Scientific Progress Report
Labex SMART
Period: Jan. 2015 - December 2016

February 2017

Laboratory of Excellence SMART (ANR-11-LABX-65) is supported by French State funds managed by the ANR within the Investissements d'Avenir Programme under reference ANR-11-IDEX-0004-02

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SMART Overview

SMART Context

In 2010 the French Government launched a program called "Investments for the Future" **(PIA: Programme d'Investissements d'Avenir)** with the main objective of supporting higher education, research, as well as transfer to industry http://www.enseignementsup-recherche.gouv.fr/pid24578/investissements-d-avenir.html (in French).

Within this program, there were competitive calls in 2010 and 2011 for different categories of projects among which projects called "Equipment of Excellence (Equipex), Laboratories of Excellence (Labex), and Initiatives of Excellence (Idex). The latter aimed at grouping French universities within larger structures called Idex. The Labex are local or national consortia of labs that address a large, long term (8 to 10 years), scientific program. The Equipex program finances new scientific equipment.

SMART, was submitted to the second Labex call in 2011 and selected by the international committee in February 2012. The main topic of the project is research on human-machine interactions. The consortium was composed of eight laboratories affiliated to seven legal institutions: University Pierre and Marie Curie, CNRS, INSERM, Institut Mines-Telecom, University Paris 8, IRCAM, EPHE. The project duration is 94 months (end date: 31/12/2019). The total funding from the PIA program is 5 M€.

SMART is within the Idex *Sorbonne Universités* (SU).

SMART Vision

Digital systems, more or less complex computing and communicating devices and artifacts are today part of our daily lives, be it in our homes or workplaces, in the streets of our cities or in public spaces where we go for business, service, shopping, leisure, or travel. We have numerous interactions with these systems and we use them for interacting with other humans. Enormous amount of data are collected and processed from which models of human behaviors are built. Access to this digital world opens unprecedented possibilities for new services and easier living.

The wide distribution in our environment of communicating and interacting devices, integrating individually and collectively perception, computation, actuation and communication capacities at different scales, and which may be mobile, creates an ambient intelligence. This requires addressing them both as integrated units and as a global networked system and conceiving infrastructures for their connectivity. Those devices produce also massive amounts of data that need to be processed efficiently to extract the relevant information and knowledge, and also stored and protected.

SMART aims to design technologies that would make the interaction of humans with those devices simpler, safer, more natural, more efficient and more adaptive. This requires to include in those systems capacities to better understand how humans act and interact, and hence to develop models of humans representing their physical capabilities, psychological trends and behaviors. It also requires studying efficient and natural interfaces and enhanced tools for a better interactivity between digital artifacts and humans.

SMART Ambition

The SMART Labex objective is to contribute to the scientific foundational bases for facilitating the inclusion of intelligent digital artifacts in our daily life for service and assistance. The project addresses underlying scientific questions raised by the development of Human-centered digital systems and artifacts in a comprehensive way.

An efficient and natural interaction with artifacts requires understanding human actions and behavior, as well as the design of natural and friendly interfaces. When those artifacts and digital devices are disseminated, networked, and sometimes mobile, it is also necessary to provide for their connectivity and for knowledge extraction, sometimes from massive data, knowledge sharing and access.

Project actions unfold along five dimensions: a) basic research and novel concepts; b) methods, technologies and tools for the design, operation, interfacing and networking of systems and artifacts interacting with humans; c) exploration of novel applications and usage; d) education curricula, and e) dissemination and exploitation of results.

As an illustrative main usage area, source of open topics and case studies for this project, the new services induced by the digital society for e-health, including the ageing society and autonomous living.

The research program is organized along five axes that address the main scientific questions and the use case:

1. "Modeling of humans": understanding and modeling of physiological and neurophysiological functions, integrated representations of the musculoskeletal system, of the basic motor and perceptive systems and of the learning and adaptation mechanisms, integrative architectures.

2. "Interfaces and Interaction with humans": design of new devices that enhance the range of interactions between human and machines (e.g., haptic devices), new interaction modalities and signals including cognitive and emotional aspects.

3. "Humans at the convergence of digital and real environments": large scale complex data processing, knowledge emergence, digital and human decision-making and socially intelligent computing.

4. "Autonomic Distributed Environments for Mobility": networking, virtualization, self-organized, self-healing and secure architectures of heterogeneous, autonomous and cooperative mobile entities.

5. "Human autonomy and e-health": innovative medical devices, from assisting robots to implanted sensors and bio-mechatronic embedded systems, and personalized care in the context of e-health for autonomous living.

SMART Teams

SMART is a specific blend of research teams of laboratories in applied mathematics, computer science, robotics, neuroscience, medical imagery, networks and distributed systems, Human-Machine interaction, electrical engineering in the same campus, with a clear and consistent research program and an education and training program, experimenting new usages in living labs, and having close ties with industry.

The Institute of Intelligent Systems and Robotics - ISIR (UPMC, CNRS): Autonomous and interactive Robotics systems; Mobility; cognitive systems; Robotics and Neuroscience; assistance to surgical and functional rehabilitation; micromanipulation; Manipulation; Haptics.

Paris 6 Computer Science Lab - LIP6 (UPMC, CNRS): Decision-making, Intelligent Systems and Operations Research, Databases and Machine-Learning, Networks and Distributed Systems, Systems-on-chip.

Human and Artificial Cognition Laboratory - Chart-Lutin (UPMC, University Paris 8, EPHE): pragmatic and semantic interactions of human and artificial systems.

Electronics and Electromagnetism Laboratory - L2E (UPMC): micro and nano-electronics, communication, physiological parameters monitoring.

Laboratory Jacques-Louis Lions - LJLL (UPMC, CNRS): Mathematical modeling of physical phenomena in physics, mechanics, biology, medicine, chemistry, information processing, Economics, finance;

Laboratory of Biomedical Imagery - LIB (UPMC, CNRS, INSERM): Medical imaging, modeling, image and signal processing, magnetic resonance imaging, microscopy, optical imaging, nuclear medicine imaging, ultrasound, Alzheimer's, cardiovascular disease, medical oncology, neurosciences.

Laboratory of the Technology of Music and Sound – STMS (UPMC, CNRS, IRCAM): Instrumental Acoustics, Acoustic and Cognitive Spaces and Sound, Perception and Design Analysis and sound synthesis, Analysis of musical practices, Real-Time Musical Interactions.

The Information processing and Communication Electronics Laboratory – LTCI (Institut MinesTelecom, CNRS): Signal processing and image, pattern recognition, 3D object modeling, conversational agents, multimedia (speech, audio, music, images, video), document analysis, multimodal biometrics was member of SMART up to 2016, when CNRS and Institut MinesTelecom, decided to stop this unit.

SMART Governance

SMART is coordinated by a Director (Raja Chatila), a Deputy Director (Mohamed Chetouani), and a Project Manager (Zoitsa Siaplaoura). Three main bodies are involved in managing and overseeing the Labex: the Executive Committee (**EXCOM**), the Steering Committee (**STEERCOM**), and the Scientific Advisory Board (**SAB)**.

The **EXCOM** is the operational body of the project. It is composed of the director and deputy director, a representative of each of the five programs and the person in charge of the Education curricula. Members:

Raja Chatila (ISIR), Mohamed Chetouani (ISIR), Patrick Gallinari (LIP6), Patrick Garda (LIP6), Benoît Girard (ISIR), Véronique Marchand (LIB), Christophe Marsala (LIP6), Catherine Pelachaud (LTCI/ISIR), Franck Petit (LIP6), Agnès Roby-Brami (ISIR), Pierre Sens (LIP6).

The **STEERCOM** oversees the general operation of the Labex. It is chaired by a representative of the main partner institution, the Idex Sorbonne Universités, and composed of:

- One representative from each of the other seven legal institutions partners of the Labex
- The directors of the eight member laboratories or their representatives
- A representative of the Doctoral Training Institute
- The SMART Labex director

Representatives of Institutions:

Sorbonne Universités: Véronique Atger

CNRS: Wilfrid Perruquetti

EPHE: François Jouen

Institut Mines Télécom: Yves Grenier

INSERM: Franck Lethimonnier

IRCAM: Hugues Vinet

UPMC: Bertrand Meyer

Université Paris 8: Mario Barra

Doctoral Training Institute**:** Jean-Dominique Polack

Representatives of Laboratories:

ISIR: Agnès Roby-Brami

L2E: Aziz Benlarbi-Delaï

Laboratoire CHART-LUTIN: Charles Tijus

LIB: Pascal Laugier

LIP6: Jean-Claude Bajard

LJLL: Benoît Perthame

STMS: Gérard Assayag

The SAB is composed of members external to the Labex partners, belonging to French and foreign higher education and research institutions and industry in the main scientific domains of SMART:

In 2015 the SAB was composed of:

Etienne Burdet, Imperial College, London, UK

Justine Cassell, Carnegie Mellon University, Pittsburgh, USA

Peter Ford Dominey, INSERM, Lyon, FRANCE

Rachid Guerraoui, EPFL, Lausanne, CH

Philippe Roy, CAP DIGITAL, Paris, FRANCE

Stuart Russell, University of California, Berkeley, USA

Alessandro Vinciarelli, Glasgow University, UK

In 2017, due to the unavailability of some members, the new composition is:

Elisabeth André, University of Augsburg, Germany

Etienne Burdet, Imperial College, London, UK

Peter Ford Dominey, INSERM, Lyon, France

Philippe Roy, CAP DIGITAL, Paris, France

Alessandro Vinciarelli, Glasgow University, UK

Britta Wrede, University of Bielfeld, Germany

SMART Strategy

SMART devoted its budget to launch the following initiatives:

- Transversal **projects** to investigate the main scientific topics of the project in a multidisciplinary approach
- **Post-doctoral grants**, to attract young scientists with high potential.
- **Doctoral program** for financing **PhD grants** to perform novel cross-disciplinary research on the project's topics in participating laboratories.
- **Internship program for master students.**
- Invited **visiting professors** to bring very high-level senior professionals to partner laboratories for participating and advising in research projects and educating local students.
- **Involvement in educational curricula** in relation with the research program for dissemination of results.
- **Summer school: "SMART COMPOSES" on Computational social and behavioral sciences.**
- **Actions within Sorbonne Universités:**
  - **Projects with IUIS (Institute for Engineering in Health)**
  - **Cooperation with INSEAD-Sorbonne Behavioural Lab**
- **Industrial partnership** for joint projects and exploitation of results.
- **International partnership and cooperation.**

Evolution and future of SMART

The first meeting of the SMART Scientific Advisory Board in 2015 has advised to identify a capstone project transversal to the Labex. Since 2015, SMART has been organizing a successful summer school (COMPOSES) on Computational social and behavioral sciences.

The Labex leadership has identified « Behavioral sciences» as a core domain to which several research projects actually belong. We therefore oriented the reflection on the capstone project – and on the future of SMART – toward the study of behavior. During 2016, discussions with two other Labex within Sorbonne University, BIO-PSY (Biology, neurosciences and psychiatry) and MS2T (technological systems of systems) have led to build a common large project aiming at founding the « Interdisciplinary Behavioral Science Institute of Paris » (IBSI). The IBSI project will have a strong structuring effect with the clear identification and development of an interdisciplinary research and education program dedicated to behavioral sciences within Sorbonne Universités, nucleated by the participating labs, members of the three Labex BIO-PSY, MS2T and SMART.

Although several broad-spectrum multidisciplinary institutes devoted to behavioral sciences are thriving at the international level, none exists so far in France. The most classical ones such as the Center for Advanced Study in the Behavioral Sciences at Stanford University have made considerable contributions to the field. Most others are recent and many focus on a specific discipline, e.g., Social Sciences, such as the "Behavioural Science Institute" at Radboud Universiteit in the Netherlands, or the "Institute of Behavioural Sciences" at Helsinki, rather oriented towards cognitive sciences and psychology. Some have specific orientations towards particular domains including economy or criminal studies for example.

A strength of the proposed IBSI-Paris project is its broad disciplinary spectrum supported by the diversity of participating groups as well as the strong contribution of computer sciences and mathematical modeling.

This project is launched at a time when two of the top universities in France for Sciences (UPMC) and Humanities (Sorbonne-Paris IV) member of Idex Sorbonne Universités are about to merge, and have close interaction with a major engineering and technology university (UTC) and one of the world top management and business school (INSEAD).

IBSI will investigate topics as diverse as behaviors related to health and well-being or to safety, decision-making in organizations and groups and the relationships between information, knowledge and decision, interactions within and among groups, autonomous and interactive systems with learning capacities, the development of behaviors and its environmental constraints, the role of emotions in decision-making and interactions with machines, the ethical dimension of human and artificial behavior.

Although the object of large research efforts, so far, these topics have been tackled separately by different disciplines, including neuroscience, psychology, philosophy, cognitive science, developmental sciences, social sciences, linguistics, mathematics, computer science, artificial intelligence and robotics, with rather little or partial interactions between them. Each of these disciplines addresses behavior at a different scale of analysis and with different methods. A main challenge of this project will be to characterize common rules that govern this dynamic object.

IBSI will be organized in « Research Areas » (RAs) to support cross-disciplinary projects within each area, as well as projects across different RAs. The domains for trans-disciplinary study of human, animal models, and machine behavior are numerous.

The five specific Research Areas that have been identified are:

1. Multimodal perception and data processing
2. Decision and Information
3. Interaction of humans and machines
4. Nudges, Influence and Inflection of behavior

5. Ethics, Norms and Values in Living and Artificial Agents

These areas are significant in defining behavior studies and are of interest to the participating teams from Neurosciences, Information Sciences and Technologies and Social Sciences and Humanities.

SMART Figures (2015-2016)

- 2 calls for internships
- 2 calls for PhDs
- 1 call for Post-docs
- 1 call for collaborative projects
- 1 call for projects with industries
- 2 summer schools
- Regular seminars
- Organization of workshops

SMART Projects

ISMES

Project ISMES

Interfaces SensoriMotrices Embarquées pour la rééducation et la Suppléance

Embedded Sensorimotor Interfaces for rehabilitation and assistance

Responsible of the project:

Agnès Roby-Brami (ISIR)

Partners:

ISIR (W. Bachta, N. Jarrassé, A. Roby-Brami)
STMS (F. Bevilacqua)
LIB (V. Marchand-Pauvert, P.F. Pradat, R. Katz, A. Lackmy-Vallée)
Salpétrière Hospital: Physical Medicine and Rehabilitation (P. Pradat-Diehl) and neurology (PF Pradat).

Web site:

http://ismes.isir.upmc.fr/

The Project at a glance

Context and Objectives:

The aim of the project is to study the benefit of techniques associating sensors and effectors-stimulators that we call "sensori-motor interfaces". Those embedded interfaces will allow online measurements of motor activity and augmented sensory feedback based on a physiological analysis of human action. Enriched sensory feedback allows to compensate the impairments of sensory loops and to reinforce the learning of new compensatory actions. The project addresses two scientific challenges: the first is to establish the necessary models to represent the motor actions in a parsimonious way from the sensors. The second is to find the efficient encoding of motor behavior to provide pertinent multisensory signals, easily interpretable by the central nervous system.

The clinical objective is to improve the autonomy of disabled persons thanks to sensori-motor learning, rehabilitation and assistive technology. To that purpose, our approach is to analyze and rehabilitate the human activities in an enriched context closer to the daily life activity and to develop assistive technology as a function of patients' needs. The project is thus closely related to clinical neuro-rehabilitation.

The multidisciplinary central task of the project is to develop sensorimotor interfaces for a better analysis of human motor actions in healthy subjects and neurological patients. The application is to develop specific interactive devices using multisensory signals (light touch, vibration, sound) in three contexts: for a better command of an upper-limb prosthesis in amputees; for the rehabilitation of gait and posture in neurological patients (light touch); for the rehabilitation of arm coordination in stroke patients (coupling gesture-sound).

Scientific progress and results

General achievements

A significant part of the SMART budget was devoted to the equipment. We acquired the equipement with a special effort for homogeneisation and duplication of experimental set-up between ISMES laboratories.

- A complete set-up for the analysis of hand and finger posture is now operational in ISIR.
- We have acquired an up-to-date hand and elbow prosthesis that are the basis of the experimental platform for the command of the prosthesis. Experiments with amputee patients are performed in Institut Régional de Médecine Physique et Réadaptation (Nancy).
- We have acquired a force plateforme and duplicated the set up for the analysis of the effect of light touch on the equilibrium. The same set-up used in ISIR is now installed in the clinics in Salpétrière and in Rothschild Hospital.

- We have developed and duplicated a braked elbow orthosis fitted with interactive interfaces for the coupling of movement and sound. We have acquired two sets of interactive musical objects and equipement for parallel experiments in IRCAM and Salpétrière Hospital.
- We have published 7 intenational journal articles (+2 in revision, 1 submitted, 2 in preparation) and 15 international conference papers.

Networking and structuring

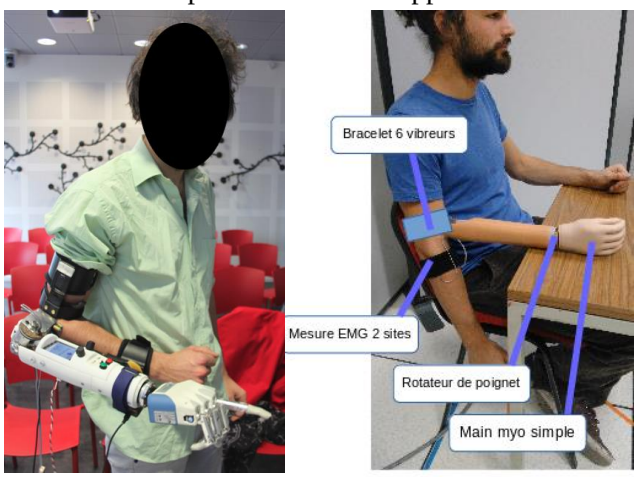
The project has supported a strong structuring achievement

- The project has initiated and structured strong relationships between the laboratories and the clinics with both institutional and personal exchanges (interns as go-between). Mainly with the MPR department in Salpétrière and also in IRR Nancy and Rothschild Hospital (Paris).
- The research initiated within ISMES has found further national support
  N. Jarrassé. PhantoMovControl, Going beyond the limits of myoelectric upper-arm prostheses: phantom hand movements for natural control. (ANR DS0413 2015, with ISM, IRR, Microvitae, Cetcopra)
  W. Bachta: I Gait, Interactions tactiles pour l'assistance à la marche. (ANR DS0704, 2016).
  N. Jarrassé Subilma Network (CNRS, défi Auton, mission pour l'interdisciplinarité).
  N. Jarrassé, project PROCOSY (Sorbonne Université Emergence 2017)
- ISMES members participate to national networks related to SMART topics:
  Institut federatif de recherche sur le handicap,
- International partnerships were consolidated:
  E. Burdet Human Robotics group, ICL, London
  M. Popovic and M. Djuric-Jovici, University of Belgrade and Center for Innovation, PHC Pavle Savic.
  J. Hermsdörfer, L. Johannsen (Technical University Munich), Franco-Bavarian project
  A. Wing, R. Reynolds Birmingham University.
  V. Sanguinetti (U. Genova).

  An international european project will be submitted (SKENTEL Stimulating knowledge and expertise using networked things for everyday living, Coordinated by C. Baber, Birmingham University with Salpetrière hospital su-contractor and as partners: TUM, ICL, NCSR Demokritos, Stroke Alliance for Europe).

Manual dexterity and Prosthesis

We have continued the analysis of dexterity in healthy subjects for grasping unimanual and bimanual instrumented objects (article in revision) and began a study in hemiparetic stroke patients (S. Macias 2016).
We have developed an innovative approach for the control of elbow prosthesis thanks to the capture of shoulder and upper-arm movement with an IMU (thesis M. Merad) and made a proof of concept in healthy subjects. We also began experiments with amputees in IRR (conference papers). The effect of sensory feedback (sound, vibrotactile…) on prehension is under investigation (E. de Montalivet, G. Arnold). The question of the corporeal integration of technique has been reviewed (Jarrassé et al. 2015). We have also studied the determinant of the bodily integration of a prosthesis in the representation of the peri-personal space (A. Gouzien) A series of experiments have been performed on the cortical control of phantom movements made by amputees (coll J. Graaf, ISM, Control).



Project PhanToMov

Light touch and equilibrium.

The effect of active light touch on posture has been analysed in healthy subjects. We have demonstrated that is is possible to drive the center of pressure in closed loop thanks to a kinesthesic feedback applied on the index by a treadmill moving in the forward-back ward direction (Verité et al. 2013, 2014). The set-up is now duplicated in Salpétrière hospital and active light touch has been tested in hemiparetic patients and in patients with amyotrophic lateral sclerosis (C. Kemlin). An article is about to be submitted. We are now studying the effect of active light touch when the treadmill moves laterally, these experiments will be performed first in healthy subjects then in patients (S. Macias). Lateral equilibrium is particularly critical in hemiparetic patients. We also plan to study Parkinsonnian patients. In a related study, we have developed an active cane, servo-controlled by the human gait thanks to IMU (Ady et al. 2013) and an interactive handle (A. Baktahvachalam). The aim of the project IGait is to couple the active handle to the cane to provide tactile feedback during locomotion.

Gesture-sound coupling

The sonification of arm movements allows for providing patients with continuous extrinsic feedback. As evidenced in a perspective paper we published in Frontiers in Neuroscience (F. Bevilacqua et al 2016), this approach is gaining momentum while several questions are remaining open on the different possible implementations. Several modes of movement-sound coupling were developed and tested in healthy subjects (Boyer 2013, Bevilacqua et al. 2013, see also Françoise et al 2015 in another situation). Thanks to the braked orthosis developed in ISIR fitted with IMU sensors, we further investigated different strategies to sonify the shoulder-elbow coordination, since this coordination appears generally severely affected in stroke patients. We also specifically studied the sonification of arm movements and demonstrated that participants adapt unconsciously their dynamics when instructed to maintain a constant sound feedback, despite controlled modification of the movement-sound relationship (E. Boyer, in preparation). Since September 2016, we have been developing clinical prototypes to conduct studies with stroke patients at Salpétrière Hospital in parallel to healthy subjects with I. Peyre (musicotherapeut) and M. Segalen (Audio-visual engineer). The clinical study will start in February 2017.

Perspectives

The perspectives for the last 9 months of the project are to continue the experiments, since the experimental set-up are now fully operational. We have recruited three people from September 2016 to September 2017: a physiotherapist half time (S. Macias) to continue the analysis of the light touch in hemiparetic patients, an audiovisual engineer (M. Segalen) and a musicotherapist half time (I. Peyre) for the project on sonification for rehabilitation.
Our further projects are to continue the transfer to the clinics. To this purpose, we applied for the prolongation of the ISMES project thanks to the SMART Labex.

