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TECHNOLOGY AND DESIGN FOR ENVIRONMENTAL  
QUALITY IN BUILDINGS AND URBAN CONTEXT



## DOCTORAL PROGRAM IN INFORMATION TECHNOLOGY

Chair:  
**Prof. Barbara Pernici**

The PhD program in Information Technology 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 School is the largest at the Politecnico in terms of number of students. There are more than 50 first year students and therefore about 150 total. The students are subject to an examination every year to evaluate the progress achieved in their research and course work. Before the end of the second year, the students have to submit a minor project (whose topic has to differ from that of the major) evaluated after a public seminar.

### 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* (coordinator Prof. Andrea Bonarini): Information systems, Database management and Information design for the web, Methods and applications for interactive multimedia, Artificial intelligence, robotics, and computer vision, Advanced software architectures and methodologies, Embedded systems design and design methodologies, Dependable systems: performance, security and reliability
- *Electronics* (coordinator Prof. Carlo Fiorini): 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* (coordinator Prof. Paolo Rocco): Control systems science and engineering, Optical measurements and laser instrumentation, Nonlinear dynamics, Planning and management of environmental systems, Operations research and discrete optimization



- *Telecommunications* (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 liason

Due to its truly 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, 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 Studies in Networked, Embedded and Hybrid Control Systems for Complex Distributed Heterogeneous Systems), and 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.

### ADVISORY BOARD

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### Prizes and awards

In 2009 the following awards have been obtained by PhD students:

**Chorafas Foundation Award:** Alessandro Colombo, Lorenzo Luini

**EWSN/CONET Best Ph.D. Thesis Award:** Luca Mottola

## CROSS-LAYER FRAMEWORKS FOR CONSTRAINED POWER AND RESOURCES MANAGEMENT OF EMBEDDED SYSTEMS

**Patrick Bellasi**

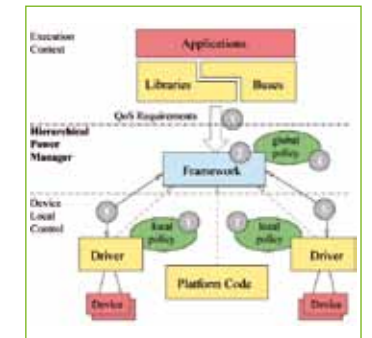
Resources management, and thus also energy saving, has become a high priority design goal for embedded multimedia mobile devices such as smart-phones. Such devices are usually based on platforms using a Multi-Processor System-on-Chip (MPSoC), which embeds a number of peripherals sharing some resources and competing on their usage. Each one of these many embedded devices are usually characterized by a set of working modes, each one corresponding to different profiles of power consumption and corresponding performances.

Modern consumer electronics products provide also multiple functionalities, ranging from classic phone calls to more complex use-cases which could involve network access and multimedia data processing and playback. These multiple usage scenarios are usually characterized by a competition on the limited resources available and thus could also involve conflicting requirements on the underlying hardware. Therefore, a proper resources and power management of such new generation platforms has become a more and more complex added value. The ultimate goal of such a management is the search of the optimal trade-off between

power saving and performances perceived by the user. Thus, it is worth to treat it as an optimization problem and investigate on the definition of solutions that are easily portable among different products.

In the light of these considerations, to effectively support the optimization of a complex platform, it is necessary (i) to have an updated and system-wide view of the available resources, (ii) to collect and aggregate QoS requirements defined by the multiple running use-case scenarios and (iii) to exploit this information within a dynamic system-wide optimization policy.

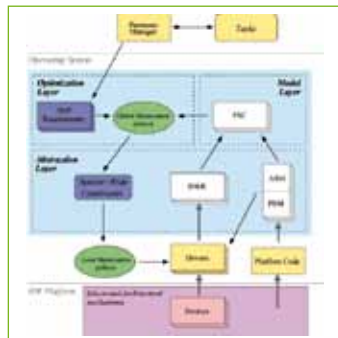
This problem is not effectively solved by current approaches. A number of frameworks has been developed that focus on specific subsystems or even single devices. These approaches result in multiple optimization strategies being implemented within the same system, with the consequent risk of overlapping control actions and conflicting decisions. Thus, these specialized frameworks used alone cannot grant system-wide optimizations. The user-space approaches that have been investigated solve this problem by means of a centralized resource and power manager which is implemented as a middleware between the applications and the operating system. Unfortunately, these



1.

approaches require to modify applications, which is not always possible. Moreover, being implemented outside the operating system they are too much abstract to efficiently exploit all the underlying hardware capabilities. Finally, the cross-layer frameworks implemented in the past are too complex to be effectively used in production devices or too simple to produce interesting results.

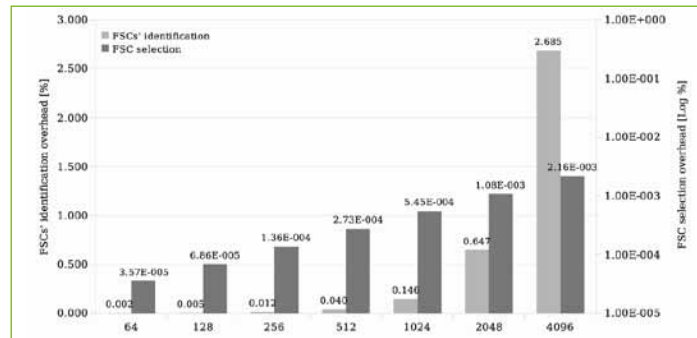
In this work, I propose a novel methodology which is able to efficiently support both resources management and power optimizations without affecting user-perceived performances. The proposed **Hierarchical Power Management** Fig.1 is based on the design of a *single coordination entity* (2) which allows both to exploit a system-wide view of resources



2.

availability, which are defined by device drivers in a platform independent way (5) and to aggregate all the applications' requirements, which are collected by a well defined and single user-space interface (3). At run-time, a *global optimization policy* (4) could exploit all the information, collected either by drivers and applications, to effectively solve a multi-objective optimization problem targeted to identify the best system-wide configuration. Finally, this entity will notify proper constraints to drivers and lets their *local optimization policies* (1) to do the fine-tuning.

A suitable approach to support portability and scalability of the control policy is to define it on the base of an abstraction and modelling layers Fig.2. An **abstraction layer** grants portability without compromising the fine-details



3.

requirement. Available resources and devices working modes are represented in a platform independent way. Resources are abstracted using a set of metrics (PSM/ASM) which can be used also to setup the multi-objective optimization problem. A working mode of a device can also be represented in the space of these metrics by identifying a corresponding device working region (DWR). The **model layer** exploits these abstraction informations to automatically build a representation of all the system-wide feasible configurations (FSCs), each one identifying a working points of the entire system where a certain QoS level can be granted. This model is suitable for supporting an efficient global optimization strategy provided by the **optimization layer**. The policy should support a multi-objective optimization

defined on the abstraction metrics.

A framework implementing the proposed methodology has been developed and integrated within the mainline Linux kernel. Its design has been defined both to be efficient and to simplify the integration of both new and existing local control policies. The experimental results Fig.3 show that our implementation exhibits negligible run-time overheads while allowing to track correctly resources usage and identifying opportunities for power optimizations that do not impact on perceived performances.

## DESIGN AND ANALYSIS OF SYSTEMS FOR MEASURING AND ESTIMATING ATTITUDE PARAMETERS IN VEHICLES

Ivo Emanuele Boniolo

In the contest of the vehicle, knowing the attitude parameters is fundamental to implement control strategies that can improve the safety. The problem is that only some variables can be directly measure, therefore estimation algorithms are needed. This is a common task in all the vehicles. The problem is not trivial if in the application there are strong constrains upon the cost, the number and the dimensions of the used sensors. Off-the-shelf some electronic apparatus (i.e. GPS and strap-down Inertial Measurement Unit) are available to measure with a high precision linear positions, linear and angular velocities and linear accelerations. These systems are expensive and are typically applied in the avionic contest in which the cost of the vehicle justify the use of high cost sensors. Considering a vehicle designed for the consumer market the mentioned apparatus cannot be applied: the aim of the research is to design estimation system using a data fusion approach based on the available signals on the vehicle. To keep the cost constrains, the output signals of the sensors mounted on a consumer vehicle may not have a high accuracy and they can be influenced by a lot of external variable as vibration and temperature.

All of the estimation algorithms have to consider this fact, so it is useful to integrate the basic procedure of the algorithms with other elaborations that can monitor the characteristic of the measured variables and correct some errors during the preprocessing. In racing application the cost constrains is less critical then the precision and dimension ones. To solve the problem of measuring the attitude variables with high precision, the electro-optical technology can be applied. In this thesis, three applications have been studied in this field:

- Estimate of the roll angle of two wheeled vehicle: the problem of measuring the lean angle has been solved through electro-optical sensors, while the estimation problem solution is based on the data fusion of inertial sensors with the frequency split principle and Kalman filtering approaches;
- Estimating of the lateral drift of a car during emergency brake: a solution based on accelerometers and gyroscopes has been proposed;
- Heading estimate in nautical application: the problem has been solved with the data fusion of magnetic and positional measurements.

## DYNAMIC COMPILATION AND PARALLELISM: THEORY AND LARGE SCALE EXPERIMENTATION

**Simone Campanoni**

Software portability suggests the generation of portable intermediate binary code, that remains independent from the specific hardware architecture and is executed by a software layer called **virtual machine (VM)**.

A virtual machine provides an interface to an abstract computing machine that accepts the intermediate binary code as its native language; in this way, the virtualization of the Instruction Set Architecture (ISA) is performed.

The first generation of VMs was entirely interpreted: they interpreted byte-code rather than compiling it to machine code and executing directly the machine code.

This approach, of course, did not offer the best possible performance, as the system spent more time executing the interpreter than the program it was supposed to be running. These first VMs quickly fell into disuse for their slowness.

The next generation of VMs used just-in-time (JIT) compilers to speed up the execution, by exploiting more memory resources.

Strictly defined, a JIT compiler translates byte-code into machine code, before the execution, in a lazy fashion: the JIT compiles a code path

only when it knows that code path is about to be executed (hence the name, just-in-time compilation).

This approach allows the program to start up more quickly, as a lengthy compilation phase is not needed before execution beginning.

The JIT approach seemed promising, but it presented some drawbacks: JIT compilation removes the overhead due to the interpretation at the expense of some additional startup cost, and the level of code optimization is mediocre. To avoid a significant startup penalty for portable applications, the JIT compiler has to be fast, which means that it cannot spend much time in optimization.

After JIT compilers became widely used, multi-core technology emerged in high-performance architectures. Such architectures need specifically designed multi-threaded software to exploit all the potentialities of their hardware parallelism.

The thesis proposes a new generation of virtual machines, called **Dynamic Look-Ahead (DLA)** compilers based on a software pipeline architecture for compilation, optimization and execution tasks. This speeds up the execution

by exploiting the parallelism provided by the multi-core technology to produce optimized code.

Strictly defined, a DLA compiler translates and optimizes byte-code looking ahead of the execution in order to both anticipate the compilation before the execution asks for it, and to produce optimized code.

The design and the implementation of a novel virtual machine framework from scratch, called **Intermediate Language Distributed Just-In-Time (ILDJIT)**, is the unifying topic of the thesis. ILDJIT includes the implementation of a JIT, an Ahead-Of-Time (AOT), i.e. a static byte-code compiler, and two different DLA compilers. Experiments and researches presented in the thesis exploit ILDJIT as underlying system.

Java byte-code first, and then **CLI (Common Language Infrastructure)** are the de facto industrial standards for the virtualization of ISA. The expressivity of the language defined within CLI, called **CIL (Common Intermediate Language)**, enables the interoperability among high-level languages such as Java, C#, C, Python, etc ... The increasing availability of

static compilers, such as .NET, Mono, Portable.NET and Gcc4NET, able to translate programs written in many high-level languages to the CIL byte-code, has given momentum to CLI. For this reason, ILDJIT targets CIL as input language.

Unlike other VM implementations, the design and the entire implementation of our VM focus on the multi-core architecture. ILDJIT spreads compilation, optimization and execution tasks over CPUs by adjusting the internal compiler parallelism (i.e. threads of the compiler) to fit best the parallelism of the underlying platform. In this way, both threads switching overhead is not introduced and available CPUs are exploited.

While a VM brings along a possible overhead, there are several ways to exploit runtime information in order to offset this penalty and to obtain increased performance. One typical optimization is based on **runtime constants**: a certain variable is known to assume a single value at runtime, but this value is not known at compile time. Runtime constants can be subject to the same range of optimizations as compile time constants, as soon as their value

is known.

A VM, therefore, would apply data-flow optimization such as constant propagation and folding, as well as more aggressive optimizations such as the specialization of functions. A typical VM takes control of the application, monitoring its performance and applying optimization passes when needed.

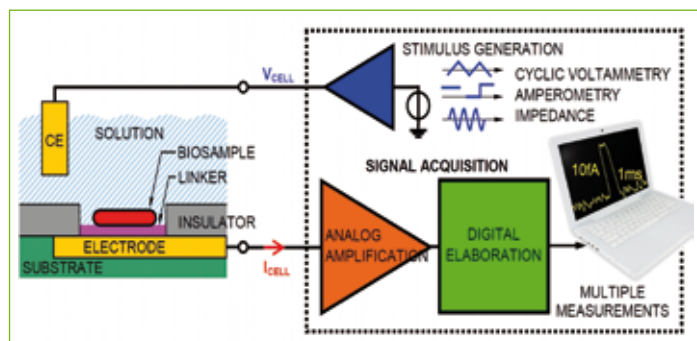
The thesis explores this direction by extending the DLA compiler.

Since new compilers, due to the large diffusion of multi-core technology, should consider the parallelization of programs in threads by exploiting the coarse-grain parallelism of the application, a study about the impact of data and control dependences on the parallelism of the application is provided. Furthermore, an algorithm to parallelize programs is proposed and evaluated.

## INSTRUMENTATION FOR ELECTRICAL DETECTION IN BIOLOGY AND IN NANO-ELECTROCHEMISTRY

Marco Carminati

Convergence of microelectronics with biology and nanotechnology is currently an exciting reality and a very fertile research area. Several scientific goals and technological challenges are faced with a novel and unavoidable multidisciplinary approach. Traditional engineering design methodologies are combined with new materials and investigation techniques, oriented to the molecular scale, in order to achieve significant theoretical and applied advances in biochemistry, material science and biotechnology. This thesis work is inserted in this field. The focus of the activity, articulated in design, realization, testing and experimental characterization phases, has been on the extension of direct current and impedance measurements at the nanoscale molecular domain. Original circuitual topologies and ad-hoc systems have been proposed and realized for addressing the so far unmet requirements of sub-pA current sensitivity and attoFarad capacitance resolution, with extended bandwidth, pivotal for direct electrical sensing of the properties of nanoscale electrochemical bio-interfaces. Two examples of biomedical applications at cellular level (in static and dynamic conditions) show

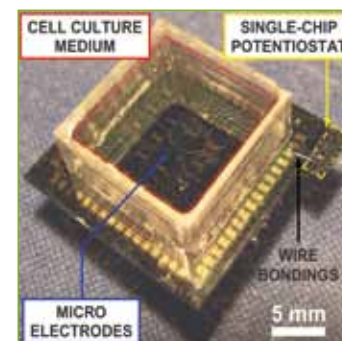


1. The electrical properties of the nanoscale bio-interface are probed with a custom instrument able to apply various voltage stimuli to the system and amplify the resulting tiny currents, down to the pA and fA range.

possible ways of combining high-sensitivity flexible electrical detection systems with microfluidic platforms and optical techniques. Several radical advantages are provided by integrated electronic detection, along with measurement challenges and the technological issues involved in a direct electrical interface of electronics with sub-micrometric biological entities. The passive properties of biological matter are recalled, along with the role of chemical functionalization of electrodes for proper immobilization of samples. Furthermore, the nature of the electrochemical interface is analyzed in depth and background theoretical information is briefly provided about the micro- and nanoscale electrochemical techniques, enabled by the designed instrumentation.

