Research Report
2009-2011
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Télécom ParisTech / LTCI

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Laboratoire Traitement et Communication de l'Information - UMR 5141
Télécom ParisTech - CNRS

Research Report 2009–2011

Laboratoire Traitement et Communication de l'Information

Département TSI

Télécom ParisTech & CNRS

Février 2012

Contents

Part I

Signal and Image Processing

Signal and Image Processing (TSI)

The research topics covered by the Signal and Image Processing department at TELECOM ParisTech are: the study of image processing in its various formats, digital, optical... for different applications like medical imaging, remote sensing, fine arts..., the study of speech, music and sound, the study of the multimedia chain, from production to distribution. Our goal is to develop new mathematical tools to process all these kinds of signals, and to apply these tools to a large variety of concrete situations.

The department is organized into four groups:

- "Statistics and applications" - STA - is a group that is devoted to the applications of statistics and probability to the field of information society at large, which has become increasingly dependent on the collection and interpretation of data and, more generally, quantitative information. The research area covers a wide spectrum from the development of new techniques and new algorithms to various applications. The activities of the group comprises the following topics: statistical learning, blind sourrce identification and separation, distributed estimators for sensor networks, time series, independent data and complex random systems, Markov Chain Monte-Carlo techniques, sequential Monte-Carlo techniques (particle filters), array processing, geolocalization, models estimation.

- "Image Processing and Interpretation" - TII - has, as its main purpose, the development of methodologies and theoretical tools for image processing, scene analysis and 3D objects. This implies global treatment of complex image processing problems, integrating multiple techniques that cover the path from raw data to high-level interpretation. The concerned applications are art items (sculptures, paintings), biomedical images, aerial and satellite images, natural image analysis. Contributions of the group can be found at theoretical level (knowledge and information representation and modeling, in 2D as well as 3D, processing, interpretation and reasoning on spatial data), at algorithmical level (in particular models for large and complex data sets), and at applicative level.

- "Audio, Acoustics and Waves" - AAO - develops signal processing techniques while keeping strong connections with the physical phenomenon that is at the source of the signals. In digital audio signal processing, the activities span the entire acquisition chain, from sound capture and transmission up to its restitution, with the goal of proposing solutions to the main problems centered around the sound, speech or music, in multimedia applications. Its contributions at the methodological level cover adaptive methods for high resolution sinusoïd tracking, sparse representations, nonnegative matrix factorisations, source separation. A central domain of applications is the analysis of audio and multimedia scenes: segmentation of broadcast streams, analysis of music, its decomposition and understanding (polyphonic separation, rythm, melody, chords). Research on biomedical signals has been recently reinforced in the group, and will be furtther stengenthed with the ongoing recruitment of an associate professor.

- "Multimedia" - MM- is a group that covers the life cycle of multimedia documents in the framework of a complete chain going from authoring tools for on-line and offline production of multimedia contents to multimodal interaction for the final user; this also includes

automated processing like enhancement of degraded pictures, verification of the identity of the user, modification of auditive and visual appearance, image segmentation and pattern recognition. The group also works on techniques that allow the analysis, compression and robust transmission of these media in heterogeneous networks. It also works on the dynamic and distributed adaptation of the transmitted data flow (including meta-data and in particular those concerning the digital rights management) with respect to context, transport conditions and terminal type.

One research topic is common to all groups, this is indexation and data mining. Summarizing and extracting informations from multimodal databases requires statistical tool for learning and mining, which are among the activities of the STA group with a particular focus on text indexation and retrieval. Indexing satellite images, extricating informations from primitives to semantic annotations was the main goal of the "Center of Competence", a joint lab between CNES, DLR and the TII group, until mid 2010. This group also develops the same kind of tools for biomedical images and for 3D objects. The AAO group is concerned by many aspects of music information retrieval: identification of rhythms, main melodies, instruments, styles, moods, tonalities either from plain audio or from mixed audio and video. Video signals are also a core activity in the MM group together with complex documents analysis (mixing printed texts, handwritten texts, pictures, graphics) and with multimodal analysis for biometry (voice, faces, fingerprints).

Our most recent recruitments were aimed towards the reinforcement of two topics: 3D images and virtual worlds on one hand, biomedical signals on the other hand.

Permanent staff [*Institut ; CNRS*] ; post-docs	[39,8 ; 13.5] ; 30.5
PhDs	58.9
Defended PhDs	58
Defended HDR	11
Journal papers [published, in press]	[238 ; 58]
Chapters and books [published, in press]	[38 ; 9]
Conference papers	455
Patents and software	2
Contractual income 2009 (july)–2011 [Private ; Public ; European] (k€)	[2255 ; 5950 ; 1218]

Chapter 1

Audio, Acoustics and waves (AAO)

Head G. Richard (P)

Permanent staff R. Badeau (MC), B. David (MC), Y. Grenier (P), N. Moreau (P, until March 2010), S. Essid (IE), J. Prado (MC);

PhD students N. Bertin (10/05-10/09), J-L. Durrieu (01/07-05/10), M. Ramona (10/06-06/10), C. Joder (11/07-09/11), L. Oudre (10/07-11/10), F. Vallet (11/07-09/11), S. Gulluni (02/08-12/11), R. Hennequin (10/08-11/11), M. Maazaoui (01/09-), S. Fenêt (01/10-); B. Fuentes (10/09-); R. Foucard (10/09-); M. Moussalam (10/09-); G. Ladreyt (10/10-); F. Rigaud (10/10-); A. Liutkus (01/10-);N. Lopez (05/11-); A. Masurelle (10/11-); X. Jaureguiberry (10/11-);

PostDocs, engineers and sabbaticals M. Lagrange (Postdoc,10/08-09/09), T. Fillon (Postdoc,10/08-), B. Mathieu (Engineer,10/08-12/10), A. Dielmann (PostDoc, 11/10-03/11), A. Drémeau (PostDoc, 09/11-).

External collaborators L. Daudet (ESPCI ParisTech), O. Derrien (LMA-Marseille), E. Vincent (IRISA), L. Devillers (LIMSI-CNRS), T. Sikora (Technical Univ. of Berlin), L. Girin (GIPSA-Lab), N. O'connor (Dublin City University).

Permanent staff [*Institut ; CNRS*] ; post-docs	[6.3 ; 0] ; 1.9
PhDs	9.3
Defended PhDs	9
Defended HDR	1
Journal papers [published, in press]	[24 ; 2]
Chapters and books [published, in press]	[7 ; 1]
Conference papers	64
Patents and software	[1 ; 1]
Contractual income 07/2009–12/2011 [Private ; Public ; European] (k€)	[121 ; 673 ; 275]

The AAO (**A**udio, **A**coustical and waves) research group is now focused on the activities previously reported under the Audio Signal Processing (*AudioSig*) project. The activities of the Optical Signal Processing (*TOS*) project have been transferred to the INFRES department in March 2009 and are entirely reported in section **??**.

1.1 Objectives

The aim of this research group is to develop digital audio signal processing methods in order to propose innovative solutions to the main problems linked to audio (speech, music,...) in multimedia applications. Our interests encompass the complete processing chain from sound capture and transmission to sound restitution. Work is conducted on a methodological level to develop new sound representations and models especially for musical signals on their application to practical problems. In particular, the group is interested in Adaptive methods for high resolution sinusoidal components tracking, sparse representations, Non-Negative Matrix factorization or hierarchical models and on their application to practical problems such as automatic indexing, compression or EEG signal processing. *Source separation* also appears to be at the heart of this research group with contributions at the methodological level and with applications in nearly all the individual research themes. *Audio and multimedia scenes analysis and indexing* currently is the central research theme of the group and includes topics such as broadcast streams segmentation into broad classes of audio events (speech/music/silence/singing,...), musical signals automatic analysis, decomposition and understanding (polyphonic audio source separation, rhythm extraction, multiple fundamental frequencies estimation, main melody extraction,...). Concurrently, a novel research direction on biological signals for Brain computer Interfaces is receiving a growing interest and will be further strengthened with the arrival in march 2012 of a new associate professor in the group.

On a different level, the group has initiated the development of a multimedia indexing and mining platform (called PLATO) which now involves several other groups and has developed a number of software tools, some of them being distributed in open source (YAAFE - an audio feature extractor [90], DESAM toolbox - a set of tools for spectral analysis of musical audio [83, 15], ...).

The group is also maintaining tight links and collaborations with both academics (Queen Mary University of London, Dublin City University, Technical University of Berlin, Institut Langevin, IRCAM, INRIA-IRISA, LABRI-CNRS, GIPSA-Lab,...) and industry (RTL, INA, Audionamix, Arkamys, Parrot, ...).

1.2 Results

1.2.1 Audio and multimedia scenes analysis and indexing

Researchers R. Badeau, B. David, S. Essid, Y. Grenier, J. Prado, G. Richard;

Highlights :

Collaborations: With industry (RTL, INA, Audionamix) and academics (Queen Mary University, Dublin City University, Institut Langevin, IRISA, IRCAM, LABRI,...)
Projects Network of Excellence IST-Kspace (*Knowledge Space of Semantic Inference for Automatic Annotation and Retrieval of Multimedia Content*), Network of Excellence 3DLife (*Bringing the Media Internet to Life*), OSEO-QUAERO (*Towards multimedia and multilingual search engines for professional and general public applications*); ANR DreAm (*Active music listening*);
Prize PhD prize in 2010 (jointly awarded by EEA club, GRETSI and ISIS) (N. Bertin)

Models and signal representations

This activity is following several research axes. The first direction, which is on a rather methodological level, aims at developing generic signal models and representations with a specific focus on audio signals, recently extended to multimodal signals. An increased effort was dedicated to

sparse signal representations with a particular interest on those based on Matching Pursuit (MP), Probabilistic Latent Component Analysis (PLCA) or Non-negative Matrix factorisation (NMF), that allow to decompose a signal using a limited number of atoms or basis functions. Several very interesting results were for example obtained for NMF concerning the stability of multiplicative update algorithms ([1, 47], or the description of beta-divergence as a subclass of Bregman divergence [10]. Several extensions of the NMF were also explored including the introduction of a new generalized model for High-Resolution NMF [45], the extension to multichannel [381], and the proposal of a general formulation of underdetermined source separation of Gaussian Processes [17]. The applicability of these methods to generic problems such as audio indexing in the (scalable) compressed domain [25], audio source separation or music signal indexing was demonstrated by introducing specific constraints deduced from the audio signal properties (use of harmonicity or temporal constraints for music transcription [2, 48, 26], use of source production or timbre models for source separation [4, 5], use of time-frequency activations to model non-stationary audio events [9],...). This methodological effort explores both deterministic and statistical approaches.

Audio indexing and blind source separation

The second direction concerns the different facets of audio indexing and audio source separation which are two intricate problems. Indeed, efficient source separation eases the transcription of the resulting sources and efficient audio indexing facilitates the source separation. In music signal transcription, the group is directly interested in the four main problems which are *multiple fundamental frequencies estimation* (e.g. detection of simultaneous notes in a polyphonic musical recording [8, 26, 64]), *rhythmical information tracking* (tempo and beat estimation [80], *harmonic information estimation* (recognition of the chords sequence [107, 379, 380]) and *timbre recognition* (musical instrument recognition in polyphonic audio [11]). Whenever possible, the results obtained are submitted to national or international evaluation campaigns. In particular in 2011, our group has obtained the best results in several subtasks of the Quaero competitive internal evaluation campaigns.

Source separation approaches were developed for specific music transcription tasks such as piano transcription [8]) and main melody estimation (by use of a NMF-based source-filter model for separating the singing voice from the musical accompaniment [5]) but also for specific audio rendering tasks such as stereo signal remastering [381]. A novel research direction was also pursued along these lines for situations where prior information is available about the sources [18]. This so called *Informed Source Separation* problem bares several similarities with multichannel audio coding in the extreme cases where the sources are available at the coding side and a novel framework was recently proposed to close the gap between audio source coding and source separation domains [99].

