Albert Benveniste

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Contents

1 Curriculum Vitæ, summary

period/date		**degree**, *award,* grade
1949–...	:	in life
1971	:	**Ingénieur de l'Ecole des Mines de Paris**
1971–1974	:	Doctorant at Centre d'Automatique de l'Ecole des Mines de Paris, Fontainebleau
1972	:	**Master thesis, Paris VI, mathematics, probability, Advisor Paul-André Meyer**
1974–1976	:	researcher at INRIA Rocquencourt
1975	:	**Thèse d'Etat in mathématics, probability, Paris VI, Advisor Paul-André Meyer**
1976–1979	:	Associate Professor, Université de Rennes I, mathématics
1979–1985	:	Consulting, CNET-Lannion B
1979–...	:	Directeur de Recherche at INRIA Rennes
1980	:	*IEEE Trans. on Automatic Control Best Transaction Paper Award* (with M. Goursat et G. Ruget)
1990	:	*Silver Medal CNRS*
1991	:	*IEEE Fellow*
1995	:	*Prix Montpetit de l'Académie des Sciences*

period/date		**international activities**
1986–1989	:	Vice-Chairman of the IFAC committee on Theory
1987–1990	:	Associate Editor for the IEEE Transactions on Automatic Control
1987–...	:	Associate Editor for the Int. J. of Adaptive Control and Signal Processing
1990–1995	:	Associate Editor at Large for the IEEE Transactions on Automatic Control
1990–...	:	Associate Editor for the Int. J. of Discrete Event Dynamical Systems
1990–1993	:	Chairman of the IFAC committee on Theory, special project on "Facing the challenge of computer science in the industrial applications of control"
1992–...	:	Associate Editor for the Proceedings of the IEEE

period/date		**national activities**
1980–1985	:	responsible for CNRS network "Outils et Modèles Mathématiques pour l'Automatique et l'Analyse des Systèmes"
1985–1987	:	board member for Committee "Automatisation des Processus Continus" (ministère de l'Industrie)
1985–1990	:	founder and head of regional research network CBI (Collaboration Bretagne Image)
1987–1996	:	founder and head of CNRS national research network C2A
1998-...	:	head of "software" chapter for Réseau National de la Recherche en Télécommunications (RNRT) funding programme

period/date		**duties at Inria**
1978–1994	:	head of group "Signal processing and Control"
1982–1994	:	member of Scientific board of Inria
1991-1994	:	head of Scientific board of Inria-Rennes (Irisa)
1994–1996	:	member of Scientific Direction of Inria
1996–...	:	attached to the Director of Inria, Prospective
1996–1998	:	in charge of new format for Inria Activity Report

References

general *Alain Bensoussan,* President CNES. *Gabriel Ruget,* ENS Cachan and Thomson-CSF.

control *Lennart Ljung,* Linköping University, Sweden, world leader in "system identification". *Shankar Sastry,* University of California at Berkeley. *Alan S. Willsky,* M.I.T.

computer science *Amir Pnueli,* Weizmann Institute, Rehovot, Israel, Turing Award. *Thierry Gueguen,* President company TNI, Brest, France.

mechanics *Hermann van der Auweraer,* head of R&D, company LMS, Leuven, Belgium.

2 Research

2.1 Mathematics

During 1970-1978, I worked in mathematics on probability theory, in cooperation with Jean Jacod, and having Paul-André Meyer as an advisor. I have contributed to the stochastic theory of Markov processes, and continuous time dynamical systems ("flows") in ergodic theory. With Jean jacod, I have extended to general Markov processes the Levy-Kintchin formula for processes with independent increments. Then I have proved embedding and isomorphism theorems for continuous time dynamical systems, and have given the complete structure of additive functionals of flows.

2.2 Signal processing and control

In 1976, as suggested by Alain Bensoussan, I started working on *adaptive systems,* i.e., dynamical systems able to adjust automatically to changes in their environment via learning. My contribution to this topic is summarized in the book [11] written jointly with Michel Métivier and Pierre Priouret. I have investigated several applications of this general technique: data transmission systems, phaselock loops, equalizers and mainly *blind equalizers*, see [19], a seminal paper, *IEEE-AC 1980 Best Transaction Paper Award.* Blind equalization consists in retrieving both the channel and the message sent, by only observing the output of the channel. Blind equalization is now a key technology in military, mobile, or generally high performance communication systems.