The measurement configuration and the fundamental specifications for current and impedance bio-sensing at the nanoscale, which lead to the design of novel custom instrumentation, are highlighted. The broad applicative context of microanalytical lab-on-a-chip systems for cellular and molecular analysis is introduced, along with an overview of multiple sensing approaches proposed in literature. Several examples of applications, which may benefit from the enhanced performances offered by the proposed systems, are discussed. Two alternative and somehow complementary potentiostats, based on two original topologies, have been proposed as the core of a flexible, modular, multiscale bench-top system and of a single-chip solution respectively. The latter is suitable for being directly embedded in analytical

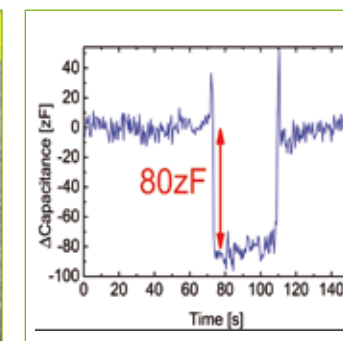
microsystems. Unparalleled performances have been experimentally demonstrated for both instruments, in particular in terms of bandwidth and of noise. The bench-top potentiostat system features a frequency range from DC to 1MHz and



2. The whole instrument has been integrated in a single chip, fabricated in standard CMOS technology. Miniaturization and performances are thus highly improved. The chip is directly connected to planar microelectrodes for electrical monitoring of cellular dynamics.

a current resolution of 10fA for a measurement time of 1s, giving a sensitivity of few attoFarad's in terms of measurable capacitance with an applied voltage of only 100mV. These performances are obtained using a low-noise wide-bandwidth integrator/differentiator stage to sense the input current and a modular approach to minimize the effect of input stray capacitances. This topology can be also integrated in standard CMOS technology and deep sub-aF capacitance resolution is achieved with a 0.35 $\mu$ m monolithic front-end. A digitally-implemented lock-in filter optimally extracts the impedance of the sample, providing time tracking and

spectroscopy operating modes. Resolution limits have been carefully analyzed. This computer-based and flexible instrument is well suited for characterizing and tracking the electrical properties of bio-molecules kept in the physiological solution, down



3. The proposed ultra-low-noise integrated front-end allows tracking impedance over time with a few zeptoFarad ( $10^{-21}$  F) resolution in capacitance variations (6V applied at 100kHz, with 100ms temporal resolution).

to the nanoscale. It thus allows, for example, to address the measurement challenges set by direct electrochemical detection of bio-molecular recognition in nanoscale affinity biosensors. Alternatively, a single-chip CMOS versatile potentiostat is also presented that allows multiple amperometric electrochemical measurements at the nanoscale. Cyclic voltammetry, impedance spectroscopy, impedance time tracking and amperometry can be performed over a full DC-1MHz bandwidth, with sub-pA resolution and over an unlimited measuring time. After a thorough literature review, the detailed design of the current amplifier, based on an original simple transistor

matching architecture, is illustrated. The results of the experimental characterization and of the electrochemical validation tests are discussed. The performances demonstrated, such as 30zF resolution with an applied 100kHz sinusoid of 1V (5zF with 6V), are suitable for electrochemical investigation at sub-micrometric interfacial electrodes, in particular for biotechnology applications and in-situ electrochemistry, embedded in microsystems and microfluidic devices. Beyond the improvement of the instrumental performances, here largely demonstrated, many issues are still open, mainly concerning the integration of CMOS smart sensing chips with microfluidic technology, biocompatible packaging and the direct use of the metal bonding pads as active electrodes. The impact on life quality of the pervasive diffusion of such miniaturized integrated microanalytical systems is envisioned to be revolutionary.

## ANISOTROPIC SEISMIC PROCESSING

**Lorenzo Casasanta**

The seismic experiment plays a central role in the exploration for hydrocarbons in the Earth's subsurface.

A typical experiment involves several sources and receivers.

A seismic trace is the recording of seismic reflections generated by a source. The dataset used in seismic processing is the collection of the seismic traces.

A very important goal of seismic processing is subsurface imaging and migration is the main imaging procedure.

The image that results from such processing enables interpreters to highlight the stratigraphical traps where hydrocarbons have accumulated. Seismic imaging requires an estimate of the velocity model of the subsurface. If an adequate velocity model is provided, pre-stack depth migration (PSDM) represents the best solution to imaging in complex structures, although it is computationally intensive. These imaging procedures must take in account anisotropy effects in order to achieve better focusing and positioning of the geological structures in the subsurface.

Still, for most of its history seismic inversion and imaging have been based on the assumption that the subsurface is isotropic, despite the general acceptance of the fact that most geological formations possess

a certain degree of anisotropy. Although P-wave velocity in anisotropic media can change significantly with propagation angle, P-waves do not split into two modes and their reflection moveout on conventional-length spreads (close to reflector depth) typically is hyperbolic. Hence, it has been customary for processors and interpreters to artificially adjust the parameters of isotropic processing flow when working with P-wave data from anisotropic media. This approach, however, has produced distorted velocity models and proved to be inadequate in compensating for the full range of anisotropic phenomena in P-wave imaging, particularly in prestack depth migration.

This mounting evidence of the need to account for anisotropy in seismic processing prompted an increased effort in seismic anisotropic processing starting from late 1980's up to nowadays with the more advanced migration and velocity model building algorithms. While extending imaging methods to anisotropic media is largely a technical issue, practical implementation of the anisotropic processing algorithms was hampered primarily by the difficulties in parameter estimation. Inverting for several anisotropic

parameters needed to characterize even the simplest anisotropic model - transverse anisotropy, the subject of this thesis - seemed to be well beyond the reach of reflection seismology.

This work can be ideally divided into two parts. The first part mainly focuses on ray-based wave propagation modeling in TI media. Using ray tracing algorithms we are able also to implement Kirchhoff pre-stack depth migration in TI media. Depth imaging algorithms require an estimate of the anisotropy parameters that describe wave propagation in TI media. Parameter estimation is the main topic of part two. This part is devoted both to tomographic migration velocity analysis for depth imaging and to a slope based velocity analysis for vertically inhomogeneous VTI media that can provide an approximate first guess for tomographic iterations.

Inversion and imaging problems require calculation at a faster speed than the ray method generally provides because calculations must be repeated for a large number of shots and receivers. It is possible to reformulate seismic ray equations in terms of phase and group velocities. This operation is advantageous because it

allows us to use either exact or approximate relations for phase velocity which, for P-waves in TI media, are parameterized directly by Thomsen's coefficients. This implies that we no longer need any kind of computational demanding back conversion to the elastic tensor.

A boundary value problem, such as two-point ray tracing, directly computes the ray path between two points. An algorithm based on Fermat's principle of stationary traveltime between fixed points can achieve this goal.

The traveltime of a sampled ray path is approximated using a quadrature formula. Finally, starting from a first guess trajectory, an unconstrained optimization scheme finds the ray point positions that minimize the traveltime.

In oil and gas exploration, ray tracing techniques are also routinely used for 3D Kirchhoff-based prestack migration. Kirchhoff migration methods require that traveltime, amplitudes and other relevant wavefield quantities (slowness vectors, caustic order, etc...) might be computed on a regular Cartesian grid representing the target of the imaging process. Here we propose an alternative approach we called depth-oriented ray tracing (zRT). This method

has three main implications. First, it simplifies wavefield quantities interpolation that can be realized by using a simple 2D scheme. Second, this approach intrinsically discards turning rays that typically are not employed for imaging in standard Kirchhoff processing. Third, depth ray tracing allows us to track the spread of the wavefronts at each depth level. Suitable ray insertion criteria can be applied to optimize the ray sampling and improve the image target coverage.

Reflection tomography it is often an effective tool for improving the velocity estimate, when the subsurface structure is complex. Besides the unpleasant fact of its non-linear nature, the tomographic operator has a huge null-space mainly due and a unique solution may not exist. Moreover, small errors in the data may cause prohibitively large variations in the estimates of the sought quantity. In addition to these difficulties, anisotropic tomography introduces further complications due to its intrinsic multi-parameter nature. The estimation of all the anisotropic parameters suffers from ambiguities and trade-offs between all of them. Thus, to create geologically feasible velocity models and

to speed up convergence of the tomography problem we introduce regularization operators and additional borehole constraints along already drilled well bores.

It has been proved that extracting local event slopes in prestack data is sufficient for accomplishing all common time-domain imaging tasks. Rather than being a prerequisite for seismic imaging, seismic velocities turn into data attributes that can be extracted from the input data simultaneously with imaging. We extend the concept of processing by slopes to VTI data in the  $\tau$ -p domain. The  $\tau$ -p or Radon transform is the natural domain for anisotropic parameter estimation in laterally homogeneous layered media with a horizontal symmetry plane because the horizontal slowness is preserved upon propagation through such media. We derive analytical expressions for mapping the data to zero slopes time through the estimation of local slope and curvature. The effective and interval anisotropic parameters turn into data attributes through the slopes and are directly mappable to the zero-slope traveltime.

# SLOW LIGHT STRUCTURES FOR OPTICAL SIGNAL PROCESSING

Antonio Cianciamilla

This doctoral dissertation concerns the study, design and experimental characterization of integrated optical slow light structures (SLSs), based on directly-coupled ring resonators (RRs). The aim of the work is the realization of reconfigurable, large-bandwidth and high-performance devices for both linear and non linear regime signal processing applications. Slow light structures exploit the spectral properties of cascaded optical resonators to reduce the group velocity of the propagating light, according to the slow-down factor  $S$ . This produces an increase of the group delay proportional to  $S$ , enabling the realization of delay lines and optical buffers with improved performances and small dimensions.

At the same time also the field intensity is increased, resulting in an enhancement of non linear effects proportional to  $S^2$  (or  $S^4$  in four wave mixing). This allows to observe efficient nonlinear interaction of optical waves at relatively low power levels and with short propagation length.

In the perspective to accomplish an all-optical signal processing, SLSs are therefore emerging as an appealing and promising approach to realize different fundamental functionalities: bit and frame synchronization, time-multiplexing, data

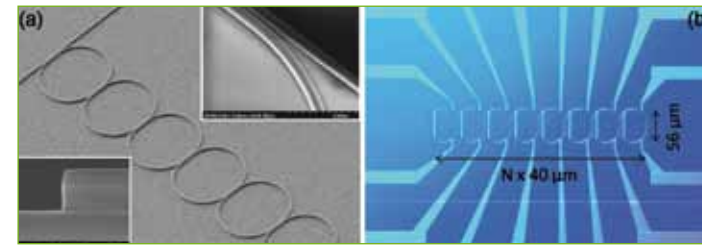
buffering and delaying, but also wavelength conversion, regeneration and retiming. However, to design devices of real interest for telecom, datacom and sensor applications, the slow-down factor and the induced delay are not the only parameters that have to be considered. On-chip miniaturization, low optical power demand, reconfigurability of the device response, large operation bandwidth and good system performances are as well mandatory features. In this work, reconfigurable coupled-resonator optical waveguide structures (or CROWs) are realized on a silicon on insulator (SOI) platform, with the purpose to fulfill all the previous requirements (see Fig. 1). High index contrast technology provides advantages in terms of footprint and bandwidth, while CROW architecture enables high design flexibility and the implementation of an efficient reconfiguration scheme based on the control of the resonance frequency of each RR. In this way, proposed SLSs are able to overcome the bandwidth limitations and the lack of dynamic activation that affect all the solutions reported to date in this field. First, close attention was paid on the analysis of all the

required building blocks (waveguides, couplers and RRs). Fabrication tolerances, design issues and characterization challenges arising from the use of high index contrast technology are deeply discussed. In particular, sidewall-induced backscattering process and its impact on devices operation are thorough investigated from both a theoretical and experimental point of view. Significant advancements are achieved in the understanding of the phenomenon, that is still an open question of great interest, especially for slow light applications.

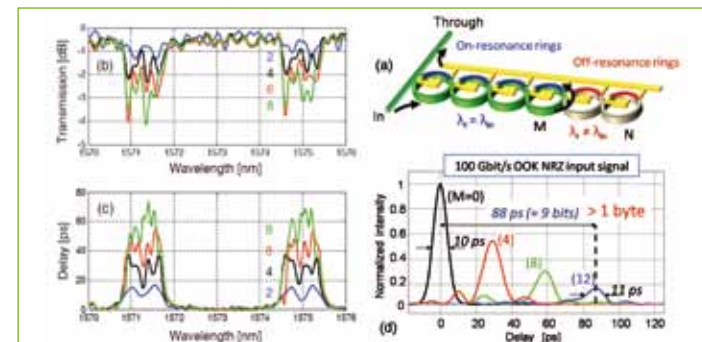
Then, the linear characterization of fabricated SLSs, in both frequency (see Fig. 2 (b) and (c)) and time (see Fig. 2 (d)) domain, is reported and discussed, in order to evaluate their performances in both static and reconfigurable operation, according to the scheme in Fig. 2 (a).

Experimental results demonstrate for the first time a continuously-tunable delay up to 1 byte, over a very large bandwidth of about 100 GHz, and with an ultra-small footprint of  $56 \times 440 \mu\text{m}^2$ . High storage efficiency and low fractional losses (0.8 dB/bit) are also reported.

System performance of the devices is tested as well, exploiting different modulation formats: 10 Gbit/s OOK,



1. Ring resonators based CROW in SOI platform. (a) SEM image of the device optical layer; details of waveguide cross section and coupling region are shown in the insets. (b) Top view of a CROW with  $N=8$  rings and thermo-optical control circuit; device dimensions are indicated.



2. (a) Reconfiguration scheme of the CROWs: by controlling the resonance wavelength  $\lambda_r$  of each resonator, the number  $M$  of on-resonance rings ( $\lambda_{in} = \lambda_r$ ) can be dynamically changed. Experimental characterization of a reconfigurable SOI CROW with  $N=20$  rings and bandwidth  $B=90$  GHz, when  $M$  is varied: (b) intensity and (c) delay spectral response for  $M=2$  (blue), 4 (black), 6 (red) and 8 (green); (d) time-domain measurement of delay, attenuation and distortion of a 10 ps gaussian pulse (black line), corresponding to a 100 Gbit/s OOK NRZ input signal, after propagation through  $M=4$  (red), 8 (green) and 12 (blue) rings.

10 Gbit/s DPSK, 100 Gbit/s OOK and 100 Gbit/s DQPSK PoDM. Error-free transmission with low values of penalties, pulse distortion and broadening are observed, demonstrating phase-preserving and compatibility with advanced transmission techniques. Performance of the thermo-

optical control system, employed to dynamically change the induced delay, is also experimentally evaluated, showing low power consumption, 12  $\mu\text{s}$  time response and negligible cross talk.

SOI reconfigurable SLSs are able to produce a remarkable

improvement also in non linear applications, thanks to the high non linear properties of silicon and to the intensity enhancement provided by slow light effect. We experimentally demonstrate, by exploiting four wave mixing interaction, the possibility to realize a phase-preserving wavelength conversion over 6.2 THz. CROW structures enable an optimum compromise between large operation bandwidth (100 GHz) and high conversion gain (16 dB with respect to a waveguide with the same length), outperforming solutions based on simple waveguides and single resonators. Finally, a deep experimental characterization of two-photon absorption (TPA) and free carrier generation phenomena is carried out in order to evaluate their effects (extra-losses and phase shift) on devices operation and to analyze the limitations imposed to their performances.