Multimedia streams segmentation

The third research direction is dedicated to the multimedia streams segmentation into broad classes of events with application to *broadcast multimedia streams* (speech/music segmentation [100], TV show structuring [106, 35]) and *musical streams* (Audio fingerprint [60], musical sound objects decomposition for electroacoustic music [68], music similarity [61, 62, 14], audio-to-score alignment [12] or more recently to dance performance analysis [215, 480]). At the methodological level, our efforts in this field are mostly based on statistical discriminative approaches and a special interest has been directed to kernel-based methods (Support Vector Machines, sequence kernels, probabilistic distances, kernel change detection, kernel LDA,...) and more recently to hybrid kernel and Bayesian network based methods. Our emphasis is targeted to the incorporation of prior knowledge on the nature and structure of the streams processed, typically temporal

dependencies and/or inter-stream correlations/dependencies, both at the signal level and the semantic level, possibly using ancillary information attached to the content (available meta-data, tags, notices,...) and/or user interaction (relevance feedback).

1.2.2 Sound capture, separation and rendering

Researchers B. David, Y. Grenier, J. Prado, S. Essid, G. Richard;

Highlights :

Collaborations: K. Abed-Meraim (STA), European project partners

Projects CapDigital-ROMEO (*a project within "¡pôle de compétitivité"¿ CapDigital, led by Aldebaran Robotics and aiming at creating a humanoid robot*), Network of Excellence 3DLife (*Bringing the Media Internet to Life*), FP-7 Reverie (*REal and Virtual Engagement in Realistic Immersive Environments*)

The objective of this theme is to improve sound field analysis and synthesis capabilities by developing specific digital signal processing methods.

Current work tackles the difficult problem of humanoid robot audition which needs, using a limited number of sensors, to be robust to movements of the robot and to highly variable environments.

This work is part of the Romeo project that aims at building a humanoid robot (Romeo) that can act as a comprehensive assistant for persons suffering from loss of autonomy. Our approach follows a two-stage blind source separation strategy. The first stage consists in a fixed beamforming preprocessing to reduce the reverberation and the environmental noise. Due to the highly constrained context of robot audition, pre-recorded Head Related Transfer Functions (HRTFs) are used to estimate the beamforming filters. The use of the HRTF to estimate the beamformers allows to capture the head and torso effect on the manifold of the microphone array. The second stage is a blind source separation algorithm based on a l_1 norm minimization sparsity criterion. Promising results were obtained with several different configurations and highlighted the merit of the fixed beamforming preprocessing for improving the separation performances [519, 377]. A recent extension was also proposed by using a modified l_p norm blind source separation criterion based on the source sparsity in the time-frequency domain. We followed a tempered approach where the sparsity constraint could be reinforced by varying the parameter p of the l_p to dynamically change from l_1 to l_0 norm. This variation is driven by a sigmoid function which allows to obtain smooth transition and to avoid the divergence of this tempered approach. The merits of this method were demonstrated and compared to more classical scheme [520].

Another axis in this domain relates to signal capture in reverberant environment using a single sensor and a dedicated collaboration with the company Arkamys has been recently started to develop novel dereverberation algorithms. Finally, under the framework of the two European projects 3Dlife and Reverie, a growing effort has been dedicated to multimedia scene capture (e.g. dance scenes) using a large variety of heterogeneous sensors. Such parallel heterogeneous data captures imply complex synchronization mechanisms but permit to tackle unexplored directions for complex multimedia scenes analysis and interpretation. This was already highlighted by the two preliminary studies on dance scene analysis that were selected as finalist for the 2011 Grand Challenge of the ACM Multimedia [215],[480].

1.2.3 Sound sources compression and informed source separation

Researchers N. Moreau, G. Richard, R. Badeau

Highlights ANR-Dream, academic collaborations (Univ. of Toulon, INPG Grenoble, ESPCI ParisTech, IRISA-Rennes)

In audio compression, the work was mostly dedicated to low to medium bit rate parametric audio coding. For low bit rate music coding applications, parametric coders are an efficient alternative to transform coders. In particular, sinusoidal modeling is widely used in response to the fact that most real-world audio signals are dominated by tonal components. Less used, the exponentially damped sinusoidal model (EDS) combined with a variable-length time segmentation is however considered as more powerful, but at the cost of an increased number of parameters. Our work has shown, however, that it is possible to design a joint scalar quantizer for amplitude, damping and phase parameters and obtain increased coding capabilities compared to the more traditional sinusoidal model [53].

On the other hand, investigations were pursued to develop highly scalable transform coders which can seamlessly operate from very low bit rate up to transparency. To that aim, sparse overcomplete representations are used to decompose the audio signals over a redundant union of bases (such as Modified Discrete Cosine Transform bases at different scales). It was also shown that the high flexibility of the signal representations used in this coder allows to tackle various audio indexing tasks (such as beat tracking or musical genre recognition) directly in the transform domain [25] or to perform a large variety of music similarity tasks or structural-based audio coding [91, 94]. More recently, a novel Random Matching Pursuit algorithm was designed which allowed to simulate a local search in a larger dictionary while operating at the cost of a search in a sub-sampled dictionary. On a more transversal axis, a comparative study of sparse greedy algorithms that were separately introduced in speech and audio research communities was conducted. It was in particularly shown that the Matching Pursuit (MP) family of algorithms (MP, OMP, and OOMP) are equivalent to multi-stage gain-shape vector quantization algorithms previously designed for speech signals coding. Following this unified view, a new family of algorithms was introduced based on cyclic minimization principles and on the recent Cyclic Matching Pursuit [6].

In parallel, our work on Informed source separation allowed us to propose a novel framework to link the two domains by exploiting source separation models and principles for multichannel audio coding. This novel method led to higher performance than those possibly achievable by standard approaches such as the standardized Spatial Audio Object Coding (SAOC) [99].

1.2.4 Biomedical signals analysis

Researchers J. Prado, S. Essid, Y. Grenier;

Highlights DGA Project MEEGAPERF (*Monitoring EEG pour l'Anticipation des PERFormances*
European Project FP7-Verve (*Vanquishing fear and apathy through E-inclusion: Personalised and populated Realistic Virtual Environments for clinical, home and mobile platforms*)

The other research direction is dedicated to the analysis of biomedical signals and especially electroencephalogram (EEG) signals recorded on asleep subjects using a single pair of sensors. Our approach to this problem has two technological breakthroughs since it aimed at an automated analysis (and not only visual) and uses a single channel EEG. The efficiency and robustness of the method developed have been measured and experimentally validated. Another application of interest concerned the analysis of biological data about colonic transit time (CTT). In particular, a dedicated approach was designed to robustly estimate this colonic transit time even in situations where the patient omits to ingest the radiopaque markers for one or two days [3].

The effort of the group in the domain of biological signals processing (and especially multichannel EEG analysis) has been recently strengthened with the acceptation of two research projects. The first project (MEEGAPERF), started in september 2009, aims at automatically providing information in real time on the psychological state of a patient from the analysis of cerebral activity using portable devices. The second project (FP7-Verve) aims at developing dedicated tools to support the treatment of people who are at risk of social exclusion due to fear and/or apathy associated with a disability. Our planed work is to automatically analyze the user's emotional state based on the processing and fusion of various biological signals, be it the audio-visual

stimuli presented to the patient, or the signals captured by the different audio-visual, motion and biological sensors (including EEG and ECG electrodes) used to monitor him/her. The arrival of a new associate professor in biomedical signal processing for Brain Computer interfaces will also allow to further develop this research direction.

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Chapter 2

Multimedia (MM)

Team leader B. Pesquet-Popescu (P).

Faculty M. Cagnazzo (MC), G. Chollet (DR CNRS), C. Concolato (MC), F. Dufaux (DR CNRS 10/10 –), J.-C. Dufourd (DE), C. Faure (CR CNRS), J. LeFeuvre (IE), L. Likforman-Sulem (MC), J.-C. Moissinac (MC), C. Pelachaud (DR CNRS), M. Sigelle (MC)

PhD students M. Abid (05/09–), A.B. El Ailah (10/09–), S. Ben Fredj (), G. Chierchia (10/11–), M. Chollet (10/11–), M. Decombas (11/10–), Y. Ding (10/10-), N. Fourati (10/11–), H. Khemiri (05/10–), P. Lauga (10/11–), H. Medina (10/10–), E. Mora (12/10–), O. Morillot (10/11–), I. Nemoianu (10/09–), C. Oprean (10/11 –), G. Petrazzuoli (11/09–), T. Maugey (10/07–11/10), M. Kaaniche (10/06–12/10), S. Hyniewska (10/08–), Q. Anh Le (07/09 –), J. Huang (10/09 –), C. Greco (09/08 –), R. de Oliveira (01/09 –), A-L Bianne (09/08–11/11), B. Rodriguez (02/09–),

Post-docs, engineers and sabbaticals R. Niewiadomski (01/09 –), M. Kieffer, Univ. Paris Sud (sabbatical, 10/09 –), A.-M. Pez(10/08 –01/10), P. Philippe (10/10–), K. Prepin (01/09-08/11), E. de Sevin (01/09 – 06/10), Cong Kinh Nguyen (01/11–12/11), Vlad Atanasiu (08/10–04/11), Jérémy Lardon (02/11–), C. Boufenar (sabbatical 1 month, 05/10), J. Le Tanou (11/11–), B. Qu (10/10–), M. Ochs (09/09 –), E. Sanchez-Soto (05/09–12/09), J. Razik (02/08–08/09), C. Riedinger (11/08–12/09), G. Valenzise (07/11–), R. Gaetano (10/10–), M. Kaaniche (01/11–), P. Milhorat (10/11–), A. Koz (10/11–), E. D'Acunto (03/10–12/10), A. Gnecchi (05/10–10/10), A. Amehraye (11/08–05/09), J.Lardon (02/11 –), S.Thomas (01/10 – 12/11), S.Stelle (01/10 – 11/11), L. Daud (01/10 – 12/11), J. Sillan (01/09 – 12/11), N. Mahler (), S. Pammi (11/11–), K. Bailly (10/10–09/11) Dirk Heylen, Twente University (sabbatical, 3 months, 2010), Candy Sidner, Worcester Polytechnic Institute (1 month, Oct. 2011)

External collaborators A. Bennazza (SupCom Tunis), C. Mokbel (UOB, Liban), C. Kermorvant (A2IA), I. Jermyn (INRIA Sophia), S. Perreau (ITR, Adelaide), E. Bratsolis (Univ. Athens), J. Farah (USEK, Liban), M. van der Schaar (UCLA, USA), C. Guillemot (INRIA Rennes), A. Esposito (Univ. Naples), T. Hueber and G. Bailly (GIPSA-Labs)

Faculty [IT, CNRS]	[7, 3.6]
PhD students	13.6
Post-docs, engineers and sabbaticals	14.6
Defended PhD theses	7
Defended HDR	2
Journal papers [published, in press]	[44, 13]
Papers in conference proceedings	126
Chapters, edited books	[6, 8]
Standardization contributions	60
Grants [public, private, european] (k€)	[3190; 455; 942]

2.1 Objectives

The research in the "Multimedia" (MM) group covers the life cycle of multimedia documents in the framework of a complete chain, going from authoring tools for on-line and off-line production of multimedia contents to multimodal interaction for the final user; this also includes automated processing like enhancement of degraded pictures, verification of the identity of the user, modification of auditive and visual appearance, image segmentation and pattern recognition. The group also works on techniques that allow the analysis, compression and robust transmission of these media in heterogeneous networks. It also works on the dynamic and distributed adaptation of the transmitted data flow (including meta-data and in particular those concerning the digital rights management) with respect to context, transport conditions and terminal type.

2.2 Main Results

The main research results obtained during the period July 2009 - December 2011 are presented below for the research areas of the Multimedia team.

2.2.1 Robust Compression and Transmission of Visual Data

Faculty B. Pesquet-Popescu, F. Dufaux, M. Cagnazzo

Main events F. Dufaux is Editor-in-Chief of the *Elsevier Signal Processing: Image Communication journal*.
In this period, B. Pesquet-Popescu was a member of the IEEE SPS Image, Video and Multidimensional Signal Processing (IVMSP) TC, of the IEEE SPS Industry DSP Technology (IDSP) standing TC, a member of the IEEE SPS Multumedia Signal Processing (MMSP) TC, Associate Editor for *IEEE Trans.on Circuits and Systems for Video Technology*, *IEEE Trans. on Image Processing*, *IEEE Trans. on Multimedia* and *Elsevier Signal Processing: Image Communication* journals. She was also a General Co-Chair of the IEEE MMSP conference (Oct.2010).
M. Cagnazzo is Area Editor of *Elsevier Signal Processing: Image Communication* and of *Elsevier Signal Processing*.

