (see Figure 1).

NEW PATH TOWARDS LOW-POWER LOW-NOISE MEMS ACCELEROMETERS

Alessandro Tocchio

Abstract

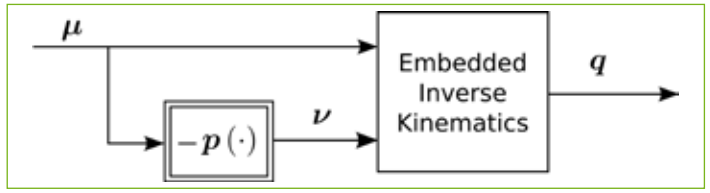
In this work, new solutions for the realization of low-power and low-noise MEMS accelerometers, are presented. As a part of a collaboration between the Department of Electronics and Information Technology and the Department of Structural Engineering of Politecnico di Milano with the industrial partner STMicroelectronics, two novel device architectures, both tailored for consumer market applications, have been developed. Therefore, the present doctoral dissertation has been organized in two parts, one for each of the two devices. The first part, deals with the design, the characterization and the modeling of new high-sensitivity uniaxial and bi-axial MEMS resonant accelerometers. The development of the suitable low-power readout electronics is also discussed. The original geometrical setting of the proposed devices allows to achieve a measured sensitivity of 455Hz/g for the uniaxial version (considerably high with respect to the previous implementations reported in the literature), for an in-plane area occupation of $(400\mu m)^2$ (considerably smaller than previously proposed architectures). A sensitivity performance of 201Hz/g/axis has been obtained for a biaxial version of the same device for nearly the same occupied area, representing to the author's knowledge the first biaxial resonant accelerometer presented in the literature. The design of the devices together with the characterization methodologies adopted are described and the obtained experimental measurements critically analysed. A great effort has been invested into the development of low-power and low-noise readout circuits suitable for these kind of devices. Two readout circuits have been studied, implemented in 150nm CMOS technology and finally tested: (i) a transimpedance based oscillator; (ii) a Pierce oscillator. The transimpedance circuit represents one of the most common solution for the realization of MEMS resonator based oscillator circuit, and it has been therefore the first solution pursued. Good performance in terms of resolution were obtained by coupling this circuit to the uniaxial resonant device, achieving an acceleration noise density of 550μg/√Hz in differential mode, for a current consumption of 80μA/axis for 1.8V supply. The second circuit, based on the Pierce topology, known for its low-power capabilities, allowed to decrease the current dissipation of a 6.6 factor, requiring a DC bias current of 12μA/axis, while ensuring better noise performance achieving 360μg/√Hz. In the second part of the dissertation, a novel MEMS accelerometer device based on the variation of the fringe capacitance between co-planar electrodes is presented. The main advantage of this device, with respect to conventional parallel-plates capacitive accelerometers, is its intrinsic immunity to pull-in instability. The device is constituted by co-planar electrodes fabricated, isolated by a dielectric layer, on top of a grounded silicon substrate. The capacitance between these electrodes is mainly formed by the fringe capacitance between the electrodes edges. A grounded seismic mass, moving over the fringe field volume by means of an external acceleration, intercepts some of the fringe field streamlines changing their configuration and thus the value of the capacitance between the electrodes. The idea beyond this device, is to decouple the sensing direction from the moving direction, obtaining a device in which no movable structures is moved towards a fixed structure polarized at a different voltage potential, minimizing the possibility of pull-in issue. Based on this concept, a first single-ended prototype of an in-plane fringe field accelerometer has been first studied through analytical and FEM simulation, CAD designed, fabricated and tested. In the present work, two test devices of the first prototype are presented, showing sensitivities between 0.4fF/g and 0.9fF/g. A model for the sensitivity optimization, developed through FEM simulations, suggests that dimensional scaling helps to increase the device sensitivity. Thus, based on this results a differential fringe field accelerometer with an improved sensitivity of 3fF/g has been designed and successfully tested. The advantages of the fringe approach on the standard parallel-plates are finally discussed.