Recruitment

Funded by SMART

Claire KEMLIN, physiotherapist in Salpetrière Hospital: half time in LIB-ISIR for two years beginning in October 2014 (convention UPMC-APHP)
Ragou ADY, PhD student in ISIR recruited for extra 7 months from Nov 2014 (assistance to equilibrium)
Jean Baptiste CAZENEUVE mechanical engineer, recruited in ISIR for 2 months (Nov-Dec 2014).
Eric BOYER, Post-doc (April-December 2015) in STMS and ISIR
Aravin BAKTAHVACHALAM Post-Doc 1 year in ISIR 9/2015-9/2016 (task: light touch for equilibrium)
Etienne de MONTALIVET, Engineer, 18 months in ISIR beginning December 2015 (task: prosthesis)
Sandra MACIAS-SORIA, physiotherapist IE, 1 year half time 8/2016-8/2017 (task: light touch LIB-ISIR).
Iseline PEYRE, musicotherapist IE, 1 year half time 9/2016-8/2017 (task sonification LIB-STMS-ISIR)
Maël SEGALEN, engineer IE, 1 year 70% time 9/2016-9/2017 (task sonification LIB-STMS-ISIR)

Gabriel ARNOLD: One year SMART post-doctoral contract for a related project (N. Jarrassé, M. Auvray).

PhD and other contractors <u>not funded</u> by ISMES

Fabien VÉRITÉ: PhD student since 2012 in ISIR (AMN), full time on the project
Manelle MERAD PhD student since 2014 in ISIR (Doctoral school SMAER), full time on the project
Adrienne GOUZIEN, medical resident in leave (APHP). Contract for 10 months (IUIS UPMC)
Part-time participation of PhD students:

Tommaso PROIETTI PhD Student (ISIR, Bourse Ile de France).
Eric BOYER (STMS, ANR LEGOS).
Jules FRANCOISE, PhD Student (STMS).
Frank GONZALES, PhD Student (ISIR and CEA).
Andrés TRUJILLO-LEON (University of Malaga).

Interns

<u>Funded by SMART:</u>
Alejandro VAN-ZANDT ESCOBAR (STMS: May-September 2013)
Laura SANCHEZ (ISIR-STMS: Feb-June 2015.
Sandra MACIAS SORIA (Feb-June 2016).
Louis RYCKEMBUSCH (March-June 2016)

<u>Other funding sources:</u>
Adriano TACILO RIBEIRO, (ISIR) Master 2 ENSTA-UPMC 2013.
Sandra MARTIN, (ISIR) M2 Cogmaster 2013.
Dijana NUIC (STMS), M2 VHMA 2014.
Wahid TOUNSI (ISIR), M2 2014
Mathilde MOIGNARD, Ecole Nationale de Photographie (ENSP), 2016, residence for the exhibition « la recherche de l'art #5».

Publications

Journal articles

EO Boyer, BM Babayan, F Bevilacqua, M Noisternig, O Warusfel, A Roby-Brami, S Hanneton, I Viaud-Delmon, From ear to hand: the role of the auditory-motor loop in pointing to an auditory source. Front Comput Neurosci. 2013 Apr 22;7:26. doi: 10.3389/fncom.2013.00026.

F. Vérité, W. Bachta, G. Morel. Closed loop kinesthetic feedback for postural control rehabilitation. IEEE Transactions on Haptics, Special Issue: Haptics in Rehabilitation and Neural Engineering. IEEE Trans Haptics. 2014 Apr-Jun;7(2):150-60. doi: 10.1109/TOH.2013.64.

Jarrassé N, Ribeiro AT, Sahbani A, Bachta W, Roby-Brami A. Analysis of hand synergies in healthy subjects during bimanual manipulation of various objects. J Neuroeng Rehabil. 2014 Jul 30;11:113. doi: 10.1186/1743-0003-11-113.

Gonzalez, F. and Gosselin, F. and Bachta, W. (2014). Analysis of Hand Contact Areas and Interaction Capabilities During Manipulation and Exploration. IEEE Transactions on Haptics. 2014, 7 (4) 415 - 429 10.1109/TOH.2014.2321395

Gonzalez, F. and Gosselin, Fl. and Bachta, W. (2015). A 2D Infrared Instrumentation for Close-Range Finger Position Sensing. IEEE Transactions on Instrumentation and Measurement. Vol 64. N.10. p.2708-2719

Jarrassé N., Maestrutti M., Morel G. and Roby-Brami A. Robotic prosthetics: moving beyond technical performance. IEEE Technology and society Magazine, 2015, 4:2 71-79. DOI 10.1109/MTS.2015.2425813.

Bevilacqua F, Boyer E, Françoise J, Houix O, Susini P, Roby-Brami A, Hanneton S, Sensori-motor learning with movement sonification. Perspectives from recent interdisciplinary studies. Front. Neurosci. 10:385. doi: 10.3389/fnins.2016.00385.

Proietti T, Guigon E, Roby-Brami A Jarrassé N. Modifying upper-limb inter-joint coordination in healthy subjects by training with a robotic exoskeleton. In revision JNER.

Martin-Brevet S, Jarrassé N, Burdet E, Roby-Brami A, Taxonomy of force exchanges during multi-digital object grasping and manipulation. Plos One in revision.

Gouzien A, de Vignemont F, Touillet A, Martinet N, De Graaf J, Jarrassé J, Roby-Brami A, Reachability and the sense of embodiment in amputees using prostheses. Soumis Nature science reports.

Merad M, de Montalivet E, Roby-Brami A, Jarrassé N, Can we achieve intuitive prosthetic control based on healthy upper limb motor strategies? Accepted in Frontiers in Neurorobotics, 2017 special issue « On the Forefront of Control for Wearable Robots »

Kemlin et al. Balance and Light Touch of moving surfaces in Post-Stroke and Amyotrophic Lateral Sclerosis Patients. en préparation pour soumission à JNER.

Conferences

F. Vérité, W. Bachta, G. Morel. Closed-loop control of a human Center-Of-Pressure position based on somatosensory feedback. IEEE Intelligent Robots and Systems (IROS). 2013

F. Bevilacqua, A. Van Zandt-Escobar, N. Schnell, E. O. Boyer, N. Rasamimanana, J. Françoise, S. Hanneton, A. Roby-Brami. Sonification of the coordination of arm movements. « Multisensory Motor Behavior: Impact of sound ». Org Pr A. Effenecberg & Gerd Schmitz, Leibnitz University Hanover. September 2013

A. Roby-Brami. A. Van Zandt-Escobar, N. Jarrassé, J. Robertson, N. Schnell, E. O. Boyer, Rasamimanana, S. Hanneton, F. Bevilacqua. Toward the use of augmented auditory feedback for the rehabilitation of arm movements in stroke patients. 17th European congress of physical rehabilitation medicine. Marseille May 2014.

J. Françoise, N. Schnell, F. Bevilacqua ; MaD: Mapping by Demonstration for Continuous Sonification ACM SIGGRAPH 2014 Emerging Technologies, Aug 2014, Vancouver, Canada, France. ACM, pp.16:1-16:1

Ady, R. and Bachta, W. and Bidaud, P. (2014). *Development and control of a one-wheel telescopic active cane*. IEEE RAS/EMBS BioRob Pages 461 – 466

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Proietti, T, Jarrassé, N, Roby-Brami A, Morel G, Adaptive Control of a Robotic Exoskeleton for Neurorehabilitation. NER 2015. 7th International IEEE EMBS Conference on Neural Engineering, April 2015, Montpellier.

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Events

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Participation to "LEGOS days 2" ANR project STMS, International Workshop on Movement Sonification and Learning, March 2-3 2015, Ircam, Paris.

Journée Prothèse, GDR Robotique, GT1 Robotique medicale, 18 juin 2015 Paris.

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Preparation of a series of multidisciplinary seminars « Corps et prothèses : vécus, usages, contextes » 4 one day workshops are scheduled in 2017, with Universities of Strasbourg, Lyon 1 and 2, Paris 1.

Seminars

Milica Djuric-Jovicic (Belgrade university) ISIR 20/06/2013
F. Bevilaqua, LIB (Decembre 2013).
Hugh Herr (MIT), ISIR 6/2014 "On the Design of Bionic Leg Devices: The Science of Extreme Interface".
Pr M. Popovic Advancing Functional Electrical Therapy (FET). ISIR, 9 November 2015.
Pr M. Latash: The Nature of Unintentional Movements, ISIR Mai 2016.
F. Bevilacqua F, Sonification et perspectives pour la reeducation. Service de MPR, La Salpétrière, 21/9/2016
B. Caramiaux Facilitating Motor Skill Learning, ISIR 16/12/2016.

Internal events:

Kick off- meeting 21/11/2013, Meeting: 12/09/2014 Meeting 15/10/2015, meeting 21/11/2016.
Meeting with C. Lenay and O. Gapenne (UTC) April 2014.
Meeting with J. Mizrahi (Technion), March 2014

General audience events:

N. Jarrassé : participation to the documentary "Bras de fer" for the series "LA BOITE NOIRE"

A. Roby-Brami « La Grande Équation », N.Mousseau (U.Montréal) Radio Ville-Marie (Québec), April 2014

N. Jarrassé: RFI Broadcast "Autour de la question" 2014 "Quel défi pour l'humain avec les technosciences ?"

N. Jarrassé: Semaines Sociales de France, Lille 2014 "l'homme et les technosciences : le defi".

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ONBUL

ONBUL

Online Budgeted Learning

Responsible of the project: Ludovic DENOYER

Partners: LIP6 (Ludovic DENOYER, Patrick GALLINARI, Gabriella CONTARDO) + ISIR (Benoit GIRARD, Mehdi KHAMASSI, Nassim AKLIL, Guillaume VIEJO)

Web site: http://onbul.lip6.fr

Objectifs

The emergence of large-scale databases and big data has recently motivated the development of budgeted machine learning models able to learn under operational constraints in term of memory/CPU consumptions, data access, etc… It involves integrating the constraints of scarce resources in the learning process itself. In parallel, in the neuroscience community, reinforcement learning online capabilities are understood as results of the coexistence of complementary learning systems, the choice of which brain learning system should be activated at each moment being also based on limited budgets (mainly in terms of computational cost: trying to minimize the amount of neural resources engaged at any given moment). Based on the observation that the recent context of learning under stress is highly relevant both for massive data processing and neuroscience, we aim to study this issue in the online learning context that seems suited for these two families of problems

The project is organized around scientific objectives and different concrete applications. The scientific objectives are to develop original budgeted learning models. We will explore two families of models: a first family where the information acquisition process will be modeled as a sequential process, and where reinforcement learning and representation learning techniques will be used together. The second family, which is more human-inspired, aims at developing model selection approaches where, at each step of the sequential process, the system has to choose between different concurrent decision/learning models, each model having its own prediction/learning ability, but also its own budget. Experiments will be made on classical machine learning models involving large amount of data (recommendation, image classification), in robotics (robot localization and navigation), and also in the neuroscience domain (modelling behavioral data).

One the key validation criteria for the project will consist in assessing the generalization ability of the proposed learning algorithms: generalization between datasets (train versus test datasets); generalization between learning contexts (how robots can generalize acquired knowledge from one environment to another (similar but not identical) one; how humans can generalize learned action values between task contexts); generalization between disciplines (how similar learning constraints formalized in machine learning and robotics can help better model principles for the limitation of human brain resources during learning and decision-making).

Scientific progress and results

Considering the previous description of what we intended to realize, we have already proposed some original approaches to the main aspects of this proposal:

1) **Machine Learning**
    a. **Main Results**

- We have proposed a new family of sequential budgeted models able to learn to acquire multiple features at each step of the process. The main advantage is that this family is able to deal with large

datasets and a large number of features while existing techniques are often limited to simpler problems and don't scale very well. Moreover, we have proposed a particularly fast and efficient model (called D-REAM) that can be learned on GPUs, and also extensions of this model to cost-sensitive problems where each acquisition has a particular cost.

- Based on the previous model, we have proposed a new model able to learn efficient active learning policies. The idea is to integrate into a supervised learning problem the labeling cost due to the building of the training dataset. In order to minimize this cost, we have extended the previous model where information acquisition corresponds to labels. Based on solving multiple task, we are able to discover a labeling policy that minimizes the number of label to ask to an expert, thus reducing the training cost of the resulting model. This work will be submitted during the next weeks.
- We have proposed a budgeted reinforcement learning model which aims at efficiently discovering options. It is motivated by the fact that research in cognitive science based on the study of human or animal behavior have long emphasized that the internal policy of such agents can be seen as a hierarchical process where solving a task is obtained by sequentially solving sub-tasks, each sub-task being treated by choosing a sequence of primitive actions. Considering this, we have proposed a model where options are discovered through a hierarchical neural network structure that is learned with the objective to both solve a particular task while minimizing the cognitive effort of the agent. This results in a new budgeted RL problem that is solved using policy gradient techniques, and that is able to discover efficient policies and options in complex environments.

b. Additional Results

- We have also proposed original **representation learning algorithms for states in a partially observed Markov Decision Process (POMDP)**. The model operates in two steps: (i) First, it learns how to find good representations on a set of randomly collected trajectories. This unsupervised operation is used to learn the system only once, and may be used to tackle different tasks sharing the same dynamical process. (ii) The model then infers new representations for any new trajectory, these representations being then used for discovering an optimal policy for a particular reward function.
- The development of sequential acquisition models has been handled by developing **specific approximated reinforcement learning models**. The underlying idea is to model the acquisition process by a Markov Decision Process where each action can be either an acquisition action or a decision action allowing the model to choose if it needs to get more information, or if it can decide what to predict. We have proposed a new reinforcement learning algorithm for the case where **the number of acquisition steps is fixed** and cannot be exceeded. Applications on image classification, where the classification model sequentially explore parts of the image have been proposed. These models have been also extended for classical prediction problems resulting in sequential methods close to experts mixture where the model can, at each timestep, choose how to transform the input, these transformations being successively applied during a fixed number of time steps (i.e fixed budget).

2) Robotics

- Extension of the budgeted machine learning models have been applied to a robot navigation simulation task. The robot is facing a series of different simulated environments with different statistical properties (different sizes, different number of obstacles, during levels of noise) and has to learn which budget (i.e. number of different actions, including movement, orienting and sensing) is optimal for each type of environment. We have first developed an algorithm to enable the robot to learn the appropriate action sequence in order to successfully localize itself within these environments for each fixed budget (1 action, 3 actions, 5 actions, etc.) (Aklil et al., 2017). We are currently extending, showing that while increasing the budget results in better localization, it also increases the learning cost, thus leading to an optimal cost-benefit ratio for each type of simulated environment. We are

currently making the robot learn this optimal ratio in an environment A and see whether this ratio can be transferred with good performance to an environment B with similar properties than A.

- We have also been working on an off-line application of this method to real robotic data: the PR2 robot having been recorded many times in different positions within an environment, recording its sensors' data (laser and camera) and odometry. Preliminary results suggest that the method can learn to select the sensor that gives the best cost-benefit ratio for robot localization (Aklil et al., in preparation). We will then apply this to online localization in the PR2 robot.
- We have applied an online gating method between two learning systems (one model-based and thus costly and the other model-free) for robot navigation. Experiments have been performed with the turtlebot. We empirically confirmed that computation time (and thus cost) is higher for model-based decisions than model-free ones, showing that incorporating budget information in the gating criterion between the two systems can help balance the cost-benefit ratio (Renaudo et al., submitted).

3) Neuroscience

- A last series of progresses we have done concerns the modeling of neuroscience data on learning in human and non-human animals. We have proposed a new meta-learning algorithm that dynamically balances the trade-off between getting new information from the environment (costly exploration) and acting according to currently learned action values (exploitation). To test the validity of the algorithm, we have co-designed with neuroscientists a non-stationary 3-armed bandit task in rats, where three levers have to be pressed and are associated with different probabilities of food reward. We found that the rat behavior is better accounted for by our meta-learning algorithm than by simple reinforcement learning without dynamic trade-off, and than a series of tested alternative models. This gives a first online solution to implicit budget processing during learning ([15,12]).
- Then we tested several different models on human behavioral data acquired by our collaborators where humans dynamically alternate between two learning processes, one requiring costly access to working-memory (costly in the sense that it takes more time to decide), the other being simple reinforcement learning. We found that human subjects use working-memory (and thus slow down their decision time) only when environmental changes make them increase their number of errors, and then reduce access to costly working-memory when their performance improves again [10].
- Finally, together with other neuroscientific collaborators, we tested a model-driven hypothesis on how humans reduce the cost of two brain learning systems necessary for two learning contexts, and then generalize between learning contexts. When subjects learned to choose between two options A and B in context C1, and two options C and D in context C2, confronting all these options in a new context C3 did not result in a simple comparison of absolute values learned for each option, as simple reinforcement learning algorithms like Q-learning would predict. Instead, humans appear to have rescaled each pair of option values in order to put all of them in a common currency. Moreover, having put option values in a common currency progressively enabled a single brain learning system to treat all option values, thus reducing activity in the part of the brain responsible for the second learning system [11].
- The last step of the project will consist in transferring these Neuroscience ideas on human and non-human animal online learning and generalization capabilities back to Machine Learning and Robotics, by seeing if these same computational principles can apply to online budgeted learning during both robot navigation and image classification.

Publications

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[2] Gabriella Contardo, Ludovic Denoyer, Thierry Artières, Patrick Gallinari: Apprentissage Sous Contraintes Budgetisées – Application à la Recommendation – Poster CAP 2014
[3] Gabriella Contardo, , Thierry Artières:Representation Learning for cold-start recommendation.ICLR 2015
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[5] Ludovic Denoyer, Patrick Gallinari: Deep Sequential Neural Network - Workshop Deep Learning NIPS 2014
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PhD Thesis

PhD student: Gabriella CONTARDO

Supervisor(s): Ludovic DENOYER & Thierry ARTIERES

Laboratory: Laboratoire d'Informatique de Paris 6 (LIP6 - UPMC)

Doctoral School: EDITE

Period: 01/10/2013 – 31/09/2017

1. Context

Machine learning has known in the last decade an explosion of popularity and performances on a variety of tasks, from image classification to natural language processing, mainly with the proposal of specific neural networks architectures such as convolutional neural networks or recurrent neural networks. However, most of today's machine learning successful methods rely on large quantity of data, usually assuming that it is available for free. It is a strong assumption as costs can happen at different levels. For instance, an input is generally seen as a vector of features: these features can have a cost of acquisition, typically in medical diagnosis, where each feature is the results of a medical test (blood sampling, fMRI,...). In such cases, optimality is defined as a trade-off between prediction quality and the feature acquisition cost that lead to the predictions. Another type of cost is the labeling cost when doing supervised learning: labeling examples usually rely on human expertise and work, which takes time and money. Moreover, cost can also be considered during training (constraining the information used to attain a certain performance) or testing. These different costs falls under what can be called in a general fashion *budgeted* learning, where learning is conducted such that it integrates the notion of the cost of acquiring the information.

This thesis focus on the test budget, where one aims at learning how to predict under a budget constraint. We present contributions for different types of problems: (i) for cost-sensitive feature acquisition, (ii) for labels constraint.

2. Contributions

2.1 Learning features acquisition strategies

Cold-start recommender system – Static feature selection: Problems with costly features can be various, but one hot-topic application that falls under this paradigm is recommender systems, and more generally personalized predictive tasks. Indeed, in these applications, the system has to make some prediction based on information on a user, such as his/her characteristics, or ratings he/she gave to some items. Obviously, all the information (features) are not available at a given time. When a new user arrives in the system, nothing is known about him/her, which usually led to interview strategy, where the system asks some question to the new user to gain knowledge about him/her. Our first contribution in this thesis is presented in [1]. We propose a model that learns in parallel an interview strategy (which questions to ask, i.e which features to acquire) and a representation learning model that allows both to work on sparse inputs and add additional information (when the user continues to interact with the system, e.g by giving new ratings on its own). Based on study that shows users prefer one-step interview (e.g 10 questions are proposed on a single web page) rather than sequential interview (where the user answer one or several questions, then click next and receives new questions), we choose to focus on learning a static interview strategy. Thus, the objective is to find an optimal subset of features to acquire, this subset being the same for every new user. We achieve so by presenting a model that shifts the usual representation learning paradigm for recommender system so that it can be formulated as neural network with a single hidden layer. We integrate in our architecture specific weights that control the feature acquisition. This leads to an efficient method that can be learned using classic gradient descent techniques and competitive with the proposed baselines.

Adaptive cost-sensitive feature acquisition - A recurrent neural network based approach: While being adapted for recommender system applications, static feature selection strategies however can become limited for more generic cost-sensitive tasks, as they are not able to adapt depending on the incoming input. Typically, in a medical diagnosis, the doctor will adapt his/her acquisition strategy depending on what has currently been

observed. Additionally, the cost of acquisition may vary from one feature to another, which is something one should integrate in the system. Therefore, we present in [2] a specific recurrent neural network architecture to tackle such adaptive and cost-sensitive acquisition process. The architecture relies on representation learning to aggregate the acquired information and to predict the next features to gather. All components being completely differentiable, the model can be learned using gradient descent techniques. It is closely related to visual attention models, however it is not limited to images inputs. Moreover, one of the main novelty w.r.t state of the art in cost-sensitive feature acquisition methods is the *batch-acquisition* ability: at each step, the system can acquire more than one feature[1]. It is an interesting property as it speed up the acquisition process (less steps needed) and can be useful if the acquisition cost is related to time (this allows parallel computation or acquisition of features at a given step). The results presented in the paper show that our model is competitive with state of the art methods, and scales well to bigger datasets (in terms of number of features).

Adaptive cost-sensitive feature acquisition - Stochastic approach: The approach describes above, while performing well on various tasks of different natures, relies on a continuous relaxation to compute the *acquisition vectors* that guide the process. Thus, we proposed a model to come closer to the actual real loss we defined for cost-sensitive adaptive acquisition. Ideally, one is expecting an acquisition system to predict sparse *binary vectors*, where a feature *i* is acquired only if the acquisition vector feature *i* is equal to one. However, they are hard to integrate in classical neural networks as it needs non-differentiable functions to obtain such vectors. We therefore choose instead a stochastic approach, where each step of acquisition is guided by sampling the expected acquisition binary vector from the vector outputed by the system at this given step. We rely on a similar recurrent neural architecture as the previous method, with representation learning to handle the aggregation of features and the prediction of the sampling probabilities. Learning these sampling probabilities vectors is done by using a policy gradient method called REINFORCE. While still giving competitive results compared to state of the art (shown in [3]), the model does not seem to perform better to the previous one, while being "closer" to the real objective loss.