Projects pôle CapDigital Sebastian2 (2008-2010), pôle CapDigital PINGO (2008-2010), CEDRE (2009-2010), ANR blanc PERSEE (2009-2012), ITEA2 AC/DC (2010-2012), FUI8 NEXEX (2011-2014)

2D and 3D video coding

Even though traditional (or 2D) video coding has been studied by the research community for more than twenty years, new methods for improving the existing compression techniques steadily pop up. This is testified by the fact that a new coding standard is under development by ISO and ITU. Our group contributed to 2D video coding with new and efficient methods based on motion vector quantization [109], differential motion estimation [177], efficient lossless coding [114], adaptive wavelet coding [257, 178, 155].

However, much attention has been addressed to three-dimensional and multiview video, since they are the *enabling technology* of many exciting new applications, such as 3D TV, immersive communication, immersive gaming, *etc.* Our team has been studing novel representation formats for this kind of data, proposing new compression techniques.

We have designed novel techniques for *disparity* estimation and coding in multiview video (disparity describes the spatial relationships between a couple of images taken from different points of view), allowing improved performances with respect to standards for multiview video coding. [125, 117, 147]

We have also been considering an emerging representation format called multi-view plus depth (MVD). In MVD, for each view we have a traditional color image plus a *depth image*. The latter allows to synthesize new viewpoints at the decoder. We developed several techniques to efficiently encode the depth information [147, 194, 179], or to use it to improve the user experience (jointly with distributed video coding techniques, see Section 2.2.1 [272]).

The research of the group in 2D and 3D video compression perfectly fits the framework of the project *ANR Blanc PERSEE* (PERceptual Scheme for 2D and 3D vidE(E)o coding), in which the members of the group are involved.

Robust video streaming through cooperative networks

Real-time multimedia streaming over computer networks is one of the most active research fields in the last years. The best performing solutions are based on the concept of *cooperative networks*, i.e. networks where each node contributes to the distribution of the content. We studied this problem in the cases of wired and wireless networks.

For the wired case, we built over an existing protocol with the aim of a system meeting video multicast requirements. We developed a new algorithm which mitigates the main problems of the previous one (slow overlay construction and potentially high end-to-end delay) [137].

For the wireless case, we considered mobile ad-hoc networks (MANETs), which are an active research field since they promise scalable and robust audio/video delivery without infrastructure. We studied the problem of real-time video streaming over MANETs and proposed a content routing/delivery protocol inherently designed for the ad-hoc wireless case, exploiting the intrinsic broadcast property of the medium [126]. This problem has several common features with peer-to-peer routing, but the additional sensible parameters of MANETs make wired solutions unfit to this case; therefore, we had to design a brand new protocol.

The resulting protocol is very effective in building and managing the overlay network. Nevertheless, it can suffer from congestion if high density or sudden churns are considered. Therefore we designed and implemented a new version of the protocol that optimizes the rate/congestion trade off. The result is a remarkable reduction of delays and of undecodable images, with a clear improvement of the user's *quality of experience*.

All these systems for video streaming must face with the problem of unreliable connections. Packets can be lost on wireless networks, or can be too delayed on wired networks. In both cases, the video decoder must be able to cope with the case where not all data produced by the encoder are available at the play-back time. A common solution to mitigate this problem is multiple description coding (MDC). In MDC, the encoded stream is structured into independently decodable elements, called descriptions, such that the decoded video quality increases for any new description received. This robustness comes at the price of a reduced rate/distortion performance. All the proposed streaming protocols work on a MDC video stream. Instead of

using some existing MDC scheme, we proposed some new methods, based on temporal split and motion-compensated image interpolation [218].

Finally, MDC is not the only technique used to adapt a video stream to a lossy channel. Among the alternatives, network coding (NC) is gathering a lot of attention. We are working on the combination of MDC and NC to obtain a robust and low-delay technique for video streaming over unreliable networks [246].

Distributed video coding

Distributed video coding (DVC) is an emerging framework for video compression that allows to greatly reduce the encoder complexity provided that the decoder can sustain an increased computational burden. Theorems from information theory assure that this paradigm has the same performance bounds as the classical encoding schemes. Therefore DVC perfectly lends itself to applications such as low-complexity video communications, sensor networks, and, more recently interactive multiview video streaming [273, 272].

We have proposed several methods to improve the performance of DVC systems, based on high-order motion interpolation [271, 269, 270], resulting in considerable gains with respect to state-of-the-art solutions.

We also proposed a new approach that iteratively improves the side information after decoding of each DCT sub-band [164, 165]. This leads to significant rate-distortion gains compared to state-of-the-art, especially for video sequences with complex motion. Another direction explores the combination of global and local motion estimation to improve side information [236]. A second activity focuses on the multi-view distributed coding. In this context, we proposed the use of machine learning (Support Vector Machine) to fuse side information obtained from temporal and inter-view predictions [202].

Semantic Video Coding

Compression standards such as H.264/AVC encode video sequences to maximize fidelity at a given bitrate. However, semantic-oriented and content-aware compression remains a challenge. In this activity, which is part of a CIFRE thesis with Thales, we have developed a new semantic video compression method using seam carving [199]. Seam carving changes the dimension of an image/video with a non-uniform resampling of each row and column while keeping the rectangular shape of the image. Our main contribution is a new approach to identify areas where seams are concentrated. On the one hand, it allows to transmit supplemental seams data at low cost. On the other hand, seams can be synthesized at the decoder in order to recover the original frame size and to preserve the scene geometry. Experiments show that our seam carving method results in significant bitrate savings while maintaining the same quality in semantically significant regions. A patent has been filed.

High Dynamic Range Video

This activity is part of the FUI project NEVEX which began in October 2011. A complete HDR (High Dynamic Range) video system, from content creation to display offers the user the possibility to receive more immersive images. Indeed, HDR images offer a wide range of brightness that can reproduce details in all areas of the image, even bright or dark. This more realistic rendering is closer to human vision than standard HDTV images.

A first objective is to develop new algorithms for inverse tone-mapping to convert existing videos to HDR. In the absence of sensor capable of directly acquiring HDR images, the operation of inverse tone-mapping is a method to create HDR content. Moreover, inverse tone-mapping is also interesting to view legacy video content on new HDR displays, which are now becoming commercially available, maximizing the potential of these screens and thus the quality of the rendered image.

A second objective is to develop a specific coding scheme suitable for HDR video. It should take into account the constraints of backward compatibility with existing schemes. The standardization of such a format will also be explored.

Visual Quality Assessement

Research in the field of video quality assessment relies on the availability of subjective scores (Mean Opinion Scores or MOS), collected by means of experiments in which groups of people are asked to rate the quality of video sequences. The availability of subjective scores is fundamental to enable validation and comparative benchmarking of the objective algorithms that try to predict human perception of video quality by automatically analyzing the video sequences. In this activity, a publicly available database of subjective quality scores and corrupted video sequences has been created, including 156 sequences at CIF and 4CIF spatial resolutions, encoded with H.264/AVC and corrupted by simulating the transmission over an error-prone network, along with MOS [121].

Current and future activities are looking into visual quality assessment for 3D video.

2.2.2 Rich Media, Adaptation and Open Source Software

Faculty C. Concolato, J.-C. Dufourd, J. LeFeuvre, J.-C. Moissinac

Main events Edition of several ISO and W3C standards, Organization of SVG Open 2010

Projects ANR Radio+(11/08–11/10), ANR HybRadio (), Cap Digital PINGO(04/08–04/10), IST FP6 NoE INTERMEDIA (10/06–10/10), ANR Georacing (01/07–03/09), FUI8 OpenHbb (10/09 – 02/12), SOA2M project/Alcatel Lucent/Institut Telecom joint laboratory (12/08–12/11), FEDER Project VUE (11/10–11/11), FUI8 End2ToEnd, ANR Calder.

Rich Media Representation

The term ”Rich Media” designates the methods, algorithms, tools or technlogies required for the processing of the new generation of multimedia content, i.e. content that encompasses natural or synthetic audio-visual material but adds animation and interactive capabilities. Rich Media technologies target a wide range of application domains: from digital TV or radio, to mobile multimedia and the Web 2.0.

The research topic that the team pursued in this area are numerous. Some work has been done towards finding the best representation for such content, as well as designing compression approaches for multimedia scene description languages, with features such as error protection and scalability. Other works focused on improving the visualization of such content [144], in particular on mobile phones. Finally, the problems related to the delivery of such content on diverse networks such as broadcast networks have been also investigated. As part of this work, the team is an active participant to standardization bodies such as W3C and ISO. The team has contributed (more than 80 contributiions) and participated to the editing of the following international standards: MPEG-4 Systems, MPEG-4 BIFS, MPEG-4 LASeR, and W3C SVG.

Interactive Services and Transmedia

New ways to structure, package and transport interactive content have been studied. The first form is ”widgets”: the team is an active contributor and implementer of the W3C Widgets suite of standards. In order to investigate the full potential of widgets, in particular in the home environment, the team has spearheaded the development of the MPEG-U standard, which extends W3C widgets to add communication capabilities between widgets and to/from external services. The team is now reformulating the developed concepts for use within the home network with web technologies, as part of the work in the W3C Web and TV IG and the Device API WG. The

second form is interactive TV: the team is active in the development and promotion of the Hybrib Broadband Broadcast TV standard, opening the way for a convergence of TV, Internet and mobile into a new model for distributed, communicating services [115].

Multimedia Adaptation and Multimodal Interaction

The adaptation of multimedia content to its context of use (terminal capabilities, network characteristics, user preference) is a very active research topic, with tight link with standardization activities such as MPEG-21 or W3C. The team explores specific problems in the adaptation of multimedia content: adaptation of protected content, adaptation of human-computer interface, and the authoring of adaptable services [144]. These problems are addressed along different axis either by defining software architectures for such adaptations (in relationship with the ASTRE Team) or by defining methods and languages facilitating the adapation of multimedia documents. A new form of multimedia consumption is emerging: our environment is days after days enriched by more and more multimedia capabilities -displays, sensors, speakers, microphones, touch screens... Our work places the user at the center of such environment and defines tools to get the best benefits of such environment when using multimedia services. Work has been done about implementation and extension of the MMI framework proposed by the W3C [192].

Multimedia Transport

Starting from 2010, the group has been actively involved in the MPEG standardization process of adaptive streaming over HTTP, through the MPEG DASH specification (Dynamic Adaptive Streaming over HTTP, ISO/IEC 23009-1). The group has proposed various modifications to the specification, published articles on the topic of DASH and interactive content delivery, and hosted one of the DASH standardization meeting in Paris. Technical tools helping creation and consumption of DASH content have been released as part of the GPAC project, and some of these tools will be given to MPEG as utility software. These tools will also be used to generate conformance sequences to be given to MPEG in early 2012.

GPAC Open Source Software

The team maintains an Open Source platform called GPAC [232], GPAC Project on Advanced Content (http://gpac.sourceforge.net), distributed under an LGPL license. This platform offers various tools for the encoding, the delivery and the playback of multimedia content, ranging from simple audio/video to full-fledge Rich Media. These tools implement state-of-the-art algorithms, methods and protocols from many standards organizations (MPEG, W3C, IETF, ETSI) and are kept in close sync with new industrial deployments. GPAC is used by the academic world (42 citations in journals or international conferences), the industrial world (integrated in several R&D projects) and the internet community (e.g. used for iPod file management). GPAC constitues the back-bone for the implementation of the team's work (Rich Media representations and adaptation) and is often demonstrated in conferences or standardization meetings.

2.2.3 Document Imaging and Interaction

Faculty L. Likforman, M. Sigelle, C. Faure

Main events L. Likforman was the General Chair of the Document Recognition and Retrieval (DRR) DRR 2010 conference.

Projects FUI Rome Mobile (2010-2012), DGA and Futur et Ruptures (2010-2013), A2iA (2008-2010), Itesoft (2011-2014)

The team has developed several HMM-based (Hidden Markov Models) approaches for handwriting recognition (work performed within projects A2iA, DGA, Futur & Rupture and Itesoft). These approaches are based on the Hidden Markov Model framework, especially sliding window systems. In such systems, it is not required to segment the word into smaller units (words or characters). Context-dependent character models have been constructed during the PhD of A-L Bianne for a word recognition approach. Parameter tying is performed through a clustering process based on binary decision trees. Original questions on characters' shapes have been proposed [113]. The word recognition approach has been extended to text-line recognition [245]. Different language models have been constructed and the whole approach evaluated on a mail reading task (DGA, Futur & Rupture; PhD thesis Olivier Morillot).