> **Problem statement and results.** The general statistical framework for *adaptive systems* is the following. We are given a sequence of vector measurements $(Y_n)_{n>0}$ collected from a system, and we assume Y_n obeys some dynamical system model the structure of which is known, but some vector parameter θ is unknown. Taking into account randomness or uncertainties, we thus assume $(Y_n)_{n>0}$ has distribution $\mathbf{P}_{\theta_\star}$, where $\theta_\star$ denotes the "true", unknown value for θ. The aim is to learn $\theta_\star$ from observing Y_n on-line; this is performed by designing a *stochastic approximation,* i.e. and iterative algorithm of the form $\theta_n = \theta_{n-1} + \gamma_n H(\theta_{n-1}, Y_n)$, where γ_n is a small gain sequence and . $H(\theta_{n-1}, Y_n)$ is the correcting term. A "first order approximant" of this algorithm, for γ_n small, is then the ODE $\dot{\theta} = h(\theta)$, where $h(\theta) = \mathbf{E}_{\theta_\star} H(\theta, Y_n)$, and we must design the correcting term $H()$ such that this ODE converges to the true value $\theta_\star$ for the parameter θ. This requires (among other) that $\mathbf{E}_{\theta_\star} H(\theta_\star, Y_n) = 0$.

My major contribution in this area has been the following. I have studied the case in which the unknown "true" parameter $\theta_\star$ is in fact slowly time-varying (the case of adaptation to a changing environment), I studied the behaviour of the above algorithm, and I gave solutions to the problem of best tracking of the system nonstationarities [11, 22, 33].

As for blind equalization [19, 25], it consists of the following mathematical problem. Consider a dynamical system $y_n = \sum_{k=0}^{\infty} h_k a_{n=k}$ where a_n is the unknown and unobserved input message, h_k is the unknown channel, and y_n is the observed output. How to retrieve at the same time both the channel and the input message? As this problem has infinitely many (irrelevant) solutions from the linear filtering point of view, subtle techniques must be developed that are heterodox in statistics. In [19] we have provided the first ever proven solution for this problem.

In 1980 I started, jointly with Michèle Basseville, the topic of failure detection and diagnostics in dynamical systems, an important topic for the maintenance of industrial and embedded systems. In 1987, we established a generic approach based on the so-called "statistical local approach" originating from LeCam in statistics. Important references are [14] and [30]. This is a topic of international excellence for our group.

Problem statement and results. Consider again a sequence of vector measurements $(Y_n)_{n>0}$ collected from a system, and we assume Y_n obeys some dynamical system model the structure of which is known, but some vector parameter θ is unknown. Now we wish to decide whether this parameter θ changed from some given nominal value (detection), and, in case of positive answer, to identify the cause of the change (diagnostics). We thus assume a nominal value $\theta_\star$ for the parameter, and we wish to check the current observations $(Y_n)_{n>0}$ against nominal distribution $\mathbf{P}_{\theta_\star}$.

We avoid resourcing to identification and provide a much cheaper solution by directly comparing $(Y_n)_{n>0}$ against $\mathbf{P}_{\theta_\star}$. To this end, consider again $H(\theta_\star, Y_n)$, and check whether this statistics has zero mean, taking into account noise and uncertainties. This is achieved by means of a Central Limit Theorem for $1/\sqrt{n}\sum_{k=1}^{n} H(\theta_\star, Y_k)$, which asymptotically behaves as a Gaussian random vector with known covariance matrix (reflecting noise and uncertainties) and a mean equal to zero if no change occurred, and different from zero otherwise. This brings the problem back to testing for the mean of a Gaussian random vector, an easy problem. Main relevant references are [11, 27, 29, 30, 44, 53, 55, 56].

From 1987 to 1994, in cooperation with Alan S. Willsky, MIT, inspired by the emerging theory of wavelets, I developed a new theory of *multiresolution signal processing* by considering stochastic processes indexed by dyadic trees (instead of the more usual **Z** integer index domain) [39]. We used this for our application with Schlumberger (cf. section 5.1).

Problem statement and results. We consider an infinite dyadic tree $\mathcal{T}$, and a stochastic process $(y_t)_{t\in\mathcal{T}}$ indexed by the vertices of the tree. Shift operators are defined on $\mathcal{T}$, from which a notion of a stationary process (i.e., with shift-invariant distribution) can be defined. Levels of $\mathcal{T}$ (formally speaking: "horocycles") model levels of resolution, and we thus have a multi-resolution model for a signal. Stationarity results in a fractal-like behaviour. We have developed a rich theory for such processes, with some applications to the analysis of data at several different resolutions. Major relevant references are [37, 38, 46].