2.2 Learning how to acquire labels for a new problem

We focus for the last part of this thesis on a different budgeted problem, where we consider the cost of labeling examples. It is usually the setting of \textit{active learning} where the system should ask an oracle for the most useful labels. However, the objective of the thesis is (generally speaking) how to learn to integrate the budget during prediction, using "interactive" systems at test-time. Thus we propose to study a different setting, inspired from one-shot learning problems. In such tasks, the goal is to learn a system that is able, during inference, to predict on new problems (i.e datasets) that have very few labeled inputs. It is close to *meta-learning*, or more specifically *transfer learning*, as the domain of inputs is the same for all problems (e.g images). Usually, the few labeled inputs are chosen randomly. We want to study how a more intelligent system, able to choose which inputs to label, would gain in performance w.r.t state of the arts approaches in one-shot learning or active learning. We are currently experimenting two models. The first is a *static/batch* approach, that considers the whole new dataset of a problem using a bidirectional LSTM, to predict which examples to label, and then outputs predictions. The second is a *sequential* approach, using a recurrent neural network coupled with REINFORCE algorithm, where at each step an example of the dataset is feed to the network, which then choose if it asks for a label or not, and make a prediction.

3. Publications

[1] G. Contardo, L. Denoyer, and T. Artieres. *Representation learning for cold-start recommendation.* In International Conference on Learning Representations (poster) ICLR 2014 - arXiv preprint arXiv: 1412.7156, 2014.

[2] G. Contardo, L. Denoyer, and T. Artières. *Recurrent neural networks for adaptive feature acquisition.* In International Conference on Neural Information Processing, pages 591–599. Springer, 2016.

1 Most of other approaches usually acquire features one at a time, or otherwise rely on pre-defined subsets or greedy algorithms on the possible subsets, which lead to combinatorial problems when the number of features grows.

[3] G. Contardo, L. Denoyer, and T. Artières. *Sequential cost-sensitive feature acquisition*. In International Symposium on Intelligent Data Analysis, pages 284–294. Springer, 2016.

[4] G. Contardo, L. Denoyer, T. Artieres, and P. Gallinari. *Learning states representations in pomdp*.In International Conference on Learning Representations (poster) ICLR 2014, pages 120–122, 2014.

[5] A. Ziat, G. Contardo, N. Baskiotis, and L. Denoyer. *Car-traffic forecasting: A representation learning approach.* In MUD@ ICML, pages 85–87, 2015.

PhD Thesis

PhD student: Nassim Aklil

Supervisor(s): Mehdi Khamassi & Ludovic Denoyer

Laboratory: Institute of Intelligent Systems and Robotics (ISIR, UPMC-CNRS)

Doctoral School: ED3C, Cerveau Cognition Comportement (UPMC)

Period: 01/10/2013 – 31/09/2017

Description (Context & Objective)

The theory of reinforcement learning has significantly contributed to researches in machine learning, robotics and neuroscience [1]. It formally specifies how an agent should choose the best actions to perform and update this choice through learning by trial-and-error so as to maximize long-term cumulative rewards. This theory has helped better understand the mechanisms underlying reinforcement-based plasticity in brain circuits dedicated for action selection [2]). In parallel, it contributed in designing adaptive agents that can learn optimal paths to rewards in simulated discretized grid worlds. However, they do not explicitly take into account the budget constraint: how much time and computational cost the agent can use to learn the task? On the other hand, budgeted learning methods have been proposed in machine learning [3], but they do not yet work online. These algorithms prove their efficiency by taking into account an explicit budget that can balance the cost/efficiency trade-off (cost of decision making, number of actions allowed, computation time, etc ...). The objective of this PhD thesis is to extend budgeted learning methods to make them work online by taking inspiration from recent neuroscience data, and to apply them to online learning in Robotics.

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[2]: Khamassi, M. and Humphries, M.; Integrating cortico-limbic-basal ganglia architectures for learning model-based and model-free navigation strategies; Frontiers in Behavioral Neuroscience; 2012

[3]: Denoyer, L. and Gallinari, P; Deep Sequential Neural Network; ArXiv; 2014

Main Results

Four experimental works have been performed:

1. We investigated neuroscience data illustrating meta-learning processes during the online regulation of exploration in rats having to learn a multi-arm bandit task under different levels of uncertainty (Figure 1 Left).
2. We simulated a robotics setup to apply budgeted learning in a localization task. We investigated the performance of a robot to localize in an unknown environment by learning a policy under a budget constraint (Table 1, Figure 1 right).
3. We applied the previous simulated case on data extracted from a PR2 robot in order to investigate the performance of such a model on a real world task implementation.
4. We are actually simulating a budgeted online learning where the robot chooses the best budget to stop the exploration of the environment by comparing the cost of using a budget with its performance in localization.

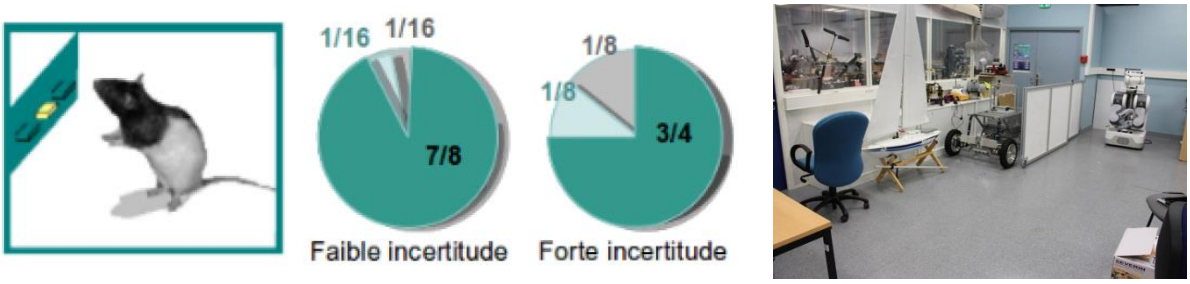


Figure 1: (LEFT) Online regulation of exploration (meta-learning) in a rat multi-armed bandit task. Rats have to choose at each trial between 3 levels, each one being associated with a different probability of reward. Model fitting on rat behavior using a meta-learning algorithm revealed that they dynamically regulate their exploration level in order to efficiently solve this task. (RIGHT) Robotics navigation setup to investigate online budgeted learning for the determination of the robot's location. This part of the work has just started and we have made the specification and started the acquisition of a dataset with different robot positions, sensing data and movements.

	Budget		
Type	1	3	5
Image classification	53.9	56.6	59.8
Forced policy			
Recurrent	49.9	67.4	75.9
Non Recurrent	55.8	60.8	61.2
Learned policy			
Recurrent	52.9	61	70
Non Recurrent	46.8	69.4	60.04

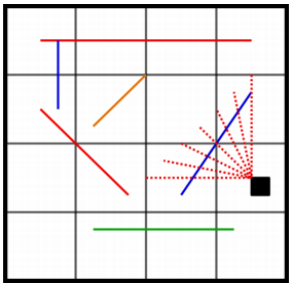


Figure 2: (LEFT) Results of Sequential action selection in robots in percentage. The model has been compared with a Neural Network classification and has been simulated with two different policy selections. The results show that the model has a better performance than the classification and that it can learn the best policy for a localization task by itself. (Right) Simulation of a 2D environment. The black square is the simulated robot, colored lines are the walls and the dashed lines are the field of vision of the robot's sensor.

Publications

- Nassim Aklil, Alain Marchand, Virginie Fresno, Etienne Coutureau, Ludovic Denoyer, Benoît Girard, Mehdi Khamassi: Modelling rat learning behavior under uncertainty in a non-stationary multi-armed bandit task. Fourth Symposium on Biology of Decision Making (SBDM 2014). Paris.
- Nassim Aklil, Benoît Girard, Mehdi Khamassi and Ludovic Denoyer: Sequential Action Selection for Budgeted Localization in Robots. First IEEE Robotic Computing (ICRC 2017). Taipei, Taiwan.

PhD Thesis

PhD student: Aurelia Leon

Supervisor(s): Ludovic Denoyer

Laboratory: LIP6

Doctoral School: EDITE (UPMC)

Period: 01/10/2015 – 31/09/2018

Context

Recently, a new family of algorithms called Sequential Prediction Models has emerged in Machine Learning. The motivation behind their development is that, while there is a plethora of standard algorithmic solutions for supervised and unsupervised training, most of the methods learn a monolithic predictor function, that is each test instance is processed in a single-step, atomic process. In contrast, some recent studies have proposed a different paradigm in which prediction is reformulated as a sequential decision process. Unrolling monolithic functions into a sequence of decisions and controlling when the final prediction is made is obviously beneficial to learn "budgeted predictors", so some of the approaches are motivated by either fast prediction or by keeping the number of costly feature evaluations low. Typical applications of these techniques are real-time object detection or web page ranking, trigger design in high-energy physics, or resource-bounded information extraction. A very interesting point is that sequential learning models can naturally take into account an explicit interaction with an expert, at two different levels:

- while sequential models behave "like experts", humans can be used to guide the learning process, and
- sequential models can naturally interact with humans by asking questions.

The Thesis will focus on budgeted Reinforcement Learning problems and will be organized along two points:

RL with Costly features

In supervised learning, some sequential models have been proposed that are able to focus their attention on relevant sub-parts of any given input datum. These models have been mainly applied on text categorization where they focus on relevant sentences of a document, on vectorial input data where they act as adaptive features selection models, and on image classification where they simulate "eyes trajectories", focusing on relevant parts of the picture.

An agent learning to interact

While interacting with a human, an agent can ask "questions" at each time-step. In other words, interacting with an expert will be one of the possible actions the agent can decide to do. By querying humans, the agent will be able to collect high-level and high-quality information that will help him to reach his objective. However, as humans don't want to intervene at each time-step, the agent must learn when to ask for direction. A way to do it is to consider that each instruction has a certain cost, and to apply RL algorithms with costly features.

Contributions

Several articles have already been written during the thesis:

- Reinforced Decision Trees, accepted at EWRL 2015 (European Workshop on Reinforcement Learning at ICML)
- Policy-gradient methods for decision trees, accepted at ESANN 2016
- Options Discovery with Budgeted Reinforcement Learning, under review at ICLR 2017 and accepted in the Deep Reinforcement Learning Workshop at NIPS 2016

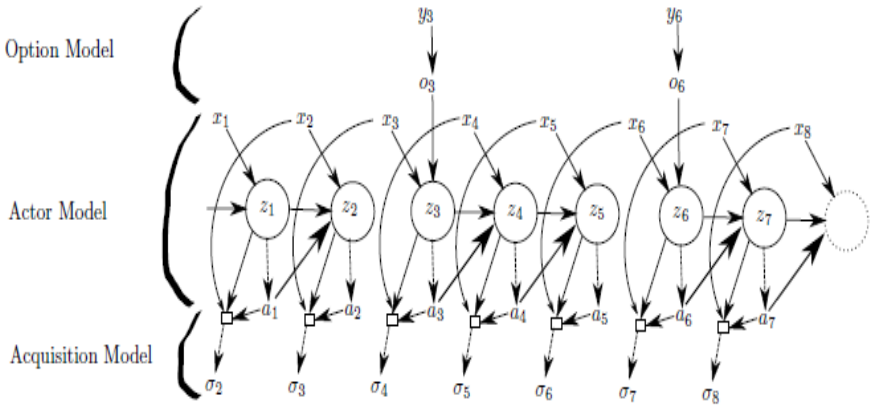
A variant of RDT called RECOC (for Reinforced Error-Correcting Output Codes) was also developed during my internship and the beginning of my thesis. Another PhD student now works on this model.

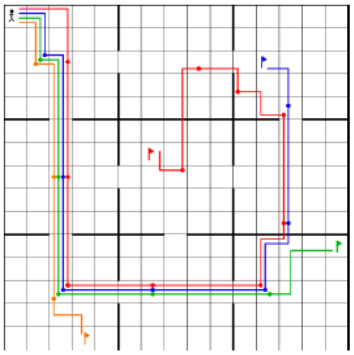
Policy Gradient for Decision Trees

The first step of the thesis was focused on using RL models as an extension to mixture of experts,. It was a way to start working on a problem where a RL agent has to learn how to sequentially apply different classifiers to reach a final decision. It consists of the model Reinforced Decision Tree (RDT) which resulted in two articles, accepted at EWRL 2015 and ESANN 2016. This work was partly done during my M2-internship.

Options Discovery with Budgeted Reinforcement Learning

We consider the problem of learning hierarchical policies for Reinforcement Learning able to discover options, an option corresponding to a sub-policy over a set of primitive actions. Different models have been proposed during the last decade that usually rely on a predefined set of options. We specifically address the problem of automatically discovering options in decision processes. We describe a new learning model called Budgeted Option Neural Network (BONN) able to discover options based on a budgeted learning objective. More precisely, it is based on the idea that a good policy is a trade-off between policy efficiency and cognitive effort: a system will learn relevant options if these options allow it to reduce the {cognitive effort for solving the task, without decreasing the quality of the solution. This idea is implemented here through a budgeted learning problem that encourages the BONN model to learn to acquire as few information as possible.



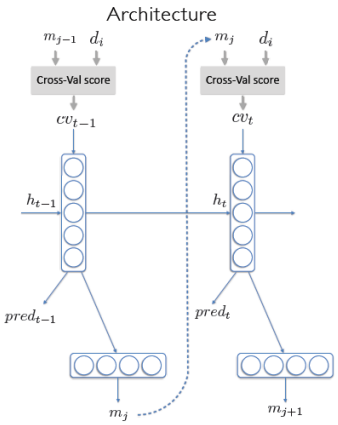

(a)

PostDoc

Djalel Benbouzid

Dr. Djalel Benbouzid has mainly worked on the extension of sequential acquisition models to the meta-problem of “learning to learn”. The idea, close to experimental design, is to learn the optimal policy which will, given a new incoming problem, sequentially learns particular instances of predefined models on this problem in order to find the ‘’best’’ model as fast as possible i.e by testing only few instances. The goal is to extend the budgeted models proposed in the project to the online setting where the goal is to learn ‘’as fast as possible’’ on every new dataset.

The proposed model is very close to the DREAM model proposed by G. Contardo in the project, but the nature of the input is very different. As data point, this approach is using a set of supervised learning problems. Each problem is described by a set of features, each feature corresponding to the test performance achieved by a given model onto this dataset. The learning objective is thus to train at least models at possible in order to discover which model will have the best performance on a new dataset. The architecture of the model is based on deep neural networks as illustrated bellow.



This model is still under investigation and an internship on this topic will start next month

SeNSE

SeNSE
Socio-Emotional Signals

***Responsible of the project**: Catherine ACHARD*

***Partners**:*

ISIR (UPMC): C. Achard, K. Bailly, M. Chetouani, S. Dubuisson, O. Grynzspan

LIP6 (UPMC): P. Garda, C. Marsala, A. Pinna, M. Rifqi

LTCI (Telecom Paris-Tech): C. Clavel, S. Essid, C. Pelachaud, G. Richard

STMS (IRCAM): F. Bevilacqua, G. Assayag

The Project at a glance

Context and Objectives

The SeNSE project, which focuses on social emotional signals exchanged during an interaction, investigates topics ranging from signal acquisition (video, audio, neurophysiological) to interaction (virtual agent, musical interaction, people interaction) including interpretation and modeling. This project brings together key partners of social signal processing, machine learning, electronics and human computer interaction. The SeNSE project will break new ground for the multi-modal analysis and synthesis of social behavior. We are particularly interested in both dynamical and temporal aspects of interaction.

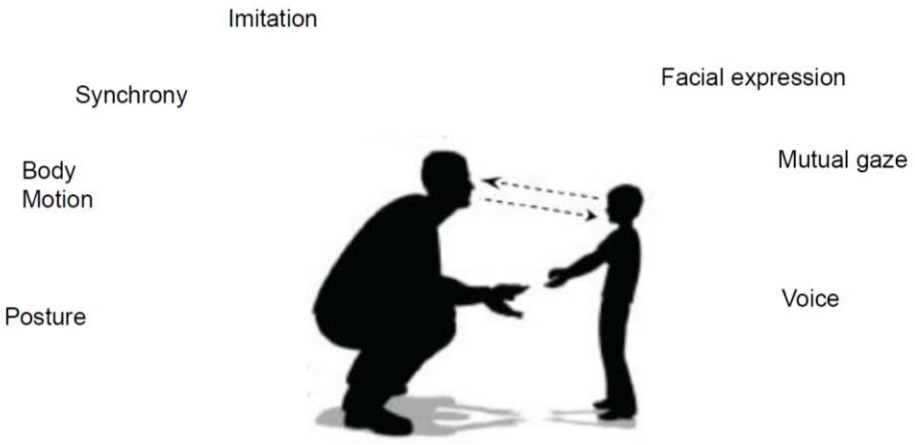


Figure 1 - Social Signals

The methodology will deal the heterogeneous nature of cues from low-level information (audio, video, EEG, ECG, EDA…) to high-level information (emotions, social attitude, user traits…). Thus, the considered signals are multimodal with their own dynamics and they may influence each other during social interactions. For example, for a virtual agent, understanding the dynamics of socio-emotional signals is one of the challenges for the analysis and synthesis of realistic behaviors. In musical interaction, analyzing and describing multi-modal signals in large group provide new paradigms for expressive and collaborative interactions.

Analyzing such situations by social signal processing techniques requires new models and methodologies. To tackle this challenging problem, we focus on three main aspects (1) developing computational models of socio-emotional behaviors considering different modalities (audio, gestural, physiological and brain signals...) (2) studying intermodal and temporal dependencies for both intra and inter personal signals and (3) designing smart devices embedding socio-emotional processing.

Scientific progress and results

General achievements

Two main aspects of SeNSE have been studied during the first 40 months (total duration 48 months).

The first one is the **synchrony in social signals**. Actually, we study multimodal signals that can be transmitted by one person or that can be exchanged during a discussion. This synchrony is studied and modeled for several purposes: qualify the quality of interaction, animate a virtual agent or find new EEG signals involved in an interaction between individuals.

The second challenge we address in this project is the **adaptation**. Again, adaptation will be analyzed and modeled. This model will be used to animate virtual agents that automatically adjust their behaviour to the interlocutor. It will also be used to recognize the emotions of a person according to a general model of emotion that will be adapted to each subject.

Modelling of synchrony in interaction

A major challenge is to study and model the synchrony between social signals exchanged during an interaction between people. Such a model can be used to better understand the processes involved in an interaction, to characterize interactions and more particularly their quality, or to generate behaviors avatars. Several works have begun on synchrony.

In the first work, performed during a **PhD supervised by C. Achard and S. Dubuisson and started in January 2015**, we are interesting in **modelling the synchrony of nonverbal audio-video signals in groups of people**. As an important task for the understanding of social interactions is the role recognition of each participant and as the roles are highly related to the synchrony between participants, we validate our model on a role recognition task. Actually, if someone has a dominant role in the interaction, there will be probably a high synchrony between its nonverbal or verbal signals and the other participant's ones. We then have proposed some approaches to automatically recognize the role of the participants of a meeting by modeling the synchrony of temporal nonverbal audio features. In our approaches the Influence Model (IM), a HMM-like, is used to model this synchrony and extract a feature vector that contains both information about temporal transitions (intra-personal data) and interaction between participants (inter-personal data.

This modelling of the meeting is used as input of a Random Forests (RF) for the role recognition task. The experiments were performed on 138 scenario meetings (approximately 45 hours recordings) from AMI Corpus. Results show that this combination of generative (IM) and discriminative (RF) approaches permits to outperform state-of-the-art recognition rates. This work has been accepted for publication in the journal Multimedia Tools and Applications.

The following of this work concerns the estimation of personality traits and social impressions during interactions. We use the ELEA dataset that has been very recently released (July 2015) and depicts groups of people (3 to 4 participants) playing a winter survival game. We extracted a rich set of audio and visual features, which are divided into three categories: intra-personal features (i.e. related to only one participant), dyadic features (i.e. related to a pair of participants) and one vs all features (i.e. related to one participant versus the other members of the group). Firstly, we predict the personality traits (PT) and social impressions (SI) by using these three feature categories. Then, we analyze the interplay between groups of features and the personality traits/social impressions of the interacting participants. The prediction is done by using Support Vector Machine and Ridge Regression that allow to determine the most dominant features for each social dimension.

Our experiments show that the combination of intra-personal and one vs all features can greatly improve the prediction accuracy of personality traits and social impressions. The best prediction accuracy reaches 81.37% for the social impression named 'Rank of Dominance'. This work has allowed drawing some interesting conclusions about the relationships between personality traits/social impressions and social features. This work has been published to the conference ICMI 2016. We now are working on feature selection and multi-tasks learning in order to better interpret the importance of each individual feature in social dimension.

In the same time, we have implemented an annotation in terms of meeting quality on the online platform Crowdflower. These annotations will be used to understand the processes involved in a good interaction of group.

Another issue, exploited during a PhD supervised by K. Bailly, C. Clavel and G. Richard and started in October 2014, concerns the synchrony with the purpose to animate a virtual agent. The goal is to develop a methodology dedicated to deduce sequences of signals expressed by humans during an interaction and to use them in order to animate an embodied conversational agent (ECA) according to different social stances. We focus on sequences of social signals such as modulations of Action Units and prosody during a face-to-face exchange. We have illustrated the proposed methodology to the SEMAINE-DB corpus from which we automatically extracted Action Units (AUs), head positions, turn-taking and prosody information. We propose a new sequence mining algorithm – Social TITARL - dedicated to the extraction of sequences of social signals featuring different social stances. The proposed algorithm relies on the use of TITARL (Temporal Interval Tree Association Rules) algorithm that has been adapted in order to integrate constraints concerning intra and inter-modality coherency. The method enables us to identify more precisely the duration of the social signals. We then propose a first implementation of the rules in the agent behavior model in order to evaluate the perception of the agent's stance. After having focused on the modelling of the listener social stances and on rules concerning sequences of AU and head-nod evolutions with time information, we work on prosodic rules. We took the best-scored rules for Poppy (friendly) and Spike (hostile) and transpose them into SSML (Speech Synthesis Markup Language) file as an input of a speech synthesis tool. We then perform an evaluation of the rule-based speech synthesis with the online platform crowdflower.

Having a better understanding of physiological human emotion elicitation would be beneficial for brain-computer interfaces. Up-to-date, these research communities focused on non-verbal behaviors such as facial expressions or gesture and very few has been done on analyzing physiological signals, whether it be on audio-visually stimulated or interactive people (imitation, synchrony).

So, we work during a PhD supervised by S. Essid and M. Chetouani and **started in October 2014,** on the development of new computational models for modeling such phenomena. In this thesis, we exploit EEG signals. Compared to other physiological signals, EEG has the advantage of capturing information related to internal emotional states, which do not result in any observable external manifestations. Thus, EEG has attracted the attention of researchers in the field of affective computing as part of the effort to perform automatic emotion recognition. Indeed, EEG signals have proven to be a precious clue in emotion classification. We address the issue of emotion recognition in the commonly used valence-arousal space. In particular, we considered a time-frequency domain representation of the EEG data input. This approach is motivated by the large literature on the relationship between EEG frequency bands and emotions. Usually, feature extraction focuses on predefined frequency bands. Being automatic latent variable extractors, nonnegative matrix factorization-based models present the advantage of not relying on ad hoc features. The figure below sums up the principle of Nonnegative Matrix Factorization (NMF), which, for a given number of patterns K, is based on the minimization of a matrix divergence between the input matrix V and the product of the output matrices W and H.