## PRACTICAL APPROXIMATIONS FOR SEISMIC INTERFEROMETRY

Sathya Costagliola

For an arbitrary 3D inhomogeneous lossless medium it follows from Rayleigh's reciprocity theorem and the principle of time-reversal invariance that the acoustic Green's function between any two points in the medium can be represented by an integral of crosscorrelations of wavefield observations at those two points. The integral is made along all the sources located on an arbitrarily shaped surface enclosing these points. Interferometric techniques are approximations of Green's theorem. In practice, the closed surface is replaced by a limited number of sources located on a small area or even just on a line. Moreover, the availability of the monopole source responses only causes the estimation of normal derivative of the pressure field with some approximations: high-frequency, far field and one-way wave assumptions are usually made. This fact introduces several artefacts and the full Green's function retrieval is not guaranteed anymore. In this scenario a summation over all the available sources in the dataset could not be the optimal solution. Because of the main contributions to the reconstructed Green's function come from sources at stationary locations, a target-oriented source selection in practice could reduce artefacts improving the SNR. For this kind

of analysis both the acquisition geometry and an a priori model of the subsurface structure have to be taken in account. In this dissertation we analyze the fundamental theory taken from the work of Wapenaar (2004) and Wapenaar and Fokkema (2006), from which seismic interferometry formulation is derived. Starting from this theory we gradually introduce the approximations that are usually made in practice. After this introductory work (described in chapter 2) we propose several solutions to overcome the problems manifesting when theoretical constrains are violated. In particular, solutions has been studied to solve the problem of spurious events and amplitude errors that appear when the ideal sources configuration assumption is violated and the medium is lossy. The main idea at the base of the work is that in a real scenario a summation over all the available sources in the dataset could be not the optimal solution. Because of the main contributions to the reconstructed Green's function come from sources at stationary locations, a target-oriented source selection could reduce artefacts improving the SNR. In practice, when the target has already been roughly localized, we can select and weight just the portions of the

data and its correlations that contribute to illuminate the target. This approach improve the summation step with the further advantage of reducing computational costs. We want to make the point that this work is mostly oriented to explicate the approximations that are used to practically handle seismic interferometry. Because of its "bootstrap" nature, the majority of this thesis can be considered as a tutorial. Some possible solutions of the incoming problems due to the approximations are given but many other areas are left to future researches. In particular all the reported examples consider a line of sources instead of an area for the sake of simplicity. However all the discussed approaches can be easily extended to a 2D acquisition geometry leading to a wider illumination and better results in a real 3D complex situation. In the following we summarized the main contents of each Chapter. Chapter 2. This chapter provides the theoretical basis of seismic interferometry starting from the representation theorem. We analyze in detail the effect of relaxing all the conditions that allow the seismic interferometry to be a practical tool, in spite of the theory. A couple of synthetic

examples are used to show the result of this limitations and the most commonly used methods to reduce the spurious contributions.

Chapter 3. The requirements for a correct virtual-source gather construction in a constant velocity medium are summarized from Metha and Snider (2008). A quantitative explanation of these qualitative considerations is given by the aim of the Fresnel zone concept. The stationary zone is analyzed and described with synthetic examples both in case of zero and non-zero virtual offsets (distance between the VS and the receiver) redatuming. The advantages of a partial summation over the Fresnel zone only are discussed by using a synthetic and a real data example. Chapter 4. Here we analyze some peculiarities about seismic interferometry in a transformed domain showing the potentials in reducing artefacts. One of the natural processing that can be done in the f-k domain is the amplitude correction that can increase SNR when just monopole sources are available. This correction is analytically derived and applied on different data examples. Chapter 5. The interferometric interpolation method is described and some consideration about missing trace nature is made. Synthetic and real data examples are used

for discussing advantages and practical aspects of the method giving some ideas for future research.

# FAST-GATED SINGLE-PHOTON AVALANCHE DIODES AND APPLICATIONS

Alberto Dalla Mora

The unceasing request of devices able to detect fast-changing ultra-faint light pulses has led to the development of detection systems based on Single-Photon Avalanche Diodes (SPADs). Such devices can measure fast signals by means of Time-Correlated Single-Photon Counting (TCSPC) technique.

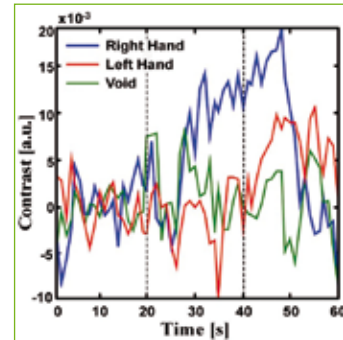
Various important applications require to avoid the detection of photons arriving outside of a well-defined time slot. In these cases, a time-gated detector is needed, enabled and disabled at a given delay with respect to the optical signal. Unfortunately, most of the single-photon detectors do not allow an efficient gated-mode operation, but the possibility to gate SPAD detectors in a fast and efficient way can lead to new applications.

Innovative front-end electronic circuits have been designed to strongly improve detectors performances in fast-gated operation (nanosecond switching time) with respect to traditional solutions, and to allow ultra-fast gated operation (hundreds of picoseconds). They have been then applied in different fields (e.g. time-resolved near-infrared spectroscopy, pulsed-laser characterization at 1550-nm wavelength with silicon SPADs, and InGaAs/InP SPAD applications). In these fields,

the sensitivity has been enhanced, the time-resolution has been increased and the applicability of SPAD detectors has been extended.

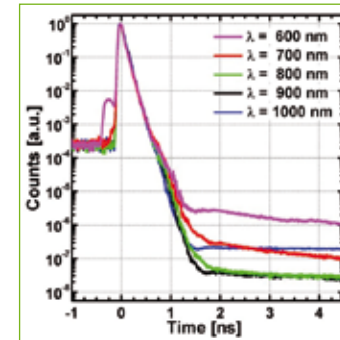
Due to the lack of reliable SPAD electrical models, new models have been conceived. They accurately simulate the SPAD quenching and restoring transitions, as well as quenching circuits faults or capacitive couplings. The effectiveness of such models has been proved thanks to many crosschecks with measurements in different operating conditions.

In near-infrared spectroscopy, the novel approach to photon migration based on time-resolved reflectance measurements performed at null source-detector separation has been demonstrated for the first time by using an instrumentation based on ultra-fast time-gated silicon SPAD. The main feature of the equipment is the rejection of early-photons by quickly enabling the SPAD right after an adjustable time-delay from the laser injection into the medium. In this way, the laser power can be strongly increased in order to enhance the number of late-photons to be detected, while avoiding the statistical distortion of TCSPC technique. The possibility to monitor brain activity has been proved by in-vivo measurements on



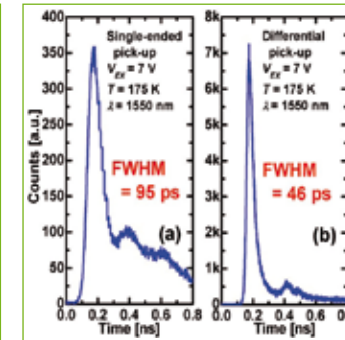
1. First in-vivo NIRS measurement of the left motor cortex activation taken at null source-detector separation

a volunteer executing a standard protocol of finger tapping (Fig. 1). It has been possible to obtain an extremely wide dynamic range of  $10^8$  in few minutes of measurement time, thus allowing the detection of photons delayed up to some nanoseconds from the injection time, with few tens of picoseconds time resolution (Fig. 2). The result represents an improvement of more than 4 orders of magnitude on the time needed to obtain the same dynamic range with the standard non-gated technique. A remarkable probing depth of 3 cm into diffusive media has been demonstrated. Moreover, the spatial resolution improvement and the increase in number of photons collected at any time with respect to larger interfiber distances have been proved. Such results have



2. Instrument response functions of the setup based on ultra-fast gated SPAD

been attained also thanks to the collaboration with Dipartimento di Fisica of Politecnico di Milano in the "nEUROPt" European project for the non-invasive imaging of brain function and disease by pulsed near-infrared light. The gated approach to optical measurements can have in future a great impact also on different biomedical applications, such as on early detection of breast cancers, time-resolved optical molecular imaging, and fluorescent decays characterization, in which a large amount of photons precedes or follows the faint optical signal to detect. Thanks to the developed circuits, it has been demonstrated that thin all-silicon heavily-doped SPADs can be used to characterize pulsed laser sources at 1550-nm wavelength on a wide dynamic range.



3. Improvement in photon-timing jitter of InGaAs/InP SPADs

A timing resolution of 25 ps has been attained. Moreover, the different performances of thin- and thick-junction silicon SPADs at 1550 nm have been characterized for the first time. Silicon SPADs are nowadays well-developed and suitable for single-photon detection in the visible and in the first part of the near-infrared spectrum (up to  $1 \mu\text{m}$  wavelength) thanks to the good photon detection efficiency, low noise, and low time jitter. Nevertheless, many applications need to detect photons in the wavelength range between 1.0 and  $1.7 \mu\text{m}$ . Germanium SPADs and InGaAs/InP SPADs are among the candidates to fulfill such requirement. InGaAs/InP SPADs are the more promising, even if they are still in development and accurate characterizations are mandatory

to understand the detector issues and to push forward the device design. A detailed characterization of recently developed InGaAs/InP devices has pointed out the main detector issues. It has been possible to propose some device improvements, especially to reduce the detector noise (such as afterpulsing phenomenon arising from a delayed release of carriers trapped during avalanche ignitions). A characterization of germanium detectors has been also performed, and experimental results demonstrate the possibility to consider germanium as an alternative material for single-photon detectors. Thanks to the new approach to gated-mode operation, it has also been possible to increase the photon-timing resolution attainable from InGaAs/InP detectors up to few tens of picoseconds (Fig. 3). Finally, it has been introduced the design of a detection module for InGaAs/InP SPADs. It aims to improve performances with respect to available detection modules in order to push forward the use of InGaAs/InP SPADs in many applications during next years.

## HIERARCHICAL AND MULTIOBJECTIVE MODEL PREDICTIVE CONTROL

**Daniele De Vito**

The Thesis aims at exploring new possible applications of Model Predictive Control (MPC) for the solution of nonstandard control issues dealing with multiobjective, multilayer and reconfiguration problems. A great effort has been paid to the design of MPC algorithms guaranteeing some fundamental properties for the resulting closed-loop system, specifically stability and robustness. In turn, this has led to the use of sometimes heavy mathematical developments. The first problem considered in the Thesis deals with multiobjective control of unperturbed nonlinear discrete-time systems, where a number of even conflicting performance measures need to be simultaneously optimized. The problem has been tackled accounting for a set of  $H_2$ -like cost functions and contemporarily minimizing all of them by means of the Receding Horizon approach. Then, this idea has been extended to cope with a set of  $H_\infty$  performance indexes for a class of systems subject to bounded disturbances and/or parameter uncertainties. In both the considered cases, the MPC paradigm has allowed to state stability results for the closed-loop system under quite standard assumptions. The algorithms designed have

been successfully applied to the model of a head box of a paper machine and to the one of a cart moving on a plane and attached to the wall via a spring and a damper with an uncertain damping coefficient, respectively. Afterwards, the research interests have moved on the study of hierarchical control systems, motivated by the large number of real problems manageable with hierarchical control structures more suitably than with classic control methodologies. Within this setting, two-level control systems have been investigated. At the high level a regulator is designed to control a plant with slow dynamics, while at the low level a number of fast subsystems (actuators) directly driving such a plant must be controlled to provide the required regulating actions. At any sampling time instant, the regulator at the high level selects the most suitable subset of actuators to be used and sends them the reference control actions they must track in actuating the plant. MPC laws have been synthesized for both levels in order to optimize the use of actuation resources and their performance. As a matter of fact, the high level MPC makes sure both to choose the "optimal" actuation configuration, by also switching

some actuators on and off as convenience purposes call for, and to compute the control actions the plant would ideally need to be correctly controlled. In turn, the low level MPC's are in charge of solving their own tracking problems guaranteeing the satisfaction of quite stringent performance requirements. The control strategy developed ensures overall convergence properties in a robust fashion. Such a strategy has been tested on the linearized unstable model of a well-mixed, non-isothermal, continuous stirred-tank reactor, but it can handle any kind of system whose structure is intrinsically or properly referable to a hierarchical arrangement. Finally, drawing from the hierarchical control ideas previously introduced, two-layer controllers with self reconfiguration capabilities in the face of actuators addition/replacement events have been taken into account. The algorithm stated can thus be placed in those research lines that attend to "Plug and Play" process control, an emerging control methodology acting as soon as a new device, in general a sensor or an actuator, is plugged/substituted into an already functioning control system, in order to automatically make it aware of the new signals which are about to be swapped among the components.

Differently from the two-level structure described above, within this framework already controlled and completely known actuators have been considered, only reducing the algorithm to be synthesized to the high level MPC. Also in this case, an overall convergence result has been derived.

## OBJECT ORIENTED MODELLING, SIMULATION AND CONTROL OF ENGINEERING SYSTEMS: AN INTEGRATED APPROACH

Filippo Donida

Recent advances in object-oriented modelling allow to tackle the simulation and the computer-aided control system design of industrial plants in a unified framework.

Traditionally there is a structural wasting of time and resources and also a potential error generation when planning and designing all the project stages separately. The inefficiency is mainly due to the fact that the environments of the plant feasibility study, the detailed simulation, the control system design, the model-based requirement analysis, the hardware-in-the-loop validation of the control system, and the operator training interface are frequently incompatible each other.

This Ph.D. work aims at providing an integrated approach to resolving the problem, based on the Modelica language. There are three main key aspects to analyze. On the modeling side, suitable methodologies must be formulated in order to support flexible levels of detail and create reuse-oriented models. On the tools side, the development of the open-source OpenModelica compiler opens potentially important opportunities, due to its open architecture, suitable to produce

a simulation code tailored for different activities. Last, but not least, the developed methodologies and functionalities are demonstrated on some applications.

In this thesis the problem of proposing a new approach for pc-related simulation activities was investigated, taking into particular account the Modelica language as the bylaw object oriented modeling language reference. This language was used as the host language for both representing multi-physics problems, when focusing on DAE-related problem, like the IVP, as well as the inter-exchange format reference, if the target had been to obtain high-level-of detail closed-loop models. This aspect nicely clarify two of the main advantages in using that language: the modularity and the capability to easily represent the hybrid systems.

From a general point of view, the thesis topics can be grouped in two main sets: the specific subject research tasks (like the IVP methods) and the activities aiming at the optimisation of the whole simulation workow organisation. The focus is on minimising the advanced simulation competences required to the user as well as the human effort

in simulation-related activities at large, thus optimising the workow and moving to a more general plug&play solution. First of all, each single step relies on highly robust methods that can be automated and, secondly, clear and open standards are well diffused and accepted allowing the applications to easily interact. Considering the control system and thus its design as a key part of all the modern integrated systems, particular attention was reserved to the problem of dening methodologies for re-using the modelling efforts for control synthesis purpose. The models for the control system synthesis have rather stringent requirements in terms of simplicity and of specific mathematical structures. According to this, two main candidates have been recognized and analysed for automatically deriving the control from the object oriented model: the Model Order Reduction technique and Linear Fractional Representation. The MOR is essential to obtain models which are simple enough to be directly used for control purposes. This activity is nowadays performed manually, and there is a clear need of methods and tools to perform this task automatically, starting from object-oriented descriptions

of the plant. Several MOR techniques, which have been recently introduced by the electronic circuit design community, were reviewed in this thesis. As an alternative to the MOR technique, the Linear Fractional Transformation was taken into account with the intent to automatically obtain reduced order LFT models starting from generic equation-based, object-oriented descriptions of nonlinear plant dynamics, with uncertain parameters. Under suitable assumptions, a first-implementation algorithm was also presented and illustrated by means of examples, thus showing the possibility of obtaining other control-design oriented representations, such as the Linear Parameter Varying representation. To complement the control-aided computer design framework, three main tasks were developed, for control development, testing and experimentation. A Function Block Modelica library has been developed for helping in control design activities. Secondly, a module for automatically obtain the Modelica closed loop simulation code starting from the model of the plant and the IEC 61131-3-compliant control algorithm was implemented. Thirdly a module for translating the Modelica control algorithm into hardware language was developed. The initialisation problem for the DAE system was also analysed, studying methods for the initialisation of the overdetermined systems

of initial equations as well as an alternative method for finding the desired solution of the IVP, using the homotopy. Even if the Initial Value Problem is well known in literature, the value added contribute of this research is in studying Modelica-derived initialisations systems of equations. In particular, the high-level Modelica model, obtained by assembling several Modelica models each one containing a determined system of initial equations can present the IVP as an overdetermined initialization problem. If this occurs, it is possible to solve the IVP with the overdetermined set of initial equations, by specifying the initialization problem as the problem of minimising the residual vector norm. This technique was demonstrated by means of a simple example in the fluid domain. Additionally, the homotopy method was used for solving the IVP of DAE. In more deep, the homotopy technique was used for moving from a simplified version of the IVP problem to the real one. At present, the simplified version of the IVP needs to be specified by hand by the user, according to the original system of equations and the nominal working conditions. Future implementations will automatically calculate a simplified version of the IVP by linearising the systems of equations around the nominal initial conditions. This procedure of solving the IVP by integrating the continuous-time switching problem is not as straightforward to use as it seems, since, along the switching solution, several

different singularities can occur. In this work every possibility is considered and analysed, by means of simplified examples. A resolution strategy is also introduced for each case. As an improvement of the proposed method it will be possible to make the IVP-homotopy technique interact with a specific continuation software, choosing the right solution branch according to some constraints, which can be automatically derived from physical considerations. The focus in this thesis is on the standardisation of the object oriented derived DAE mathematical models, based on the XML standard. The definition of the DAE standard allows easy coupling of the Modelica compiler front-ends with diverse application back-ends that require the system equations as inputs. Finally, it would be interesting to investigate how this kind of formalism could be employed to describe sub-models that could then be aggregated at a higher level, by introducing some kind of connector concept. This might allow some form of separate compilation strategy, at least for a certain class of problem which do not lead to higher index DAEs when connecting the submodels. In conclusion, even if the results for each implementation obtained are highly encouraging and some integrated methodologies were tested through test implementations, to the best of the author's opinion, there is still some way to go, especially if considering the assessment of the proposals in an industrial scenario.