In 1992, with Q. Zhang, A. Iouditski and B. Delyon, I started working on black-box identification of nonlinear systems, using wavelets and other nonparametric methods [50, 51]. An important cooperation with Lennart Ljung, Linköping University in Sweden, resulted in the current preparation of the *Nonlinear Modelling Toolbox* for Matlab, which is to be commercialized by Mathworks.

Problem statement and results. The basic mathematical problem is the following. We have an input/output system $y_n = f(x_n) + v_n$, where y, x are observed, v is a noise, and f is an unknown nonlinear function for estimation. As f is not characterized by finitely many parameters, this is called a non-parametric estimation problem. "Simple estimators" (in small dimension function spaces) for f will have a smooth look, but will also smooth out details of interest in f, while complex estimators will be sensitive to noise. The bias/noise tradeoff is thus central. The key difficulty is to provide good estimators for functions that are not uniformly smooth (e.g., mostly smooth, but with sparse singularities). Wavelet networks, wavelet based estimators, and more general classes are efficient at that [36, 50, 51].

2.3 Vibration mechanics

A major application area for our techniques is that of *structure analysis* in vibration mechanics. The aim is to identify and monitor the vibration characteristics (modes and/or finite element parameters) of structures *under operational conditions,* not laboratory experiments. Motivated by the break-down of the offshore platform Alexander Kiland in north sea in 1980 (killing over 50 people), we started this study in 1980 (CNEXO contract on offshore structures) by investigating the problem of structural identification, and, in 1985, we got our first results on damage detection under operational conditions. The main difficulty is that one has to separate the effect of excitation (unknown and not measured, and irrelevant) from that of the structure itself (the quantity of interest). Until the mid 90's, this subject was considered as highly prospective in the mechanical engineering community ; on the other hand, while we had important results in the late 80's [58], we were not able to communicate them in the mechanical engineering community, due to different cultural background. These remained mostly unknown until we met Hermann van der Auweraer, in 1994, from LMS International, Leuven, Belgium, a world leading company in structural measurements and analysis. We now have developed a class of so-called "subspace tests" for early damage detection, and we are still working very hard at improving this, in cooperation with LMS.

Problem statement and results. We start with a mass-and-spring approximation of the vibrating structure: $M\ddot{\mathbf{Z}}(t)+C\dot{\mathbf{Z}}(t)+K\mathbf{Z}(t) = \nu(t)$, where $\mathbf{Z}$ is the displacement, M, C, K are the mass, damping, and stiffness matrices, and ν is the ambient, unobserved excitation. We observe a few degrees of freedom: $Y(t) = L\mathbf{Z}(t)$. The problem is 1/ to identify the *modes* from the observations (modes are the eigenvalues and observed part of the eigenvectors of the state differential equation), 2/ to detect if there is some deviation from a given nominal model (given as a collection of nominal modes), and 3/ in case of a deviation, to analyse the cause of the change (change in mass/stiffnes, localization of the damaged elements). The difficulty is: a/ the input excitation is unknown and not measured, b/ it is frequently *nonstationary,* thus making problems 2 and 3 particularly hard. Our solution consists in monitoring the range space of the observability matrix of the considered dynamical system, this is called a *subspace algorithm.* To this end, we first have designed a subspace test algorithm, using the general approach indicated above [29, 32, 56, 57, 58, 63] (in fact, things went in the converse way: we first found a simple version of subspace test, then we generalized this, then we were able to re-derive a larger class of subspace tests). Then we have proved [26, 28] the robustness of subspace methods for identification and testing against nonstationary excitation, a difficult result.

2.4 Computer science

In 1981, motivated by the difficulty in developing hardware for TV and speech coding, I started cooperating with Paul Le Guernic, a computer scientist at Irisa, on real-time systems development. We both invented the SIGNAL language in 1985, and met at that time Gérard Berry (inventor of ESTEREL) and Paul Caspi and Nicolas Halbwachs (inventors of LUSTRE). This started the community of *synchronous languages,* a concept promoted by Berry. Our early work on SIGNAL is reported in [65, 68, 69, 71]. The idea of SIGNAL was mathematically very simple: for a reactive system, a specification should be a discrete time, dynamical system, in which *different* time indices can be used and related together, we called them *clocks.* In the family of synchronous languages, this point of view was unique to SIGNAL.