Experiments are currently performed with EMOEEG database. This is a multimodal dataset where physiological responses to both visual and audio-visual stimuli are recorded, along with videos of the subjects, with a view to developing automatic emotion recognition systems. The experimental setup involves various sensors, namely EEG, ECG, EMG and EOG signals, in addition to skin conductance information. The

experiment was lead on 8 participants from both genders. The stimuli used included both sequences of static images from IAPS dataset and shot video excerpts focusing on negative fear-type emotions.

We developed EEG based emotion detection system using NMF for feature extraction and SVM for classification. Within this framework, we address the problem of emotion recognition using a multi-task approach, motivated by previous works on valence/arousal interdependencies. We exploit arousal labels to control valence-related feature learning and vice versa, using Group Nonnegative Matrix Factorization (GNMF). Some promising results were obtained, F1-scores obtained proving that the use of arousal labels to control the valence classification task improves its performance. A paper presenting such work and called "Multi-task feature learning for EEG emotion recognition using Group Nonnegative Matrix Factorization" was submitted to ICME 2017.

Modeling of adaptation in interaction

Another important aspect of interaction is the adaptation. Two works have begun in parallel on this topic.

The first work concerns a PhD Work on **adaptation to partner's behavior, supervised by F. Bevilacqua and C. Pelachaud.** We have implemented the influence model to manage turn-taking behaviors among agents. Each agent is represented by an HMM made of 5 states (Speaking, Listening, Wanting-to-Speak, Giving-Speech and Idle). This approach is similar to the model proposed recently b Brian Ravenet's turn-taking model (Ravenet et al, 2015), but offers more flexibility by implementing a full probabilistic approach for transition between state and observation of non-verbal parameters (gaze, gesture). A study has been carried on to show that our influence model can reproduce Ravenet's model behaviour. The different parameterization of the influence model allows for generating different behaviors that will be studied using a perceptive study. The influence model is general and can be applied to other cases of collective and social interaction. For example, we are investigating the application of our model in music interaction between human and artificial agents, as currently developed in the ANR projects DYCI2 and CoSiMA.

The second work, done in the context of a **PhD supervised by M. Rifqi, A. Pinna, P. Garda and C. Marsala and started in November 2014,** aims to learn **a general model of emotional states that will then be adapted to each individual**. The final application is to create an embedded and adaptive architecture which can automatically recognize emotion from physiological signals, in a context of affective gaming.

The first step, already presented in the first deliverable, was to perform a state of the art on emotion representations, affective gaming and methods for automatic emotion recognition.

The last year, we have set an experimentation in order to collect physiological signals on gamers during a video game session. This experimentation has been jointly conducted by INSEAD-Sorbonne Behavioral Lab (official name "Centre Multidisciplinaire des Sciences Comportementales Sorbonne Universités-INSEAD") during the months of May and June.

A panel of 58 participants have played on the game FIFA2016 on a PC. The analysis of the collected data is currently under process. From this dataset, several machine learning experiments have been conducted. First of all, the learning task consists in determining arousal and valence values of emotions set by a subject from its physiological signals. Preliminary results of this machine learning experiments show that the Linear SVM performs well for user-dependent emotion recognition. A reasonable choice of segmentation length of the physiological signals can be found around 14s and by means of a standard normalization approach. We have also shown that learning performance with feature selection is significantly better than without feature selection. It can also be highlighted that for valence classification, respiration, EMG, and EDA are the most important features, instead, for arousal classification, ECG, EMG and EDA are the most important ones. The performances of the feature selection is scattered across different subjects, which means that the recognition of emotions is a difficult inter-user task.

At the same time, a new approach of adaptive classification model for changing data has been proposed: adaptive fuzzy decision tree [Yang et al., 2016]. This approach enables the tuning of the fuzzy decision tree

when temporal data varies among time. It is able to absorb and adapt to small drift in the data stream. It is an approach well-adapted to handle physiological signals in predictive settings.

As a summary, we have carried out an experiment to collect physiological signals and self-assessment under the context of a football simulation game. Different experimental settings such as learning algorithm, normalization, segmentation length, feature selection, signal importance have been analyzed and discussed. Machine learning preliminary results show promising results on user-dependent classification. However, large individual variability exists, which makes the recognition model difficult to generalize through different subjects. Future work will focus on developing subject specific model and on implementing the algorithm on the embedded system.

Future Work

In the following, regarding the computational models, we will finish to develop and evaluate models dealing with (1) emotional behaviors and (2) temporal dependencies of intra and inter individual behaviors. These will be performed for analysis, modeling and synthesis phases in human-human and human-virtual agent situations.

Event

Workshop on "Man-Machine Interface"

Paris, December 2015, 94 participants

http://www.gdr-isis.fr/index.php?page=reunion&idreunion=289

Recruitments

INTERNSHIPS

- **Comparaison of sequence mining methods for emotion generation,** A. Jaskolski, M2 Internship (march-july 2017) Supervisors : T. Janssoone (ISIR-TelecomParisTech), Soumia Dermouche (ISIR)
- **Study of multimodal synchrony during social interaction**, F. Aujoux, M2 Internship (march-july 2014). Supervisors: C. Achard (ISIR), S. Dubuisson (ISIR)
- **Modeling the temporality of multimodal social cues exchanged during natural interactions**, S. Fang, M2 Internship (july-december 2014). Supervisors: C. Achard (ISIR), S. Dubuisson (ISIR)
- **Multimodal analysis and recognition of social signals**, L. Chen, M2 Internship (march-august 2014). Supervisors: C. Clavel (LTCI-CNRS) and K. Bailly (ISIR)
- **Study of the judgment of agency in the gaze modality**, S. Recht, M1 Internship (March-June 2014). Supervisor: O. Grynszpan (ISIR)
- **Modeling of neurophysiological activity related to the dynamics of an interaction with latent variables analysis**, A. Hajlaoui, M2 Internship (april-august 2014). Supervisor: S. Essid (LTCI-CNRS), M. Chetouani (ISIR)

PHD THESIS

- **Embedded architecture and physiological sensors,** W. Yang, 2014-2017. Supervisors: C. Marsala (LIP6), M. Rifqi (LIP6) and A. Pinna (LIP6)
- **Multimodal analysis and recognition of social signals: application to social stance generation in virtual agents,** T. Janssoone, 2015-2018. Supervisors: G. Richard (LTCI-CNRS), C. Clavel (LTCI-CNRS) and K. Bailly (ISIR)
- **Study of social cues exchanged during natural interactions,** S. Fang, 2015-2018, Supervisors: C. Achard (ISIR) and S. Dubuisson (ISIR)
- **Temporal Adaptation of Interaction,** Kevin Sanlaville, 2013-16. Supervisors: C Pelachaud (LTCI-CNRS), F. Bevilacqua (STMS) , G. Assayag (STMS)

- **Modeling interactional neurophysiological activity using latent variables,** A. Hajlaoui, 2014- 2017, Supervisors: M. Chetouani (ISIR) and S. Essid (LTCI-CNRS)

Publications and communications

Chapter

- Chloé Clavel, Angelo Cafaro, Sabrina Campano, and Catherine Pelachaud, Fostering user engagement in face-to-face human-agent interactions: a survey, in A. Esposito and L. Jain (Eds), Toward Robotic Socially Believable Behaving Systems - Volume II: Modeling Social Signals, Springer Series on Intelligent Systems Reference Library (ISRL), (pp. 93-120), 2016

Refereed Articles

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- Gabor Aranyi, Florian Pecune, Fred Charles, Catherine Pelachaud and Marc Cavazza, Affective Interaction with a Virtual Character Through an fNIRS Brain-Computer Interface, Front. Comput. Neurosci, volume 10, 2016.
- Nesrine Fourati, Catherine Pelachaud, Perception of emotions and body movement in the Emilya database, IEEE transactions on affective computing, to appear.
- Angelo Cafaro, Brian Ravenet, Magalie Ochs, Hannes H. Vilhjálmsson, Catherine Pelachaud, The Effect of Interpersonal Attitude of a Group of Agents on User's Presence and Proxemics Behavior, ACM Transactions on Interactive Intelligent Systems (TiiS), volume 6, july 2016.
- Maurizio Mancini and Beatrice Biancardi and Florian Pecune and Giovanna Varni and Yu Ding and Catherine Pelachaud and Gualtiero Volpe and Antonio Camurri, Implementing and evaluating a laughing virtual character, Transactions on Internet Technology (TOIT), Special Section on Affect and Interaction in Agent-based Systems and Social Media 2016
- Clavel, C., Cafaro, A., Campano, S., & Pelachaud, C. (2016). Fostering user engagement in face-to-face human-agent interactions: a survey. In Toward Robotic Socially Believable Behaving Systems-Volume II (pp. 93-120). Springer International Publishing.
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- R. Bawden, C. Clavel, F. Landragin, Towards the generation of dialogue acts in socio-affective ECAs: a corpus-based prosodic analysis, Language Resources and Evaluation, Springer Netherlands, 2015
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Refereed international Conference Papers

- Fang, S. and Achard, C. and Dubuisson, S., Personality classification and behaviour interpretation analysis: an approach based on feature categories. International Conference on Multimodal Interaction 2016.
- Pecune, Florian and Cafaro, Angelo and Ochs, Magalie and Pelachaud, Catherine, Evaluating Social Attitudes of a Virtual Tutor, Intelligent Virtual Agents: 16th International Conference, Proceedings, Springer International Publishing 2016, pages 245–255.
- Soumia , Catherine Pelachaud, Sequence-based multimodal behavior modeling for social agents,

Proceedings of the 18th ACM International Conference on Multimodal Interaction, ICMI 2016, Tokyo, Japan, November 12-16, 2016.

- C. Langlet, C. Clavel, Grounding the detection of the user's likes and dislikes on the topic structure of human-agent interactions, Knowledge-Based Systems (2016), doi: 10.1016/j.knosys.2016.05.038
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- Angelo Cafaro, Nadine Glas, Catherine Pelachaud, The Effects of Interrupting Behavior on Interpersonal Attitude and Engagement in Dyadic Interactions, In Proceedings of the 16th International Conference on Autonomous Agents and Multiagent Systems (AAMAS'16), Singapore. May 2016
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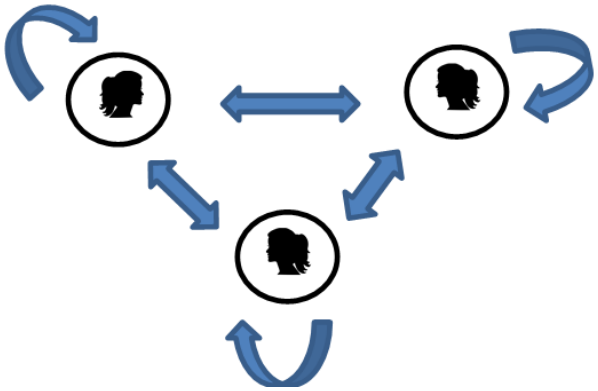
PhD Thesis

Study of social cues exchanged during natural interactions

S. Fang, 2015-2018
Supervisors: C. Achard (ISIR) and S. Dubuisson (ISIR)

During the first year of Sheng Feng's PhD, we mainly focused on one of the important tasks for the understanding of social interactions and has also become an important application for social signal processing that concerns the recognition of the role of each participant during a meeting. The synchrony between participants is highly related to the role each one plays during the conversation. For example, if someone has a dominant role in the interaction, there will be probably a high synchrony between its nonverbal or verbal signals and the other participant's ones. We then have proposed some approaches to understand the underlying mechanisms of interactions, in particular to automatically recognize the role of the participants during a meeting by modeling the synchrony of temporal nonverbal audio features. In our approaches illustrated on Figure 1, the Influence Model (IM), a HMM-like, is used to model this synchrony and extract a feature vector that contains both information about temporal transitions (intra-personal data) and interaction between participants (inter-personal data).

Figure 2 - The IM considers both intra and inter personal transitions



Each meeting is thus modeled by an IM with 4 chains, one chain per participant and 2 state values per chain. This modeling generates a matrix H that contains 4×4 sub-matrices of size 2×2. H includes both information about transition probability and influence between chains and is then transformed into a feature vector of size 64 for the classification. Then two solutions are used to recognize the four roles whose global frameworks are given in (Fang et al. 2017).

The experiments were performed on 138 scenario meetings (approximately 45 hours recordings) from AMI Corpus. Using the output of IM as input feature of a RF classifier has three main advantages. First, the complexity is greatly decreased by using IM compared to using HMM or coupled HMM, particularly when the number of participants becomes high, or when the number of state values increases. Secondly, the matrix generated by an Influence Model encodes both intra and inter personnel information, so it is a good descriptor of the interaction between people involved in a group. Finally, compared to using a single IM scheme for role classification, applying a combination of generative (IM) and discriminative (RFs) models greatly improves

the recognition rates (from 0.49 to 0.58 on AMI database) and also slightly outperforms state-of-the-art recognition rates. This work has been accepted for publication in Multimedia Tools and Applications journal.

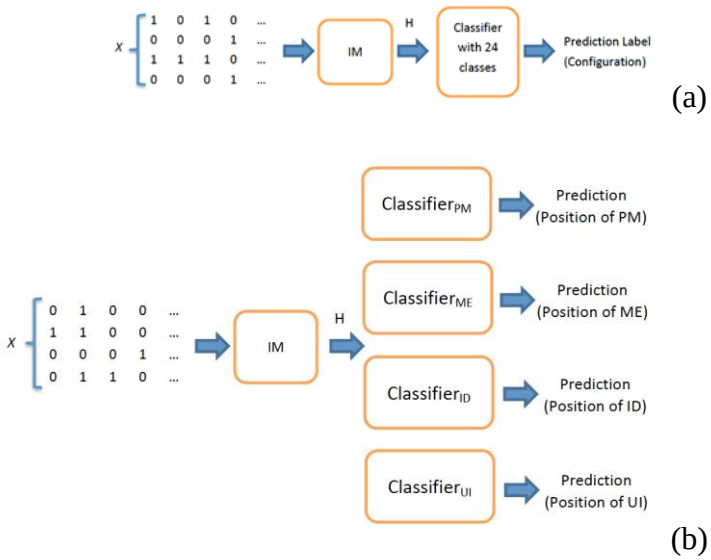


Figure 3 - The two approaches using IM and RF that have been studied. (a) a single classification is made with 24 labels corresponding to the 24 role configurations of a meeting, and (b) 4 independent classifications (one for each role) with four labels (the position of the role in the meeting).

Our current works focus on recognizing and understanding social dimensions (the personality traits and social impressions) during small group interactions, as well as on estimating quality of this interaction. For that, we work in the ELEA dataset that was very recently released (July 2015) and depicts groups of people (3 to 4 participants) playing a winter survival game. This dataset provides audio data, from which we have derived turn taking and video data from which movements have been extracted. Participants have also filled 3 questionnaires to get their personality traits, their dominance/leadership scores, as well as their perception of the interaction. Moreover, the scores obtained by each group to the game are also given. We have divided into three categories the set of audio and visual features: intra-personal features from speech and visual activity (*i.e* related to only one participant), dyadic features from speech activity (*i.e.* related to a pair of participants) and one_vs_all features from speech activity (*i.e.* related to one participant versus the other members of the group). The global framework is presented below.

In a first time, we predict the personality traits and social impressions by using the three feature categories previously described. As personality traits, we use the Big Five Personality Model that describes the personality through five dimensions also called OCEAN: openness to experience (O), conscientiousness (C), extraversion (E), agreeableness (A) and neuroticism (N). There are five social impressions derived from the provided answers: perceived leadership (PLead), perceived dominance (PDom), perceived competence (PCom), perceived Liking (PLike) and rank of dominance (RDom).

Then, we analyse the interplay between groups of features and the personality traits/social impressions of the interacting participants. The prediction is done by using Support Vector Machine (SVM, with RBF kernel) or Ridge Regression (RR) which allows to determine the most dominant features for each social dimension. We used RR as a classifier in two different ways. In the first method, called RR-med, the original personality traits and social impression values are used to train a RR model. Then the predicted values from the RR model are thresholded with respect to the median to get a binary label (0 if smaller, 1 if larger). In the second method, called RR-0/1, all the original personality traits and social impression values are first thresholded with respect to the median value to get labels 0 or 1 (0 if smaller, 1 if larger). The RR is trained with these binary values and the predicted values are compared to 0.5 to generate the predicted label.

Table 1 - Classification results on different feature categories

Features	O	C	E	A	N	PLead	PDom	PCom	PLike	RDom
Intra	61.76	69.61	64.71	62.75	73.53	76.47	71.57	70.59	74.51	71.57
Dyadic	59.56	57.60	60.54	59.07	55.88	66.42	63.23	57.60	59.31	59.31
One_vs_all	64.71	62.75	63.73	65.69	59.80	68.63	68.63	54.90	71.56	73.53
Fusion	73.53	79.41	77.45	77.45	79.41	80.39	76.47	72.54	77.45	81.37

Our experiments and comparisons, presented in Table 1 for the method called RR-0/1, show that intra-personal features lead to the highest accuracy, compared to dyadic and one_vs_all features. However, one_vs_all features contribute a lot to improve the performance (combined with intra-personal features) by considering the relationships between the target participant and the other ones. By combining the one_vs_all features and intra-features, the classification accuracy is greatly improved. The highest one reaches 81.37% for the social impression named 'Rank of Dominance'.

Ridge Regression coefficients (or weights) can be interpreted as the importance of the features to predict variables. We have sorted the weights by their absolute value and list the top five features with highest absolute values for each variable. A first conclusion is that the interruption information is very meaningful, since at least one of the top 5 ranked features is linked to interruptions for all the predicted variables. Other interesting conclusions are addressed by analyzing the importance of each social feature during the prediction of personality traits/social impressions (see our ICMI paper for more details).

To validate our results on task cohesion, it is important to have a ground truth. By using the Crowdflower platform (https://www.crowdflower.com), we have asked people to annotate video. For that we have proposed a questionnaire that contains 14 questions on which people should give their degree of agreement (on a 4 value Likert-scale). We get 6 annotators for each presented video. We are still studying results. We also attempt, in the last year of the PhD thesis, to characterize a link between the personality traits and the quality of the interaction.

Associated Publications and orals:

- Sheng Fang, Catherine Achard, Séverine Dubuisson, Modeling the synchrony between interacting people: application to role recognition, Multimedia Tools and Applications, to appear.
- Fang, S. and Achard, C. and Dubuisson, S., Personality classification and behaviour interpretation analysis: an approach based on feature categories. International Conference on Multimodal Interaction 2016.
- Sheng Fang, Catherine Achard, Séverine Dubuisson : SeNSE - Study of social cues exchanged during natural interactions, GDR ISIS, 02/12/2015

PhD Thesis

Modeling elicited emotional activity using latent variables

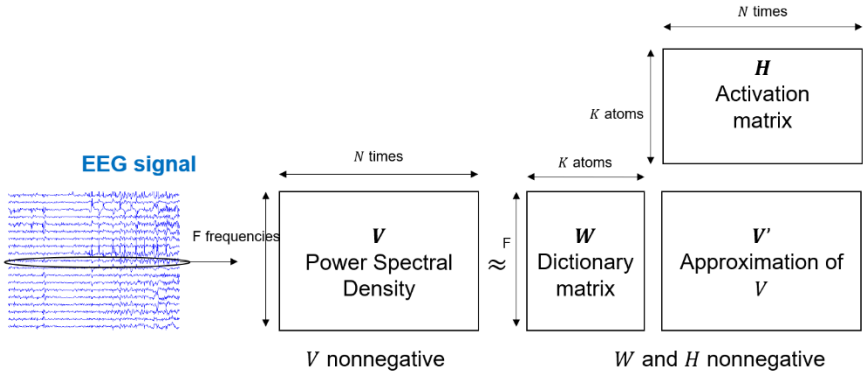
PhD student: Ayoub HAJLAOUI

Supervisors: Mohamed CHETOUANI (ISIR) and Slim ESSID (Télécom Paris)
Dates: October 2014 – October 2017

1) Introduction

The development of affective computing needs a better understanding of human emotion elicitation. Research in emotion recognition mainly relies on verbal or non-verbal cues such as facial expressions and eye gaze. The main limitation of these cues is their alterability, whether voluntary or not. On the other hand, physiological modalities such as Electroencephalography (EEG) do not suffer from such a drawback. Compared to other physiological signals, EEG has the advantage of capturing information related to internal emotional states, which do not result in any observable external manifestations. Thus, EEG has attracted the attention of researchers in the field of affective computing as part of the effort to perform automatic emotion recognition. Indeed, EEG signals have proven to be a precious clue in emotion classification. We address the issue of emotion recognition in the commonly used valence-arousal space.

In particular, we consider a time-frequency domain representation of the EEG data input. This approach is motivated by the large literature on the relationship between EEG frequency bands and emotions. Usually, feature extraction focuses on predefined frequency bands. Being automatic latent variable extractors, nonnegative matrix factorization-based models present the advantage of not relying on ad hoc features. The figure below sums up the principle of Nonnegative Matrix Factorization (NMF), which, for a given number of patterns K, is based on the minimization of a matrix divergence between the input matrix V and the product of the output matrices W and H.



NMF principle

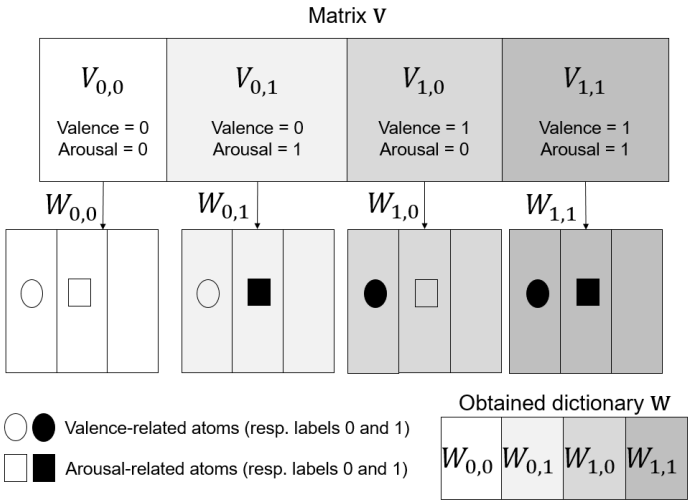
2) Current work

The use of the EEG modality raises several issues, among which emotion and EEG data representation and feature extraction. Within this framework, we address the problem of emotion recognition using a multi-task approach, motivated by previous works on valence/arousal interdependencies. We exploit arousal labels to control valence-related feature learning and vice versa, using Group Nonnegative Matrix Factorization (GNMF).