A related and new study (started in 2010) is the characterisation of handwriting for retrieving similar documents (with respect to the handwriting). A retrieving application, REX, [163] has been developed which compares documents from orientation-based features [162]. Such features are extracted from normalized histograms of edge pixel orientations.

A new subject (within project Rome Mobile) started in 2010 which aims at decomposing web pages into functional blocs (header, content, footer, title...). Such decomposition is useful for web page adaptation to small screens and mobile phones. Our approach is based on machine learning (Support Vector Machines) using a set of efficient features (based on both content and typography) extracted from web page's blocks.

Document Image restoration based on seminal work of J. Darbon and M. Sigelle on Total Variation has been applied to ancient documents [167]. A new approach resulting from the combination of Total Variation (TV) and Non Local Means has been proposed [133] in collaboration with J. Darbon (CMLA and UCLA) and E. Barney Smith (Boise State Univ.) TV was also used for image denoising, by exact sampling (CFTP) and a relation was highlighted with the submodularity for Markovien models by Marc Sigelle, in collaboration with J. Darbon (CMLA ENS Cachan) and S. Peyronnet (LRI Orsay).

M. Sigelle continued the collaboration with I. Jermyn (INRIA ARIANA) and S. Perreau (UNISA Adelaide Australia) on the topics of (discrete) diffusion processes, which can be applied both to modelling of traffic routing in ad hoc networks and to image restoration [282, 281]. The same techniques have been applied with success in stochastic and markovian optimization of the base station placement, in collaboration with M. Coupechoux (INFRES) and J-M. Kélif (Orange Labs)

Finally, we continued the work on markovian segmentation of multispectral and multivariate images and Stochastic Expectation Maximization (SEM) hyperparameter estimation, with application in teledection (joint work with E. Bratsolis from Univ. of Athenes).

2.2.4 Audio-visual Identity/Imposture and Virtual Worlds

Faculty G. Chollet, C. Pelachaud, M. Sigelle, M. Charbit

Main events C. Pelachaud and T. Boubekeur, co-editors special issue on Facial Modeling, IEEE Computer Graphics and Applications, to appear in 2010; C. Pelachaud co-organizer of a Workshop held in conjunction with AAMAS 2009; she is since 2007 secretary of the Humaine association on emotion; she is part of the selection committee of ANR CONTINT (since 2008), ANR Blanc CSD9 Sciences Humaines et sociales (in 2009).

Projects ANR-SurfOnHertz (2010-2013), ANR-ORGAMI2 (2010-2013), AAL-vAssist (2011-2014), FUI-ARHOME (2011-2013), ANR KIVAOU (2008-2010), ANR MYBlog3D (2006-2010), CompanionAble: IP de IST (2008-2012), ANR blanc OUISPER (2006-2009), IST IP-CALLAS (2006-2010), IST STREP-SEMAINE (2008-2011), IST NoE-SSPNet (2009-2013), COST Action 2102 (2006-2010), ANR CECIL (2009-2011), ANR GV-Lex (2009-2011), ANR IMMEMO (2009-2011), Projet Web2.0 MyPresenting Avatar (2009-2011), ANR IMMEMO (2009-2011), Bilateral Contract Dialonics (2011-2013), Feder Anipev (2011-2014), FUI Play Serious (2011-2014), ILHAIRE (2011-2014), TARDIS (2011-2014), REVERIE (2011-2014), VERVE (2011-2014), STIC-Asie IMEI (2011-2013)

Two main directions of investigation are present in this theme:

Biometry and Speech/Face Synthesis/Recognition/Verification

The speech team was created in 1983 when Gérard Chollet joigned TELECOM-ParisTech (called ENST at the time). The focus was centered on coding, synthesis and recognition. In the 1990, speaker verification was added, followed by language identification seven years ago. At that time, audio-visual speech and speaker recognition became a topic of interest. The Biosecure network of excellence was an opportunity to promote open-source software for major biometric modalities (face, voice, audio-visual speaker, signature, iris, hand shape...) This led to the publication of a reference book ([303]) and to the development of databases, reference systems and benchmarking protocols. The FP6-Securephone project was an opportunity to integrate audio-visual identity verification on a mobile phone. Audio-visual identification also finds applications in video indexing (InfoM@gic project, PhD theses supported by OrangeLabs, ANR-SurfOnHertz...) Face tracking, super-resolution and 3D morphable models of faces are issues under study in the ANR-KIVAOU, ANR-ORIGAMI2 and FET-ILHAIRE projects and are evaluated in the context of the NIST-MBGC campaigns. Multilingual speech recognition is still a major topic for our team. Languages of interest include french, english, dutch, spanish, german and italian. Speech recognition and synthesis are being experimented in projects such as the ANR-MyBlog3D, the FP7-IP-Companionable, AAL-vAssist and FUI-ARHOME in the context of Spoken Dialogue Systems. Our team contributed to the development of the french version of the OpenMary TTS system. Our coder still needs to be improved in terms of speaker and language independence. A similar approach is developped in the context of the ANR OUISPER project aiming at the development of a Silent Speech Interface (driven from tongue and lip movements).

Interaction and Embodied Conversational Agent

We have been developing an interactive platform of an Embodied Conversational Agent GRETA (virtual entity endowed with human-like communication capabilities) (work done within the National projects MyPresentingAvatar, ANR IMMEMO, ANR CECIL, ANR GV-Lex and European projects NoE SSNet, Fet-Open ILHAIRE, STREP TARDIS, IP VERVE) [142, 252],[119]. Greta is open source platform under GPL licence (http://www.tsi.enst.fr/p̃elachau/Greta/; more than 100 downloads in 1 year; it is used in several international projects as well as material for academic purposes).

We have continued our research on expressive embodied conversational agents over several research directions:

- Emotional behaviors: we have developed a model to compute expressions of emotions as sequences of multimodal signals ordered through time and space [139, 250, 248, 247]. A language was derived to encapsulate these temporal and spatial relationships. Evaluation of this model has been undertaken. Perceptual studies were conducted to measure if such an approach increases recognition rate of emotions from the six basic set or of complex emotions. We use this model to increase the lexicon of emotional behaviors of the virtual agent. This work is part of the project ARN CECIL. Within this project, we have also developed a realistic skin rendering model of the face [815]. Within the project ANR IMMEMO, we are investigating the relationship between emotions and nonverbal behaviors using machine learning approach.

- Social behaviors: we are studying one particular behavior: smile [141, 251],[255]. It can take several conformational shapes (asymmetry of lip corners), temporal values (fast onset, short duration) and communicative functions (amused, polite, embarrassed smiles). At first we have developed an interface to allow human users to design a large variety of smiles onto a virtual agent. Then we have evaluated these signals in a discourse context. We are using the obtained results to develop a model to compute the user's potential perception of the virtual character's social stance depending on its smiling behavior. This work is part of the project EU NoE SSPNet.

- Interactive agents: within the EU project SEMAINE, we have developed a real-time platform allowing users to converse with virtual agents exhibiting different personality traits [111, 136, 149,

119],[172, 198, 174, 173, 197, 171, 237]. We are using this platform to several of our work. In particular regarding the modeling of behavior synchrony as a sign of engagement (part of SSPNet and Telecom-ParisTech Synch project) [153, 277, 276].

- The platform of the virtual agent Greta has been rewritten to be independent on the technology it runs on, as well as on its embodiment (part of the project Web 2.0 MyPresentingAvatar) [252]. The new version can also control the NAO robot [228, 230, 229, 214, 258]. This work is part of the ANR project GV-Lex.

Perspectives: in the near future we will continue our work on social signals (EU project SSPNet) and will work on laughter (EU project ILHAIRE). We will continue our work on synchrony not only in dyads but also in large conversational groups (EU project VERVE). We will extend our work on human-agent interaction system, in particular regarding dialog system (EU project TARDIS).

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2.4 References

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Chapter 3

Statistics and Applications (STA)

Team leader F. Roueff (P, on sabbatical leave at Univ. Catholique de Louvain, Belgium, 09/2010–12/2010).

Faculty K. Abed Meraïm (MC), G. Blanchet (DE), P. Bianchi (MC), O. Cappé (DR CNRS), J-F. Cardoso (DR CNRS), M. Charbit (P), S. Clémençon (P), C. Févotte (CR CNRS), G. Fort (CR CNRS), A. Garivier (CR CNRS), J. Jakubowicz (MC, until 10/11), C. Lévy-Leduc (CR CNRS), E. Moulines (P), J. Najim (CR CNRS), F. Roueff (P).

PhD students A. Attaya (11/10–), S. Audière (10/08–12/11), S. Barembruch (10/07–09/10), A. Bader (12/10–), E. Chautru (10/09–), A. Dematteo (10/11–),M. Depecker (10/07–12/10), M. Jala (11/10–, also with Orange Labs Issy-Les-Moulineaux), E. Kaufmann (09/11–), M. Kharouf (01/07–06/10), O. Kouamo (09/07–01/11, also at Univ. Yaoundé 1, Cameroon), N. Ksairi (10/08–03/10, also with Supélec), S. Le Corff(10/09–), A. Lefèvre (10/10–, also with INRIA/Sierra) A. Lung-Yut-Fong (10/08–12/11), N. Mahler (02/08–12/11, also at ENS Cachan), G. Morral Adell (10/11–), S. Philippi (10/07–11/10), S. Robbiano (10/09–), P. Sendorek (04/11–),A. Schreck (09/2011–), N. Sokolovska (11/06–02/10), M. Thameri (10/10–), J. Villard (11/08–12/11, also with Supélec), T. Wohlfarth (02/10–), J. Yao, R. Zhang (10/10–), B. Zheng (02/10–).

Post-docs, sabbaticals T. Rebafka (12/09–09/10), O. Dikmen (02/10–01/12), C. Dhanjal (11/09–10/11), B. Miasojedow (10/11–08/12), R. Gaudel (09/10–08/11), A. Kammoun, L.-V. Lozada (02/10–08/10,02/11–08/11, N. Mahler (08/11–), L. Oudre (10/11–01/12), D. Rohde (07/10–06/11), A. Saumard (11/10–11/11); M.S. Taqqu (Prof. at Boston Univ., 3 months), V. Reisen (MC, Vitória Univ., Brazil, 3 months).

Faculty [IT, CNRS]	[5.5, 5.3]
PhD students	7.2
Post-docs, sabbaticals	4
Defended theses	6
Defended HDR	4
Journal papers [published, to appear]	[75,32]
Papers in conference proceedings	96
Grants [public, private] (k€)	[655,576]

3.1 Objectives

During the last twenty years, scientific discovery has become increasingly dependent on the collection and interpretation of data and, more generally, quantitative information. There's a general consensus that the core academic disciplines that are most relevant to the information society encompass computer science, mathematics and statistics. The Statistics and Applications (STA) group at LTCI plays an important role in this context by focussing on statistical methods and their application in domains relevant to the information society at large.

The members of the STA group are actively participating to teaching, typically at the master level and in the fields of probability, statistics, signal processing, machine learning and applied mathematics, at Télécom ParisTech but also in several other Grandes Ecoles of the ParisTech institute (Ecole Polytechnique, ENSAE) and universities (M2 *Modélisation aléatoire* at Paris 7 Denis Diderot, M2 *Modélisation Vision Apprentissage* at ENS Cachan, M1 *Mathématiques de la Modélisation et de la Décision* at University Paris-Dauphine).

The STA group has developed long term research collaborations with several academic Parisian partners such as Univ. Paris 7 Denis Diderot (LPMA and ADAMIS), Univ. Paris 10 Nanterre (MODAL'X), Univ. Paris-Est (IGM), Institut d'Astrophysique de Paris, Univ. Paris-Dauphine (Cérémade), research groups in other ParisTech schools (CMBIO, Mines and CERMICS and CERTIS, Ponts) and with the Ecoles Normales Supérieures Ulm (INRIA projects TREC and WILLOW) and Cachan (CMLA). Such collaborations are essential to the group for achieving long term research programs, and, more generally, for exchanging ideas and views within a stimulating academic environment.