## OVERLAY NETWORKS FORMATION: MODELS AND ALGORITHMS

Jocelyne Elias

Overlay networks have recently emerged as an effective means to provide a flexible, robust, and scalable platform for distributed applications, while leaving the underlying Internet infrastructure unchanged. This work tackles the overlay network design problem considering both centralized and fully distributed approaches.

On one hand, we address the centralized overlay network design problem using the Service Overlay Network (SON) paradigm, and we propose several mathematical models and heuristics for the optimal design of SONs. More specifically, we introduce two network optimization models that determine the optimal assignment of users to access overlay nodes, as well as the capacity reserved for each overlay link, while taking accurate account of traffic routing. We also propose two overlay network design models that further select the optimal number and location of the overlay nodes to be deployed, as well as the optimal coverage of network users to maximize the SON operator's profit. Furthermore, we develop a set of efficient SON design heuristics to get near-optimal solutions for large-scale network instances in a reasonable computation time. Finally, we perform an extensive

performance evaluation of the proposed centralized optimization framework in several realistic network scenarios.

On the other hand, this thesis also proposes two novel socially-aware overlay network design games to deal with the fully distributed overlay network formation problem.

The first game combines both individual and social concerns in a unified and flexible manner, and the second game uses a Stackelberg approach, where the overlay network administrator leads the users to a system-wide efficient equilibrium by buying an appropriate subset of the overlay network links. We evaluate the performance of the proposed games, through the determination of bounds on the Price of Anarchy and other efficiency measures, as well as by simulating several realistic network scenarios, including real ISP topologies.

Numerical results demonstrate that: (1) our proposed SON design models and heuristics plan very effective overlay networks, even in the case of very large network instances, and (2) our proposed distributed network formation algorithms are able to lead client users to form stable and efficient overlay networks, obtaining in several

cases the optimal solution that could be planned by a central authority.

Hence, we conclude that the proposed solutions can be very effective when applied to real Internet scenarios.

## MPSOCS: METHODS AND TECHNIQUES TO TACKLE DESIGN COMPLEXITY.

Luca Fossati

Multi-Processor Systems-on-Chip (MPSoCs) are becoming the prevalent design style to achieve tight time-to-market design goals for high-performance embedded devices, simplifying the verification process and providing flexibility and programmability for post-fabrication reuse. MPSoCs are complex systems, usually composed of multiple off-the-shelf processing cores, memories, and application specific co-processors; together with the cited benefits, such complexity brings a number of issues and challenges for system architects, software and hardware designers, and for verification specialists and system integrators. These may be best met by revisions of old tools (e.g. improving their ease of use, their modeling capabilities, etc.), by devising new techniques to deal with MPSoC complexity (e.g. more efficient algorithms for the exploration of the design space), and by raising the abstraction level at which decisions are taken with new methodologies. In addition to this, MPSoCs are, by their nature, processor-centric and thus software-centric; as a consequence larger and larger portions of current applications are being implemented in software and their development starts dominating the cost of the

whole system becoming critical for the system's release schedule. This work considers the MPSoC modeling and development process according to the *platform based design* by separating the various aspects of the design and by using a predefined customizable hardware platform as the base design block. In this context, MPSoCs are approached from three different perspectives: a) modeling and simulation of the hardware platform, b) analysis and optimization of the software layer, and c) design space exploration. After presenting a general overview of the MPSoC design challenge and of the main techniques employed for their design, the focus moves to the original contributions of this work, which can be summarized as:

1. Introduction of *Reflective* and *Introspective* capabilities in Hardware Description Languages, providing a complete solution in the form of a System-Level Simulation platform called ReSP (*Reflective Simulation Platform*). The framework exploits Python's reflective capabilities, augmenting SystemC components with full observability of their internal structure. This enables run-time composition and dynamic management of the
2. Development of a methodology for the high-level design space exploration of reconfigurable platforms, focusing in particular on devices with embedded Field Programmable Gate Arrays (eFPGAs) components.
3. Implementation of an innovative System-Call Emulation subsystem used for the preliminary exploration of concurrent and real-time applications, to guide the designer in the choice of the target Operating System, and as a support for early HW/SW partitioning.
4. Definition of a fast Design Space Exploration algorithm that exploits the domain knowledge provided by the definition of a design platform. The idea is to move the exploration complexity from simulation to statistical analysis of parameter transformations. Exploration is modeled as a Markov Decision Process (MDP), and the solution to such MDP corresponds to the sequence of transformations to be applied to the platform to maximize the desired

objectives. The proposed approach requires to simulate the system only in particular cases of uncertainty, massively reducing the simulation time needed to perform the exploration of a system, while maintaining near-optimality of the results.

5. Design of TRAP (*Transactional-level Automatic Processor generator*), an innovative Architecture Description Language specifically designed to provide: (a) intuitive and easy specification of the architecture, (b) generation of fast Instruction Set Simulators, and (c) modeling capabilities for a wide range of architectures.

The presented methodology, development flow, and tools have been tested and evaluated using a vast set of single-and multi-threaded benchmarks, with both POSIX Threads and OpenMP programming styles. In addition three real-life applications (pbzip, pgzip, and ffmpeg) demonstrate the effectiveness of the approach.

## NEW ADVANCED TECHNIQUES FOR RADIO RESOURCE MANAGEMENT

**Giordano Lorenzo Galati**

In the next future, wireless communication systems will move towards the achievement of high transmission rates for both fixed and mobile users. The main topics of this thesis are the investigation of adaptive radio resource allocation strategies in the presence of a finite number of modulation and coding profiles and the evaluation of their impact on the interference distribution in a multi-user/multi-cellular wireless network based on Orthogonal Frequency Division Multiplexing Access (OFDMA). These kinds of allocation procedures are based on the assumption of having a perfect knowledge of the Channel State Indicator (CSI) and they involve many degrees of freedom (i.e. frequency, time, space, modulation, coding and power). Each allocation algorithm could be built following many different strategies and according to the required Quality of Service (QoS), fairness and complexity criteria.

The content of the thesis mainly covers the following points:

1. Investigation of the resource allocation approaches operating in the frequency domain, namely suited to OFDMA systems. Proposal of novel algorithms, comparison with existing methods and impact on

the system performance (coverage and throughput) in a multi-cellular scenario. Moreover, advantages and drawbacks of the strategies based on the maximization of the transmission rate or on the minimization of the transmission power.

2. Resource allocation approaches operating in two dimensions, frequency (i.e. sub-channels) and time slots. Different classes of algorithms are implemented: they are based on heuristic approaches and they extend some of the OFDMA sub-optimal solutions to the two dimensional context. This part was validated by means of a dynamic system simulator for IEEE 802.16 in which traffic model, QoS and scheduling are properly implemented.
3. Investigation on the relation between resource allocation (in terms of frequency, power and fairness criteria) and generated interference inside a wireless multi-cellular network. This relation is not trivial since, when allocation algorithms allow a reduction of the average transmitted power in order to adapt it to the nearest modulation and coding scheme, the overall network interference

tends to decrease, modifying the SINRs distribution and causing a new update in the assignment of the available resources. The system acts as a loop that converges to a stable solution after a certain number of iterations.

## OPTIMAL AND ROBUST CONTROL OF SWITCHED LINEAR SYSTEMS WITH DELAYS

Luca Galbusera

Switched systems are a class of dynamical systems characterized by the interaction of a continuous behaviour and discrete events triggering instantaneous changes in the model. Depending on the situations, such events can be produced within the system itself or imposed by an external action. By exploiting such a formalism, it is possible to model a plethora of real-worlds applications, as power converters, chemical processes, temperature control systems and mechanical apparatuses. In the control community, the interest in switched systems has considerably grown over the last decades. A notable portion of the recent literature on this topic is devoted to the stability analysis and stabilization problems. Other research fields embrace structural properties, optimal and robust control and some further system-theoretical aspects. Significant interest can also be observed in studying special classes of switched systems, such as switched systems with time delays.

This thesis aims at providing new contributions to the control theory of switched systems, with a particular emphasis on the optimal and robust control of continuous-time switched linear systems and switched linear systems with delays by

means of switching.

The first part of the dissertation is devoted to switched linear systems and contains two main contributions.

We first propose new results on the robust stabilization and  $H_\infty$  disturbance attenuation problem by defining a suitable state-feedback switching law and possibly a continuous control action hinging on the use of piecewise Lyapunov functions. Our theoretical results are expressed as sufficient conditions based on the solution of a set of bilinear matrix inequalities.

An important point about such a method is that achieving the described control objective does not require any element in the set of models we consider to be stable. Furthermore, it also accounts for possible model uncertainties and sliding modes acting on the system, which are usually neglected in the previous literature.

The second contribution we propose referring to standard switched linear systems consists in a different approach to the solution of the  $H_\infty$  disturbance attenuation problem by means of switching. By exploiting the connection between the classical  $H_\infty$  control theory and the theory of differential games, we model our control objective as the solution of

a two-person zero-sum differential game in which the players are represented by the controlled switching signal and the disturbance input. A saddle equilibrium for this game is then found as the solution of a Hamilton-Jacobi-Isaacs equation.

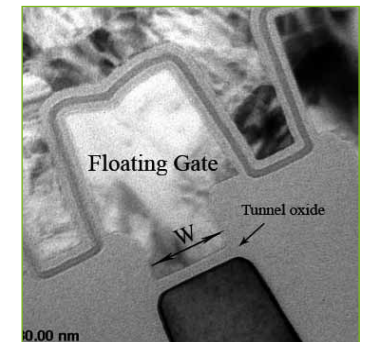
The second part of the thesis extends some methods and concepts illustrated above in order to address the  $H_\infty$  control of switched linear systems subject to time delays. By referring to the recent literature on standard linear systems with time delays, we introduce different criteria for the solution of the problem under analysis: both delay-independent and delay-dependent results are proven, which enable us to deal with various classes of delays. Also in this case, the control action consists in a state-dependent switching and issues related to possible model uncertainties and sliding modes acting on the system are accounted for in our formulations.

## RELIABILITY ISSUES IN ULTRA-SCALED FLASH MEMORIES

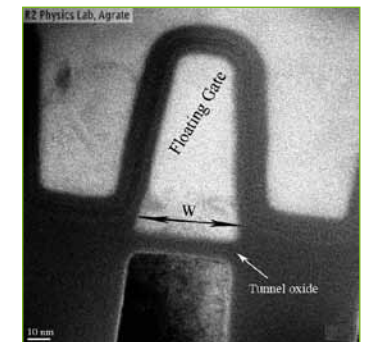
Michele Ghidotti

The constant improvements in the silicon technology exhibited over the years by the semiconductor industries have resulted in a continuous reduction of the electron devices feature size. These technological developments strongly impact in device performance and production costs. In particular, in the memory segment, both aspects play a fundamental role to launch a widely successful product. In the last few years, the non-volatile memories branch has become one of the most important revenue sources for the microelectronics companies (in 2008 the worldwide semiconductor market sales were about \$255 billion, of which roughly \$21.3 billion concern non-volatile memories), for this reason increasingly efforts are dedicated to improve this technology. This thesis deals with reliability issues in ultra-scaled Flash memories; memories employed in modern electronic equipments daily used. For this reason, it is of fundamental importance to investigate these memory devices. One of the most important reliability issues in the last technological nodes is the Random Telegraph Noise (RTN). This phenomenon affects the threshold voltage  $V_T$  of the memory cell. The correct  $V_T$  reading is

required to read correctly the information stored in the device. Therefore, first of all, a physics-based statistical model is presented. Afterwards, experimental measurements are investigated to understand how  $V_T$  evolves after reproducing the device use conditions and to validate the theoretical model. Since the demand to reduce as fast as possible the technology feature size, an inquiry about the technological scaling impact on the RTN is accomplished too. Beyond the 60 nm technology node, the granularity of the charge stored in the device is not more negligible and this fact influences the accuracy to perform the program operation. This means that the statistical nature of the electrons injection into the floating gate spreads the  $V_T$  distribution of the array cells. The feature size reduction affects negatively the distribution because spread becomes wider (less electrons are necessary to program the cell, roughly few hundreds) and it becomes more and more difficult to control the cell  $V_T$  by the program algorithm. An investigation is carried out to quantify how much this phenomenon affects the  $V_T$  distribution broadening. Another issue began to show its effects in sub-100 nm technologies concerns the cells interference. The cells floating



1. Scanning Electron Microscopy (SEM) image of a 70 nm NAND Flash memory cell



2. Scanning Electron Microscopy (SEM) image of a 48 nm NAND Flash memory cell

gates are so close each other that a cross-talk is established by the field oxide among the gate stacks. A  $V_T$  change is observed during the reading operation and, especially, in the retention phase. The  $V_T$  loss displays a dependence on the program pattern of the adjacent cells, thus modeling and

characterization of both program and erase transients have been performed to understand the nature of this aspect. These phenomena contribute all together to corrupt the data stored, causing the memory failure and thus the worn-out.

## NUMERICAL MODELS OF CONDUCTION, SWITCHING AND STRUCTURE RELAXATION IN PHASE CHANGE MEMORIES

Simone Lavizzari

Mainstream Flash non volatile memories are predicted to face fundamental scaling limits in the next technology nodes, therefore several emerging technology have been recently proposed. Among these, Phase Change Memory (PCM) and resistive-switching RAM (RRAM) show several interesting features such fast read/write, low voltage operation and superior cyclability, as well as promising scalability.

This thesis focuses on Phase Change Memory (PCM), which basic structure is presented in Fig. 1, and in particular on transient effects involved in threshold switching and on structural relaxation of the amorphous phase. PCM relies not only on phase transitions between the two structures of the chalcogenide materials, but also on electronic switching in the amorphous material between OFF and ON conductive states and vice versa. Transient effects associated with both transitions, like the delay time for threshold switching, the switching time and the recovery time for the ON to OFF transition, play a fundamental role in the operation of the PCM device, namely program, erase and readout processes. The transient simulation of threshold switching in phase change memory (PCM) devices is therefore essential for the

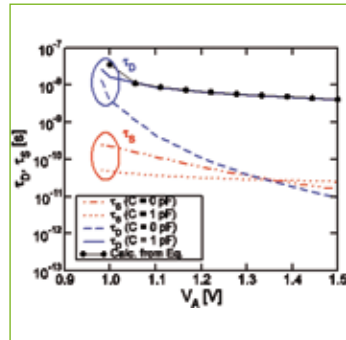


1. Schematic of a simple cylindrical PCM. The active chalcogenide material is contacted by a thin metallic plug, the heater, which heats the GST through electrical pulses. The cell is in the set state when the chalcogenide is all crystalline (left), by contrast the reset state (right) is characterized by the presence of amorphous chalcogenide

prediction and optimization of cell behavior depending on the circuit parameters and for the understanding of the ultimate limit of speed operation. Analytical Poole-Frenkel (PF) model for conduction and energy gain model for threshold switching are used to evaluate the transient effects. The current and field transient at the basis of the switching phenomenon are discussed with the aid of appropriate numerical models. The impact of cell parasitics, in particular the parallel capacitance, is addressed. Fig. 2 shows the dependence of the delay and switching times versus the applied voltage and the parasitic capacitance. Note that PCMs are predicted to be programmed in a time down to hundreds of ps.