We call session the recording of a given subject at a given time of the day. Given a definition of sub-groups of the matrix V, GNMF adds to NMF constraints that force the atoms extracted from the same sub-group of V to be similar. Such similarity is expressed by adding to the objective function we want to minimize a term of

distances between the atoms of the same sub-group. Within this framework, Serizel et al.[2] proposed a model which can tackle two dependencies, that is to say two kinds of groups at the same time, with a focus on recording session dependency. Their model inspired our derivations of GNMF.

In our multi-task approach, the considered sub-groups are signal chunks corresponding to different couples of valence and arousal labels. For each session, GNMF allows us to use valence and arousal information to compute the atoms of the session dictionary W, as shown in the figure below.



Learning a dictionary matrix W with GNMF

Based on activation matrices, the classification is made independently for each session, that is to say the recording of a given subject at a given time of the day. Some promising results were obtained, F1-scores obtained proving that the use of arousal labels to control the valence classification task improves its performance. A paper presenting such work and called "Multi-task feature learning for EEG emotion recognition using Group Nonnegative Matrix Factorization" was submitted to ICME 2017.

3) Future work

This opens the perspective of generalizing this multi-task approach to an inter-session scheme. Additionally, focus will be made on the extension of such classification tasks to multi-label cases, with a particular attention to ensure that the constraint of similarity is bigger for GNMF sub-dictionaries corresponding to closer labels than for sub-dictionaries corresponding to distant ones. More specifically, the valence classification task is more challenging when the arousal is low, which has to be tackled with a particular focus on sub-dictionaries corresponding to low arousal labels.

Moreover, we will focus on inter-subject correlation as a measure of arousal, in an attempt to establish a link between high agreements and high activations assessed. To this end, dynamic annotations, which are a major contribution of the EMOEEG corpus, but which have not been fully exploited, will be studied more in depth. Such a study might help us get a better understanding on why emotion classification performs much better on some participants than on others.

Finally, we also want to use Group Canonical Correlation Analysis while keeping this promising idea of using the information of one axis (valence/arousal) to perform classification on the other. It would be interesting to apply this CCA method directly to raw EEG data matrices, and then to use it on atoms extracted by NMF, to assess the effect on NMF on such a process.

[2] R. Serizel, S. Essid, et al., "Group nonnegative matrix factorisation with speaker and session variability compensation for speaker identification," in *2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. IEEE, 2016, pp. 5470–5474.

PhD Thesis

Multimodal analysis and recognition of social signals: application to social stance generation in virtual agents

T. Janssoone, 2015-2018

Supervisors: G. Richard (LTCI-CNRS), C. Clavel (LTCI-CNRS) and K. Bailly (ISIR)

We have worked on the first step of a methodology dedicated to deduce sequences of signals expressed by humans during an interaction. The aim is to link interpersonal stances with arrangements of social signals such as modulations of Action Units and prosody during a face-to-face exchange. The long-term goal is to infer association rules of signals. We plan to use them as an input to the animation of an Embodied Conversational Agent (ECA). We have illustrated the proposed methodology to the SEMAINE-DB corpus from which we automatically extracted Action Units (AUs), head positions, turn-taking and prosody information. We have designed the Social Multimodal Association Rules with Timing (SMART) algorithm. It proposes to learn the rules from the analysis of a multimodal corpus composed by audio-video recordings of human-human interactions. The methodology consists in applying a Sequence Mining algorithm using automatically extracted Social Signals such as prosody, head movements and facial muscles activation as an input. This allows us to infer Temporal Association Rules for the behaviour generation. We show that this method can automatically compute Temporal Association Rules coherent with prior results found in the literature especially in the psychology and sociology fields. The results of a perceptive evaluation confirms the ability of a Temporal Association Rules based agent to express a specific stance.

Context and objectives

Embodied Conversational Agents (ECAs) can improve the quality of life in our modern digital society. For instance, they can help soldiers to recover from PTSD (Post Traumatic Stress Disorder) or help a patient to undergo treatment if they are empathic enough to provide support. The main challenge relies on the naturalness of the interaction between Humans and ECAs. With this aim, an ECA should be able to express different stances towards the user, as for instance dominance for a tutor or friendliness for a companion. This work proposes the SMART framework for the generation of believable behaviours conveying interpersonal stances.

Our work focuses on the scheduling of the multimodal signals expressed by a protagonist in an intra-synchrony study of his/her stance. Intra-synchrony refers here to the study of multimodal signals of one individual whereas the inter-synchrony studies the synchrony between two interlocutors. We focus on the sequencing that provides information about interpersonal stance as defined by Scherer as the ”*characteristic of an affective style that spontaneously develops or is strategically employed in the interaction with a person or a group of persons, coloring the interpersonal exchange in that situation (e.g. being polite, distant, cold warm, supportive, contemptuous)*”. Indeed, the scheduling of non-verbal signals can lead to different interpretations: Keltner illustrates the importance of this multi-modality dynamics: a long smile shows amusement while a gaze down followed by a controlled smile displays embarrassment.

We are working on an automatic method based on a sequence-mining algorithm which aims to analyse the dynamics of the social signals such as facial expression, prosody, and turn-taking to deduce association rules with temporal information directly from social signals by transforming social signals into temporal events. The association rules are learnt from a corpus and will provide time-related information between the signal-based events in a sequence. However, one major difficulty to find these rules is that they are blended into each other due not only to the stance but also to other constraints such as identity, biomechanical constraints or the

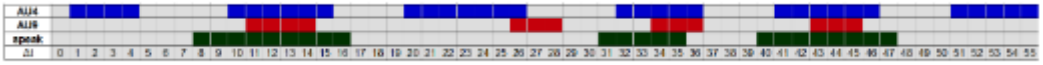
semantic contents of the given utterance. For instance, two persons can have a warm exchange but one frowns because he/she is dazzled by the sun. Another example is that the AU 26, jaw drop, can signify surprise but can also be activated due to the speech production mechanisms.

After a survey of existing Temporal Constrained Systems solutions (Chronicle, Episode, etc), we focused on The Temporal Interval Tree Association Rule Learning (Titarl) algorithm because of its flexibility and its ability to express uncertainty and temporal inaccuracy of temporal events. Indeed, it can compute time relation as rules between events (before/after), negation and accurate time constraints such as

"*If there is an event D at time t, then there is an event C at time t+5* ".

This temporal learning approach to find temporal associative rules from symbolic sequences allows to represent imprecise (non-deterministic) and inaccurate temporal information between social signals considered as events.

A temporal rule gives information about the relation between symbolic events with a temporal aspect. In our case, the events are the social signals (AUs, head nods, prosody, turn taking) considered as discrete events after a preprocessing step of symbolization.



For example, with the input of Fig.2, a temporal pattern could be:

If an event "activation of AU4" happens at time t while state Speak is active, then an event "activation of AU9" will be triggered between t+Dt and t+3Dt with a uniform distribution

which can be symbolized by the following rule

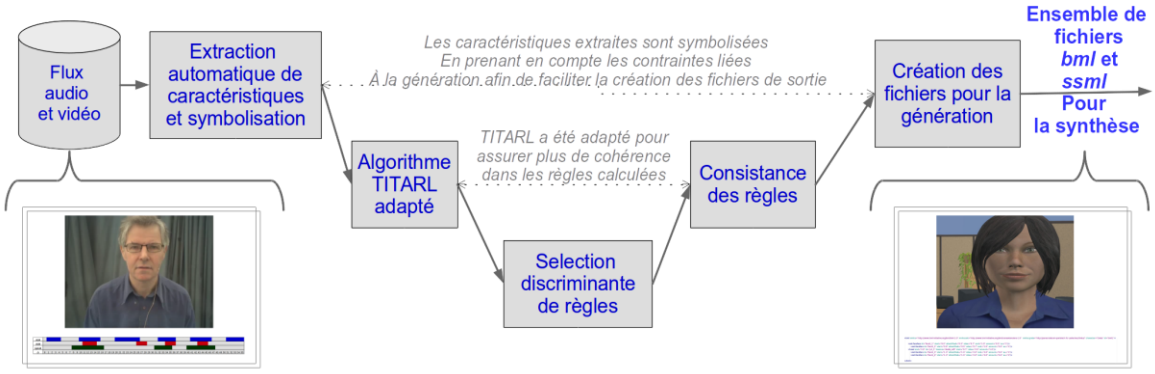
$$AU4_{\substack{\text{off to low} \\ Speaking}} \xrightarrow{\Delta t, 3\Delta t} AU9_{\text{off to low}}$$

Some characteristics of a rule can be computed to validate its interest. If we look at the following rule r

$$A \xrightarrow{\Delta t_{min}, \Delta t_{max}} B$$

then the confidence of a rule is the probability of a prediction of the rule to be true. We are also interested in the support of a rule which is the percentage of events explained by the rule. Finally, TITARL ensures a good precision in the rule that is the temporal accuracy of the prediction, i.e., a low dispersal of the distribution of the events A (standard deviation) verifying the rule r.

We have modified TITARL and integrated it in a framework that aims to take audio-video files as an input and automatically generate files that are required to generate the behaviour of an Embodied Conversational Agent with a specific stance. The design of our framework is visible in the following figure



Main Results

We applied SMART on the SAL-SOLID SEMAINE database to illustrate our methodology. This corpus uses the Sensitive Artificial Listener (SAL) paradigm to generate emotionally coloured interactions between a user and a 'character' played by an operator. It proposes video and audio data streams of this Face-to-Face interaction where the operator answers with pre-defined utterances to the user's emotional state. We only focus here on the operator part where, for each session, he acts four defined roles, one by one, corresponding to the four quadrants of the Valence-Arousal space. Spike is aggressive, Poppy is cheerful, Obadiah is gloomy and Prudence is pragmatic. As a first step, for this study, we only focus here on two roles of the operator part, one friendly, Poppy, and one hostile, Spike. This represents 48 interactions of 34 minutes recording, 25 with Poppy, 23 with Spike, played by 4 different actors. This kind of data makes us restraint our study to the affiliation axis of the Argyle's theory of stance. We performed studies to validate the extracted rules by comparing them to the results obtained in the literature in two steps. We retrieve that AUs corresponding to smile and cheek raiser (AU6, AU12) were linked to Poppy while brow lowerer (AU1/2 and AU4) were more linked to Spike.The literature explains that friendliness involves smile and cheek raiser while hostility is linked to brow lowerer.

Strengthened by the previous study, we conducted an evaluation of videos of an ECA generated from the best ranked Social Temporal Association Rules specific to a character. We processed the rules into BML files to use as an input of a virtual agent generation tool. The aim is to evaluate the perception of the agent's stance. We took the three best scored rules after 3 addition steps learned over the actor of the Semaine-SAL database in a listening status for each Poppy (friendly) and Spike (hostile). From these six rules, we got sequences of AU and head-nod evolutions with time information as we focus to the listener part. We also log the occurrences of each events verifying each rule to transpose them into BML files. These BML were used to generate video sequence with the virtual agent using the corresponding social signals. Hence we were able to synthesize an agent following these rules, with the timing of each transition set to the time of the highest occurrence. We used an agent to play each of this six rules and recorded its performances. We then used an online rating platform to evaluate our videos. Despite the very basic process of generation, rules characteristic of Poppy were perceived friendlier than the Spike's ones.

Communication

Associated Publication:

- **- Temporal Association Rules for Modelling Multimodal Social Signals,** *Authors* : Thomas Janssoone, *Publication date* : 015/11/9, *Conference* :Proceedings of the 2015 ACM on International Conference on Multimodal Interaction
- **- Des signaux sociaux aux attitudes : de l'utilisation des règles d'association temporelle,** *Authors* : Thomas Janssoone, Chloé Clavel, Kévin Bailly, Gaël Richard, *Publication date* : 2016/6/13, *Journal :* WACAI 2016, Workshop • Affect • Compagnon Artificiel • Interaction

- **- Using Temporal Association Rules for the Synthesis of Embodied Conversational Agents with a Specific Stance,** *Authors* : Thomas Janssoone, Chloé Clavel, Kévin Bailly, Gaël Richard, *Publication date :* 2016/9/20, *Conference* : International Conference on Intelligent Virtual Agents

Others :

- Participation at the GDR-ISIR : Poster (2015-12-02) and presentation (2016-11-15)
- ISSAS summer school, 2016. Price for the best student's project
- Scientific mediation at Cité des Sciences, thesis presentation and experiments with the public

PhD Thesis

Temporal Adaptation of Interaction

Kevin Sanlaville, 2013-16
Supervisors: C Pelachaud (LTCI-CNRS), F. Bevilacqua (STMS) , G. Assayag (STMS)

In this PhD project, we are interested in modeling the temporal adaptation of the interaction between agents. We have principally focused on Turn-Taking occurring in conversations. We have first performed a literature study on the characterization and modeling Turn-Taking. Following Clark's conversation models, we proposed a 5-state model (Speaking, Listening, Wanting-to-Speak, Giving-Speech and Idle) to describe the virtual agent conversational behavior.

Based on this state representation, we developed a probabilistic model considering that a given speaker might partially access to the signals of the other speakers and can thus only infer the inner states of the other speakers (such as the intention of "Wanting-to-Speak"). Precisely, we implemented a Hidden Markov Models taking into account the 5 turn-taking states and the verbal/non-verbal cues as observations.

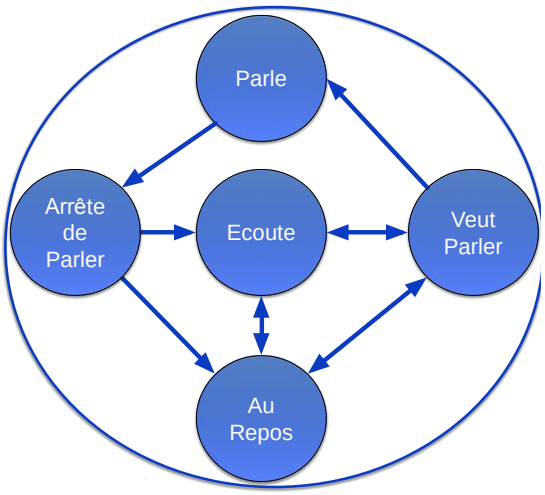


Fig 1 Agent State Model

As in conversations we adapt our behavior based on the interactions with our interlocutors, we also need to take into account the relationships and the effects between the agents. In order to model such group dynamics, we proposed to implement an Influence Model, which can be seen as "tractable" coupled HMMs (Dong et al., 2007). We anticipate that some parameters of this model could be modified during the interaction process, enabling therefore the adaptation of behaviors and possibly the emergence of synchronicity. The theoretical bases of this work have been presented at the Doctoral Consortium of the Intelligent Virtual Agent (IVA) Conference in 2016.

The graphical representation of our implementation of the influence model is presented in the figure below. Each agent is modeled by a single HMM, which is connected to all of the others. The agent behaviors are modeled by parameters describing speaking/not speaking, as well as non-verbal parameters. Currently, the observation consists in a vector of discrete quantities, but continuous variables will also be implemented. During the training phase, the parameters of the influence model parameters are computed using an EM (expectation maximization) algorithm (Dong et al., 2007).

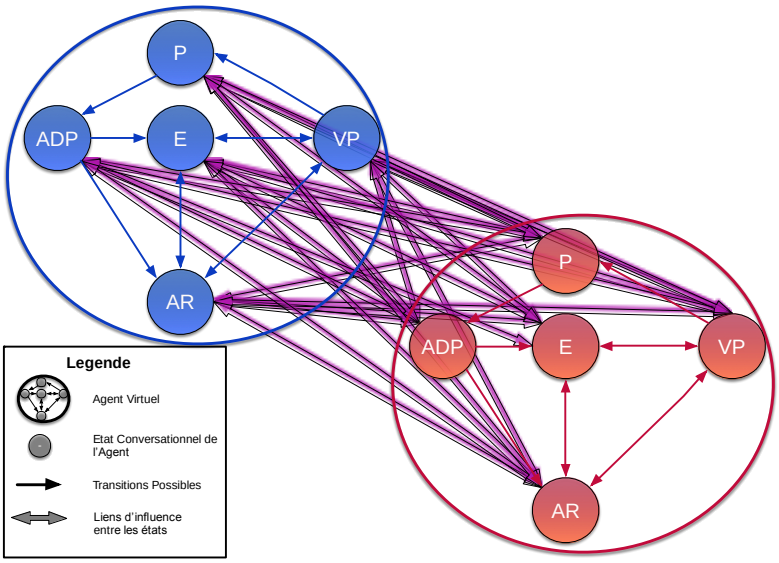


Fig 2 Influence Model (shown here each for 2 agents)

As a first evaluation step, we use synthetic data generated by the model developed in Ravenet et al., 2015. We consider a conversation between four agents VIB (Pécune et al., 2014) sampled at 4 Hz. This data includes three types of observations: describing if the agents are speaking, moving their arms and their gaze direction. As Ravenet's group conversation model allows for simulating social attitudes, we have designed agents with different social attitudes towards each other. These conversation data were used to train out model (adapting the Matlab influence toolbox http://vismod.media.mit.edu/vismod/demos/influence-model/software-usage.htm, Dong et al. 2007).

Our experiments showed that, in this context, training data over 15 minutes of conversation is necessary for the convergence of model parameters. As the influence model also enables to generate data, it is possible to compare average behavioral parameters from our model with the ones generated by Ravenet's model. Considering different cases from neutral to dominant agents, we found that the average time speech time, silent-speaking transition time and speech overlaps between agents lie typically within less than 5% differences between the generated data from Ravenet and our models. To visualize our results, we have integrated the generated data into the GRETA-UNITY platform already used by Ravenet et al. (2015). These animations will be used to perform a perceptual study.

Associated publications:

- K. Sanlaville, G. Assayag, F. Bevilacqua, C. Pelachaud, Emergence of synchrony in an Adaptive Interaction Model. In Intelligent Virtual Agents 2015 Doctoral Consortium , Delft, Netherlands, August 2015
- K. Sanlaville, F. Bevilacqua, C. Pelachaud, G. Assayag, Adaptation in an Interactive Model designed for Human Conversation and Music Improvisation: a preparatory outline, Workshop Affect, Compagnon Artificiel Interaction (WACAI'1), 2014, Rouen

References (selected)

- [Clark, 1996] Clark, H. H. (1996). Using language, volume 1996. Cambridge university press Cambridge.
- [Dong et al., 2007] Dong, W., Lepri, B., Cappelletti, A., Pentland, A. S., Pianesi, F., and Zancanaro, M. (2007). Using the influence model to recognize functional roles in meetings. In Proceedings of the 9th international conference on Multimodal interfaces, pages 271–278. ACM.
- [Pecune et al., 2014] Pecune, F., Cafaro, A., Chollet, M., Philippe, P., and Pelachaud, C. (2014).

Suggestions for extending saiba with the vib platform. In Proceedings of the Workshop on Architectures and Standards for Intelligent Virtual Agents at IVA, pages 336–342.

- [Ravenet et al., 2015] Ravenet, B., Cafaro, A., Biancardi, B., Ochs, M., and Pelachaud, C. (2015). Conversa- tional behavior reflecting interpersonal attitudes in small group interactions. In International Conference on Intelligent Virtual Agents, pages 375–388. Springer International Publishing.

PhD Thesis

Embedded architecture and physiological sensors

W. Yang, 2014-2017.
Supervisors: C. Marsala (LIP6), M. Rifqi (LIP6), A. Pinna (LIP6), and P. Garda (LIP6).

The main goal of this thesis is to create an embedded and adaptive architecture which can automatically recognize emotional states from physiological signals, in the context of affective gaming. The first step was to realize a state of the art on emotion representations, affective gaming and methods for automatic emotion recognition. It was the object of the first deliverable.

The second step was dedicated to design an experimentation in order to collect physiological signals on gamers during a video game session. This experimentation has been done this year thanks to a fund "*Soutien au démarrage d'études comportementales*" granted by the Centre Multidisciplinaire des Sciences Comportementales, Sorbonne Universié - INSEAD. The equipments consisted in a BIOPAC MP-150, a PC and the videogame FIFA'2016 (see Fig.1).

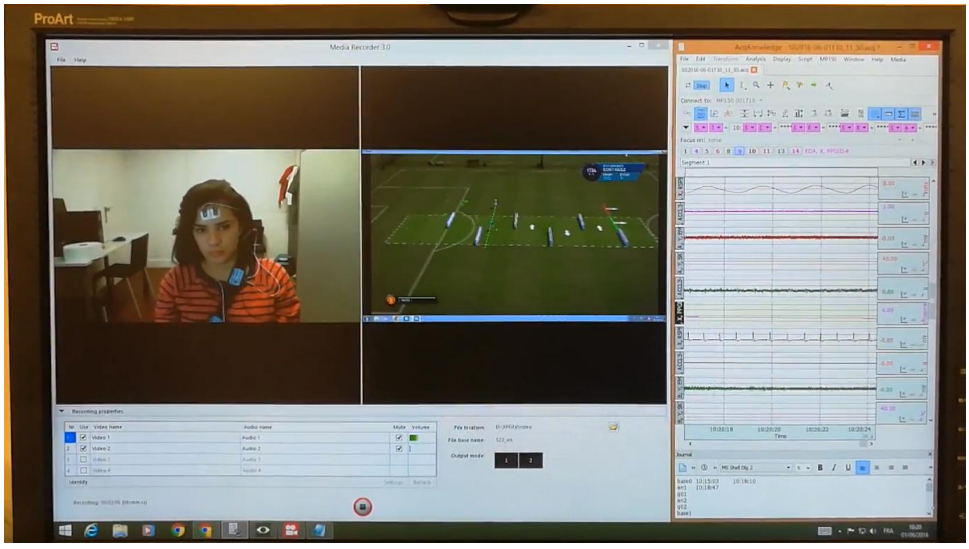


Fig. 1: Experimental scene

An interface, developed in Java, enabled to annotate the motion capture of the video game by emotion categories and also by arousal and valence. The objective of this experimentation has been to collect data in order to analyze the relationship between physiological signals and self-evaluation of the game for objective events of the play. A panel of 58 participants of different genders, ages, and skill levels, took part in this study. For each participant, a set of 3 game plays have been recorded (see Fig. 2).

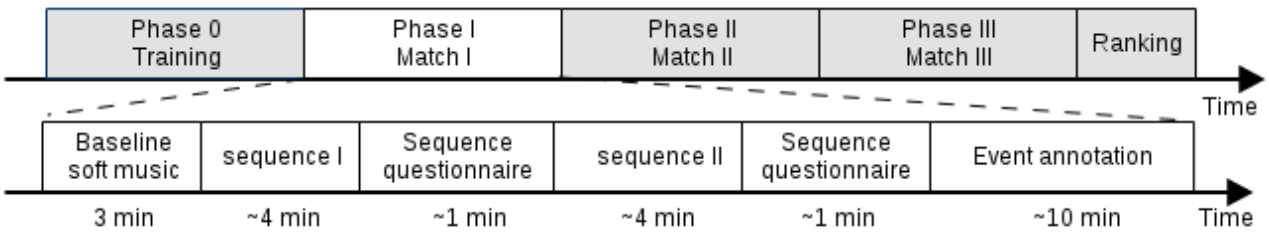


Fig. 2: Experimentation protocol

The physiological signals are measured during the whole sequence of the experiment. Overall, the dataset contains over 120 hours of logged events, game play, video of the participant's face, physiological data and subjective assessments.