These academic relationships parallel industrial partnerships. The latter have been developed in the framework of national research projects (ANR), bilateral contracts, or the funding of Phd theses (through CIFRE conventons). Beside favoring our financial autonomy, such partnerships bring practical applications which are helpful for our opening and to remaining active on new research prospects. In the last years, regular industrial partners include the Commissariat à l'Energie Atomique (CEA), Thales Avionics, Renault, France Télécom R&D and Direction Générale de l'Armement (DGA), Amesys, Natixis, Liligo.com.

The group enjoys a high national and international recognition with editorial board members in high quality journals such as Bernoulli, ESAIM P&S, Stoch. Proc. and their Appl. (E. Moulines) and the Journal of the Royal Statistical Society, Series B (O. Cappé), DSP journal (K. Abed Meraïm) as well as regular participation as program comity members in the major international conferences(IEEE ICASSP, IEEE statistical Signal Processing workshop, International Conference on Machine Learning, Neural Information Processing Systems, European Signal Processing Conference) or associate editors of special issues (Journal on Advances in Signal Processing). The group regularly organizes or co-organizes scientific events such as the summer school (C. Févotte, *Ecole d'Eté en traitement du signal et des images* in Peyresq (2010)), special sessions in international conference (G. Fort, AMSDA 06/11); national workshop (G. Fort, GDR ISIS

11/11, P. Bianchi, GDR ISIS 02/12), as well as recurrent scientific seminars in the Parisian region (*séminaire parisien de statistiques*, ParisTech Machine Learning reading group *Smile*). E. Moulines received the Silver Medal of CNRS in October 2010, for his work on Probabilities applied to Signal Processing and Machine Learning. He was awarded the FRANCE TÉLÉCOM award of the french Science Academy (grand prix de l'Académie des sciences).

C. Lévy-Leduc and F. Roueff were invited to give talks at the 58th World Statistics Congress of the International Statistical Institute (2011) and at the "Journées MAS" in 2010. P. Bianchi was invited to give talks at the 5th ICST International Conference on Performance Evaluation Methodologies and Tools (2011) and at the "Journées MAS" in 2010, along with C. Lévy-Leduc and F. Roueff.

3.2 Main results

3.2.1 Statistical Learning

Contributors O. Cappé, A. Garivier, S. Clémençon, C. Févotte, C. Lévy-Leduc, E. Moulines, F. Roueff.

Projects ANR projects MGA (Graphical Models and Applications, 2008–2011), BEMOL (Prediction of internet users' behavior, simulation and collaborative filtering, 2008–); Contracts with France Telecom R&D (two theses) and and Liligo.com (1 phd thesis), Renault (1 phd thesis).

The group has a long standing interest in **graphical models** and, more generally **Bayesian methods**. In the context of the MGA project, we contributed both to general methodological questions (in particular regarding the online learning of parameters [556, 531]) and to the advance of methods for statistical natural language processing. On the latter topic, as a follow up to our work on the use of Lasso (or L1) type regularization for training of large scale conditional random field (CRF) models [393], we developed an highly efficient software called `Wapiti` [507]. `Wapiti` is faster than existing alternatives and is highly competitive for sequence tagging tasks as demonstrated, in particular, by the independent evaluations posted on MLcomp `http://mlcomp.org/`, a community website for objective comparison of machine learning programs. On the other hand, we have continued our statistical investigations on Variable Length Markov Models (see for instance [357]).

Since 2007, the group has a raising interest in **reinforcement learning** and its applications to telecommunications. The PhD of Sarah Filippi (2007-2010), funded by Orange Labs, was motivated by cognitive radio problems [331] and targetted internet advertisement [485]. These non-stationary applications brought us into investigating adapted bandit algorithms [488]. We also strongly defend the use of Kullback-Leibler divergence in optimistic algorithms: we proved in [487] the optimality of a resulting upper-confidence bound algorithm for bandit problems, and we proposed in [451] an improved algorithm for reinforcement learning in discrete Markov Decision Processes. Recently, we joined the ANR project Bandhits and co-advise a new PhD thesis on Bayesian methods for bandit problems. Moreover, in the PhD thesis of Marjorie Jala funded by Orange Labs, we propose active learning methods for the estimation of upper quantiles of the exposition to electromagnetic fields which are strongly inspired by bandits algorithms.

In the context of supervised learning, significant advances in the ranking problem from practical and theoretical perspectives both at the same time have been made in [337], [338], [339] and [341]. Strong empirical evidence supporting the efficiency of the techniques thus developped are presented in the PhD thesis defended by Marine Depecker (2007/10, in collaboration with Renault Technocentre). This work is now prolongated by the PhD thesis of S. Robbiano, currently considering "multi-class" extensions and plug-in approaches, see [459].

Unsupervised ranking, sometimes termed as "rank aggregation", is also a crucial issue in e-commerce, in database middleware or in information retrieval. In the context of the Digiteo project

Bemol (in collaboration with ENS Cachan and the company "Mille-Mercis"), novel techniques for rank aggregation have been developed in [458], [471] and [489], offering promising alternatives to the classical "median approach". In the unsupervised domain, theoretical grounds for pairwise clustering methods are set in [455].

Statistical learning based on functional data is another emerging topic of the group. Whereas, the PhD thesis of N. Mahler (2008/10, in collaboration with ENS Cachan and Strategic Risk Management) and that of R. Zhang (2010/13, in collaboration with ENS Cachan and BNP Exane) deal with applications of machine-learning to Finance, where input and output data are naturally multivariate time-series, the PhD thesis of Till Wohlfarth focuses on travel price forecasting, *cf* [535] and [534], and also faces issues raised by time-series in the context of nonparametric prediction. Extensions of recently developed nonparametric scoring methods have also been proposed in the functional situation, see [456]. More generally, techniques for dealing with structured data such as graphs have also been studied within the group (projects ANR Viroscopy, Digiteo Bemol), see [457], [467], [468], [559] or [470].

Finally, the design of model selection techniques based on data-dependent complexity penalization is a future line of research of the group, see [533] (Futur & Rupture "Meta-Rank" 2010/11, Digiteo project "Crank-Up" in collaboration with the Lip6 of UPMC 2011/12).

3.2.2 Blind Source Separation and Identification

Contributors K. Abed Meraïm, J-F. Cardoso, C. Févotte, M. Charbit, E. Moulines, A. Garivier, P. Bianchi.

Projects ANR project TANGERINE (Theory and applications of nonnegative matrix factorization, 2009–), research contract with CEA, PEA project AINTERCOM with DGA/Amesys (Plan d'étude amont, 1 phd thesis), Cap Digital project ROMEO funded by Ile-de-France region (1 thesis with AAO team), research contract with WITHINGS (Master thesis).

Blind source separation is an important topic of statistical signal processing. In the ROMEO project, in collaboration with AAO team, our task is focused on the blind source separation (BSS) topic using a microphone array. Source separation is a very important step for human-robot interaction: it allows latter tasks like speakers identification, speech and motion recognition and environmental sound analysis to be achieved properly. Within this framework, we focused on the challenging problem of blind source separation in a real reverberant environment using combined beamforming and sparsity based BSS techniques [519, 520].

Data is often nonnegative by nature, consider for example pixel intensities, amplitude spectra, occurrence counts, food consumption, user scores or stock market values. Nonnegative matrix factorization (NMF) is a linear regression technique with growing popularity in the fields of machine learning and signal/image processing. NMF, and its extension to nonnegative tensor factorization (NTF), are young research topics that call for answers to many open problems. The background for most of the research on NMF in the Stats group is the ANR project TANGERINE. The following topics have been addressed: model selection and learning algorithms [352],factorization with structural constraints [511, 481], online and stochastic algorithms [512, 484]. Several applications have been considered such as music transcription [379, 380], audio source separation [381, 557] and identification of dietary behaviors [340].

A final field of interest for non-cooperative communications is **blind signal source identification** (or detection). It is assumed that the signal coming from an unknown transmitter has been intercepted. In the context of AINTERCOM project, we developed blind demodulation approaches using approximate Maximum Likelihood methods [317], [316].

3.2.3 Sensor Networks

Contributors K. Abed-Meraim, P. Bianchi, M. Charbit, G. Fort, J. Jakubowicz, E. Moulines, J. Najim, F. Roueff.

Projects ANR projects SESAME (consistent estimation and large random matrices), SVELTE (Système d'évaluation de la dépense énergétique et de la condition physique pour la prévention et le traitement de l'obésité), C-FLAM (Coordination Flotilla Localization and Mapping), research contracts with THALES-Valence (1 phd Thesis).

Our interest lies in applications of mathematical and statistical tools to the performance evaluation and the optimization of sensing and communication systems. The term *sensor* should be understood in a wide sense, including physical sensors (accelerometers, microphones, etc.), smart phones, processors or mobile robots. Both centralized and decentralized network architectures have been investigated. Centralized systems are characterized by the existence of a fusion center which gathers and processes the sensors' observations as a whole. On the opposite, decentralized systems are formed by autonomous sensors and rely on distributed algorithms to achieve the global mission. A large part of the results in this theme have been obtained in collaboration with the COMNUM research group (COMELEC) (see [371, 441] for some examples of joint works).

In the framework of **centralized systems**, a special attention has been devoted to applications to **source detection and localization**. In the context of a joint work with the CEA and CNRH-hospitals (ANR project SVELTE), signal processing and classification methods have been applied to accelerometric data collected by body sensors [420]. An industrial contract with CEA leaded to original algorithms for the localization of infrasound sources and the estimation of their angles of arrival [547].

Motivated by application to *cognitive radio* and sensor networks (ANR project SESAME), we investigated several problems related to hypothesis testing in centralized sensor networks. We analyzed the error probabilities of different test statistics for various probabilistic model [326, 327, 420]. In the later references, original methodological tools are developped in the asymptotic regime where the number of sensors tends to infinity, allowing to obtain closed form expressions of the **error exponents** associated with the tests. In particular, the design of relevant quantizers maximizing the error exponent is an important issue, which has been studied in [420]. On the other hand, **random matrix theory** has been used as a central tool for the analysis of detection problems in large sensor networks. For instance, the study of the fluctuations and the large deviations of the extreme eigenvalues of sampled covariance matrices are crucial to characterize error exponents [326]. In parallel, random matrix theory has also been extensively used for solving wireless communication problems. We have recently been able to complete the performance analysis of *Ricean* Multiple Input Multiple Output (MIMO) channels [349, 362]. The analysis of Ricean channels is difficult because of the presence of a line-of-sight component. A thorough study of the mutual information of Ricean channels has been performed, culminating with the computation of the ergodic capacity.

In the framework of **decentralized systems**, we investigated the issue of distributed optimization and distributed statistical estimation by means of **gossip algorithms**. Gossip algorithms provide efficient cooperation techniques which allows the sensor to exchange messages and share their local information in an efficient fashion, in such a way that a consensus is eventually achieved in the network. We study the convergence of these algorithms in [438] and in a recent journal submission, and analyzed the asymptotic behavior of the estimation error in [441] where we also discuss application to power control. Applications to smart grids have been investigated in [472]. In the context of ANR project C-FLAM, we also investigate an application to motion coordination of autonomous underwater vehicles in a recently submitted paper. In the scenario of large wireless communication networks, we also investigated distributed resource allocation in [371]. Finally, a new communication protocol for *relay channels* has been proposed and analyzed in [503] and in a journal paper currently in revision.

3.2.4 Monte Carlo Methods

Contributors O. Cappé, S. Clémençon, G. Fort, E. Moulines.

Projects ANR Projects BigMC (Issues in large scale Monte Carlo, 2009–2012), C-FLAM (Coordination Flotilla Localization and Mapping, 2008–2011); Siminole (Large-scale simulation-based probabilistic inference, optimization, and discriminative learning with applications in experimental physics, 2011–2014) and Viroscopy (Stochastic modeling and statistical inference for propagating infectious diseases: from micro to macroscopic behavior , 2008–2011). Digiteo project Bemol (2009–2011).

The group has acquired a high reputation in the domain of Monte Carlo methods by working on Sequential Monte Carlo (also called Particle Filtering), Markov chain Monte Carlo (MCMC) and novel Monte Carlo approaches at large. The group contributes actively to methodological and theoretical advances in Monte Carlo methods and also works on selected applications, most often in the context of collaborative projects.