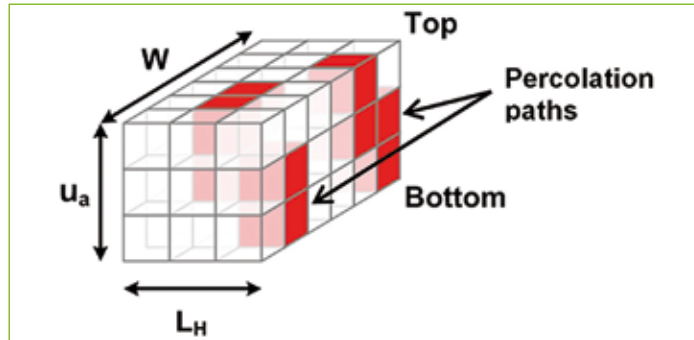
Moreover the current fluctuations due to  $1/f$  noise in PCM devices are modeled and explained with numerical Monte Carlo simulations, enabling for delay statistics and for reliability assessment of read disturb in PCM devices. Since PCM relies on the electrical properties of the chalcogenide materials to represent the stored bit of information, its reliability is affected by structural relaxation (SR) in the amorphous chalcogenide phase, which results in a temperature-accelerated time evolution of the electrical properties of the active material. Electrical measurements for increasing annealing time and temperature indicate that SR can be described by a defect annihilation process in the amorphous chalcogenide material.





2. Calculated delay time  $\tau_D$  and switching time  $\tau_S$  as a function of the applied voltage  $V_A$  and for zero and non-zero parasitic capacitance.  $\tau_D$  is mostly limited by RC effects in the presence of the capacitance, as demonstrated by the comparison with calculation results.  $\tau_S$  is almost constant around 100 ps

Addressing the time, temperature and bias dependence of SR effects on the amorphous  $\text{Ge}_2\text{Sb}_2\text{Te}_3$  (GST) material used in PCM cells is therefore fundamental for reliability prediction, especially in multi-level cells to optimize the read condition for the purpose of reducing the impact of SR on the reliability of the device. Finally the impact of the scaling on the resistance window and fluctuations is described by a distributed Poole-Frenkel (DPF) model for electrical transport in PCM cells. Fig. 3 depicts the basic idea behind the model: the current follows low-resistive paths, resulting in random localized current filaments. In particular, the



3. Schematic for the 3D-DPF model: the simulated amorphous volume consists of elemental cubes with 1 nm side, acting as PF traps with a characteristic emission energy  $E_T$ , resulting in a resistive random network (RRN) of resistances  $R_i$ . Percolation paths are shown in red

anomalous resistance scaling and random telegraph noise (RTN) are described, allowing also for scaling projections at technological nodes  $F = 48 - 8$  nm, showing no particular issues in case of isotropic scaling approach.

## INTEGRATED DETECTION OF ANOMALOUS BEHAVIOR OF COMPUTER INFRASTRUCTURES

Federico Maggi

Network connected devices such as personal computers, mobile phones, or gaming consoles are nowadays enjoying immense popularity. In parallel, the Web and the humongous amount of services it offers have certainly become the most ubiquitous tools of all the times. Facebook counts more than 250 millions active users of which 65 millions are using it on mobile devices; not to mention that more than 1 billion photos are uploaded to the site each month. One year ago, Google estimated that the approximate number of unique URLs is 1 trillion, while YouTube has stocked more than 70 million videos as of March 2008, with 112,486,327 views just on the most popular video as of January 2009. And people from all over the world inundate the Web with more than 3 million tweets per day. Back in December 1990 the Internet was made of one site and today it counts more than 100 million sites is just astonishing. The Internet and the Web are huge and they both became the most advanced workplace ever. In fact, almost every institution is connected to the Internet and relies on its infrastructures for the majority of their transactions; most of the time monetary transactions. Unfortunately, during their daily work activities, people typically pay poor or no attention at

all to the risks that derive from exchanging information over such a complex, insecure infrastructure. The Internet is indeed an extremely unsafe place, with more than 1,250 known data breaches between 2005 and 2009 and an estimate of 263,470,869 records stolen by intruders. The cause of today's security issues is the combination of two phenomena: the high amount of software vulnerabilities and the effective, wide-range exploitation strategy. In fact, in parallel to the explosion of the Web 2.0, attackers and the underground economy have quickly learned that a sweep of exploits run against every reachable host have more chances to find a vulnerable target and, thus, is much more profitable compared to a single effort to break into a high-value, well-protected machine. As a result, the underground economy created a very proficient marketplace where everyone can buy credit card information for as low as \$0.06-\$30, full identities for just \$0.70-\$60 or rent a spam campaign service for \$3-\$40 per week plus \$2-\$20 for the web page design. The aforementioned, dramatic big picture may lead to think that the malicious software will eventually infect every host connected to the Internet

and no effective remediation exists. However, a more careful analysis reveals that, despite the complexity of this scenario, the security problems that must be solved by a security infrastructure can be decomposed into relatively simple tasks. In fact, a computer infrastructure has several weak spots to protect to avoid system violations. Given such hypotheses, we proposed to enhance and adapt classic intrusion detection methodologies to mitigate the aforementioned issues in a complex computer infrastructure. First, our research focuses on protecting the operating system, central to any computer, to avoid malicious code to subvert its normal activity. Secondly, we concentrate on protecting the web applications that, because of their immense popularity, have become the most targeted entry point to compromise a system. Last, we investigate novel techniques capable of identifying related events (e.g., alerts reported by intrusion detection systems) to build new and more compact knowledge to detect malicious activity on large-scale systems. The aforementioned subjects are described in the following. Our contributions regarding host-based protection systems focus on characterizing

a process' behavior through the system calls invoked into the kernel. In particular, we engineered and carefully tested different versions of a multi-model detection system using both stochastic and deterministic models to capture the features of the system calls during normal operation of the operating system. Besides demonstrating the effectiveness of our approaches, we confirmed that the use of finite-state, deterministic models allow to detect deviations from the process' control flow with the highest accuracy. However, our contribution combines this effectiveness with advanced models for the system calls' arguments resulting in a significantly decreased number of false alarms. Our contributions regarding protection systems for web-based products focus on advanced training procedures to enable learning systems to perform well even in presence of changes in the web application source code --- particularly frequent in the Web 2.0 era. We also addressed data scarcity issues that is a real problem when deploying an anomaly detector to protect a new, never-used-before application. Both these issues dramatically decrease the detection capabilities

of an intrusion detection system but can be effectively mitigated by adopting the techniques we propose. Last, we focused on the use of different stochastic and fuzzy models to perform automatic alert correlation, which is as post processing step to intrusion detection. We proposed a fuzzy model that formally defines the errors that inevitably occur if time-based alert aggregation (i.e., two alerts are considered correlated if they are close in time) is used. This model allow to account for measurements errors and avoid false correlations due to delays, for instance, or incorrect parameter settings. In addition, we defined a model to describe the alert generation as a stochastic process and experimented with non-parametric statistical tests to define robust, zero-configuration correlation systems. The main question that we attempted to answer in our research work is, "to what extent classic intrusion detection approaches can be adapted and integrated to mitigate today's Internet threats". Examples of such threats include attacks against web applications like SQL injections, client-side malware that force the browser to download viruses or connect to botnets, and so forth. Typically, these attempts are called "malicious activities".

The short answer is that as long as the technologies (e.g., applications, protocols, devices) will prevent us to reach a sophistication level such that malicious activity is seamlessly camouflaged as normal activity, then intrusion detection techniques can be employed as an effective countermeasure. This is because intrusion detection systems -- in particular those that leverage anomaly-based techniques -- are specifically designed to detect unexpected events in a computer infrastructure. The crucial point of anomaly-based techniques is they are conceived to be generic. In principle, they indeed make no difference between an alteration of a process' control flow caused by an attempt to interpret a crafted JavaScript code and one due to a buffer overflow being exploited. Thus, as long as the benign activity of a system is relatively simple to model, then intrusion detection techniques are the building block of choice to design effective protections.

## ULTRA COMPACT ELECTRONIC SYSTEMS FOR LUMINESCENCE ANALYSIS WITH SINGLE PHOTON DETECTORS

**Stefano Marangoni**

All the applications potentially interested in multi-channel single photon measurement can be divided in two categories: in some cases the information is contained in the extremely low source intensity, in other cases the information is contained in the photon time of arrival on the detector's area. So, in the first case the goal is obtaining a good signal-to-noise ratio, while in the second case the goal is the detection of a single photon with low time uncertainty. These aims can be achieved nowadays with photomultiplier tubes (PMT), high-sensitivity CCDs, or in the last years with EMCCDs, but each of these detectors has some drawbacks if used for parallel, multichannel applications. In fact, PMTs have very good temporal resolution and single photon capability, but they are bulky and fragile, so their use in parallel system is difficult. CCDs are very good detectors for the detection of weak luminescence in parallel, but only if the signal to detect allows very long acquisition time. Instead, if the signal is very weak and it is enabled only for short period, there is the need of single photon capability and CCDs are not the right detector to use. Moreover, if the information is contained in the arrival time of the photons, CCDs are not able to perform

the correct measurement. EMCCDs overcome CCD limit exploiting electron multiplication and allowing single photon detection with multiple pixels in parallel, but they cannot be used in application requiring high temporal resolution.

SPAD detectors are the most promising devices in all the applications in which it is requested multi channel detection with very good timing resolution or with single photon capability. In fact, it combines the typical advantages of microelectronics (miniaturization, integration capability, ruggedness, low voltage, low power, low cost, etc.) with single photon capability and very good timing resolution. The single-pixel SPAD is a detector well developed and it was used in a lot of applications with extremely good results, as demonstrated for example by publications on journal as Science. The potential of the single pixel SPAD is evidenced also by the commercialization of this detector by different companies and by the birth of a spin-off company of Politecnico di Milano. This very advanced research area represents the state of the art at the beginning of this Ph.D., that has the aim of developing the first prototypes based on SPAD arrays. This goal is

achievable only affronting all the problems concerning a SPAD array, from the device structure to circuital aspects. The starting point of the work reported in this thesis is a 6x8 SPAD array for protein microarray analysis. The development and the realization of a complete apparatus for protein microarray analysis based on this detector will be described in Chapter 3. The system is part of a research program supported by the European Commission, named Nanospad project. According to the goals of the NANOSPAD project, this system can be further integrated with a microfluidic device, in order to obtain a complete apparatus for allergen specific IgE detection in low-cost allergy tests. This system demonstrate that SPAD arrays have very interesting characteristics for low luminescence applications, allowing a potential breakthrough in this field in terms of cost of the apparatus, compactness and analysis time. This project helped evidencing the critical points and the potentiality of SPAD arrays and the knowledge acquired has been useful for the further projects. In particular, developing this apparatus the problem of crosstalk emerged; for this system prudentially it was

chosen to increase the minimum distance between two working pixels dividing the array in four interleaved sectors, while in parallel to the development of the system the mechanism of crosstalk was deeply investigated (Chapter 4).

It was demonstrated that one of the main contributions to crosstalk comes from a narrow-band (less than 100~nm) of near-IR spectral components (between 1100 and 1200~nm) reflecting off the bottom of the chip (especially the ones reflecting with an angle of incidence greater than the critical angle, since total internal reflection takes place).

An optical model was developed, in order to predict the dependence of crosstalk on the position of the devices within the array. Numerical simulations based on this model gave results in very good agreement with experimental data; the model not only helped to gain more insight on the crosstalk dynamic but it represents a useful tool to choose the best array configuration for keeping crosstalk low. In particular, thanks to the work here reported, it was possible to make two conclusions.

First, increasing the doping level of the substrate it's possible to reduce significantly the optical crosstalk. Second, since crosstalk

doesn't show a monothonic decreasing behavior with the distance, it's possible to realize compact array, with short pitch between pixels. The results on the optical crosstalk

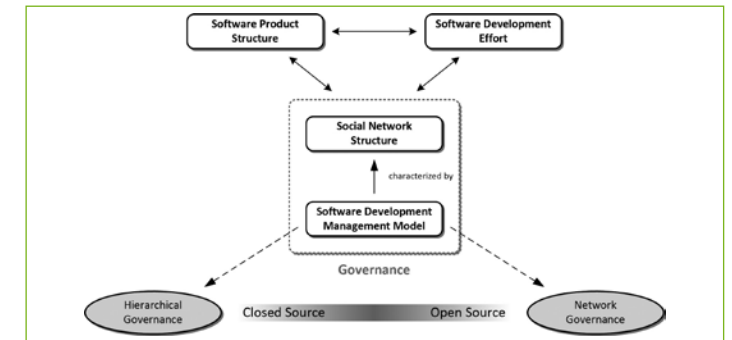
allowed the development of a module using a 8 pixel SPAD array with a reduced pitch between pixels, without multiplexing. Moreover, the knowledge acquired with Nanospad project has been useful to develop the eight pixel module in extremely compact dimensions. The results on the optical crosstalk allowed the development of a module using a 8 pixel SPAD array with a reduced pitch between pixels, without multiplexing.

Moreover, the knowledge acquired with Nanospad project has been useful to develop the eight pixel module in extremely compact dimensions.

## AN EMPIRICAL ANALYSIS OF THE IMPACT OF SOCIAL NETWORK STRUCTURE ON THE ECONOMICS OF SOFTWARE PROJECTS

Francesco Merlo

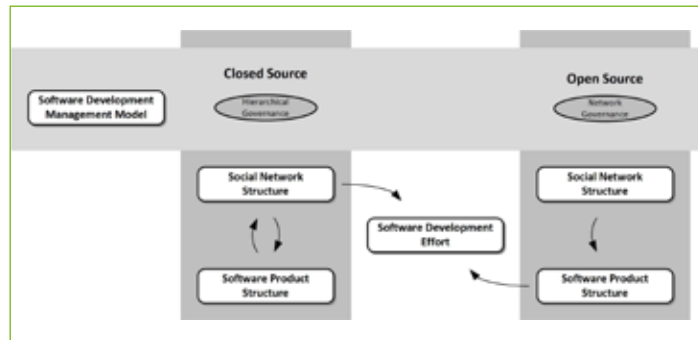
The goal of the research presented is to analyze the set of relationships existing among three variables, namely the structure of a software product, the development effort, and the structure of the social network of developers. The relationship among the structure of a product and the social structure of the team of developers is a topic of much interest in the product development literature. Considering the context of software development, it has been observed that organizational structure and software product structure present mutual influences in their evolution; it has also been recognized that the structure of the social network of developers influences the ability of sharing knowledge among its members. These results provide the theoretical foundations to support the hypothesis that the shape of the social network of developers and the network outcomes (i.e., the software product) are mutually related: networks are forms of social organization, which are more than the sum of the actors and their links, and their performance in producing outcomes is considered to vary with regard to their structural patterns of relations. The structure of the social



### 1. Overall theoretical framework

network of developers is analyzed as a governance-related variable: based on previous outcomes of organizational theory, it is assumed that governance, not directly measurable, can be structured as the ensemble of two measurable variables: the Social Network Structure and the Software Development Management Model. Previous results have proved that both general network structure and the position of each individual within the network influence the information that flows through the network, and that centralization facilitates integration and coordination in a network. Based on these considerations, the Social Network Structure variable is defined by considering the three most referenced centrality measures in the literature. The Software Development Management

Model variable is instead focused on the evaluation of the process responsible for the control of project scope, progress, and continuous commitment of developers, which is also called project governance. Both these variables lead to the characterization of the common underlying theoretical concept of Governance. The relationships among the structure of the software product, the development effort and the structure of the social network of developers are analyzed by considering two different yet complementary contexts in software development, such as those of Closed Source and Open Source. This choice has been motivated by three reasons: first, one of the most commonly recognized weaknesses in the literature on software development is that analyses are very seldom oriented to the comparison of



## 2. Summary of empirical results

different software development models, thus leading to a paucity of significant results. One of the objectives of the research is to adopt the broadest perspective possible on the software development context, focusing on both proprietary and Open Source development models. Second, the Closed Source and the Open Source software development models provide very different approaches to the same problem, i.e., that of software development, and both have demonstrated to be able to achieve excellent results and outcomes from both managerial and technical perspectives. Third, the software development management models adopted in Closed Source and Open Source are extremely different, although they can be considered as the two extremes of a unique continuum of possible project governance approaches to be applied to software

development. In particular, the traditional management model of Closed Source software development is that of hierarchical governance, common in structured contexts and companies such as software houses developing proprietary software. In contrast, the management model in the Open Source context may be extremely varying. However, it is generally acknowledged that network governance is a management model suitable to describe the one typically adopted in Open Source software development contexts. Network governance “uses informal social mechanisms to coordinate and safeguard interactions between actors in a network, and provides a theoretical framework for examining how the efforts of a worldwide programming team of volunteers can be coordinated effectively”.