From this dataset, several machine learning experiments have been conducted. First of all, the learning task consists in determining arousal and valence values of emotions set by a subject from its physiological signals. Preliminary results of this machine learning experiments show that the Linear SVM performs well for user-dependent emotion recognition. A reasonable choice of segmentation length of the physiological signals can be found around 14s and by means of a standard normalization approach. We have also shown that learning performance with feature selection is significantly better than without feature selection. It can also be highlighted that for valence classification, respiration, EMG, and EDA are the most important features, instead, for arousal classification, ECG, EMG and EDA are the most important ones. The performances of the feature selection is scattered across different subjects, which means that the recognition of emotions is a difficult inter-user task.

Besides the experimental study of affective gaming and data analysis, a new approach of adaptive classification model for changing data has been proposed: adaptive fuzzy decision tree [Yang et al., 2016]. This approach enables the tuning of the fuzzy decision tree when temporal data varies among time. It is able to absorb and adapt to small drift in the data stream. It is an approach well-adapted to handle physiological signals in predictive settings.

As a summary, we have carried out an experiment to collect physiological signals and self-assessment under the context of a football simulation game. Different experimental settings such as learning algorithm, normalization, segmentation length, feature selection, signal importance have been analyzed and discussed. Machine learning preliminary results show promising results on user-dependent classification. However, large individual variability exists, which makes the recognition model difficult to generalize through different subjects. Future work will focus on developing subject specific model and on implementing the algorithm on the embedded system.

References

[Yang et al., 2016] W. Yang, Ch. Marsala, A. Pinna, M. Rifqi, P. Garda : “Arbres de décision flous adaptatifs”, 25e rencontres francophones sur la logique floue et ses applications (LFA), La Rochelle, France, pp. 65-72 (2016)

SMART-BAN

SMART-BAN

Self-organizing, Mobility Aware, Reliable and Timely Body-Area-Networks

Responsible of the project: Julien Sarrazin

Partners: L2E, LIP6, LTCI

Web site: http://www.smart-labex.fr/index.php?perma=SMART-BAN

The Project at a glance

The SMART-BAN project aims to optimize the energy consumption of wireless Body Area Networks for medical applications while minimizing its impact on the human body. The project gathers researchers from different fields ranging from electromagnetics and communication theory to computer science. By undertaking a trans-disciplinary approach, fundamental energy limitations will be drawn and optimal communication strategies for reliably routing and aggregating data will be developed.

Context and Objectives

To improve the efficiency of the medical sector, recent years have witnessed the emergence of wireless Body Area Networks (BANs). BANs are sensor networks that are embedded on the human body and provide useful healthcare monitoring such as EEG, ECG, blood pressure... The use of wireless technology to interconnect sensors enables practical and seamless means to monitor patients and thus can lead to more efficient management in hospital or during mass-casualty disasters. As sensors become more and more miniaturized, BAN could be worn permanently by people, thereby enabling continuous monitoring. One could then dream of preventing striking decease. Continuous monitoring also represents a comfortable and effective economic way of taking care of age-related illnesses.

However, to consider such a future, BAN will need to have a huge autonomy. That is why the main goal of the SMART-BAN project is to find a way to reach the fundamental lower limit of power consumption in BAN. This will be achieved by jointly taking into account the physics involved in the wireless propagation around the human body and the dynamic distributed topology of the BAN sensor network. This approach will enable the greatest autonomy as well as reducing the human exposure to electromagnetic waves.

- SMART-BAN: *20 conferences, 6 journals, 1 seminar (GreenBAN 2014)*

Scientific progress and results

A Body Area Network (BAN) is a challenging network in the sense that its topology is dynamically changing over the time. In addition, constraints in terms of energy are drastic, taking into account the limited room available on the sensors for the battery. Consequently, in order to one day consider medical applications such as post-surgery monitoring for instance (lasting typically 1-3 weeks), it is important to decrease as much as possible the energy consumed by the BAN. To do so, SMART-BAN is undertaking a transversal approach

where the analysis of the physical layer is taken into account into the MAC and network layers to assess the whole sensor network.

Regarding the **physical layer**, since sensors are wirelessly communicating to each other's, it is necessary to understand the complex propagation mechanism of electromagnetic waves around the body. This task consists in both electromagnetics modeling and radiofrequency measurements, and has led to developing channel models that describe the dynamic attenuation faced by a signal between a transmitter and a receiver. These models are then used in protocol layer software to assess different routing algorithms and scenarios. From the performed measurements, we can also assess the performance in terms of data rate, QoS, and energy consumption, of the physical layer of the IEEE 802.15.6 standard, which is a BAN-dedicated standard for wireless communications. In particular, we showed that using higher data rates in BAN, which is typically more power consuming, can significantly reduce the amount of energy required to transmit a given data. In some scenarios, such as the monitoring of breathing and heartbeat rates in hospital for instance, it could be possible to completely avoid the necessity of wearable sensors thanks to a remote radar (hence avoiding power consumption issues). In fact, we recently showed that using millimeter-wave enables an accurate contact-less estimation of both the respiratory and heartbeat rates simultaneously.

Concerning the **network layer**, we began by looking at how to provide an efficient broadcast given the WBAN specificities, in particular their mobility and channel characteristics: WBANs use a radio medium for communication and alternate connection and disconnection periods. This type of scenario is common in the delay tolerant networks environment and a few algorithms for broadcast have been proposed in this context. In his master internship, Federico Petruzzi modified the Omnet++ network simulator to evaluate the performance of these algorithms and to propose relevant adaptations. He implemented the most relevant proposals found in the literature and included to the simulator a dynamic channel model that corresponds to the WBAN environment. Under this realistic simulation environment, he was able to evaluate the success probability, the delay required to flood the whole network and the required number of packets emissions. He also managed to extract some general results (e.g. almost half of the time is spent reaching end nodes in the BAN) and to evoke algorithms combinations to improve performance. On the theoretical side, Federico worked on time varying graphs and on the adaptation of this formalism to the unreliability resulting from the WBAN radio channel. This investigation has been further continued by the thesis of Wafa Badreddine. Wafa investigate broadcast strategies dedicated to WBAN. Wafa first analyze several broadcast strategies inspired from the area of Delay Tolerant Networks (DTN). The proposed strategies are evaluated via the OMNET++ simulator that we enriched with realistic human body mobility models and channel models issued from the recent research on biomedical and health informatics. Contrary to the common expectation, her results show that existing research in DTN cannot be transposed without significant modifications in WBANs area. That is, existing broadcast strategies for DTNs do not perform well with human body mobility. However, our extensive simulations give valuable insights and directions for designing efficient broadcast in WBAN. Furthermore, we proposed a novel broadcast strategy that outperforms the existing ones in terms of end-to-end delay, network coverage and energy consumption. Additionally, we performed investigations of independent interest related to the ability of all the studied strategies to ensure the total order delivery property when stressed with various packet rates. These investigations open new and challenging research directions. In the thesis of Gewu Bu we focused the converge-cast protocols. This study is the first extensive work on total order reliable convergecast in multi-hop Wireless Body Area Networks (WBAN). Convergecast is a many-to-one cooperative scheme where each node of the network transmits data towards the same sink. Our contribution is threefold. First, we stress existing WBAN convergecast strategies with respect to their capacity to be reliable and to ensure the total order delivery at sink. That is, packets sent in a specific order should be received in the same order by the sink. When stressed with transmission rates up to 500 packets per second the performances of these strategies decrease dramatically (more than 90% of packets lost). Secondly, we propose a new posture-centric model for WBAN. This model offers a good characterization of the path availability which is further used to fine tune the retransmission rate thresholds. Third, based on our model we propose a new mechanism for reliability and a new converge-cast strategy that outperforms WBAN dedicated strategies but also strategies adapted from DTN and WSN areas. Our extensive performance evaluations use essential parameters for WBAN: packet

loss, total order reliability (messages sent in a specific order should be delivered in that specific order) and various human body postures. In particular, our strategy ensures zero packet order inversions for various transmission rates and mobility postures. Interestingly, our strategy respects this property without the need of additional energy-guzzler mechanisms. The internship of Nesrine Khernane focused on the privacy aspects in WBAN. In this study, we propose and present the design and the evaluation of a secure lightweight and energy efficient authentication scheme BANZKP based on an efficient cryptographic protocol, Zero Knowledge Proof (ZKP) and a commitment scheme. ZKP is used to confirm the identification of the sensor nodes, with small computational requirement, which is favorable for body sensors given their limited resources, while the commitment scheme is used to deal with replay attacks and hence the injection attacks by committing a message and revealing the key later. BANZKP reduces the memory requirement by 56, 13% compared to TinyZKP, the comparable alternative so far for Body Area Networks. Also, the simulation results demonstrate that our proposed scheme is 17 and 5 times more efficient in term of execution time, and uses 94.11% and 80% less energy compared to TinyZKP and W-ECDSA, respectively.

Recruitment

- **1 PhD**:
  - **Quentin BRAMAS** (*LIP6*), "Self-organizing, Mobility aware, Reliable and Timely Body Area Networks", at LIP6, started in October 2013

- **1 Postdoc**:
  - **Zhongkun MA** (*L2E*), "Channel modeling in Body Area Networks (BAN)", started in June 2014

- **8 Masters**:
  - **Huiliang LIU** (*Tsinghua University, China*), "Wireless Communications in Body Area Networks", February-July 2014
  - **Guy Landry DJATCHE SIMO** (*UPMC*), "Gestion d'autonomie et churn dans GreenNet", March-August 2014
  - **Frederico PETRUZZI** (*Politecnico di Torino*), "Models and Design of communication protocols for WBAN and simulation on GreenNet platform", April-September 2014
  - **Wafa Badreddine** (*UPMC*) "Efficient Broadcast strategies in WBAN", February-July 2015
  - **Nesrine Khernane** (*UPMC*) "Security and privacy in WBAN", February-July 2015
  - **Gewu Bu** (*UPMC*) "Efficient Converge-cast strategies in WBAN", February-July 2016"
  - **Cong Chen** (*Université de Bretagne Occidental*), "Wireless Communications in Body Area Networks", February-July 2015
  - **Krati Sethi** (*IIT Bombay*), "Real-time demonstrator for Wireless Communication in Body Area Networks", May-July 2016

Publications

- **Journal papers**:

[1] L. Petrillo *et Al.*, "*Wideband Off-Body Measurements and Channel Modeling at 60 GHz*", **IEEE Transactions on Antennas and Propagation**, 2016

[2] Q. Bramas, S. Tixeuil, *"The complexity of data aggregation in static and dynamic wireless sensor networks"*, **Information and Computation,** Available online 9 December 2016

[3] H. Liu *et Al., "Performance Assessment of IR-UWB Body Area Network (BAN) based on IEEE 802.15.6 Standard",* **IEEE Antennas and Wireless Propagation Letters**, 2016

[4] T. Mavridis *et Al., "Millington Effect and Propagation Enhancement in 60-GHz Body Area Networks",* **IEEE Transactions on Antennas and Propagation**, DOI: 10.1109/TAP.2015.2505741, 2016

[5] T. Mavridis *et Al., "Near-Body Shadowing Analysis at 60 GHz"*, **IEEE Transactions on Antennas and Propagation**, 2015

[6] L. Petrillo *et Al.*, "*Statistical On-Body Measurement Results at 60 GHz*", **IEEE Transactions on Antennas and Propagation**, 2014

- <u>International conference proceedings</u>:

[1] G. Bu, M. Potop-Butucaru, "*Total Order Reliable Convergecast in WBAN"*, **18th Int. Conference on Distributed Computing and Networking (ICDCN 2017*),*** Hyderabad, India, January 5-7, 2017**.**
[2] J. Sarrazin *et Al., "Antenna Radiation Efficiency Considerations in Body Area Networks"*, **Bodynets**, Turin, Italy Dec. 2016
[3] N. Khernane *et Al.*, "BANZKP: *Broadcast Strategies in Wireless Body Area Networks"*, ***13th IEEE International Conference on Mobile Ad Hoc and Sensor Systems (MASS 2016),*** Brasília, Brazil, October 10-13, 2016
[4] T. Zhang *et Al., "Impact of Random Body Movements on 60-GHz Doppler Radar for Real-Time Monitoring of Vital Signs",* **Bodynets**, Turin, Italy Dec. 2016
[5] Q. Bramas *et Al. "Distributed Online Data Aggregation in Dynamic Graphs"*, **In the 36th International Conference on Distributed Computing Systems (ICDCS), 2016 IEEE,**
[6] Q. Bramas, S. Tixeuil *"Benchmarking Energy-Efficient Broadcast Protocols in Wireless Sensor Networks"*, **In the 4th Edition of the International Conference on Networked Systems, NETYS 2016, Springer International Publishing.**
[7] T. Zhang *et Al., "Non–Contact Estimation at 60 GHz for Human Vital Signs Monitoring Using a Robust Optimization Algorithm"*, **IEEE Antennas and Propagation Symposium (APS)**, Fajardo (USA), Jul. 2016
[8] S. Razafimahatratra *et Al., "On-body propagation characterization with an H-plane Substrate Integrated Waveguide (SIW) horn antenna at 60 GHz"*, **European Microwave Week (EuMW)**, Paris, Sept. 2015
[9] W. Badreddine *et Al., "Broadcast Strategies in Wireless Body Area Networks"*. ***Proceedings of the 18th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM 2015),*** Cancun, Mexico, 2015**.**
[10] Q. Bramas *et Al., "WiSeBat: Accurate Energy Benchmarking of Wireless Sensor Networks"*, **Proceedings of the Forum on specification and Design Languages**, 2015
[11] Q. Bramas, S. Tixeuil, *"Wait-free Gathering without Chirality"*, **Proceedings of SIROCCO, Springer**, 2015
[12] Q. Bramas, S. Tixeuil, *"The Random Bit Complexity of Mobile Robots Scattering*", **14th International Conference Ad-hoc, Mobile, and Wireless Networks, ADHOC-NOW**, 2015
[13] Q. Bramas, S. Tixeuil, "*The Complexity of Data Aggregation in Static and Dynamic Wireless Sensor Networks*", **In Stabilization, Safety, and Security of Distributed Systems** (Andrzej Pelc, Alexander A. Schwarzmann, eds.), **Springer International Publishing**, 2015
[14] Z. Ma *et Al., "Antenna radiation characterization for on-body communication channel using creeping wave theory"*, **9th European Conference on Antennas and Propagation (EuCAP)**, p.1-4, 13-17 April 2015
[15] S. Razafimahatratra *et Al., "Horn antenna design for BAN millimeter wave on-body communication"*, **IEEE Antennas and Propagation Symposium (APS)**, Memphis (USA), July 2014
[16] L. Petrillo *et Al.*, "*Experimental On-Body Shadowing on Torso at 60 GHz"*, **International Conference on Body Area Netwroks (BodyNets)**, London, September 29 – October 1, 2014
[17] J. Sarrazin *et Al., "Channel modeling for 60 GHz Body Area Networks (BAN)",* **International Conference on Communication Systems (ICCS-2015)**, Pilani (India), Oct. 2015 (<u>Invited talk</u>)
[18] J. Sarrazin *et Al.*, "*Antenna efficiency influence in Body Area Networks (BAN)*", **International Conference on Communication Systems (ICCS-2013)**, Pilani (India), 18-20 Oct. 2013 (<u>Invited talk</u>)

- <u>Other conferences</u>:

[1] Q. Bramas *et Al., "<u>De la Survie Énergétique des Réseaux de Capteurs</u>"*, **17èmes Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications, ALGOTEL-2015**
[2] Q. Bramas, S. Tixeuil, *"<u>Agréger Rapidement des Données est Difficile</u>"*, **17èmes Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications, ALGOTEL-2015**

Events

International Workshop on Green Solutions for Body Area Networks - GreenBAN
6-7 November 2014 at UPMC, 56 participants, 25 speakers

The objective of the International Workshop on Green Solutions for Body Area Networks is to present the latest developments in energy efficient Wireless Body Area Networks. It aims to bring researchers working in the field of BAN with a focus on energy as well as in the field of power supply for such networks. http://www.greenban2014.upmc.fr

During the workshop, SMART-BAN partners presented the following topics:

- H. Liu, J. Sarrazin, F. Deshours, A. Benlarbi-Delaï, P. De Doncker, Z. Liu, "Performance Evaluation on IR-UWB BAN with OOK Modulation"
- Q. Bramas, S. Tixeuil, "The Complexity of Data Aggregation in Body Area Networks"
- T. Mavridis, L. Petrillo, J. Sarrazin, A. Benlarbi-Delaï, P. De Doncker, "Polarization Impact on 60 GHz Indoor Off-Body Communications"
- C. Chaudet, F. Petruzzi, M. Potop-Butucaru, "Analyzing Various Broadcast Strategies in WBAN"
- Z. Ma, J. Sarrazin, L. Petrillo, T. Mavridis, P. De Doncker, A. Benlarbi-Delaï, "Antenna Characterization for On-Body Communication Channel Using Creeping Wave Theory"

PhD Thesis

Quentin Bramas

Supervisor: Sébastien Tixeuil
Laboratory: LIP6
Doctoral School: EDITE, Paris
Period: 2013-10-01 to 2016-09-30

Context and Objectives

This PhD takes place within the SMART-BAN project (**www.smart-labex.fr/index.php?perma=SMART-BAN**), which aims to optimize the energy consumption of wireless Body Area Networks for medical applications while minimizing its impact on the human body. The goal of this PhD was to propose models of medical Body-Area-Networks and strategies for routing and information dissemination in Body-Area-Networks.

Scientific progress and results

Several measurement campaigns have been conducted in various BAN projects, in order to evaluate the channel behavior and evolution when an equipped user walks, runs, falls, etc. These measurements are often realized on a point-to-point link in a single scenario and the approach may fail in giving sufficient insights related to what could be obtained through multi-sensors on the same body… Our goal, in this task, is to provide a model of the network topology and of its dynamicity with the wearer movement. Based on the individual measurement campaigns realized in partner projects, our aim is to create a generic and configurable dynamic graph model that complies with all measurements and represents dynamic aspects. Specific algorithmic tools for distributed coordination in dynamic networks have been investigated [2,3,4,7]. While we proved that, in general, the algorithmic complexity of the problem is not practically tractable [4,6], we were able to devise online solutions in specific instances of dynamic networks [8]. We also set up a simulation platform for the measurement of energy consumption [1,5].

Phd Thesis:

1. Quentin Bramas *"Energy-Centric Wireless Sensor Networks"* (*"Réseaux de capteurs sans fil efficaces en énergie"*). **Pierre and Marie Curie University, Paris, France 2016**

International journal:

2. Quentin Bramas, Sébastien Tixeuil, *"The complexity of data aggregation in static and dynamic wireless sensor networks"*, **Information and Computation, Available online 9 December 2016, ISSN 0890-5401, http://dx.doi.org/10.1016/j.ic.2016.12.004.**

International conference proceedings:

3. Q. Bramas, W. Dron, B. Fadhl Mariem, K. Hachicha, P. Garda, S. Tixeuil, *"WiSeBat: Accurate Energy Benchmarking of Wireless Sensor Networks"*, **Proceedings of the Forum on specification and Design Languages**, 2015
4. Q. Bramas, S. Tixeuil, *"Wait-free Gathering without Chirality"*, **Proceedings of SIROCCO, Springer**, 2015
5. Q. Bramas, S. Tixeuil, *"The Random Bit Complexity of Mobile Robots Scattering"*, **14th International Conference Ad-hoc, Mobile, and Wireless Networks, ADHOC-NOW**, 2015
6. Q. Bramas, S. Tixeuil, *"The Complexity of Data Aggregation in Static and Dynamic Wireless Sensor Networks"*, **In Stabilization, Safety, and Security of Distributed Systems** (Andrzej Pelc, Alexander A. Schwarzmann, eds.), **Springer International Publishing**, 2015

7. Q. Bramas, T.Masuzawa, S. Tixeuil, *"Distributed Online Data Aggregation in Dynamic Graphs"*, **In the 36th International Conference on Distributed Computing Systems (ICDCS), 2016 IEEE, pp. 747-748.**
8. Quentin Bramas et Sébastien Tixeuil "*Benchmarking Energy-Efficient Broadcast Protocols in Wireless Sensor Networks".* **In the 4th Edition of the International Conference on Networked Systems, NETYS 2016, Springer International Publishing.**

Other conferences:

9. Q. Bramas, W. Dron, B. Fadhl Mariem, K. Hachicha, P. Garda, S. Tixeuil, *"De la Survie Énergétique des Réseaux de Capteurs"*, **17èmes Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications, ALGOTEL-2015**
10. Q. Bramas, S. Tixeuil, *"Agréger Rapidement des Données est Difficile"*, **17èmes Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications, ALGOTEL-2015**

Workshop:

11. Q. Bramas, S. Tixeuil, "The Complexity of Data Aggregation in Body Area Networks", **GreenBAN**, 2014

Post-Doc

Name: Zhongkun MA

Supervisor: Julien Sarrazin

Laboratory: L2E

Period: June 2014 – May 2015

Descritption

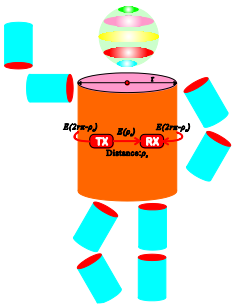
This post-doc takes place within the SMART-BAN project, which aims to optimize the energy consumption of wireless Body Area Networks for medical applications while minimizing its impact on the human body. The project gathers researchers from different fields ranging from electromagnetics and communication theory to computer science. By undertaking a trans-disciplinary approach, fundamental energy limitations will be drawn and optimal communication strategies for reliably routing and aggregating data will be developed.

The goal of this post-doc is to analyze, characterize and model wireless communications around the human body in the framework of Body Area Networks (BAN). In particular, on-Body communications for medical applications are investigated. The job is to study the propagation channel and the antenna's influence when people are still or in motion. Developed models are then used in network simulation software in order to determine consumed energy limitations and to develop optimal communication strategies so that to increase BAN's autonomy.

Results

Creeping wave theory was originally intended to be applied to a Hertzian dipole radiation around the bending earth surface as demonstrated in Fig.1. It is re-visited for BAN (Body Area Network) channel modeling, where the human body was modeled as cylinder (see Fig.2). The formulation includes both the characteristics of antenna and human tissues, in which the field density at a distance can be directly obtained by input power and antenna gain over infinitely large PEC (perfect electric conductor) plane.