New challenges in MCMC methods deal with adaptive methods and interacting Monte Carlo processes. The group has a strong expertise in convergence analysis of classical MCMC algorithms; in the past two years, the group answered to some of these new challenges by developing new tools for the theoretical study of these new MCMC samplers. These works have been developed in collaboration with researchers from Paris 6, Univ. Paris Est (in the context of the BigMC project), and Univ. of Michigan (USA) [312, 313, 555, 355].

In the context of the ANR project C-FLAM, lead by the LIRMM, the group developed new Simultaneous Localization and Mapping algorithms. Our approach consists in answering the Localization problem by using Sequential Monte Carlo methods, and the Mapping problem by adapting online Expectation-Maximization algorithms (previously proposed by our group [329, 556]) [509, 486].

Interacting and branching particle system techniques and sequential Monte-Carlo methods have been developped and used for *rare event simulation/probability estimation* in the context of food risk analysis and that of mathematical epidemiology (ANR project Viroscopy - 2008/11), see [336] and [322]. In [489] (Digiteo project Bemol - 2009/11), dedicated MCMC techniques have been developped in the purpose of rank aggregation.

Following our past experience in the context of the ANR project ECOSSTAT, where the group contributed to the development of an original adaptive importance sampling scheme [421, 367] (with associated distributed software implementation [367]) for Bayesian analysis of multi survey cosmological data, we launched a new project in this field in 2011. This project called Siminole and also funded by the ANR is lead by the LAL in Orsay and our contribution is focused on the exploitation of cosmic ray data gathered in the context of the Auger experiment.

3.2.5 Time Series

Contributors O. Cappé, M. Charbit, S. Clémençon, C. Lévy-Leduc, E. Moulines, F. Roueff.

Projects Research contract with Natixis (1 phd thesis), Research contract with Echosens (1 phd thesis), CNRS-FRS-WBI mobility program, Project DGA REI (Recherche Exploratoire et Innovation) ISREPTMu (Interception de signaux radar en présence de trajets multiples), ANR project Mataim (Anisotropic models for textures with applications to medical imaging).

Following the thorough analysis of semi-parametric Wavelet methods for estimating the **long memory parameter** that we conducted in the past years, we have explored new directions in this topic: robust estimation of the memory parameter ([368]), non stationary (change-point and locally stationary) long memory modelling ([558, 369, 389]), non-Gaussian and non-linear long memory processes ([334, 390]). We have studied the asymptotic properties of a new robust estimator of the autocovariance of Gaussian processes having either short or long-range dependence in [375]. These results have been established thanks to the asymptotic properties of general U-processes in the long-range dependence context of [374]. A large part of these works were conducted in a long standing collaboration with M.S. Taqqu (Boston Univ.).

We also pursued our work on the topic of **change point** detection. The method proposed in a previous research project for centralized anomaly detection in the Internet traffic has been

extended to deal with a decentralized anomaly detection approach in [376] and [517] in which a robust change-point detection method based on multivariate rank statistics is proposed. Finally, we proposed a multiple change-point estimation with LASSO in [363].

The Markov assumption being among the weakest assumptions involved in time series modelling, renewal theory for **Markov processes** has been used for analyzing the (asymptotic and non asymptotic) behavior of sample means, U-statistics and extreme-value statistics based on general Markovian data, in [321], [335] and [323]. Preliminary extensions to Hidden Markov Chains are developped in [465].

Ongoing applications in statistical signal processing based on time series or random fields modelling include radar processing and medical diagnosis [530, 733].

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Chapter 4

Image processing and understanding (TII)

Team leader I. Bloch (P).

Faculty A. Almansa (CR1 CNRS, HDR), E. Angelini (Assoc. P, HDR in 2011, on leave in Australia for six months in 2010), I. Bloch (P), T. Boubekeur (Assoc. P), H. Brettel (CR1 CNRS, HDR), M. Campedel (Assoc. P), J. Delon (CR1 CNRS, HDR in 2011), E. Eisemann (Assoc. P, since 12/09), Y. Gousseau (P, HDR in 2009), S. Ladjal (Assoc. P), H. Maître (P), P. Memari (CR2 CNRS, since 10/11), J.-M. Nicolas (P), S. Rital (Research Engineer), M. Roux (Assoc. P), H. Sahbi (CR1 CNRS, HDR in 2011), T. Tanzi (P, until 2010), J. Tierny (CR2 CNRS, since 10/10), F. Tupin (P).

PhD students *Defended (dates are for the defense):* E. Aldea (12/09), J. Anquez (9/09), C. Le Men (9/09), D. Lesage (10/09), J. Rabin (12/09), N. Sabater (12/09, with ENS Cachan).
J. Baussé (10/10), M. Bredif (5/10), D. Cerra (5/10), N. Chenouard (1/10), D. Craciun (7/10), G. Fouquier (2/10), B. Galerne (12/10, with ENS Cachan), G. Lehureau (4/10), C. Mallet (11/10), F. Mosca (10/10), T. Napoléon (7/10), G. Palma (2/10), A. Shabou (11/10), H. Sportouche (12/10), N. Widynski (11/10, with UPMC), J. Wojak (12/10).
S. Audière (12/11), P. Birjandi (9/11), P. Blanchart (9/11), M. Bouali (6/11), E. Bughin (10/11, with ENS Cachan), C. Deledalle (11/11), V. Duval (6/11), G. Facciolo (3/11, with Univ. Pompeu Fabra), G. Hochard (3/11), M. Marim (4/11), B. Petitpas (12/11, with Univ. Marne la Vallée), H. Soubaras (1/11), M. Tepper (3/11, with Univ. Buenos Aires), C. Vanegas (1/11), G.-S. Xia (3/11).
Current (dates are for the beginning of PhD): C. Aguerrebere (4/11), N. Bourdis (1/10), B. Buchholz (10/09), J. Caron (10/08, with Univ. Amiens), F. Dellinger (10/10), N. Faraj (12/09), M. Gargouri (11/11), N. Geeraert (9/11), I. Ghorbel (2/09), A. Graciano (9/08, with Univ. Sao Paulo), T. Guillemot (10/10), C. Herold (12/10), M. Hollander (1/10), J. Huang (10/09), Q. A. Le (10/09), Y. Le Montagner (10/10), B. Mazin (9/10), A. Newson (9/10), G. Pizaine (6/09), J.-B. Poisson (10/10), G. Quin (9/10), A. Roman Gonzalez (9/09), L. Schemali (1/11), P. Schmitt (10/11), X. Su (10/11), G. Tartavel (10/11), J.-M. Thiery (10/09), Y. Traonmilin (7/11), G. Vialaneix (12/09), U. Verma (10/10), P. Vo (10/10), Y. Yang (10/10), F. Yuan (9/10-9/11).

Post-docs, engineers and sabbaticals J. Anquez (1/10-6/10), L. Babou (7/09-2/11), A. Bretto (1/10-8/10), F. Cao (9/10-4/11), S. Chevallier (3/11-8/11), S. Dahdouh (10/11-12/11), J.-P. De la Plata (8/09-7/11), E. Erdem (7/09-3/10), F. Fayard (5/10-4/11), G. Fouquier (7/09-3/11), M. Horta (4/11-9/11), S. Lee (7/09-2/11), X. Li (6/09-6/10), M. Lindenbaum (3/11-8/11), K. Loquin (3/10-10/11), A. Marquez (9/9-10/10), M. Moghrani (9/09-8/10), V. Pascucci (6/11), Y. Pinto (3/11-10/11), T. Ritschel (5/10-9/11), X. Rondeau (10/09-3/11), Y. Rouchdy

(10/09-12/10), H. Sportouche (4/11-12/11), O. Tankyevych (1/11-8/11), C. Vanegas (1/11-4/11), A. Zureiki (7/09-10/09).

External collaborators M. Datcu (CoC chair, until 6/10).

Faculty [IT, CNRS]	[11, 4.6]
PhD students	29
Post-docs, engineers and sabbaticals	10
Defended PhD theses	36
Defended HDR	4
Journal papers [published, in press]	[105, 12]
Papers in conference proceedings	177
Chapters and books	25
Grants [public, private, european] (k€)	[1461, 1203, 120]

Table 4.1: The reference period for the main TII figures is from July 2009 to December 2011, except for publications in journals, conferences and books where it covers January 2009 to December 2011.

4.1 Objectives

The objective of the group is to develop methodologies and theoretical tools for image, scene and 3D object processing and interpretation. The main approach consists in solving globally complex problems, based on rigorous theoretical bases, and integrating multiple and complementary techniques, for deriving interpretations from data. Applications focus on medical imaging, aerial and satellite imaging, natural image analysis. Contributions of the group can therefore be found at theoretical level (knowledge and information representation and modeling, in 2D as well as 3D, processing, interpretation and reasoning on spatial data), at algorithmical level (in particular to implement the developed models for large and complex data sets), and at applicative level. The group is well recognized, in both academic, institutional and industrial domains. It has numerous collaborations with other universities, and is supported by grants and contracts. The different research activities are closely linked together, which is one of the strong features of the group.

Over the last two and a half years, two professors left, one to join a research team in Sophia-Antipolis at Mines ParisTech, and the other at the end of the CoC joint laboratory with CNES and DLR. On the other hand, during this period the group has benefited from the appointment of two CNRS researchers and one associate professor, strengthening research axes mainly in computer graphics, but also in medical imaging. The good reputation of the group and its visibility, in France as well as at an international level, are confirmed by the number of publications, but also by the number of collaborations, mentioned below for each research axis, and by its attractiveness for CNRS candidates, post-docs and PhDs.

The scientific animation of the team includes a general seminar and several specific ones (medical imaging, compressed sensing, radar imaging, 3D and computer graphics...). PhD candidates are invited to present their work at the end of the first year of their PhD, so as to gather comments from the whole team and initiate discussions among them, thus favoring cross-fertilization of ideas. A mid-term evaluation is also organized for all PhD candidates. We also pay attention to the accompanying process of the PhD theses, beside the direct scientific supervision, including a help to prepare their future.

4.2 Main results

The main research results obtained during the period mid-2009-2011 are presented below for the research areas of the TII team, both from a theoretical and methodological point of view, and from an application perspective.

4.2.1 Mathematical methods for images

Faculty A. Almansa, I. Bloch, J. Delon, Y. Gousseau, S. Ladjal, H. Sahbi, F. Tupin.

Projects ANR projects (CALLISTO, MATAIM, OTARIE, FREEDOM), FUI (9th call) CEDCA, Cifre and CNES PhD fundings, CNES research funding, DGA/REI MRIS and Tracking, ECOS Sud (U06E01), STIC AmSud (MMVPSCV).

Collaborators L. Alvarez (U. Gran Canaria, Spain), J.-F. Aujol (U. Bordeaux 1), F. Cao (DxO Labs), V. Caselles (UPF, Spain), T. Buades, A. Desolneux, S. Durand, B. Galerne, T. Hurtut, L. Moisan (U. Paris Descartes), S. Dubuisson (UPMC), M. Lindenbaum (Technion, Israël), S. Masnou (U. Lyon 1), J. Darbon, J.-M. Morel, M. Nikolova (ENS-Cachan), L. Denis (U. Saint-Etienne), P. Musé (U. de la República, Uruguay), J.-C. Olivo-Marin (Institut Pasteur), A. Pardo (U. Catolica, Uruguay), M. Mejail (UBA, Argentine), P. Pérez (Technicolor, Rennes), G. Peyré and J. Salomon (U. Dauphine), J. Rabin (U. Caen), J. Salmon (U. Denis Diderot), M. Sigelle (Télécom ParisTech), A. Sobolevskii (Poncelet Lab., Moscou), L. Vese (UCLA, USA), W. Wang (U. Wuhan, China), A. Bretto (U. Caen).

Texture and natural images modeling

This research theme deals with the stochastic modeling of natural images. First, generative models taking into account scaling phenomena in natural images have been developed. These models (dead leaves, shot-noise, transparent models) are grounded in the theory of marked point processes, whose marks are geometrical structures. The most recent works in this area are concerned with texture synthesis using spot-noise models, see [618] and the companion online IPOL demo [1], as well as the stochastic modeling of transparency [617]. Much effort has also been devoted to the study of the impact of various restoration image models on the textured aspects of natural images, as explained below, see [588, 601, 602]. An important achievement is that a model previously developed in our team, the *scaling dead leaves model*, has been retained by the company DxO to evaluate the ability of imaging devices to preserve textures in natural images, and as such is routinely used by the main industrial actors in the domain, ranging from Nikon to the NASA. Oriented toward public audience, the model has appeared in the 2011 FNAC summer catalogue for DSLR cameras.