Empirical evidence suggests that different management models have different impact on the drivers of the Software Development Effort: in the Closed Source context, the coordination mechanism is based on the structure of the social network, while in the Open Source context the main driver of productivity is the structure of the software product. The influence of the Social Network Structure on the Software Product Structure provides support to the Conway’s law, indicating that the structure of the software product typically reflects the organizational structure of its development team. In the Closed Source context there is empirical evidence of a feedback effect of the Software Product Structure on the Social Network Structure, coherently with the “mirroring hypothesis” of traditional engineering fields. Conversely, in the Open Source context, the dynamicity of the social network structure prevents its use as a coordination mechanism: results confirm such hypothesis, by bringing evidence of no effects of Software Product Structure on the Social Network Structure.

# A METHODOLOGY FOR THE DESIGN AND THE ANALYSIS OF RELIABLE EMBEDDED SYSTEMS

Antonio Miele

Nowadays, the necessity of enforcing the correct behavior of digital systems has considerably increased with respect to the past due to the aggressive advantages in the integrated circuit manufacturing process of the last years (e.g., technological scaling or noise margin reduction), which is leading to the realization of devices more sensible to transient faults, usually referred to as *soft errors*. This situation, particularly hazardous in safety- and mission-critical systems, is becoming serious also for common applications when considering the embedded systems’ pervasiveness in today’s life. As a consequence, the quest for reliability also for non-critical applications has gained a lot of momentum, making reliability a first-class citizen in the embedded system design scenario, at the same level of classical parameters, such as performance and power.

Being the problem not new, although becoming more and more relevant, literature offers a wide set of reliability-oriented design techniques, devoted to the introduction of fault detection or tolerance properties in the designed system. It is common practice in embedded system design to consider the system hardening

step separately from the other activities; in fact, the usual approaches consist of adopting a commercial off-the-shelf reliable solution, or selecting a single reliability-oriented technique on the basis of the designer’s experience to be applied in a straightforward fashion. However, as the design of embedded systems is becoming a more and more complicated task, approaches that do not perform a systematic analysis of different hardening strategies do not suffice since they may lead to expensive or non-optimized solutions. As a matter of fact it is necessary to consider reliability issues during the overall design process in a holistic way, “melting together” all available resources, to drive the several decisions by exploiting the synergy of both the more classical aspects and reliability-oriented ones. Similarly, the assessment of the actual reliability level of the identified solution is another challenge related to the described scenario. The current trend to postpone the reliability assessment to the later phases of the design flow on a system prototype is not appealing, because failure in achieving the desired level of reliability would be detected too late, leading to a loss of money and time. Conversely, an early

evaluation should be performed in the first phases of the design flow, to offer a prompt feedback for system refining, thus leading to an even more optimized solution.

Given these motivations, we argue that as new paths are taken towards the design and the development of embedded systems, we need to deal with their reliability issues right from the beginning and consider them for the overall design flow. For these reasons, we give reliability a primary role even in non-critical application environments, weaving its requirements and features together with the other, more classical, elements. Therefore, the objective and the challenge of this thesis is to demonstrate this claim, by providing a new methodology for the *design* and the *analysis* of embedded systems with reliability features. The methodology is intended as an enhancement of the standard HW/SW co-design flow by introducing novel activities dealing with the reliability issues, aiming at exploiting the advantages of this design flow also in the scenario of reliable embedded system design. Versatility and flexibility are two key aspects of the proposed methodology for adapting to the several situations where different

reliability requirements are expressed, specific target platforms are adopted and a variable set of reliability-oriented techniques is available.

First, new flexible approaches are proposed for the design of embedded systems; they provide the designer with the possibility to explore the design space composed by all the reliable implementations of the considered system obtained by applying hardening techniques, and to compare the different solutions in terms of costs and benefits with respect to a set of metrics, including both classical and reliability-oriented ones. Then, novel strategies for the analysis of the implemented systems based on fault injection are defined aiming at providing an early evaluation offering an overall feedback for the system refining. These strategies aim at providing not only fault coverage statistics as usually done in literature, but also error propagation and fault classification to accurately study the motivations of the possible system failures. More specifically, the thesis proposes a new system-level synthesis approach that integrates a reliability-related layer introducing activities to apply fault management techniques and metrics for the design space

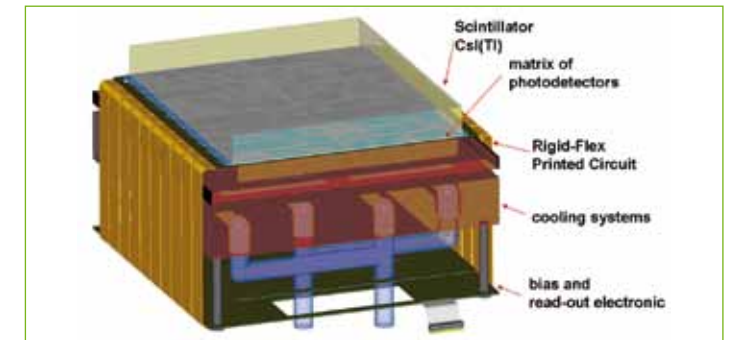
exploration. The methodology is also ported to the FPGA scenario with a framework that specializes the methodology for the given technological platform, exploiting its reconfiguration capabilities. Similarly, the reliability-related analysis has been addressed at two different abstraction levels, at first working on the system specification (in SystemC and TLM) and later by means of a reliability analyzer based on a fault injector implemented on a SRAM-based FPGA. For each of the two scenarios, a flexible and programmable framework has been designed for simulating the injection of faults and analyzing their effects.

## DEVELOPMENT OF A HIGH RESOLUTION ANGER CAMERA FOR NUCLEAR IMAGING APPLICATIONS

**Roberta Peloso**

Nuclear medical imaging is a generic term that covers many imaging techniques based on the interaction of ionizing radiations into biological tissues, with the common aim to gather information about metabolic activity of the studied object, where information is in the form of an image representing the concentration and distribution of the chemical, radioactive compound injected into the patient.

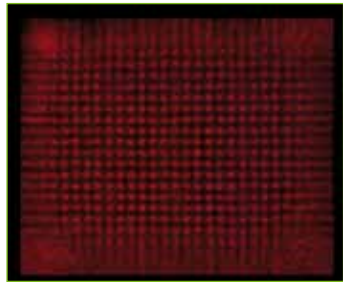
Almost every existing nuclear medicine imaging system is based on the architecture of the gamma camera introduced by its inventor, Hal O. Anger in 1958. In a conventional Anger Camera, the detection of gamma photons and the derivation of their source position are based on a two-stage energy conversion, preceded by the selection of the gamma photons traveling in a precise direction with respect to the entry plane of the imager thanks to a collimator. In the first level of conversion, the energy of each selectively passed gamma photon is used to create several thousand visible photons thanks to a scintillating crystal made of sodium iodide (NaI). In the second level of energy conversion, an array of photomultiplier tubes (PMTs) converts the energy of the visible photons in an electric signal. The original design proposed by Anger is still widely used



**1. Design of the Hicam camera based on the Anger architecture. High performances will be reached thanks to the use of a matrix of SDDs as photodetectors**

today and NaI crystals coupled to PMTs are still of widespread use in the nuclear imaging field. Nevertheless, a great number of alternatives have been explored for the design of the detector head as the p-intrinsic-n photodiodes (PINs) and the avalanche photodiodes (APDs). Silicon Drift Detectors, SDDs, have recently shown to be a competitive device for the readout of scintillators. When coupled to CsI:Tl scintillator, SDDs have shown to achieve both good energy resolution and a sub-millimeter position resolution in  $\gamma$ -ray imaging. This work regards the development of new Anger camera based on SDD. Good results are obtained in the last years thanks to the DRAGO (DRift Array-based Gamma camera for Oncology) project, led by Politecnico

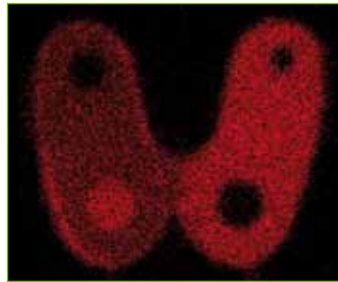
of Milan, which regards the development of a high-resolution Anger camera based on a monolithic array of 77 SDDs, with an active area of 6.7 cm<sup>2</sup>, coupled to a CsI:Tl scintillator crystal. This camera has shown a resolution of 0.35mm FWHM, and uniform imaging capabilities over its field-of-view, with potential applications in the field of small animal imaging and intraoperative probes. To cover larger format of Anger cameras to be used especially for human imaging, arrays of SDDs of larger active areas are employed in the framework of the HICAM (High resolution CAMera) project, supported by European Community. The new camera, under development, is composed of 100 SDDs of 1cm<sup>2</sup> each, in a 10x10cm<sup>2</sup> format, and would represent the largest



**2. Distribution of the  $^{99m}\text{Tc}$  irradiation points obtained with a grid of holes of 0.5mm of diameter, pitch 2 mm. The system shows a very good intrinsic spatial resolution, <1mm as expected**

gamma-ray imager based on SDDs developed so far and is foreseen to be employed in medical imaging applications where high-position resolution and camera compactness are of primary concern. The Hicam camera will be characterized by: high intrinsic spatial resolution, < 1mm, and high overall spatial resolution, ~ 2.5mm@5cm; energy resolution: < 15%@140keV; compactness and ease of positioning of the detector head; compatibility with large magnetic field for the possible integration with MRI instrumentation. A drawing of the prototype of the detection head of the camera is shown in Fig. 1.

Thanks to its high system performances, the Hicam camera will be a relevant tool in the field of medical research. It will contribute to combat cancer by offering more effective



**3. Acquisition of the phantom for thyroid studies filled with 2mCi of  $^{99m}\text{Tc}$ . The image is the result of the sum of four different acquisitions of 5 minutes each**

and earlier diagnosis of specific targeted cancers and improving the probability of implementing successful therapies, monitoring changes in cellular uptake during the follow-up of the disease. A smaller camera was also produced, composed of 5 arrays of 5 SDDs each with 5x5cm<sup>2</sup> FOV and it is now in use for the experimental tests and for the characterization of the camera. The first set of measurements, conducted with the cooperation of Ospedali Riuniti di Bergamo, allows to understand the main working principles of the system and to define some important guide lines for the development of the final prototype with 10x10 cm<sup>2</sup> FOV. At the moment, the events reconstruction with the Hicam camera is made through a centroid algorithm. Some preliminary measurements

have been carried out to evaluate the response over the whole active area and to test the spatial resolution achievable. During the measurements the detector was kept at a temperature of -10°C. A lead phantom was produced with a constellation of drilled holes, diameter of 0.5mm, in a 2 mm thick lead plate, with 2 mm pitch. The acquired image is shown in Fig. 2. The measured spatial resolution, including the contribution of the grid is of 1.8mm with an average value respect two directions, according to expected performances of the system.

The system performances were also evaluated using thyroid phantoms with inserted radioactive volumes of different concentration and dimensions, simulating a 30-40 g thyroid with hot and cold nodules, Fig. 3.

The combination of different imaging processes will enable the possibility to improve medical diagnostic and during the last years efforts were made to obtain a simultaneous multimodal acquisition. Due to the intrinsic insensitivity of the SDDs to magnetic fields, the HICAM camera has potentialities to be used also in combination with MRI. Thus, this category of gamma camera opens new and important possibilities for the research and for future projects.

## MODELING AND SIMULATION OF SYSTEM IN PACKAGE

Alexey Petrushin

One of the most recent trends in semiconductor industry is related to the integration of a bunch of chips exhibiting different functionalities into a single package. Such systems are called Systems in Package (SiP). The dice can be placed side by side or stacked vertically. The presence of a certain number of dice inside a single package allows higher chip density on the PCB and better performance due to the reduction of connections, as well as a cost cutback. In addition, SiP provides integration flexibility; fast time-to-market and permits a combination of different semiconductor technologies. The advantages offered by SiP address market demand for multifunction high density devices. SiP solutions are used in numerous applications for example: mobile phones, digital cameras, GPS, PDA and so on. In order to fully exploit the advantages that SiP provide, careful electrical and thermo-mechanical design are found to be vital. Furthermore, in order to increase the functionality and to reduce the design cycle time effective design solutions are required. The use of fast and reliable electrical and thermal models is in fact essential in SiP design in order to permit the increase of the engineering efficiency and to reduce costs. One of the main challenges of SiP is signal integrity (SI) of the tracks connecting different dice within the package. Of course, signal integrity issues such as timing, noise and electromagnetic interference become more significant with

increasing operation frequency and power supply voltage reduction. In order to perform accurate SI analyses, one has to envision models of the dice I/O which are precise and sufficiently simple for fast simulation tasks. In the last decade, high level behavioral modeling of I/O interfaces has become a standard, most specifically, the Input Output Buffer Information Specification (IBIS) standard. The development of more advanced behavioral buffer models is required, due to some limitations of common transistor-level (TL) SPICE simulations. The increase of circuitry complexity leads to more complex TL models which become inconvenient to use and complicated to extract from IC design. Another limitation of TL models is a long simulation time. This limitation becomes even more significant given that time-domain transient analyses are the most common simulations for signal integrity assessment and are the most expensive in the terms of computer time. Finally, TL models disclose intellectual property information and should be encrypted. This makes these models even more complex and complicated to use. The IBIS models consist of static (Current vs. Voltage) and dynamic (Voltage vs. Time) data arranged in tables in text format. The complexity of IBIS model does not depend on the complexity of circuitry of buffer and simulation time is therefore smaller than that required for a full TL simulation. Moreover, IBIS models do not reveal intellectual property and it is not necessary to encrypt

them. Unfortunately, in some applications IBIS provides unrealistic or incorrect simulation results. With switching speed increasing and signal level and fast changing supply current, the power supply can produce a significant amount of power/ground noise called simultaneous-switching noise (SSN). SSN noise provokes such effects as signal overshoot/undershoot, delay, skew or may ever cause false switching. Even though SSN has a significant impact on the performance of high-speed systems, the IBIS standard does not model this effect. In effect, some way of SSN modeling in IBIS was recently presented by IBIS Open Forum community. This limitation is due to the very basic choice of IBIS model to extract data assuming that the power supply is ideal, thus when the power drop or ground bounce occurs, the model still refers to unchanged supply voltages. An incorrect SSN modeling is mainly due to lack of information about pre-buffer current and gate modulation effect. The pre-buffer current is the current that flows in the logic circuit that comes before the final buffer stage and is connected to the same supply rails. This current provokes the rail voltage collapse, which affects the noise performance. Gate-modulation effect is due to the consequent change of the gate-source voltage ( $V_{gs}$ ) of the output transistors. In fact, to take into account the SSN, the supply rails should no more be considered as ideal voltage sources with zero Thevenin equivalent

resistance and consequently the gate-source voltage is not more constant. Since the IBIS tables are extracted supposing a fixed gate-to-source voltage, Vgs modulation is neglected.

In addition, the IBIS specification does not address over-clocking issues. It is supposed that the IBIS model is used in the application where the clock frequency never exceeds a transition time from one logic state to another. Therefore, when a period of the input signal is less than time windows of V-t curves, IBIS may produce highly imprecise results. Another necessity for precise I/O buffer simulation is an accurate die capacitance modeling. *Die capacitance* is the capacitance seen looking from the output pad into the buffer and is included in the IBIS model as a single constant capacitance or as four constant capacitances split between the supply rails. Actually, *die capacitance* has a non-linear, frequency-dependent and state-dependent characteristic. Though such behavior of the *die capacitance* is well-known it was not introduced in IBIS specification, even through this introduces additional errors in high frequency simulations.

In addition, it is worth noting that the IBIS specification establishes only rules for creating models but does not contain information about how to use this model. Thus, the IBIS model may provide different results when running on different EDA tools. For example, some simulators are able to deal with the over-clocking issue while others fail when switching occurs into an unfinished edge providing unrealistic simulation results.

Moreover, the threshold voltage at which the buffer switches from one logical state to another depends on the simulator. Usually this value is fixed by the simulator while different buffers may actually have different. Imprecise switching

voltage definition leads to delay or advance of the transition. The results obtained by different simulators may therefore be significantly different, thus the accuracy of simulations based on IBIS models depend also on the used simulator.