A drawback of this formulation approach is that it requires on-body antenna gain measurement, which is very difficult in practice. To overcome this difficulty, we successfully demonstrate the difficult and complicated on-body antenna gain measurement can be substituted by measuring antenna gain above PEC plane to determine field density by simulation, which is much easier to be employed in practice. Taking advantage of the time gating technique, the PEC plane employed in simulation and measurement does not have to be infinitely large. The obtained results are plotted in Fig. 3 and Fig. 4 for PEC and dielectric cylinder cases, respectively. The experiment validation is still under going to prove the above concept.



Publications

Z. Ma, J. Sarrazin, A. Benlarbi-Delaï, L. Petrillo, T. Mavridis and P. D. Doncker, "Antenna Radiation Characterization for On-Body Communication Channel Using Creeping Wave Theory", European Conference on Antennas and Propagation (EUCAP 2015).

Fig.1. Creeping wave theory to model dipole radiation

Fig.2. Model human body as cylinder.

Fig.3. Analytical and simulated E-Field radiated by monopole antenna around PEC cylinder

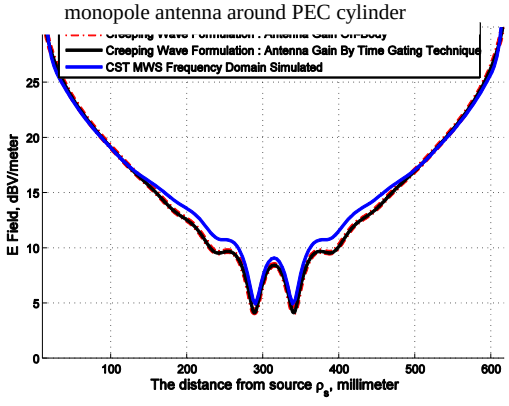
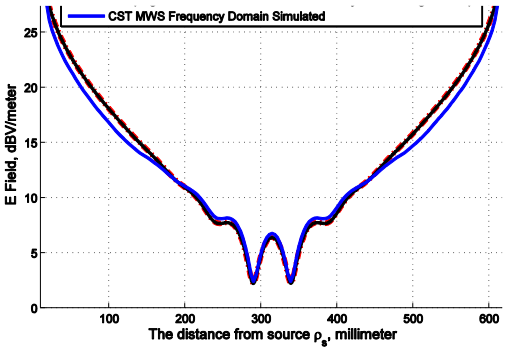


Fig.4. Analytical and simulated E-Field radiated by monopole antenna around dielectric cylinder (relative permittivity 50 and conductivity 1.7 S/m)



SpinalCOM

SpinalCOM

Responsible of the project: S. Feruglio, LIP6[3], UPMC Univ Paris 06, CNRS UMR 7606

Partners: LIB[4], UPMC Univ Paris 06, INSERM U1146 - CNRS UMR 7371
CHU[5] Pitié-Salpétrière, APHP

Web site: http://www.smart-labex.fr/index.php?perma=SPINALCOM

THE PROJECT AT A GLANCE

Abstract: The usual imaging techniques provide only limited information, there is an unmet need for methods to assess the functional consequences of the Spinal Cord Injuries (SCI) and the effect of therapeutic interventions. To meet this need, the SpinalCOM project aims to investigate a new imaging approach of the Spinal Cord (SC) on animal model, through the realization of a multimodal communicating device for measuring the activity of the SC. This approach will establish locally and specifically the functional state of the SC, which will provide a breakthrough in the care and therapeutic trials in SCI.

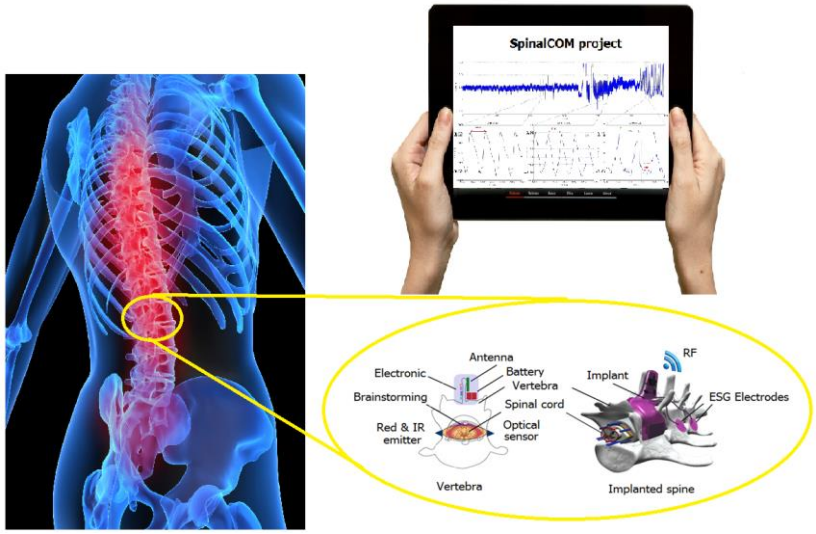


Fig. 1 – Illustration of the SpinalCOM project.

Context: Trauma of the Spinal Cord (TSC) and pathologies of the spine are major causes of mortality and disability. Their incidence is 28,000 new cases per year for Europe of 49 countries and 12,000 for the US [1]. For France, there are about 1,200 cases per year of vertebro-medullar injuries [2]. In the orthopedic and trauma surgery department of the Pitié-Salpêtrière hospital, nearly 50 surgeries are performed each week (chronic pathologies, acute or traumatic) [3]. After the acute phase, secondary mechanisms, including vascular, impact the functional prognosis.

The Magnetic Resonance Imaging (MRI), which is a noninvasive imagery, is essential for the assessment of lesions at the acute stage and to seek complications at the chronic stage (syringomyelia, in particular). However, it does not provide functional information, which is crucial to judge the consequences of secondary injury mechanisms and the effectiveness of spontaneous recovery mechanisms or after therapeutic interventions. It is the same for myelography, which is a scan where injection of contrast media is also essential. Functional MRI (fMRI) of the SC is a method under development. However, it faces significant limitations. The temporal resolution of fMRI is modest and the spatial resolution is limited by artifacts associated with inhomogeneous magnetic properties of the spine and the physiological movements, including breathing (for

[3] With O. Tsiakaka (PhD student), and F. Vallette (assistant Pr).
[4] With H. Benali (research director INSERM), P.F. Pradat (hospital doctor – neurologist), and V. Marchand (research director INSERM).
[5] Since 2015, with J. Azoulay-Zyss (hospital doctor - neurophysiologist), and Hugues Pascal-Moussellard (Hospital doctor, University professor, Head of Department of Orthopedic and Traumatologic Surgery).

review, see [4]). Even if progress is made in healthy subjects, it is still uncertain whether this method could, one day, be applied to monitor TSC. Moreover, as all non-mobile devices with patient, even if such examination can be repeated, it does not provide continuous information. It imposes a total immobility of the subject. We are in distant conditions for normal living conditions of the subject. Also on the functional assessment plan, electrophysiological techniques, such as SSEP (Somatosensory Evoked Potentials) or MEP (Motor Evoked Potentials), are useful as well for pre-operative assessment of medullar impairment and they are also commonly used for intraoperative monitoring. These techniques, which provide high temporal resolution as compared to MRI, are quite invasive, sometimes painful, and currently inappropriate in monitoring medullar function in daily living condition. Echo-Doppler is also an interesting non-invasive technique. However, the obtained data are rather qualitative. Indeed, only the plethysmograph on a large zone is obtained.
Thus, there is an unmet need for methods to assess the functional consequences of TSC and, as part of clinical trials, the effect of surgical strategies, pharmacologic, or appropriate rehabilitation [4-9].

Objectives: The SpinalCOM project aims to establish the proof of concept of an innovative low-cost tool for the continuous ambulatory collection of electrophysiological and metabolic parameters simultaneously at the SC level in the big animal, before a potential transfer to the human being. The device employs the Diffuse Optical Imaging (DOI) principle and is implemented using a photodetector and a minimum of 2 pulsed light sources at different wavelengths, with associated electronic, for acquisition of information about 2 forms of haemoglobin (HbO_2 and other Hb's components) in real-time. This first embedded system is coupled with a tailor-made instrumentation to acquire bio-potentials occurring during the SC electrical activity (ESG - ElectroSpinoGram). Note that the evaluation of metabolic activity is based on the measurement of the oxygenation rate of hemoglobin by DOI, which is directly related to the metabolic activity of neurons due to neuro-hemodynamic coupling. The SC is also studied by near infrared spectroscopy, typically, but with classical intraoperative monitoring equipment, which does not allow chronic measurement [10-13]. In addition, in current experimental works [14-16], it is the small animal which has been used as a model. The relevance of measuring nerve activity by ESG is, in turn, supported by numerous experimental studies [17-21].

SCIENTIFIC PROGRESS AND RESULTS

Positioning and results: The SpinalCOM project is a bioengineering project, at the interface of physics, processing architecture and medicine. To our knowledge, there is no system or project providing a device for continuously measuring both metabolic and electrophysiological parameters at the SC level. We can find fabulous smart medical implant in France, such as the BCI project of Clinatec or the artificial eye of Pixium Vision, for example. However, the smart orthopedic prosthesis stays a dream at this date. Moreover, the proposed project presents no real equivalent measurement system for comparison/reference.
Previously, in 2010, an elementary wired probe was developed LIB, in partnership with LIP6. It was tested on 6 cats for about 10 hours [16]. This study has provided proof of concept for the visualization of neural processes by DOI in small animal. In September 2013, the SMART labex [28] has supported this project for 2 years (65k€), in order to realize the proof of concept of this type of multimodal measurement on porcine model (closer to the human being).
During this last period, various (in vivo and in vitro) experiments have been performed on FBM pig model in collaboration with the XP-MED company (subcontractor). With a spectrophotometer, the in vivo optical characterization of the SC was performed (see figure 4) and proof of feasibility of these types of measurement have been made and published (see figure 6) [25-27]. Some hard points have been identified and are actually addressed through the PhD of O. Tsiakaka (under direction of S. Feruglio), about the realization of a design methodology of this kind of device. A study is also in progress to find the best tradeoff between SNR, response time and power consumption (PC). Moreover, in parallel, various new prototypes (see figures 4 and 6) with software interface (for command and signal processing) have been developed, and are still in progress. Finally, a multi-physics modeling of the implant in its environment was conducted in order to optimize conception, to minimize in vivo experiments and to understand unexpected results. We must now improve the model of some blocks (the biological environment, mainly) and take into account certain additional phenomena.

The future: Since December 2015, the SMART labex support is finished. Actually, we try to find funding to continue to develop our system and to realize the next experimentations. Since discussions with the SATT-Lutech did not result in financial support, recently, an ANR project has been deposed with 5 academic partners (LIP6 in collaboration with a laboratory of biomechanics, one of optics, a veterinary school and a various departments of the Pitié-Salpétrière University Hospital Center) and a society, specialized on orthopedic implants. Moreover, many discussions have been debuted with various persons (engineers of societies, researcher of academic world, doctors, and veterinarians) about smart implant and neural stimulation, thanks to Aviesan, mainly.

Research on this project has as its primary purpose medicine. Nonetheless, it was full marketability when combined with a true technology transfer strategy. SpinalCOM'objectives are to:

1) offer a new multimodal approach to functional investigation of the SC following injury in vertebrates;
2) develop a new system to help in diagnosis and management;
3) create proof of concept which will be tested on big animal models, before transferring to humans.

In fine, this project finds its clinical application in the field of TSC through the implementation of a multimodal device on the vertebrae during orthopedic surgery, performed in the usual care of TSC. This device is likely to produce a breakthrough, especially for monitoring patients during and also after the surgical operation and as part of the evaluation of innovative therapeutic approaches.

At short term (3 years), we will focus on vertebrate animals in order to propose a tool for researchers and veterinarians. As for humans, the developed tool could contribute to the understanding of injury mechanisms after TSC. It may also be used to evaluate new innovative therapies and technologies in rehabilitation and functional rehabilitation. Looking ahead, the deployment of multiple devices in a network fashion will acquire valuable additional information for all of the medical community (role of the SC, its operation in interaction with the brain, its autonomy relatively to the latter). This will involve the development of a miniaturized (SoC) biocompatible device that will be remotely powered and telecommunicating. Then, in the longer term (10 years, typically), we hope that the device will be tested and implemented on humans.

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Fig. 2 – Experimental room

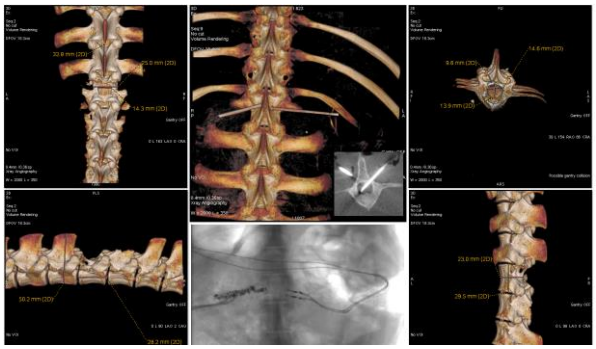


Fig. 3 – Vertebrae's images during in vivo experiments

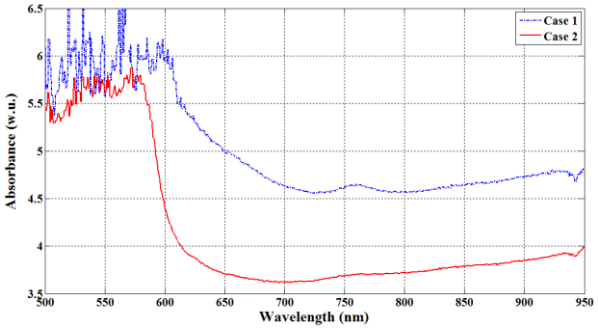


Fig. 4 – In vivo spectral response of the SC before and after laminectomy

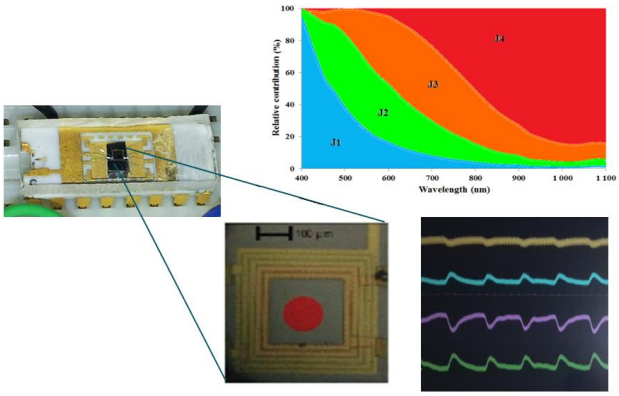


Fig. 5 – Multispectral photodetector

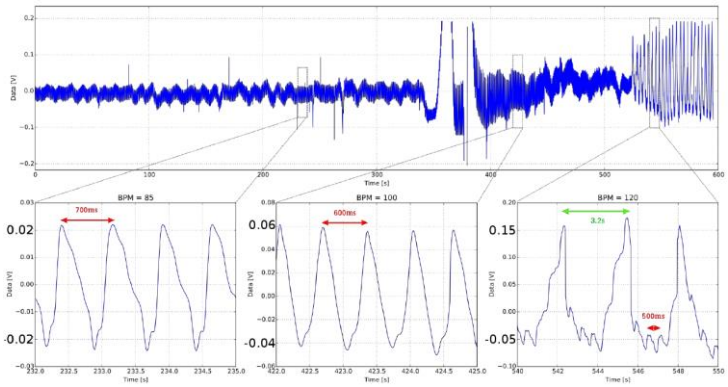
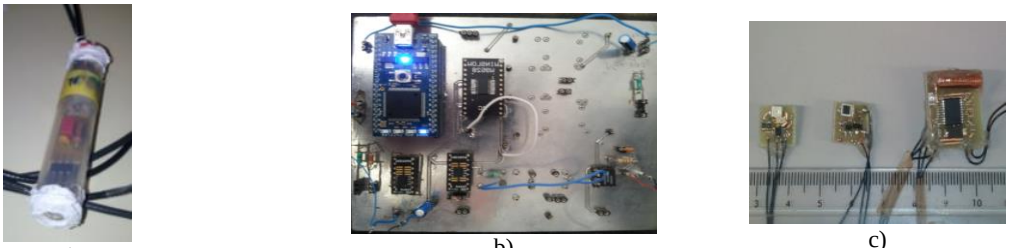


Fig. 6 – In vivo photoplethysmogram of the SC obtained by DIO



a) b) c)

Fig. 7 – Example of prototypes: a) Big encapsulated receiver, b) Board for commands and signal processing, c) RF prototype, with its 3 blocks (emitter, receiver, and signal processing & RF emission).

RECRUITMENT

- 1 thesis: « *Design of telecommunicating neurological implant* », ***O. Tsiakaka***, Doctoral school PhD scholarship (PhD research grant *EDITE de Paris*), from October 2014.
- 1 study's Engineer: « *Electronic Instrumentation Engineer for Biomedical Application* », ***M. Feher*** (April – Sept. 2014).
- 6 trainees:
  1. « *Software and signal processing for a spinal cord implant* », ***D. Robertaud***, Engineer student 4th year, Ecole Centrale d'Electronique (ECE) Paris (May – Jully 2015).
  2. « *Contribution to the modelling of an implant for the chronic imaging of the spinal cord* », ***R. Ghanem***, Master 2 SESI, UPMC-Paris 6 (April – Sept. 2014).
  3. « *Contribution to the realization of an implant for the chronic spinal cord imaging* », ***O. Tsiakaka***, Master 2 SESI, UPMC-Paris 6 (April – Sept. 2014).
  4. « *Digital implant for the functional imaging of the spinal Cord* », ***H. Saadi***, Master 2 SESI, UPMC-Paris 6 (April – Sept. 2014).
  5. « *Modelling of a communicating neurological implant in its environment to the multimodal imaging of the spinal cord* », ***D. El Azzi***, Master 2 SDI, UPMC-Paris 6 (April – Sept. 2013).
  6. « *Optical modelling of CMOS Photodetector* », ***A. Karami***, Master 1 SESI, UPMC-Paris 6 (July 2013).

PUBLICATIONS

- **Refereed articles:**
  1. S. Feruglio, T. Courcier, O. Tsiakaka, A. Karami, A. Alexandre-Gauthier, O. Romain, V. Aimez, P.G. Charette, P. Pittet, G.N. Lu : « *A CMOS Buried Quad p-n Junction Photodetector Model* », IEEE Sensors Journal, Vol. 16 Issue 6, p 1611-20, Nov. 2015.
  2. S. Feruglio, T. Courcier, A. Karami, A. Alexandre-Gauthier, O. Romain, V. Aimez, P.G. Charette, P. Pittet, G.N. Lu: « *Opto-electrical Modeling of CMOS Buried Quad Junction Photodetector* », Key Engineering Materials, Trans Tech Publications, Vol. 605, pp. 470-473, June 2014.
- **Refereed Conference Papers:**
  1. O. Tsiakaka, M. Terosiet, O. Romain, A. Histace, H. Benali, P.F. Pradat, F. Vallette, M. Feher, S. Feruglio : « *In Vivo NIRS Monitoring in Pig Spinal Cord Tissues* », The 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Milan, Italy, pp. 1-4, Aug. 2015.
  2. O. Tsiakaka, O. Romain, M. Terosiet, A. Histace, H. Benali, P.F. Pradat, F. Vallette, A. Alexandre-Gauthier, M. Feher, S. Feruglio : « *Study of the Spinal Cord Activity in the Pig* », 5èmes Journées d'Etude sur la TéléSANté (JETSAN), Compiègne, France, pp. 1-4, 27-28 May 2015.
  3. O. Tsiakaka, O. Romain, H. Benali, P.-F. Pradat, S. Feruglio: «*Imaging of Haemodynamic Spinal Cord Activity in the Pig* », The 7th International IEEE EMBS Neural Engineering (NER), Montpellier, France, pp. 1, 22-24 April 2015.
- **National conference papers:**
  4. O. Tsiakaka, M. Terosiet, O. Romain, H. Benali, V. Marchand, P.F. Pradat, S. Feruglio : « *Vers une imagerie fonctionnelle ambulatoire de la moelle épinière* », Colloque de la Fédération d'Electronique de l'UPMC « Internet des objets pour les applications biomédicales », Issy-les-Moulineaux, France, pp. 1-2, 10 Nov. 2016.
  5. O. Tsiakaka, M. Terosiet, O. Romain, H. Benali, V. Marchand, P.F. Pradat, S. Feruglio : « *SpinalCOM: Ambulatory monitoring of the Spinal Cord* », Colloque du GDR SoC-SiP, Nantes, France, pp. 1-2, 8-10 June 2016.
- **Other:**
  6. 1 popular article for the UPMC Communication Department Univ Paris 06: http://www.upmc.fr/fr/recherche/actualites_de_la_recherche/dossiers_thematiques/objets_connectes_reseaux_big_data_science_des_donnees/imagerie_sans_fil_de_la_moelle_epiniere.html
  7. Participation in various seminars in different laboratories (BMBI UTC IUIS, ETIS UCP-ENSEA, IMEP-LAHC INPG UJF, INL UCL, LIB UPMC).

EVENTS

- “Fêtes de la Science“ 2013 and 2014.
- Various seminars in Master 2 informatics (specialty SESI) in relation with the project.

PhD Theses Program

PhD Thesis

Complex network dynamics for the study of structure-function relationship in the human brain

Aurélie Garnier

Defended in December 17, 2015

One of the current issue in neurosciences is to elaborate computational models that are able to mimic brain imaging outputs and allowing to study the relationship between structure and function in the human brain. This work concerns two scales of modeling and we have developed dedicated tools to analyze the models. At the local scale, we have proposed a new ordinary differential equation model for neural activities. We have characterized and classified the behaviors that the model can generate, we have compared the model outputs to experimental data and we have identified the dynamical structures of the neuronal compartment underlying the generation of pathological patterns.

Then, a compartment modeling neurotransmitter dynamics and their feedback on neural activity has been added to obtain a neuro-glial mass model. We have obtained the theoretical characterization of the impact of these feedbacks on the neuronal excitability by the original formalization of the variation of a bifurcation value in an optimization under constraint problem. Finally, we have proposed a network model in which nodes dynamics are based on the local neuro-glial mass model and embedding both neuronal and glial connectivities. We have numerically observed the propagation of the information with respect of each coupling and then both of them, we have highlighted qualitative differences between the neuronal activities and the gial ones in each node, and we have interpreted the transitions between compartments with the dynamical structures identified in the local models.

The neural mass approach considers interactions between neuron populations by averaging individual neuron activities in each population. Regarding this, the activities generated by these models can be directly compared to experimental data measured by imaging methods allowing to record cumulated activities from hundreds to thousands of neurons, depending on their spatial resolution. Neural mass models classically consider a main pyramidal cells population and an interneurons population, and model the excitatory pyramidal feedback by two distinct approaches. We have proposed and analyzed a model including both these approaches, i.e. including direct and indirect excitatory feedbacks on the main population. To classify the dynamics generated by the model, we have analyzed and numerically localized the bifurcations from codimension 1 to codimensin 4 structuring the model dynamics, depending on the excitation ways (non specific imput amplitude, density of the synaptic connexions between populations, direct and indirect excitatory feedback coupling gains).