> **Problem statement and results.** According to SIGNAL, a specification is a transition system of the form $R(X_{-}, X)$ in which X_{-}, X are the past and current state and R is a relation; typically, states are sensed via a finite set of variables taking values in some associated domain. Runs (or "trajectories") for this specification are obtained by iterating relation R infinitely many times, from some initial condition. Composing specifications is simply obtained by considering the conjunction of such transition relations, very much like systems of equations in math. This is not at all new. The new and interesting idea is to add to every domain of data, a distinguished symbol $\perp$ to refer to *absence.* In this way we make presence/absence explicit and become thus able to reason about synchronisation and formally manipulate clocks. Whence the so-called "clock-calculus" of SIGNAL, which synthesizes the global synchronisation for a program from partial, local synchronisation given in the specification. Mathematically speaking, this is very much like handling infinite sequences with many different time indices (the "clocks", they can be several thousands) in an assisted way. Thus we can refer to a signal or to a subsystem only when it is active, and we need not to mention it otherwise. Specifying a real-time and reactive system in SIGNAL thus becomes affordable, even if very complex synchronisation mechanisms are involved.

This point of view revealed extremely fruitful when dealing with systems built from components, as time references should be local to components and not universal. Also it proved instrumental in dealing with the problem of targeting asynchronous architectures, see the Sacres project and recent references. Taking advantage of these features, we are currently developing a variation of SIGNAL to serve as a behavioural semantic backbone for the UML notation in object oriented software design. Also, I believe that we can easily extend synchronous programming techniques from SIGNAL to a certain degree of dynamic creation, sufficient for reactive systems applications based on object oriented design techniques.

> **Problem statement and results.** In our previous model, the notion of absence was global to the specification: the system evolves according to a sequence of (global) transitions (mapping past to current state) and thus the presence/absence status of each variable is known at each transition. When we move to distributed systems, such a global notion of state is no more relevant, as it is generally not possible (or at least very costly) to sense globally the state of a distributed system: building the global state requires

to communicate according to complex protocols which by no means can be considered implicit. Thus we need to consider models of dynamical systems suitable to distributed systems: these are known. Events at one given site can be totally ordered as usual, and remote events can be related only if some specific information tells us so (e.g., emission/reception of a message is an example of such a relation). These are models in which time is only *partially ordered.*

The synchrony/asynchrony problem refers to the ability to move consistently from our first view to the second one. We have characterized when this can be done correctly [79, 80], and, as a byproduct, we get a method for automatically generating protocols that will allow a correct deployment on a distributed architecture; the new feature is that those protocols are tightly tailored to the considered application, and thus are in some sense "minimal cost". All this is implemented in our SIGNAL compiler by Paul Le Guernic and his team in the framework of Esprit-Sacres project.

All this work is the basis for a continuing cooperation with TNI, a small company in software engineering located in Brest, France. TNI is currently marketing the SILDEX tool for SIGNAL, for aeronautics and control applications [1].

2.5 In between, somewhere

Being active in both control and computer sciences, I always dreamed blending the two in some way. This was not obvious. My first success was the establishment of a version of probability theory suitable for *distributed systems* in the computer science setting, in which no notion of a global state is available. In particular, jointly with Bernard Levy (UC Davis), I developed a compositional theory of random variables [72], having some relation with Bayesian networks. Then, with Eric Fabre and Claude Jard, I developed an extension of Hidden Markov Model (HMM) theory to distributed systems [54]. Our aim is to apply this theory and algorithms to failure diagnostics in telecommunication networks, a research in progress.

Problem statement and results. Consider a stochastic automaton in which both transitions and events attached to the transitions are random; this is also referred to in mathematical theory of probability as a semi-Markov chain, and to Hidden Markov Model (HMM) in pattern recognition. The problem is to infer the most likely hidden state transition from observed sequence of events (the so-called Viterbi algorithm). This is a central tool in

[1] See `http://www.tni.fr/` and `http://www.tni.fr/sacres/`

speech recognition today, and one possible approach for the fault diagnostics of discrete event systems. We have provided a generalization of this tool for distributed systems, in which no global state is available and time is a partial order. More precisely, we have extended HMM theory to Petri Nets with their partial order, true concurrency, semantics. The generalization is not at all easy, and we work hard at deriving a distributed version of the Viterbi algorithm.

3 Interaction with scientific community

3.1 Within France

See summary in section 1, I only comment major items.