Image analysis and computer vision.

These last years, we have developed or applied various mathematical tools for the analysis, indexing or matching of images.

Among these tools, let us first mention optimal transportation equations. These equations enable the definition of metrics between weighted features and yield elegant ways to compare images. We have recently proposed two complementary studies on the subject of optimal transportation on the circle, one in a continuous setting [591] and the other one in a discrete setting [651, 653]. This last study compares for different retrieval tasks the transportation metrics with the classical distances used in computer vision.

Another methodological aspect of our researches deals with *a contrario* methods, developed by Desolneux et al. to automatically fix detection thresholds for image analysis. In particular,

[1] http://www.ipol.im/pub/algo/ggm_random_phase_texture_synthesis

we applied these methods to the problem of image matching. We have developed a complete chain for the matching of images from local descriptors (such as SIFTs). This procedure encompasses the descriptors themselves, a transportation metric adapted to circular histograms (relying on optimal transportation), an unsupervised matching criterion, and a validation, RANSAC-like step [651, 854]. In the particular case of block-matching of epipolarly-rectified stereo pairs, the *a contrario* methodology, complemented with more classical criteria to avoid self-similarity and fattening effects has proven very efficient to build up dense sets of reliable matches [658]. This yields disparity maps computed up to an unprecedented accuracy level, closely matching our theoretical accuracy estimation [659]. Check also the accompanying online demo [2]. The a contrario methodology also allows for parameterless and unsupervised graph-based clustering [666] without any shape prior. Applications ranging from high-dimensional data analysis to restoration of images and 3D data are being explored.

Another approach for point matching was developed for change detection problems: a change detection algorithm was introduced, based on a new interest point matching approach combined with the epipolar geometry. The main contribution of our method includes: (i) a statistical-based criterion combined with the geometry of scenes, able to reliably detect changes in pairs of images and (ii) the extension of the method in order to handle archives of videos where the temporal coherency is exploited to further enhance the performances. In this context, the validity of our method is demonstrated through a realistic ground truth including many labeled changes [749].

Still in a probabilistic framework, during the PhD of A. Shabou, new graph-cut based optimization approaches of Markovian models have been proposed. They rely on a random sampling of sub-sets of states for three global moves (expansion, swap and jump) with associated graph constructions. They allow an efficient compromise between memory size and quality of the obtained optimum [868].

Among the other tools that we have investigated and applied, let us quote topographic maps. This tool turns out to be particularly efficient for the indexing of satellite images [636], the indexing of texture [672] or the analysis of artistic line-drawings [626], even in the presence of a wide range of geometrical and radiometric changes. The method developed in [672] is an extension of the classical granulometry from mathematical morphology.

Restoration of images and image sequences

In the last few years, our group has become quite active in the field of image restoration.

In the case of single-frame restoration, many denoising problems have been tackled. We have proposed several extensions and in-depth studies of Non-Local Means methods. In [602], we propose an in-depth study of such denoising methods and give a method for the automatic and local setting of parameters. In [588], it is proposed to use adaptive and generic patches to improve denoising results. In [586], the method is extended in a probabilistic approach, allowing to process images for which a distribution of the parameters of interest is available (Poisson, Gamma, Wishart distributions...). This framework also permits to process vectorial data [587].

In the domain of impulsive degradations, we have conducted an extensive study of the popular TV-L1 model, showing that it is equivalent to some morphological filtering and acts as a granulometry [601]. The TV regularization model under local L2 constraints showed effective in the context of irregularly sampled blurred and noisy data [611, 725]. It was also shown useful for destriping MODIS images [641].

In order to restore larger and more extreme degradations of images, we also took interest in image inpainting. We developed an approach relying on the automatic combination of patch-based methods and geometrical interpolation [573], permitting the restoration of both the texture and the geometry of images over large regions. This subject has also been addressed in a related work on the variational interpretation of copy-paste methods [630]. Some of the previous works require an accurate knowledge of internal camera parameters like the intrinsic blur kernel (PSF). In [585] we showed that accurate estimation of the PSF is well posed, without regularization,

[2] http://www.ipol.im/pub/demo/bms_binocular_stereo_pipeline/

provided an appropriate white noise image is used for calibration. See the accompanying IPOL demos [3] [4].

Recently, we have oriented an important part of our restoration activity toward multi-frame restoration. This research direction is intimately related to different research projects, in particular one ANR project (ANR FREEDOM JCJC 2007-2011) on movie restoration, one collaborative project with the firm DxO Labs, and one PHD thesis supervised in collaboration with the firm Technicolor. As part of the research project FREEDOM, we have proposed two contributions related to contrast and color: the first one concerns the restoration of local radiometric problems in image sequences [589], and the second one is an efficient method for the removal of artifacts [652] introduced by contrast and color changes. Another contribution deals with the detection and restoration of occluding defects in movies [753].

Tracking

Another contribution based on probabilistic methods addresses tracking issues in image sequences, by incorporating different types of information in the probabilistic model [608, 671]. Our approach is based on particle filtering, and we have proposed original ways to introduce spatial relations, represented in a fuzzy set framework (see Section 4.2.2), either between different positions of one object during time, or between several objects for multiple object tracking problems (PhD of N. Widynski). In this case, we also proposed a ranked partitioned sampling method, so as to handle the most visible objects first. Multiple appearance models and adaptive fusion of multiple cues have also been proposed. These new models and the associated algorithms provide better results than state of the art methods, in terms of accuracy of tracking, object association, and handling partially occluded objects. Multiple object tracking has also been addressed using multiple hypotheses methods, for biological applications in cluttered environment [765, 766] (collaboration with Institut Pasteur).

Another topic is multi-view tracking of objects in video surveillance, which consists in segmenting and automatically following objects through different camera views. In this work, we present a multi-view object matching and tracking approach based on canonical correlation analysis. Our method is purely statistical and encodes intrinsic object appearances while being viewpoint invariant. We have shown that our technique is easy-to-set, theoretically well grounded and provides robust matching and tracking results for traffic surveillance [799].

Tracking has also been exploited in segmentation problems, in particular for elongated structures such as blood vessels, using particle filters and minimal paths according to adaptive metrics (see also Section 4.2.5).

A new project on multi-view tracking has also been launched, based on particle filter, to estimate the shape parameters and the pose of a face for authentication based on face matching (collaboration with LIP6 and Morpho, PhD of C. Herold).

Mathematical morphology

In parallel to the work mentioned above on granulometry and TV restoration, our contribution in mathematical morphology concerns the representation and handling of qualitative and imprecise information in different settings, such as formal logics [560, 731], including description logics for ontological reasoning, fuzzy sets [568], and more recently hypergraphs [746] and bipolar information [745, 569, 816] to model both positive information (observations, preferences) and negative information (constraints). In all these frameworks, we proposed appropriate complete lattices and connectives, leading to good properties of mathematical morphology operations. These operations can then be used for various tasks, such as preference modeling and spatial reasoning.

[3] http://www.ipol.im/pub/algo/admm_non_blind_psf_estimation/

[4] http://www.ipol.im/pub/algo/damm_blind_psf_estimation_from_scaled_image_pairs/

4.2.2 Image understanding and spatial reasoning

Faculty I. Bloch, M. Campedel, H. Maître.

Main events CIARP 2010 conference.

Projects ANR DAFOE, CNES PhD thesis and research projects funding, collaboration with J. Atif (LRI), C. Hudelot (ECP), J. Inglada (CESBIO), R. Cesar (U. Sao Paulo, Brazil).

Our work on modeling spatial relations within the fuzzy set framework has evolved towards complex relations such as *along*, *surrounds*, *to go across*, *parallel to*, both for individual objects and for groups of objects [665, 716, 882]. New fuzzy connections have also been proposed, and applied to filtering problems [646, 650]. These relations are based on mathematical morphology operators, and their use for spatial reasoning was formalized in different settings (PhD of G. Fouquier, C. Vanegas, A. Graciano). One relies on graph-based reasoning, where a graph modeling the available knowledge about a scene (on objects and their spatial relations) guides a sequential segmentation and recognition process [616]. The order in which structures are segmented is adapted to each image, by combining spatial relations and saliency information. In case of failure of a segmentation step, a backtracking procedure was proposed as well. Another approach relies on the search for a global solution by expressing the recognition as a constraint satisfaction problem [647, 716], or as an inexact graph matching problem [648]. Finally ontological reasoning was proposed, by introducing mathematical morphology operators in description logics in order to define spatial relation concepts [816]. In the same line, a preliminary work associating description logics, formal concept analysis and mathematical morphology was developed. The first reasoning service we proposed within this framework is abduction, in order to provide the best explanation of a scene according to the available knowledge [731].

During the project DAFOE4app (ANR project, 2007-2010), an engineering collaboration between Telecom ParisTech and Mondeca has been initiated. The common goal was to create and develop an interactive tool to assist satellite image interpreters. Results have been obtained, with the support of CNES, in the creation (and free diffusion) of two OWL ontologies: the image ontology is able to describe the image content and the feature extraction process whereas the scene ontology identifies land cover classes; these ontologies integrate spatial relationships between image objects as well as other semantic relationships. A prototype of the annotation tool, based on Mondeca technology has also been proposed. However further engineering development would have been necessary to make it really operational. Such a tool is an ideal way to demonstrate the usefulness of both low-level image processing algorithms and semantic reasoning in the context of satellite image interpretation.

4.2.3 Learning, indexing and retrieval

Faculty M. Campedel, M. Datcu (until 2010), H. Sahbi.

Projects Infomagic, K-space.

Besides recognition and spatial reasoning, spatial relations have also been used in structural learning for image classification, based on original graph kernels including spatial relations [901] (PhD of E. Aldea).

Two important projects were completed during this period, Infomagic and K-space, leading to the publications of two books [910, 914], as major outcomes of the work carried out within these projects.

This research theme was also developed specifically in the context remote sensing imaging, as described in Section 4.2.6.

Most of the work in machine learning during this period was devoted to visual recognition and search, along three main lines.

Image annotation in interconnected networks & activity recognition. In this work, we introduced a novel image annotation and retrieval approach based on support vector machines

(SVMs) and a new class of kernels referred to as context-dependent (CD). The main contribution of our method includes (i) a variational approach which helps designing our CD kernel using both intrinsic features and the underlying contextual information, and (ii) the proof of convergence of the CD kernel to positive definite fixed-point, usable for SVM training and other kernel methods. When plugged in SVMs, our CD kernel consistently improves the performance of image annotation and retrieval, compared to context-free kernels, on hundreds of thousands of Flickr images [863, 660, 864]. We also extended this CD kernel in order to handle activity indexing and recognition in video sequences [899].

Conditional random fields for Object Class Segmentation (OCS). In this work, we proposed a novel superpixel-based framework for object class segmentation using conditional random fields (CRFs). The framework proceeds in two steps: (i) superpixel label estimate, and (ii) CRF label propagation. Step (i) is achieved using multi-scale boosted classifiers over superpixels and makes it possible to find coarse estimates of initial labels. Fine labeling is afterward achieved in Step (ii), using an anisotropic contrast sensitive pairwise function designed in order to characterize the intrinsic interaction potentials between objects according to 4-neighborhoods. Finally, a higher-order criterion is applied to enforce region label consistency of OCS. Experimental results demonstrate the effectiveness of the proposed framework [829].

2D to 3D object retrieval. In this work, we introduced a complete "2D to 3D object" retrieval framework. Given a (collection of) picture(s) or sketch(es) of the same scene or object, the method allows us to retrieve the underlying similar objects in a database of 3D models. The contribution of our method includes (i) a generative approach for alignment able to find canonical views consistently through scenes/objects, and (ii) the application of an efficient and effective matching method used for ranking. The results are reported through the Princeton Shape Benchmark and the Shrec benchmarking consortium evaluated/compared by a third-party. In the two gallery sets, our approach achieves good performance and outperforms the other runs [645].

4.2.4 Computer graphics, digital geometry and rendering

Faculty T. Boubekeur, E. Eisemann, J. Tierny (and P. Memari since October 2011).