HUMAN-CENTRIC BEHAVIOUR OF REDUNDANT MANIPULATORS UNDER KINEMATIC CONTROL

Andrea Maria Zanchettin

Robotics aided manufacturing is nowadays a technology with a high level of maturity. Thanks to their flexibility, industrial robots are adopted in several transformation processes such as welding, painting, deburring, assembly, etc.
Despite the benefits of articulated manipulators in industrial production, there are today several obstacles to obtain a more widespread use of robots. They still need a lot of skilled engineering effort for installation, setup and programming. They also require closed-ended environments, with physical protection devices to separate them from human workers, and this limits their flexible usage.
For this reason, some of the most attractive studies in this field focus on the development of strategies to enforce safety in human robot interaction. In fact, common industrial manipulators are still not able to cooperate with human beings in a natural way.

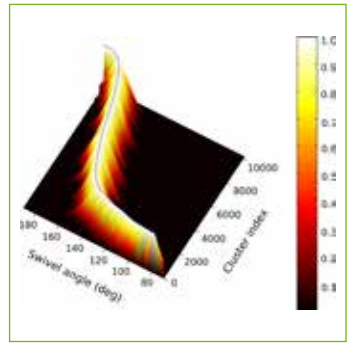
The original contribution of this thesis to the field of human-robot interaction concerns the exploitation of the kinematic redundancy of next generation industrial manipulators to achieve a natural-looking motion and facilitate a psychologically safe interaction between humans and robots.
This work is organized in three Parts. In the first Part, a general user-oriented framework for redundancy resolution in industrial robotic manipulators is proposed and applied to several simulation and experimental cases. In Part II, a detailed kinematic study on the human arm motion and the identification of a redundancy resolution criterion to explain human-like motion patterns are presented. Part III describes the implementation, based on the framework discussed in Part I, of the identified human-like redundancy resolution on a 14-DOF dual-arm anthropomorphic industrial manipulator and discusses the evidence of an increased social acceptability.



1. Block diagram of the proposed framework.

The first original contribution of this thesis is a general framework for redundancy resolution in industrial manipulators. The flexibility of the proposed approach is discussed. In particular, it is shown that the selection of the redundancy resolution criterion is totally decoupled from the implementation of the algorithm adopted to generate joint angle references. Any user-defined redundancy resolution criterion can thus be enforced. Potentialities of this new methodology are experimentally verified on an industrial robot in a case study where functional redundancy occurs.
The proposed redundancy resolution technique has been experimentally applied to different industrial applications. In particular the possibility to handle the case of multiple degrees of redundancy as well as the capability to cope with sensor driven task modifications are discussed.

The second Part presents the experimental campaign carried out to study the natural motion of the human arm and in particular to address the identification of a suitable way to describe how humans resolve the kinematic redundancy of their arm. The protocol of the experiments as well as the procedure to extract joint variables is discussed.
Based on these experiments, a nonlinear correlation analysis performed using the acquired data is introduced. A clear correlation has been found between the hand pose and the elbow swivel angle which was used to characterize the redundant DOF of the human arm. The existence of such relationship is first proven with statistical methods using a clustering approach and multivariate correlation statistics. Then, the correlation has been identified using a least-squares algorithm. This relation effectively explains the motion of the arm and lends itself to easy application in the kinematic control of a robotic arm.



2. Estimated correlation.

3.ABB concept robot FRIDA.

In the last Part of the thesis, the identified correlation has been exploited in the robotic controller to achieve a natural-looking motion for a 14-DOF prototype robot. Experiments on volunteers with collection of physiological data aimed at discussing the acceptability of robot trajectories are discussed in order to give a validation to the work contained in this dissertation. The experiments have shown that the resulting motion appeared more natural compared with other redundancy resolution criteria. The outcome these experiments showed that the human-like redundancy resolution strategy developed in this thesis can be adopted to effectively reduce the robot-induced stress in humans working side-by-side with robots.