From 1987 to 1996 I have created and headed the C2A national research network. This network focussed on the technologies needed to develop reactive and embedded systems (aeronautics and avionics, automobile, telecoms, process industry, and the like). In addition to academic partners from both computer science and control, industrial partners have included EDF, GDF, IFREMER, BERTIN, CISI, CETIA, CGEE-ALSTHOM, CGE-Marcoussis, MERLIN-GERIN (now Schneider),THOMSON-AVG, SIMULOG, VERILOG, TNI, Snecma, and more. This group has strongly contributed to the promotion of synchronous languages, and has led in particular to the launching of Eureka-Synchron project. It was also the origin of Esprit SACRES project.

At Inria, since about 1990, I have been playing the role of a sort of *marketing manager* for research, attached to the board of the institute. My duty is 1/ to focus on some industrial areas (embedded systems, telecommunications), 2/ to analyse and understand bottlenecks and needs from industry, and 3/ to infer from this suggestions for research activities and new projects. In particular I have contributed to building a scientific partnership between Alcatel and Inria ; to this end, a 1 year consultancy was performed at corporate level, from which several important research projects resulted, involving different groups at Inria.

Since 1998, I am head of the "software chapter" for the RNRT National Funding programme for research in telecommunications. I have headed the selection of projects for three rounds, each of them distributing about 50 Million FF (nearly 10 Million US$).

3.2 Worldwide

As a programme for my period as a Chairman, IFAC Committee on Theory, I have proposed the IEEE-IFAC joint project "Facing the Challenge of Computer Science in the Industrial Applications of Control". The purpose was to understand interactions between computer science and control in industry and research. For this I performed interviews of people at technical managerial level at Thomson-CSF, GEC-Alsthom, Siemens, see reports in [34, 35, 40, 41, 42, 43].

In 1997 I created the conference *Formal methods in safety critical embedded systems,* FemSys. I have been co-chairman of FemSys'97 and FemSys'99. This is an original event, as it is targeted to advanced R&D engineers from industry, and to academia, which appeared to be an interesting mix. Exhibition was a major part of the event.

I have been PC member of a number of conferences in control, and more recently, in computer science. I have been expert for grant submissions at NSF-Usa, NSF-Canada, NSF-Australie, SBIR-USA, NUTEK-Sweden, FSR-Sweden (Foundation for Strategic Research).

4 Students

The table to follow summarizes my advisory activities. A $\star$ indicates that I am co-advisor.

period	**nom**	**subject**	current situation
1977-1979	C. Richard	TV intra-image coding	Thomson TCE
1978-1980	C. Chauré	speech coding	Thomson Sintra
1980-1982	C. Labit	TV inter-image coding	DR-INRIA
1980-1982	M. Prevosto	vibration mechanics	IFREMER
1981-1983	P. Bouthemy	Meteo Images	DR-INRIA
1982-1984	D. Pelé ⋆	Geophysics	CCETT
1984-1986	R. André-Obrecht	speech recog.	CNRS, Toulouse
1985-1987	A. Rougée ⋆	vibration mechanics	CGR
1986-1988	G. Le Vey ⋆	vibration mechanics	Ec. Mines Nantes
1986-1988	S. Huan Yu ⋆	speech recog.	Startup Californie
1989-1991	B. Gach ⋆	vibration mechanics	Valeo
1990-1992	Q. Zhang ⋆	Wavelet networks	CR-INRIA
1991-1993	B. Claus	Multiscale Sig. Proc.	Startup Boston
1992-1994	E. Fabre	Bayesian networks	INRIA
1993-1995	G. Mathis ⋆	diagnostics	Ingenia
1996-1998	S. LePotier ⋆	mobile comm.	CCETT-FT
1996-1998	A. Aghasaryan ⋆	TMN, diagnostics	CNET-FT
1997-1999	L. Tromp ⋆	hybrid syst. diagnostics	

5 Contracts

5.1 Signal processing and control, and vibration mechanics

- CCETT (TV lab. of France Telecom), 1979-1980, 50,000FF, TV coding. Responsible. Patent.
- CNET (research lab. of France Telecom), 1980-1982, 100,000FF, speech coding. Responsible. Patent.
- Schlumberger, 1981, 150,000FF, Well logging in geophysics. Responsible.
- CNET, 1982-1983, 100,000FF, Blind equalizers in data transmission. Participant.
- CNEXO (now IFREMER, National Lab. for sea), 1982-1984, 150,000FF, Structural identification of offshore structures subject to vibrations. Responsible.

- CCETT, 1982-1983, 50,000FF, TV coding with motion compensation. Responsible. Patent.

- Schlumberger, 1982-1983, 180,000FF, dipmeter data processing in well logging. Responsible.