Since SiP technology increases the operation speed and circuit complexity of the electronic systems, SI analysis becomes crucial in their design, the above-listed issues of I/O buffer simulation should be considered as weighty limitations. These limitations force the designers to look for alternative ways to describe the I/O buffers for simulation purposes. The main focus of this research is to develop new behavioral macro model of I/O buffers based on IBIS specification and VHDL-AMS language. The new model is supposed to provide fast, accurate and numerically stable simulation of I/O buffers and hides both the fabrication process and the circuit intellectual property. The thermal design plays also a key role in SiP development. In this regard, the challenge of SiP design is to allow the dissipation of enormous amounts of heat that can lead to hot spots as well as stress on solder joints and die attachment, with possible problems of device reliability. Such features of SiP as: presence of multiple thermal sources, small distance between the chips, small surface area for heat dissipation etc. generate new problems in thermal management. The computational approach or so-called *detailed thermal modeling* is common for thermal analysis and allows an accurate determination of the thermal field in the device. However, it has certain important drawbacks: huge computer memory demand, large computation time and requires the user to have good knowledge on fluid mechanics and heat transfer.

The limitations of such computational approach may be

overcome using a so-called *compact model* that defines the package structure as well as a few thermal resistances which are not directly related to the internal structure of the package. Though *compact models* permit to perform accurate, time and computational saving thermal analysis of the system, they have significant drawback. The main problem is the determination of thermal resistance values: in fact, they are normally obtained by fitting the results of *detailed models*, whose calculation procedure needs to be repeated whenever any package characteristic is varied. Since long computation time huge computational resources are needed to perform thermal analyses using detailed models, the *compact model* can hardly be used at the early stage of the design when the structure of package is not defined completely, and when, on the other way, fast simulation results are especially needed in order to minimize the design time. The second focus of this research is therefore to develop thermal models that could be used in the early stages of designs when it is important to have a thermal estimation method fast and easy-to-operate with acceptable precision. This part of research is devoted to analytical stationary thermal model of multi-die BGA packages and dynamic lumped thermal models with a case study in mobile phone applications.

In summary, the goal of this work was to contribute ideas and procedures in the field of macro electrical and thermo-modeling for SiP applications, that is, to improve the existing methods and to look for alternative ways for effective time-saving modeling that could provide the verification of electrical and thermal properties of SiP before manufacturing.

## DESIGN OF LARGE-SCALE DISTRIBUTED AND PEER-TO-PEER INFRASTRUCTURES WITH QUALITY OF SERVICE

Alessandro Poli

The first part of my work is devoted to the performance analysis of *peer-to-peer video streaming systems*. Peer-to-peer systems are an effective way for content providers to distribute media content to a large set of users, with limited investments for computing and networking infrastructures. These systems rely on the provisioning of network and computing resources by users that are receiving video streaming services. These systems appear to be self-scalable, since an increase in the number of users is compensated by an additional availability of resources, at no costs for content providers. However, performances of these systems can be greatly affected by the uncontrollable behavior of the users, who can disconnect without notification, consequently impacting on the quality of the video stream received by other users. Results obtained with this work can be beneficial to content providers in order to evaluate the cost/benefits tradeoff that peer-to-peer systems can offer; moreover, results can be exploited by designers of peer-to-peer video streaming systems for increasing the efficiency and the overall performance.

The second part of my work is devoted to present two additional themes, both

related to the design and the optimization of ICT (Information and Communication Technology) infrastructures. Two types of infrastructures have been considered: *distributed infrastructures*, made up by server farms running applications used by the users of an information system, and *municipal wireless access networks*, used to provide a wide range of services, including the internet access, to the citizens of large cities. The first scenario refers to the design of distributed infrastructures using the new Application Oriented Networking technologies, in order to jointly allocate computing and network resources; this approach is innovative, since current literature faces the two problems separately. The adopted optimization methodology minimizes costs, given a predefined performance level. The second research scenario is the optimization of municipal wireless networks, given the conformation of the ground, buildings' positions, the list of physical supports able to host access points, and the positions of interconnection points towards the backbone network. The methodology is able to identify the minimum cost solution that satisfies end-to-end performance constraints.

These two themes share with the peer-to-peer video streaming analysis, the property of referring to systems whose optimization, by means of the algorithms commonly used in the literature, is not feasible. The problem stands in the lack of scalability of the tools and the algorithms used by the academic community – but also in the industry – when facing with large scale infrastructures, such as the ones considered in this thesis. The scalability issue is mainly given by implementation problems, and also by the algorithmic approach; the search for a strictly optimal solution can be put in place only if the size of the problem is very limited. For example, in the field of municipal wireless networks, current best algorithms, aiming at finding optimal solutions, are able to cope with a maximum of 10-30 nodes, while interesting real case scenarios must take into account hundreds of thousand candidate node sites. A gap of such extent between current algorithms and the real size of the problems, from our point of view, is substantial, and needs to be bridged.

# AUDIO SIGNAL UNDERSTANDING: LOCALIZATION, AUTHENTICATION AND FEATURE-BASED ANALYSIS

**Giorgio Prandi**

There exists a wide variety of applications where sound classification and recognition play a major role. All these applications have a great deal in common, as they are all based on feature analysis. However, the variety of the audio signals that can be encountered in the many possible applications is very rich, and this has a significant impact on the structure of the analysis algorithms, particularly with reference to preprocessing. The thesis addresses the problem of audio signal analysis with reference to a specific Audio Signal Understanding (ASU) system, whose structure is designed to accommodate a wide range of applications of interest. This structure, in fact, includes a powerful preprocessing section based on space-time processing, which makes the system suitable for acquiring signals in uncontrolled conditions. This section is envisioned with the purpose of improving the acquisition quality of the signals to be analyzed and making the acquisition as independent as possible of the surrounding environment. The stages that follow can therefore focus on the signal source only, and can afford more sophisticated feature analysis. In fact, the reference ASU system includes tools for validating and analyzing audio streams at various levels of abstraction and complexity. In particular, the thesis focuses on three specific problems related to the reference ASU system: the former concerns the problem

of improving the quality of the acquired signal using various configurations of synchronized microphone clusters and distributed sensor networks, with particular reference to acoustic source localization problem. The second concerns the authentication of a sound stream. Through this technique, we make sure that the content of the analyzed signal has not been modified, whether intentionally or unintentionally. The third problem that we approach concerns the extraction of information on an audio stream based on feature analysis. In the simplest case, we focus on the classification of simple audio events, but we increase the complexity of the problem to the case of finding high-level features that describe the temporal evolution of the genre of a music stream. In the following sections we introduce and explain briefly the algorithms and techniques proposed in our work.

## Acquisition and preprocessing

We consider the problem of signal acquisition and preprocessing, with a particular focus on distributed acoustic source localization approaches: knowing the position of the sound source, in fact, is important for tuning spatial filtering techniques such as beamforming, while distributed solutions can be considered when the use of compact microphone arrays is not feasible. This is why, in our work we studied techniques that enable distributed localization by fusing microphone arrays measurements

(by addressing the problem of localizing an acoustic source by optimally fusing the observations provided by distributed microphone arrays) and by efficiently exploiting a distributed network of microphones; with respect to the first technique, we consider a two-step process: first, each array provides an estimate of the source position by measuring the TDOAs between each pair of microphones of the array. Then, these estimates are optimally fused taking into account the geometry of the arrays, in order to provide the final estimate of the source location. For the latter case the acoustic source localization is performed by taking into account the trade-off between the localization performance and the expense of resources: in fact, a minimization of the localization error would require to use as many sensors as possible; at the same time, as the number of microphones increases, the cost of the network inevitably tends to grow, while in practical applications only a limited amount of resources is available. Therefore, at each time instant only a subset of the sensors should be enabled in order to meet the cost constraints. We propose a heuristic method for the optimal selection of this subset of microphones, using as distortion metrics the Cramer-Rao Lower Bound and as cost function the total distance between the selected sensors.

## Authentication

With the increasing diffusion of

digital content of the past few years, the possibility of tampering with multimedia content has now become quite a widespread practice. In addition to the ease of access to such manipulations, the problem of the diffusion of unauthorized copies of multimedia content is magnified by a widespread security vulnerability and the rampaging peer-to-peer sharing over the Internet, where digital content is typically distributed and posted. This is particularly true in the case of audio files, which represent the most common example of digitally distributed multimedia content. Some versions of the same audio piece may differ from the original because of processing, due for example to compression, resampling, or transcoding at intermediate nodes. In other cases, however, malicious attacks could take place by tampering with part of the audio stream and possibly affecting its semantic content. Often, for the sake of information integrity, not only is it useful to detect whether the audio content has been modified or not, but also to identify what type of attack has been carried out. In general, one of the reasons why it is preferred to identify how the content has been tampered with is that, given an estimate of where the signal was manipulated, one can establish whether or not the audio file is still meaningful to the final user. In the thesis we propose a low bit-rate, hash-based authentication system for tampering detection and localization, whose architecture is composed by two actors: on one hand, we have the content production entity (CP), which acquires and/or distributes the legitimate and authentic copies of the original audio content. On the other hand, there is the content authentication entity (CA), the block which performs the

authentication task related to the content released by the CP. The CP disseminates copies of the original content through possibly untrusted intermediaries, which may tamper with the authentic file manipulating its semantics; at the same time, the CA, may get its own copy of the audio file from nodes different from the starting CP. In order to protect the integrity of the multimedia content, the CP builds a small hash signature of the audio signal. To perform content authentication, the user sends a request for the hash signature to an authentication server, which is supposed to be trustworthy. By exploiting the hash, the user can estimate the distortion of the received content with respect to the original. Furthermore, if the tampering is sparse in some basis expansion, the system produces a tampering estimation which identifies the attack in the time-frequency domain. The system uses compressive sensing and distributed source coding principles to generate the hash and to estimate the tampering at the CA side.

## Low-level and high-level feature analysis

The signal description and analysis phases are strictly related to the application scenario and to the type of information that must be extracted from the signal itself and given to the user. In particular, low-level features can be used when low-level characteristics of the signal carry sufficient information for the goal at hand, and need not be rendered to the user. High-level features are needed when the analysis is based on some high-level semantic aspects of the audio stream and the descriptors are returned to the user as semantic characteristics of the signal. We chose to consider the low and high-level extrema by means of two application examples. The

first example is related to a binary classification task, where the goal is to assess whether an acoustic event belongs to a given class of events or not: in particular, we describe an audio event detection system that automatically classifies an audio event as ambient noise, scream or gunshot, using low-level features and machine-learning techniques. It uses two parallel Gaussian Mixture Model classifiers for discriminating screams from noise and gunshots from noise. Each classifier is trained using different features, selected according to a hybrid filter/wrapper process. In some cases, the analysis task requires to use a higher-level semantic description to present the results to the user in the form of feature values or to perform the analysis by considering semantic aspects of the stream. In this case, the final representation of the signal can be the result of several analysis stages performed on lower level descriptions of the considered audio stream. The second example goes in this direction by illustrating how to generate high-level descriptors to perform classification and semantic visualization of the content evolution of a music stream: the system performs the visualization and classification task by means of three high-level, semantic features extracted by computing a reduction on a multidimensional low-level feature vector through the use of Gaussian Mixture Models. The visualization of the semantic characteristics of the audio stream is implemented by mapping the value of the high-level features on a triangular plot and by assigning to each feature a primary color. The genre classification part exploits a set of three-dimensional one-against-one Support Vector Machines trained on some target genres.



## NoC-BASED RECONFIGURABLE EMBEDDED SYSTEMS DESIGN

Vincenzo Rana

The seismic experiment plays a central role in the exploration for hydrocarbons in the Earth's subsurface. A typical experiment involves several sources and receivers. A seismic trace is the recording of seismic reflections generated by a source.

The dataset used in seismic processing is the collection of the seismic traces.

A very important goal of seismic processing is subsurface imaging and migration is the main imaging procedure. The image that results from such processing enables interpreters to highlight the stratigraphical traps where hydrocarbons have accumulated. Seismic imaging requires an estimate of the velocity model of the subsurface.

If an adequate velocity model is provided, pre-stack depth migration (PSDM) represents the best solution to imaging in complex structures, although it is computationally intensive. These imaging procedures must take in account anisotropy effects in order to achieve better focusing and positioning of the geological structures in the subsurface.

Still, for most of its history seismic inversion and imaging have been based on the assumption that the subsurface is isotropic, despite the general acceptance of the fact that most

geological formations possess a certain degree of anisotropy. Although P-wave velocity in anisotropic media can change significantly with propagation angle, P-waves do not split into two modes and their reflection moveout on conventional-length spreads (close to reflector depth) typically is hyperbolic.

Hence, it has been customary for processors and interpreters to artificially adjust the parameters of isotropic processing flow when working with P-wave data from anisotropic media. This approach, however, has produced distorted velocity models and proved to be inadequate in compensating for the full range of anisotropic phenomena in P-wave imaging, particularly in prestack depth migration.

This mounting evidence of the need to account for anisotropy in seismic processing prompted an increased effort in seismic anisotropic processing starting from late 1980's up to nowadays with the more advanced migration and velocity model building algorithms. While extending imaging methods to anisotropic media is largely a technical issue, practical implementation of the anisotropic processing algorithms was hampered primarily by the difficulties in parameter estimation.

Inverting for several anisotropic parameters needed to characterize even the simplest anisotropic model - transverse anisotropy, the subject of this thesis - seemed to be well beyond the reach of reflection seismology.

This work can be ideally divided into two parts. The first part mainly focuses on ray-based wave propagation modeling in TI media. Using ray tracing algorithms we are able also to implement Kirchhoff pre-stack depth migration in TI media. Depth imaging algorithms require an estimate of the anisotropy parameters that describe wave propagation in TI media. Parameter estimation is the main topic of part two. This part is devoted both to tomographic migration velocity analysis for depth imaging and to a slope based velocity analysis for vertically inhomogeneous VTI media that can provide an approximate first guess for tomographic iterations.

Inversion and imaging problems require calculation at a faster speed than the ray method generally provides because calculations must be repeated for a large number of shots and receivers. It is possible to reformulate seismic ray equations in terms of phase and group velocities. This operation

is advantageous because it allows us to use either exact or approximate relations for phase velocity which, for P-waves in TI media, are parameterized directly by Thomsen's coefficients. This implies that we no longer need any kind of computational demanding back conversion to the elastic tensor.

A boundary value problem, such as two-point ray tracing, directly computes the ray path between two points.

An algorithm based on Fermat's principle of stationary traveltime between fixed points can achieve this goal.

The traveltime of a sampled ray path is approximated using a quadrature formula. Finally, starting from a first guess trajectory, an unconstrained optimization scheme finds the ray point positions that minimize the traveltime.

In oil and gas exploration, ray tracing techniques are also routinely used for 3D Kirchhoff-based prestack migration. Kirchhoff migration methods require that traveltime, amplitudes and other relevant wavefield quantities (slowness vectors, caustic order, etc...) might be computed on a regular Cartesian grid representing the target of the imaging process. Here we propose an alternative approach

we called depth-oriented ray tracing (zRT). This method has three main implications. First, it simplifies wavefield quantities interpolation that can be realized by using a simple 2D scheme. Second, this approach intrinsically discards turning rays that typically are not employed for imaging in standard Kirchhoff processing. Third, depth ray tracing allows us to track the spread of the wavefronts at each depth level. Suitable ray insertion criteria can be applied to optimize the ray sampling and improve the image target coverage.

Reflection tomography it is often an effective tool for improving the velocity estimate, when the subsurface structure is complex. Besides the unpleasant fact of its non-linear nature, the tomographic operator has a huge null-space mainly due and a unique solution may not exist. Moreover, small errors in the data may cause prohibitively large variations in the estimates of the sought quantity. In addition to these difficulties, anisotropic tomography introduces further complications due to its intrinsic multi-parameter nature. The estimation of all the anisotropic parameters suffers from ambiguities and trade-offs between all of them. Thus,

to create geologically feasible velocity models and to speed up convergence of the tomography problem we introduce regularization operators and additional borehole constraints along already drilled well bores.