Main events Eurographics Young Researcher Award (E. Eisemann), Honorable mention of the Dirk Bartz Prize for Visual Computing in Medicine [584].

Projects IP Reverie, NoE 3DLife, ANR Ispace&time, MediaGPU, CeCil, KidPocket, FETUS, CIFRE EDF, CIFRE Useful Progress, "Chaire Modélisation des Imaginaires".

The computer graphics team of the TII group conducts its research activities in 3D geometric modeling, rendering, perception, visualization and computer vision.

In modeling, the group has developed several fast methods for surface simplification, filtering and reconstruction based on linear and adaptive stochastic approaches [570], separability [884], locality principles, and variational geometry [664]. A structuring-curve system has been proposed for deformation, 2D painting [735], and shape learning to reconstruct scans [628]. A quad remesher for polygonal surfaces as well as an interactive one has been designed to integrate user constraints in real time [668]. Another approach has been presented to reuse examplar databases for generating new quadrangulations from predefined styles [667]. Some of these contributions have been applied for realistic anatomical modeling (see Section 4.2.5).

In rendering, the group has developed new algorithms for global illumination on GPU [624], in screen- [815], object- [656] and hybrid [858] spaces, and has proposed a new static [572] and/or spatio-temporal scene analysis for expressive [755], amortized [812], and stereo rendering [783]. A new real time geometry synthesis stage has also been proposed [909, 814]. Optical phenomena stemming from virtual cameras (depth of field, lens flare, motion, etc.) have been studied in detail to improve realism but also to offer artistic control [625, 632]. Finally, a remote rendering system has been developed [649].

Several projects have been conducted on the perceptual component of rendering techniques and have led to new methods offering a higher (perceived) screen resolution than the physical one [595], and a better detail preservation [596], as well as higher quality stereo rendering [597].

In visualization, a new approach was proposed to explore interactively large-scale simulations based on a topology pre-analysis [571]. Also, a new method for topological verification was able to illustrate the shortcomings of various realizations of isosurface-extraction methods that are publicly available [610].

In computer vision, a benchmark and a visual research engine [604] based on a new set of local descriptors and a machine-learning approach have been developed, built around a new system for interactive 2D [605] and 3D [664] design, to discover and create content from huge data bases. Another technique registers photos and 3D terrain models to perform automatic geo-localization, object recognition and to add annotations [734].

4.2.5 Medical imaging

Faculty E. Angelini, I. Bloch, T. Boubekeur, J. Delon (and P. Memari since October 2011).

Main events Joint Lab with Orange Labs (WHIST), Honorable mention of the Dirk Bartz Prize for Visual Computing in Medicine [584].

Projects ANR (FETUS, Kidpocket, IPHOT), Visiting Scientist fellowship at CSIRO (Australia), MINIARA, CIFRE PhD theses funding. Collaborations with Siemens, Philips, General Electric, Dosisoft, Fovea, Orange Labs (J. Wiart), Institut Pasteur (J.C. Olivo-Marin), ISEP (F. Rossant), U. Columbia (A. Laine), hospitals (Cochin - Saint Vincent de Paul, Bicêtre, XV-XX, Lariboisière...).

Our work on segmentation of normal and pathological brain structures is strongly related to our research in spatial reasoning (see Section 4.2.2), where anatomical knowledge is represented using structural formalisms, and used to guide the segmentation and recognition [616, 647] (PhD of G. Fouquier). These ideas have also been exploited in other medical applications. Analysis of longitudinal changes of brain pathologies has been an important focus of research, supported by very active collaborations with several academic and clinical sites. The project on low-grade brain tumor growth has matured [563, 726] and has led to the launch of a new PhD co-supervised with the Hospital Lariboisière. A new collaboration with CSIRO was launched, on the topic of longitudinal analysis of brain white matter lesions on Alzheimer patients. Quantitative longitudinal image analysis is likely to become a major field of investigation for our group, with close links being built with the University Paris Descartes, specialized in human and small animal vascular and tumoral imaging for longitudinal evaluation and identification of biomarkers.

Anatomical modeling has also benefited from great activities and new strong links between the medical imaging and the computer graphics teams (see Section 4.2.4). Several joint supervisions of PhD students, post-doctoral fellows and research engineers have led to the strengthening of this activity, focusing on the segmentation of obstetrical images in US and MRI [727, 729, 728] (PhD of J. Anquez), and the design of dedicated modeling tools for the construction of pregnant women bodies from segmented medical images [564, 565, 584], deformed in various positions for dosimetry simulations. In the same line, segmentation of whole body MRI children images for anatomical modeling at different ages is currently addressed [801]. These works were carried out in close collaboration with Orange Labs, within the joint laboratory WHIST.

Vascular imaging was also an important focus of research, with a collaboration with Siemens Corporate Research (PhD of D. Lesage) and then Philips Healthcare (PhD of G. Pizaine). Stochastic, discrete and continuous methods were investigated for the segmentation of small and large vessels [828, 852], with various types of geometric constraints and various levels of supervision and training. A new direction of investigation focuses on the combination of geometric constraints and vessel tree labeling constraints. The long-term collaboration with Columbia University has led to the graduation of a jointly supervised PhD student working on IVUS images, for the segmentation of coronary vessels [818, 819, 820] and the joint supervision of a PhD candidate on

the quantification of myocardial strain from 3DUS images. We have also continued the work on the reformulation of deformable models with Surface Function Active [599, 600] for real-time segmentation performance.

During this period, the MINIARA project on oncological applications was completed, with contributions on the segmentation of tumors and organs at risk, exploiting complementary information from PET and CT data (PhD of J. Wojak), and on the follow-up of patients, using constrained level sets approaches [892]. Dedicated registration tools for protontherapy were also developed (PhD of J. Baussé).

In mammography, we focused on the analysis of tomosynthesis images and developed original filters [650] (see Section 4.2.1), and segmentation methods, dedicated to masses, using fuzzy approaches, and spiculated lesions, using *a contrario* approaches [730, 848, 846] (PhD of G. Palma).

A few years ago, a new research track was investigated in biological imaging, in collaboration with Institut Pasteur (PhD of N. Chenouard), with new results on multiple objects tracking in cluttered environment, both in 2D and in 3D [765, 766] (see Section 4.2.1). Regarding the activity in optical imaging, the group has launched a fruitful collaboration with Institut Pasteur and the ESPCI/Institut Langevin for the exploitation of Compressed Sensing in microscopy imaging. The Phd of M. De Moraes Marim has led to breakthrough publications introducing CS-based denoising [834], temporal acquisition schemes and digital holography imaging [837, 639] for fast image sampling and efficient image reconstruction in realistic microscopy imaging setups. This work has received a best student paper award at the conference ISBI 2010 [837]. A new PhD student is now working on the optimization of the image reconstruction process dedicated to temporal CS microscopy imaging [825, 826].

A close collaboration with ISEP and XV-XX hospital was launched on eye imaging, using multiple modalities. In optical coherence tomography (OCT) we proposed an original method to detect all retinal layers, using parallel deformable models, which applies in normal and pathological cases, and from which quantitative measures are derived, supporting the analysis of retinal structure variability and the early detection of alterations [620] (PhD of I. Ghorbel). A recent technique based on adaptive optics was then exploited to detect photoreceptors and estimate their density [831]. Finally, eye fundus images were used for the segmentation of blood vessels and their classification into arteries and veins [657].

A new topic was recently launched within the WHIST lab, on brain-computer interfaces (BCI), for large public applications. The first contribution concerns the detection of eye movements and blinking in EEG signals, and their use as control signals for BCI tasks (PhD of Y. Yang). Optimal selection of spatial filters and of the number of electrodes is now addressed.

4.2.6 Aerial and satellite imaging

Faculty A. Almansa, M. Campedel, M. Datcu (until 2010), J. Delon, Y. Gousseau, H. Maître, J.-M. Nicolas, S. Rital, M. Roux, F. Tupin.

Projects CNES PhD theses and research projects funding, ANR EFIDIR, REI-DGA, Magellium, CIFRE Thales, Terra Numerica. Collaborations with DLR (A. Reigber), U. Parthenope II Italy (G. Ferraioli), U. Sao Paulo Brazil (T. Perciano, M. Horta), CEA (R. Binet), U. UPEMLV, IGN.

Within the TerraNumerica project (CapDigital), we extended our work on the processing of **3D point clouds** [900]. The analysis of 3D point structures with the Hough transform associated to an entropic measure led to the detection of parallel planes and allowed the separation of building facade elements (walls, balconies, windows and doors).

Another axis was the analysis of full-waveform **lidar data** for the automatic classification of urban areas on one side and littoral scenes on the other side. This work demonstrated the contribution of radiometric calibration features to high classification accuracies [638, 637] (PhD with MATIS, IGN).

Concerning the generation of **3D models from multiple images**, our focus was the construction of a low cost system allowing non-specialists to make 3D measurements with minimal set of constraints on the image acquisition [851]. The concerned applications are related to surface roughness and dendrometric parameters measurements (PhD with UPEMLV).

In **stereovision**, recent research focused on high precision and subpixel approaches, in particular by estimating meaningful matches in order to improve disparity maps [658, 659].

For **SAR imagery**, research is led at different levels: at the signal level with the development of statistical models and denoising approaches, and at the region or object level, particularly for the fusion of radar and optical imagery.

At the signal level, works on the statistical modeling of SAR images based on Mellin transform have been completed with the introduction of Meijer distributions which allow the definition of a unifying framework. Concerning denoising approaches, non-local means extended to a probabilistic framework are very efficient either for amplitude images [586], or interferometric / polarimetric data [587] (PhD of C. Deledalle, see also Section 4.2.1). A Markovian formalism and different estimators with adapted optimization approaches define an elegant context for the fusion of multi-channel interferometric data [615, 661] (PhD of A. Shabou, REI project).

For pattern recognition and image interpretation, many efforts have been dedicated to the fusion of SAR and optical images (PhD of G. Lehureau, PhD of H. Sportouche) with SVM methods or with explicit object detection and likelihood optimization [663]. Network extraction has also been investigated with Markovian approaches for SWOT images of rivers (CNES project) and for road detection in a multi-temporal and multi-sensor framework (PhD of T. Perciano). In the PhD of G. Hochard, the analysis of long temporal series on the Serre-Ponçon dam has led to a selection method for interferograms which could be applied for change detection applications.

During the EFIDIR project (ANR MDCO, 2008-2011), theoretical works have been conducted to better understand the problem of complex data interpolation and phase vortex. Concerning glacier monitoring, correlation based approaches on amplitude images have been developed with adapted similarity criteria [612] (PhD of R. Fallourd). Man-made corner reflectors have been positioned on Argentiere glacier to serve as ground truth and help understanding the backscattering mechanisms of metric resolution images like TerraSAR-X and Cosmo-SkyMed.

The **joint CNES-DLR-Télécom ParisTech Competence Center (CoC)**, created in June 2005, ended in June 2010. Its activities were focused on information extraction and satellite image understanding for both optical and SAR images. Numerous PhD theses have been defended since 2009 on a high variety of subjects going from low level image description [566], classification [634] to (semi-) supervised active learning tools [567] and knowledge representation [716].

Even if this project is now finished, strong collaborations with CNES[5] are maintained on specific applicative projects (called EXITER, SAFER European project and KAL-Haïti ANR), which were initiated from 2008 to 2011, in the context of rapid mapping, or more methodological ones, for instance based on hypergraph representations [786, 655]. Close relationships with expert interpreters from SERTIT[6] were also developed to better promote the competence center results related to the quick production of relevant land cover maps. SERTIT and CNES provided us with rich datasets to scientifically evaluate information extraction and classification tools and also to derive new products (as processing chains) to be used by interpreters. Hence scientific and applicative evaluations were performed exploiting platforms like KEO (ESA platform) as well as public tools like OTB (Orfeo Toolbox[7]) and GIS (Geographical Information System). Not restricted to engineering tasks, the rapid mapping application leads to research problems like: how to combine information from different images of the same scene? At different times? How to exploit different sources of information like old maps and images? How to integrate object description, semantics and reasoning in interpreters tools like GIS?

[5] http://www.cnes.fr
[6] http://sertit.u-strasbg.fr/
[7] http://orfeo-toolbox.org/otb/

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