- CNEXO, 1984-1986, Structural damage monitoring of offshore structures subject to vibrations. Responsible.

- CNET, 1985-1986, 200,000FF, speech signal segmentation. Responsible.

- CNEXO, 1986, Structural damage monitoring of offshore structures subject to vibrations, follow-up of the former one. Responsible.

- EdF (Electricité de France), 800,000FF, Structural identification and damage monitoring of rotating machinery. Participant.

- Joint government grant, with CGEE-Alsthom, 1988-1989, 200,000FF, Assessment of failure detection techniques developed in our group. Participant.

- CNET, 1986-1988, 300,000FF, acoustic-phonetic speech recognition. Responsible.

- Alcatel-Alsthom-Recherche, 1988-1990, 50,000FF, consulting on failure detection and monitoring techniques. Responsible.

- Joint government grant, with Alcatel-Alsthom-Recherche, 1990-1992, 200,000FF, Wavelet and neural networks for control. Responsible.

- EGT-Alsthom, Belfort, 1990-1994, 150,000FF, Identification and condition based maintenance of gas turbines. Participant and head of contract negociations. Prototype system implemented by EGT-Alsthom.

- Schlumberger, 1993-1995, 200,000FF, Multiresolution signal processing with applications to well logging in geophysics. Responsible. Results implemented on industrial product.

- EdF, 1994-1996, 400,000FF, Non-intrusive identification of electricity consumption in utilities and houses (which equipment contributes to what consumption). Participant.

- Renault, 1994-1996, 200,000FF, Monitoring and diagnostics of a catalytic converter. Participant.

- CNET, 1996-1998, 200,000FF, Failure diagnostic in telecom networks. Participant.

- Eureka-Sinopsys european project, headed by LMS International (Leuven Measurement Systems), 1996-1999, 1 Million FF for Inria. Responsible for Inria.

- RNRT project Magda, 1998-2000, 700,000FF for Inria. FT-Cnet (leader), Alcatel, Ilog, Inria, Univ. Paris Nord. Developing distributed diagnostics techniques for telecommunication networks.

5.2 Computer science

- Joint government contract for the C2A research group, 1988-1990, 800,000FF, synchronous languages. Responsible.

- Joint government contract for the C2A research group, 1990-1992, 1 Million FF, follow-up of the former one. Responsible.

- Joint government contract for the C2A research group, 1991-1993, 500,000FF, in support of the preparation of the Eureka-Synchron european project. Responsible.

- Joint french army contract for the C2A research group, 1994, 500,000FF, in support of the preparation of the Eureka-Synchron european project. Responsible.

- Joint government contract for the C2A research group, 1992-1994, 1.5 Million FF, follow-up of the former one. Responsible.

- Eureka-Synchron european project, 1993-1996, Verilog (France, leader), TNI (France), Schneider-Electric (France), Snecma (France), Saab Military Aircraft (Sweden), VTT (Finland), Inria (Rennes, Rocquencourt, Grenoble, Sophia-Antipolis), GMD (Germany). Head D. Pilaud, Verilog. Responsible for Inria.

- Alcatel-Alsthom-Recherche, 1994, 50,000FF, consulting ("research marketing "), resulting in the contracts to follow, plus other ones not involving myself. Responsible.

- "Reutel", Joint government contract with Alcatel-Alsthom-Recherche, 1996-1997, 500,000FF, Object oriented techniques for telecom software engineering. Participant.

- Alcatel-Alsthom-Recherche, 1998-2000, 3 Million FF, follow-up of the former one. Participant.

- Esprit I&T project SACRES, 1995-1998, 1.5 Million FF for Inria. Synchonous programming technology for Safety Critical Embedded Systems. Siemens (leader), iLogix, TNI, BAe, Snecma, Offis, Inria, Weizmann Inst. Participant.

- Esprit LTR project SYRF, 1996-1999, 600,000FF for Inria-Rennes. Synchronous languages. Verimag (leader), Inria-Rennes, Inria-Sophia Antipolis, GMD, Linköping Univ., Prover Technologies, EdF, Schneider Electric and Saab Military Aircraft. Participant.

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[8] C. Richard, A. Benveniste, and F. Kretz. Recursive estimation of local characteristics of edges in TV pictures as applied to ADPCM coding. *IEEE Trans. Communications*, COM-32:718–728, 1984.

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le traitement du signal et l'analyse de systèmes vol 1, Editions du CNRS, Paris, 1982.

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