It has been proved that extracting local event slopes in prestack data is sufficient for accomplishing all common time-domain imaging tasks. Rather than being a prerequisite for seismic imaging, seismic velocities turn into data attributes that can be extracted from the input data simultaneously with imaging. We extend the concept of processing by slopes to VTI data in the  $\tau$ -p domain. The  $\tau$ -p or Radon transform is the natural domain for anisotropic parameter estimation in laterally homogeneous layered media with a horizontal symmetry plane because the horizontal slowness is preserved upon propagation through such media. We derive analytical expressions for mapping the data to zero slopes time through the estimation of local slope and curvature. The effective and interval anisotropic parameters turn into data attributes through the slopes and are directly mappable to the zero-slope traveltime.

## COMPARISON OF DIFFERENT WATER SYSTEM DESCRIPTION AND RUNOFF FORECAST TECHNIQUES FOR THE OPTIMIZATION OF RESERVOIRS MANAGEMENT

Andrea Salvetti

The design of efficient policies for multi-purpose reservoirs management can be formulated as a multi-objective decision problem, which, in turn, can be reformulated as a family of optimal control problems. The water system is described by a cyclostationary discrete-time model, possibly nonlinear, and subject to random input (of either uncertain or stochastic nature).

The stochastic optimal control problem is usually defined over an infinite horizon and both the state and the control can be constrained. Theoretically, the solution of the stochastic optimal control problem can be obtained by applying the optimality principle. However, the problem statement is usually so complex that an analytical solution of the Bellman equation cannot be obtained. This equation can thus be solved numerically through the discretization of the state, control and disturbance sets. Several methods exist for the numerical resolution of the Bellman equation for different problem formulation (such methods will be referred to, in the following, as Stochastic Dynamic Programming methods, or SDP). The limits of SDP are: first, that it provides an approximate solution; second, and most importantly, that the computing time increases

exponentially with the dimension of the state, control and disturbance (the so called *curse of dimensionality*). Many real problems are thus intractable with this approach.

The objective of the research here presented is, on one side, the development and testing of a robust runoff forecast method, which explicitly take into account the uncertainty involved in the runoff formation process at the catchment scale. A novel parameter optimization procedure (Kling-Gupta Criterion) is introduced and tested and advantages and drawbacks compared to the traditional RMSE-based optimization procedure are discussed. On the other side both an off-line and an on-line approach are adopted for solving the Control Problem of a specific water resources management case study, the Lake Ceresio, in order to overcome the well known curse of dimensionality of the SDP.

The on-line approach, in fact, allows for reducing the problem complexity, thus making it tractable with SDP, when the high dimensionality stems from components of the water system that are not influenced by the control action (e.g. the natural catchments that generate the reservoirs inflow). Through on-line resolution, in fact, the state

of such components can be neglected and their output be considered as a random input of the 'reduced system'.

However the approach cannot be applied when the high dimensionality is due to components whose dynamics depends on the control (e.g. reservoirs networks or when also the downstream water users must be described by dynamical models).

As for the on-line approach, it foresees that the policy be designed at the moment when the control action is taken. For this, at each time instant, one solves a stochastic optimal control problem over a finite and receding horizon.

Since the problem is solved on-line, the description of the random disturbance that act on the system (i.e. their probability distribution or membership set) can be updated in real-time, based on available observations. In other words, part of the information about the system is considered as an exogenous information instead of being included in the state vector, thus reducing its dimension. In the case of reservoir management, the exogenous information is typically constituted by measures of meteorological variables, which are used to feed a dynamic predictor of the reservoir inflow. At each

time instant, a finite-horizon, stochastic optimal control problem is formulated, based on the statistics provided by the dynamic predictor. Since the state of the system is reduced, the on-line problem can be solved with stochastic dynamic programming. The approach is known in the literature as Partial Open Loop Feedback Control (POLFC). Different simulation experiments of the system subject to the POLFC scheme were performed, to analyze the impact of different choices of the inflow predictor (heteroscedastic or homoscedastic), and of the receding horizon length. The value of exogenous information (in the present case, inflow estimates for the previous days and precipitation measures) for the reservoir management was assessed by comparison with the performances of the system subject to the a priori policy, i.e. the policy that solves the off-line stochastic optimal control problem where the inflow process is described by an a priori, cyclostationary probability distribution. In order to solve the POLFC scheme, first an empirical model for the inflow prediction, based on precipitation measures, was identified. The proposed model is nonlinear and heteroscedastic: the prediction error variance, in fact, is not assumed as a

constant parameter but it is the output of a dynamical system. The research focused on the extension of a log-arimax heteroscedastic model to shorter temporal time step (6 hours) and on the testing and application of a new optimization procedure (Kling-Gupta Criterion), as an alternative to the well established Root Mean Squared Error procedure.

The thesis is organized as follows: In the first chapter, the management problem of multi-purpose reservoirs is formulated in its general form. Main issues and critical aspects of the problem are presented, together with a general introduction and classification of the principle solution approaches that have been proposed in the literature. In chapter 2 the framework of the present study is presented and the information concerning the case study (Lake Ceresio) is introduced. Chapters 3 and 4 deal with the analysis of auxiliary data and the reconstruction of the historical behaviour of the regulator by means of Lazy Learning techniques. In chapter 5 and 6 the indicators and the water system of the design problem are defined. In Chapter 7 the classical off-line approach is introduced and solved for the Lake Ceresio case study. Chapter 8 introduces the POLFC scheme in its general

form and its application to the management problem of Ceresio Lake. Chapter 9 is devoted to the description of the heteroscedastic model that was proposed for the prediction of the Ceresio inflow. Finally, chapter 10 presents some simulation results obtained by applying the POLFC scheme to the Ceresio lake and using the heteroscedastic model introduced in the previous chapter.

## MULTI-PROVIDER SERVICE AND TRANSPORT ARCHITECTURES

Stefano Secci

The dissertation presents various technical solutions to improve the level of collaboration among providers in support of inter-provider network services. The scientific contribution embraces different networking research facets, from IP routing to G-MPLS provisioning and network design optimization, applying concepts from graph theory, game theory and operations research.

By an in-depth analysis of recent Internet routing traces, we show that the current inter-domain (connection-less) routing suffers from a lack of coordination that produces inefficiencies and frequent route deviations.

With respect to this issue, relying on concepts of non-cooperative game theory, we propose coordination strategies to improve the current BGP routing across peering settlements, while preserving the providers' independence and respective interests. We show that their implementation can avoid congestion on peering links, reduce significantly the routing cost and successfully control the route deviations.

The mathematical model can be extended to support a new form of peering agreement extended to multiple providers, but its adoption may appear too weak with respect to alternative solutions able to guarantee end-to-end cross-provider Quality of

Service (QoS).

The support of strict end-to-end QoS constraints for added-value services imposes, indeed, a higher level of collaboration on the multi-provider agreement.

It is required to reserve resources for own services in other providers' networks. These requirements bring towards a new interconnection model, the «provider alliance», as a cooperative framework that providers shall deploy to allow dynamic connection-oriented service routing and provisioning. We define the functional architecture of a service plane managing service-related data within the provider alliance, together with the instantiation and activation of multi-provider tunnel and circuit services.

We highlight the required protocol extensions for the distributed (router-level) path computation and the dynamic resource reservation, which have been implemented and validated in a testbed.

We define, moreover, specific AS-level routing algorithms that scale with the proposed model, supporting pre-computation and directional transit metrics. Finally, we show how providers shall cooperate also to statically reserve link resources, in an optimal and distributed fashion, modelling the economical incentives and the strategic position of each provider

in such a cooperation with the application of concepts from cooperative game theory (precisely, the Shapley Value concept).

In the second part of the dissertation, we tackle more physical issues related to the provisioning of tunnels and circuits across Internet eXchange Point (IXP) infrastructures.

We present a novel very-high-capacity optical transport architecture, called the Petaweb, as a possible next generation IXP solution and, more generally, as a possible very-high-capacity transport architecture.

It consists in a regular direct interconnection scheme of electronic access nodes via optical switches disconnected from each other. This structure can allow a simple inter-provider G-MPLS signalling, can drastically simplify traffic engineering operations, and can facilitate modular upgrades of network elements, at the expense of potentially higher installation costs.

We formulate the design dimensioning problem of the Petaweb composite-star topology, which is NP-Hard, and propose a scalable and efficient heuristic approach. Moreover, we propose a quasi-regular structure for

the same transport architecture, less costly and slightly more complex (requiring wavelength conversion), for which we also formulate the design problem and propose an efficient heuristic.

We argue by simulations that the physical dimensioning of classical multi-hop optical networks under additive path metric minimisation (such as the delay) would produce a solution that tends toward a quasi-regular Petaweb structure. To conclude, we analyze how practically a network planner decision-maker shall trade-off -- when discriminating among many Petaweb solution alternatives -- the various performance criteria with the level of reliability, survivability and availability.%, using interactive decision maps.

## COOPERATIVE RETRANSMISSION PROTOCOLS IN FADING CHANNELS: Issues, Solutions and Applications

Igor Stanojev

Future wireless systems are expected to extensively rely on cooperation between terminals, mimicking MIMO scenarios when terminal dimensions limit implementation of multiple antenna technology. On this line, cooperative retransmission protocols are considered as particularly promising technology due to their opportunistic and flexible exploitation of both spatial and time diversity. In this dissertation, some of the major issues that hinder the practical implementation of this technology are identified and pertaining solutions are proposed and analyzed. Potentials of cooperative and cooperative retransmission protocols for a practical implementation of dynamic spectrum access paradigm are also recognized and investigated. Detailed contributions follow. While conventionally regarded as energy efficient communications paradigms, both cooperative and retransmission concepts increase circuitry energy and may lead to energy overconsumption as in, e.g., sensor networks. In this context, advantages of cooperative retransmission protocols are re-examined in this dissertation and their limitation for short transmission ranges observed. An optimization effort

is provided for extending an energy-efficient applicability of these protocols. Underlying assumption of altruistic relaying has always been a major stumbling block for implementation of cooperative technologies. In this dissertation, provision is made to alleviate this assumption and opportunistic mechanisms are designed that incentivize relaying via a spectrum leasing approach. Mechanisms are provided for both cooperative and cooperative retransmission protocols, obtaining a meaningful upsurge of spectral efficiency for all involved nodes (source-destination link and the relays). It is further recognized in this dissertation that the proposed relayingincentivizing schemes have an additional and certainly not less important application, that is in dynamic spectrum access for property-rights cognitiveradio implementation. Provided solutions avoid commons-model cognitiveradio strict sensing requirements and regulatory and taxonomy issues of a property-rights model.

## CONFIGURABLE DIGITAL ELECTRONIC ARCHITECTURE FOR THE SOLUTION OF COMPLEX MATHEMATICAL MODELS

Andrea Suardi

In the analysis of dynamics of many real complex systems, descriptive mathematical models permit to simulate their behavior in different specific operating conditions. This is the case of physics, engineering, finance, medicine and so on. Quite all applications involve complex mathematical models that cannot be handled by means of closed form calculations but just through approximated numerical resolution techniques. For instance this is the case of models of very fine grained systems, such as human body organs, which are represented by very sparse matrix of extremely high dimensionality (several millions of elements). In order to perform an electronic processing of these models, the necessary hardware structures for an efficient implementation of the required algorithms for data handling are based on configurable devices, spatial computing (FPGA) and temporal computing (DSP) architectures. The deep architectural and functional diversity of the two solutions involves specific strategies of algorithm implementation and code writing for performance maximization from each one of them. The presented research activity is devoted to design a new hardware and software FPGA-based reconfigurable computing

system that provides a significant increase of performance for a wide set of High Performance Computing (HPC) applications. In particular, a specific application set of problems in the field of behavior of physical systems has been focused. Although these phenomena can be represented by mathematical models, they require numerical resolution that is extremely computing intensive. This is due to the high amount of data to manage and the high number of computations to carry out. Specifically, the mathematical calculations involved are the solutions of sparse and large linear systems of equations that cannot be achieved with direct methods, e.g. the Cholesky decomposition. In this case, an iterative method is necessary. Among available iterative algorithms, the Conjugate Gradient (CG) method is one of the most commonly used. Fundamental advantages of the CG method are the rapidity of convergence and an intrinsic low level algorithm parallelization due to its plain structure. A new high efficient fully FPGA based implementation of CG iterative solver algorithm has been proposed. It is able to manage double precision floating point data, great amount of data using external memory, data exchange with

a PC host unit and suitable for any problem size. Particularly care has been taken to both CG algorithm implementation and to ancillary resources design. Design optimization of CG algorithm implementation has to face with several preliminary aspects. The implementation of some basic mathematical functions of Basic Linear Algebra Subprograms (BLAS) such as Vector-Vector Multiply (VVM) and Sparse Matrix-Vector Multiply (SMVM) are most used. FPGA floating-point implementation of BLAS operations poses lot of challenges. Limitations in the available resources, such as the number of slices, the size of on-chip memory and the number of I/O pins, impose multiple constraints on architectural design. These constraints, as well as the inherent characteristics of BLAS operations, result in various design tradeoffs that has been taken care and a new one has been proposed. On the other hand ancillary resources allow data exchange with host system and with storing elements such as local memories. Therefore a general purpose data exchange framework has been developed in order to be suitable for hosting several algorithms for the resolution of

complex mathematical models, such as the proposed CG, the Preconditioned CG, the Jacobi method, etc...

The adopted design technique, optimizing the easiest computing operation and looking also at global system troubles, allows to assure high computing power to everyone at low cost.

A general purpose FPGA-based board and PC driver in Linux environment are designed. Key features of this mixed software-hardware system is software compatibility with the most used mathematical algorithms for the resolution of complex mathematical models, hardware compliant with a standard high speed bus interface, such as PCI Express, and ready for Green-IT hardware requirements.

From a hardware design point of view the board schematic is drawn, whole board is simulated in order to fit the high speed requirements of off chip communication networks and consequently the layout rules are defined.

On the other hand the driver design focuses both on high speed low level kernel mode PCI-Express communication management and on easy to use high level user mode interface.

The experimental setup environment and system performance measurement are settled. The experimental setup

environment is based on a custom system simulation framework that emulates the design board. However it is not used the designed board for test purpose because it has not yet been available.

In order to test accurately the proposed architecture, selections of test matrices from different sources were used including the Matrix Market collection and University of Florida Sparse Matrix Test Suite. It is showed that the proposed FPGA implementation outperforms state-of-art microprocessors while running at a 15x slower clock rate.

Even if the designed system has been validated with a specific mathematic algorithm, its modular design structure and its system features allow a significant speed-up in a wide variety of high computing applications.

Both based with floating point operations or non-floating point one. The encouraging outputs of this research activity have driven us to investigate the commercialization of the developed system.

This has also been done drawing up a business plan that will be reference guide for future development of the proposed system.

## MULTI-IMAGE INSAR ANALYSIS OVER THE THREE GORGES REGION: TECHNIQUES AND APPLICATIONS

**Teng Wang**

Three Gorges Project (TGP), the largest hydroelectric project in the world, is one of the most significant constructions in China. Since the TGP greatly changed the natural terrain of the upriver gorges, regular surveys over this region with the remotely sensed images are highly needed. Multi-image Synthetic Aperture Radar Interferometry (InSAR) analyses have proven to be effectively capable for obtaining precise measures of elevation and displacement of the detected targets. In this work, more than one hundred InSAR images have been processed to measure and analyze the topography, land use, and deformation over the Three Gorges Region.

By exploiting single interferograms with the facilitations from external topography data, a reliable Digital Elevation Model (DEM) from a tandem interferogram with a short normal baseline has been generalized. Moreover, by the proposed coherence decomposition analysis, an approximate temporal coherence map can be extracted with the detected point-like targets.

On the other hand, with different time series InSAR analysis methods, i.e. Permanent Scatterers (PS), Stanford Method for Persistent Scatterers (StaMPS) and Quasi-PS (QPS) techniques, we are able to

monitor the slow landslides in Badong and the stability of the Dam. In the Badong test site, we found two subsidence areas within the new built Badong town by the StaMPS technique. Then we presented and applied the QPS technique and successfully obtained much higher spatial density measurements. Finally, we carried out the QPS and PS analysis over the Three Gorges Dam site. From the QPS results, we found that there exist no visible temporal subsidence of the Dam from 2003 to 2008. By analyzing the measured deformation trends, we presumed that the dam declined slightly on account of the upriver water pressure over the riverbed crust. Then from the PS results, we found that the time series deformation of the dam strongly related to different water levels. A seasonal deformation pattern can be observed as well.