This analysis allowed us to build a dictionary of the behaviors generated by the model and to study their distribution in the parameter space of direct and indirect excitatory feedback coupling gains. This partition is a powerful tool for parameters identification problems: we have illustrated its use by reproducing experimental data, recorded in epileptic mice using the mesial temporal lobe epilepsy (MTLE) mouse model. We have then developed a neuro-glial mass model embedding the neural mass model and a glial compartment. This model considers the dynamics of glutamate and GABA that are released by the neurons during synaptic exchanges and are reuptaked by astrocytes. The key element of this new model is to taking into account the impact of the neurotransmitter concentrations onto the local neuronal excitability, and thus on their activity. In this context, the neuronal excitability threshold is identified by a bifurcation value modulated by the state variables of the glial compartment. Insofar as it is impossible to obtain an explicit formulation of this threshold with respect to the parameters, we have formalized the characterization of its variations in an optimization under constraint problem.

Then, we have deduced the impact of glial deficiencies on the general behavior of the system. These results allows to formulate the following assumptions: a dysfunction involving the GABA glial reputake induces a decrease of the neural activity, whereas a dysfunction involving the glutamate glial reputake can have distinct effects depending on the ratio between the glutamate feedback strength on the main neural population and the

glutamate feedback strength on the interneuron population. We have quantitatively characterized the model responses depending on the parameters, allowing future experimental investigations. Finally, we have developed a network model which nodes represent local neuro-glial populations.
Each node dynamics is based on the local neuro-glial mass model previously studied. The dynamic interactions between nodes derived from the classical neuronal coupling and from the glial coupling emerging from the step by step communication between astrocytes. The undeniable advantage of such a model is the possibility to differentiate the impact of each type of connectivity upon the network activity. We have then reproduced the propagation of hyperexcitability from a node to the whole network under distinct hypotheses for the connectivity. We have identified the succession of distinct transitions between neuronal activities structures depending on the type of connectivity (neuronal, glial or both). In particular, we have shown that the system can be resilient, in a manner that is comparable to the resilience demonstrated in the case of a local glial dysfunction for the neurotransmitters reuptake. We have compared these in silico data to experimental data obtained from the MTLE mouse model and bring the sequence of observed dynamics (without modification of parameters values) close to the initiation of rhythmic discharges.

This work tackle distinct fields of applied mathematics: (i) neuroscience modeling to formalize new physiological mechanisms which were experimentally identified in the last decade, (ii) qualitative analysis of dynamical systems and other mathematical tools (e.g. optimization) to theoretically characterize the distinct dynamical structures of the model and deduce biological mechanisms underlying physiopathological behaviors, (iii) development of codes to numerically localize bifurcations, to illustrate behaviors which were theoretically proven, to quantitatively reproduce experimental time series and to observe network behaviors. The results obtained in this work represent a first progress in holding the role of local and global neuro-glial interactions, especially in neuronal hyperexcitability phenomenons.

Publications (Peer Reviewed)
2016 A. Garnier, A. Vidal, H. Benali, A theoretical study of the role of astrocyte activity in neuronal hyperexcitability using a new neuro-glial mass model, to be published.
2015 A. Garnier, A. Vidal, C. Huneau, H. Benali, A neural mass model with direct and indirect excitatory feedback loops: identi_cation of bifurcations and temporal dynamics, Neural Comput., Vol. 27, pp. 329-364.
Proceedings (Peer Reviewed)
2015 A. Garnier, C. Huneau, A. Vidal, F. Wendling, H. Benali, Complex dynamics for the study of neural activity in the human brain, RITS 2015, Dourdan, France.
2014 A. Garnier, C. Huneau, A. Vidal, F. Wendling, H. Benali, Identi_cation of dynamical behaviors in epileptic discharges using a neural mass model with double excitatory feedback, Proceedings of ICCSA 2014, Normandie University, Le Havre, France, pp. 205-210.

PhD Thesis

Thesis Title: Haptic Stimulation of the Entire Hand
Supervisor: Vincent Hayward
PhD Student (2015-2018): Basil Duvernoy
Institut des Systèmes Intelligents et de Robotique
Université Pierre et Marie Curie (Paris-6)
vincent.hayward@isir.upmc.fr
basil.duvernoy@isir.upmc.fr

Background & objective. Human is social by its nature. Thereby the interaction between individuals is a basic need. Audition and vision happen to be the two main sensory channels used to get practical information of our environment. Hence a person who still has both can easily interact with the world. Also a deaf or a blind person is capable to discuss and exchange as well, since one of the two modalities is still accessible. But when it comes to people who cumulate both handicaps, daily life becomes much more complex..

The main goal of this project is to overcome this deficiency of information by creating an apparatus of haptic stimulation. Since the only way for a deafblind to accurately extract information is by touch, a lot of different tactile languages have been developped since the beginning of the XX century. The most widely used language is a tactile stimulation on the palm of the hand thanks to taping and sliding. Our apparatus is based on it in order to be useful for the wider part of deafblinds.

The device is developed on the idea of a direct communication apparatus, working as a live translator, but has a broader array of possibilities. Communication today takes another form thanks to the technologies. This is not the first project working on sensory substitution for deafblind. However, none respects the temporal characteristic of the skin, ergonomy of the hand, portability, decent price and other aspects like a prolonged use, manufacturability, reproducibility, accessible, hygiene or sweat.

In relation to the concerned population, the project should be freely accessed, so that anyone who is not specialized in haptic design can use and transform the prototype for her or his personal requirements. Therefore the electromechanical system and the electronic are made by simple elements that are easily assembled. The mechanical part, where the user put his hand on it, could be printed by a generic 3D printer. The software will include a voice recognition and a text treatment to access at informations through internet pages.

Controllable individually, the 24 actuators could oscillate to 1 kHz in order to stimulate the entire tactile sensation bandwith. This characteristic provides a large interval of movement like the sliding which is based on the apparent motion illusion. Thanks to these actuators, it is theoretically possible to recreate almost all symbols of the tactile languages of deafblind alphabet.

Report of activities: Oct 2016 - Jan 2017.

- Creation of a coil winding
- Lecture of articles which are related to:
  - functions of the hand
  - rest of the hand
  - haptic illusion
  - biomechanics of the skin
  - haptic perception
- 3D modelling of the apparatus
- Physical assembly of each piece in order to create the apparatus
- First meeting with a deafblind, Annie, thanks to the Association Nationale des Personnes SourdAveugles.

PhD Thesis

PhD Student (2015-2018): ***Justine Saint-Aubert***

Supervisor: Sinan Haliyo
Institut des Systèmes Intelligents et de Robotique
Université Pierre et Marie Curie (Paris-6)

Virtual worlds evolve towards an active interaction with human. Where before a virtual object was just displayed, the user is now able to change his state through manipulation or exploration. For example in an ideal scenario, the user would take a virtual object in his hand, observe it from different angles then put it down on a virtual table. All this sequence of actions is ease if virtual objects can return force. Unconsciously, we know when release the object because we feel the contact with the table. This implies to couple the virtual scene with a haptic device. The thesis carries out the idea to obtain a natural 3D haptic interaction between a virtual world and the user. One of the first requirement is to colocalized signal, i.e. to feel forces in the same spatial position where we see the virtual object. A second one is to insure a realistic rendering of the virtual scene displayed. It means feel no forces when the simulation shows no contact and provide right in formations to the users during the contact.

Co-located interface with low inertia

Many interfaces already attempt to colocalize visual and haptic cues. Although it's technically possible the overlap a stereoscopic display with the workspace of an off-the-shelf haptic device, this inevitably leads to a very small usable volume because of visual and physical occlusions. Moreover, the user must not feel internal force given by the device itself, meaning backlash, friction, inertia ... Cable mechanisms are the only candidate to fill all these requirements. The end-effector is suspended by taut wires, each one attached to a motor on the ground [1]. We created a device based on this concept and co-located it with a virtual scene [Scheme 1].

Scheme 1*: The user watches the reflection of the screen across the glasses. He manipulates the black sphere connected by wires able to rend forces. This device is located in the same space than the reflection, i.e colocalized.*

The interface has been conceived and implemented during the year. The device entirely functional is in the MAP Room of the ISIR laboratory. We tested it during the Science festival on more than fifty person from various background without any issue. The very fast adaptation of people (less than ten seconds) is very promising. As a final step, we currently set up a proper experiment to highlight the importance of the co-localization on the dexterity during manipulation.

Completely disconnect the user from the device

The realization of the first prototype inform us on some drawbacks of the system. The main one concern a practical limitation: even if the mechanical structure has a very low inertia, this provided by rotor of each motor is perceptible by user. We he moves the end effectors, he feels a resistance regardless s of the simulation.

As an alternative, we decided to completely slack the wire during some part of the simulation in order to prevent undesirable effect to reach the hand of the user. This simple idea hides a complex realization because when a contact occurs, no slack cable must remain in order to avoid unnatural latency. A regulation of the slack length based on the prediction of users' movement must be provided. Moreover, the effect on the user perception were completely unknown. Therefore, we developed a first simple algorithm and tested in a pilot study on the device. The feasibility of the idea has been proved in practice. Results shows the efficiency on the strategy during the free simulation and warn about some unwanted effect during the contact. We plan to submit a paper to *WorldHaptic 2017* conference on this subject. The next step will be to modify the algorithm to improve the contact perception.

Impact of different mode of exploration.

Beyond the manipulation, humans needs to explore surfaces of the virtual object. In biology, this point is primordial to detect some malformation on the cells for example. With the present device, the end-effector can be used as a tool to probe the virtual object. But this transmission of information through an object, implies a deduction of the shape coming from a dynamic sensing of various direction of force. However, some previous studies prove the importance of skin deformation during this interaction. In particular, that induce by changing the orientation according the tangent of the surface explored [Scheme 2].

***Scheme 2**: Simulate a shape is equivalent to orient the surface according to the tangent of the surface [2]. Image form [3].*

We decide to couple this last information with the force one already present, by creating an active end effector in the haptic device able to orient the surface under the finger tip. A design of the mechanical part and electronical part has been realized. This according to haptic perception requirement (no friction, no backlash) and its future implementation in the cable mechanism (low mass, no external force on wires ...). Presently, a prototype is built. As a final objective, study about the impact of each one on the shape perception will be performed on user.

Works achieved :

- **Design and conception of an entire visio-haptic interface.**
- **Demonstration during the Science festival**
- **New strategy in the control of cable consisting on slack some wires**
- **Test of the new strategy on the user perception and submission of a paper for *WorldHaptic 2017.***
- **Investigate the possibility of simulate shape in the haptic interface.**
- **Design the mechanism for this purpose.**

Works in progress :

- **Experiment and paper on the co-localization in the device.**
- **Provide an algorithm for the contact with slack strategy.**
- **Achieve the prototype of shape simulation.**

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PhD Thesis (2016-2019)

Sahar Hssain
Thesis supervisor: Véronique Marchand-Pauvert
Co-supervisor of thesis: Pierre-François Pradat

Amyotrophic lateral sclerosis (ALS) specifically affects motor-neurons. The ADSH team in the LIB has recently confirmed, by coupling single-channel EEG and diffusion MRI, that patients also have an early subclinical sensory impairment (Iglesias and al., 2015). Preliminary results in single-channel EEG to the peripheral nervous system showed that somatosensory evoked potential (SEP) were reduced in patients compared to controls and the difference between the 2 groups appeared to be more or less strong according to the components. It can be seen, for example, at P25 there is a greater difference than at N20, which can be explained by decreased cortical excitability at the level of the primary motor cortex due to degeneration of central motor neurons. It seems that the difference is also major at N60 and P100, but the cause is still unknown. The size of the SEP depends on the sensory inputs that reach the cerebral cortex and on the integrating properties of the networks responsible for these inputs. Consequently, a change in the size of the SEP may result from a modification of the sensory inputs and / or a change in the excitability of the cortico-subcortical networks. Sensory Impairment revealed in the ALS raises the question of the respective role of sensory inputs and properties of cerebral neural networks in the size of SEP.

The aim of my thesis is to develop a method of processing and a new tool for automated analysis of the EEG signal to extract the part of SEP related to the network properties, independent of sensory returns, in order to evaluate the functional integrity of cortical-sub-cortical brain networks.

The first objective is to develop this tool from data collected from healthy subjects by coupling the EEG multichannel (72 acquisition channels) with magnetoencephalography (MEG). The coupling of these two approaches makes it possible to identify and localize with very good temporal and spatial resolution the cortical and sub-cortical sources of the different components of the SEP. Then, a wavelet analysis, taking into account the signal at the Erb point, will be carried out to evaluate the contribution of sensory inputs. Furthermore, to quantify the sensory inputs, various stimulation intensities of the median nerve at the level of the wrist will be tested and the resultant afferent volley will be quantified by a collecting at the level of the supraclavicular fossa (Erb point), the N9 component reflecting the sensory inputs, raw of any neural treatment. The influence of sensory feedback on SEP will be evaluated from sources. The treatment developed in this first study will be applied to amyotrophic lateral sclerosis (ALS), the third neurodegenerative disease after Parkinson's and Alzheimer's disease, and the most common disease affecting motor neurons. The second objective of the thesis project is to apply the treatments developed in the first part from the EEG signal to evaluate the integrative properties of cerebral networks in patients with ALS. In addition, we will study different sensory modalities by comparing electrical stimulation of peripheral nerve trunks, which are not specific, skin and tendon stimulations. These last two modalities will make it possible to evaluate the respective contribution of the sensory impairment and the properties of the brain networks, and also to specify the sensory impairment, ie to determine whether the cutaneous afferents and proprioceptive afferents are disrupted in the same proportions or not.

As a first step, I realized signal processing in MEG and EEG with different types of software. The signal received was very noisy, its filtering allowed me to have an exploitable signal and to extract the components of interest. Thanks to a recalibration of MRI anatomy and signal MEG/EEG, I was able to localize the sources of activity in relation to the early and late evoked potentials. To localize the sources for N20, N60 and P100, I averaged the cerebral activation of all the subjects over three time periods for stimulation intensities. The next step will be to coupling EEG with the MEG and the fMRI to study cerebral mapping and determine areas of activity related to the sensory-cognitive-motor system. The fMRI study will also confirm the sources of cerebral activity induced by the stimulation of peripheral afferents.

Iglesias C, Sangari S, El Mendili M-M, et al. Electrophysiological and spinal imaging evidences for sensory dysfunction in amyotrophic lateral sclerosis. BMJ Open 2015;5: e007659.

PhD Thesis (2015-2018)

Title: Distributed agreement in dynamic networks
Advisors: Luciana Arantes, Pierre Sens
Student: Denis Jeanneau

Context

The general context is the definition of new services in next generation networks. In these networks, base stations can broadcast and share multimedia information with all the mobile devices in range.
With the increasing density of devices, the stations will not be able to ensure the propagation of information by themselves. The new services must therefore exploit the direct communication possibilities between mobile devices. As a result, communication protocols must be redesigned in order to adapt to the user-related mobility constraints of devices.

Dynamicity is a therefore a key property of these new distributed infrastructures: physical devices in new networks or virtual machines in clouds can come and go at any moment, be subject to failures or move around. This brings new challenges for distributed algorithms which usually consider static and known topologies.
This thesis aims to study agreement algorithms that are at the heart of distributed applications running in dynamic networks. These algorithms can be found in most services related to data replication or sharing data between users. The most fundamental agreement problem is the consensus [8, 9]: it requires that all system users eventually decide a common value amongst a set of proposed values. Consensus allows for coherent data replication and is thus massively used in distributed database systems.

Consensus was largely studied in small or large scale configuration while considering, for example, potentially very long but bounded transmission delays between nodes. However, very little research has been focused on cases where the topology evolves dynamically and the stability assumptions necessary to ensure algorithm convergence [10].

Thesis goals

The goal is to define consensus algorithms adapted to dynamic topologies. These algorithms will rely on a dynamic graph model using the TVG (Time-Varying Graph) formalism [3]. Other than the strictly algorithmic side of things, the aim from a theoretical perspective is to identify the necessary and sufficient graph conditions to ensure the correctness of the algorithm in terms of both safety (two distinct values cannot be decided) and liveness (every correct user must decide a value). The few works considering distributed algorithms in the presence of mobility and failures make strong and unrealistic assumptions on the underlying graph, and eventually consider either a static or a connected graph [14, 2]. However in reality, the communication graph is perpetually evolving. The fundamental question is: \is it possible to ensure a deterministic consensus in a dynamic graph, and under which minimal topology stability condition?".

To answer the question, this thesis considers the solution of failure detectors [4]. A failure detector is a local oracle providing each process with unreliable information on process crashing or leaving the system. These detectors have been used to circumvent the impossibility of solving the consensus problem in the presence of failures in an asynchronous system [9].

Contributions and progress

Rather than merely studying the classical consensus problem, we chose to solve the more general problem of *k*-set agreement, which includes consensus.

The first step is the implementation of the $\sum_k$ failure detector, which was proved to be necessary to solve *k*-set agreement [1]. In a first article [11], we defined its equivalent $\sum^{\perp}_{,k}$ for dynamic networks and proposed two algorithms capable of implementing it in such a network. Intuitively $\sum^{\perp}_{,k}$ prevents the network from partitioning into more than *k* independent subsets.

But $\sum^{\perp,k}$ is not sufficient. In a second contribution [12], we defined the $\Pi\sum^{\perp,x,y}$ failure detector, which includes the properties of $\sum^{\perp,k}$ along with a leader election property. We proved that this new detector is sufficient to solve *k*-set agreement. We then proposed a first algorithm implementing the properties of $\Pi\sum^{\perp,x,y}$ and a second one solving *k*-set agreement (and therefore consensus) using $\Pi\sum^{\perp,x,y}$. This article also includes a wider discussion on the connectivity properties that must be added to a traditional failure detector in order to adapt it for dynamic networks.

Finally, a third contribution [13] focuses on a different but related problem: the reliable broadcast problem. The article [13] is a collaboration with researchers from Brazil and consists in using the VCube method [7] to accomplish a reliable broadcast in an asynchronous network.

Future research

Several perspectives are considered for the remaining of this thesis.

A first research opportunity consists in extending the VCube method to dynamic networks. This idea is promising because the structure of the VCube topology seem to lend itself well to dynamicity, but existing papers only use it in static networks.

Another research opportunity consists in continuing to adapt failure detectors to dynamic systems by studying the problem of mutual exclusion. Mutual exclusion [6] is another classical problem of distributed algorithms that was not studied in the context of dynamic networks. The T failure detector, which was proved to be necessary and sufficient to solve mutual exclusion in static systems [5], could be redefined to account for dynamicity.

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PhD Thesis (2014-2017)

Learning affordances in open-ended environments

Carlos Maestre
Supervisors:
Stephane Doncieux (ISIR)
Christophe Gonzales (LIP6)

Service robots are expected to fulfill tasks in home-related environments, such as cluttering a table. To this end, they must have some skills to interact with objects. These are threefold: (i) knowledge related to the robot itself, associated to the concept of self and some basic motion capabilities, i.e. its kinematic model; (ii) knowledge related to interpreting its environment, e.g. segmentation, identification and tracking of objects; (iii) skills to interact with the environment, composed by (a) motion skills to produce changes on it, as grasp and push primitives; and (b) cause-effect knowledge, to reach a particular goal. In this work, the first two parts of the robot expertise are considered as available. The focus is on the acquisition of motion skills by a robot to interact with its environment. A cause-effect relation is called causality [1]. The causality relations with objects in an environment are known as affordances. An affordance has been formalized as a relationship between an agent and its environment to obtain certain effect after applying a behaviour or action on an entity or object [2].The affordance learning can be based on a dataset of action-effect relations of a robot with the environment. The acquisition of this interaction information is a key aspect in the affordance literature [3].

Most of the works related to affordance learning provide some motion skills to interact with a constrained set of objects. These motion skills are usually represented as a repertory of predefined action primitives, e.g. push and grasp. These primitives are specific for the constrained set of objects, producing a rich dataset of action-effect relations. For example, a robot could be asked to clutter a table with a predefined set of objects on it. In this case, a pick-and-place primitive could be provided to the robot to arrange them. However, in daily situations, environments are usually open-ended, i.e. only partially known, with incomplete object information. A repertory of predefined motion primitives, specific for some known objects, may not be enough when new objects appear. For example, on the previous cluttering scenario, the robot can only execute a pick-and-place primitive action. If a basket ball, not graspable by the robot's end-effector, is put on the table, the robot will fail to perform the "put on one side" effect. Thus, how can a robot adapt its motion skills to the features of an unforeseen object, in order to extend its dataset of action-effect interactions, to be able to learn missing affordances?

The definition of general purpose primitives in these environments could entail a high complexity, due to the large variety of possible object features. Developmental Robotics aims at making robots acquire their own knowledge through their interaction with open-ended environments thanks to an active exploration, adapting to new situations, similar to what infants do [4]. The active exploration of an open-environment can be executed through an unsupervised exploration, called motor babbling [5]. However, this babbling would not be enough to identify all the available action-effect interactions in the environment. A constrained effect-driven exploration must complete the missing interaction information, extending the dataset, allowing to learn new affordances, adapting its motion skills to the features of the environment. To that end, we propose an iterative method named Adaptive Affordance Learning (A2L), in which a robot continuously adapts its motion skills to the features of its surrounding objects, enlarging the information to interact with them, improving its affordance knowledge. Recalling the cluttering scenario, if the robot cannot grasp the basket ball, using this method it will try to generate new interactions with the object modifying the pick-and-place primitive, e.g. constantly closing the end-effector. Then, this new primitive would be used to generate new contacts with the ball, possibly learning to push the ball to the table.

Using this method, a robot continuously generates and adapts its motion skills to the features of the objects around it, generating datasets allowing the learning of the available affordances[6]. Some motion priors are available for the primitive generation and adaptation. These priors are not related to any specific object or scenario, e.g. the distance and orientation between the end-effector and an object are relevant to interact with it. The method uses a Bayesian Network (BN) [1] to represent discrete affordances, as in [6]. Therefore, the affordance learning consists in creating a BN representing these action-effect relations. A validation step is executed to assess the acquired affordance knowledge. The validation is effect-oriented, trying to reproduce the already identified effects after interacting with the environment.
A2L contains two phases:
a) Basic affordance learning phase: it is a first contact of a robot with its environment. Using this method, a robot makes a naive goal-free babbling of the environment to gather some initial information about it. During the babbling some effects can be identified, result of executing some actions. These action-effect relations are stored into an initial dataset. At the end of this phase, a robot must reproduce a limited number of effects; even though it is still also possible that some of the learned affordances are incorrect, generating different effects to those expected, e.g. moving an object in a wrong direction.
b) Adaptive affordance learning phase: the goal of the robot in this phase is twofold: (i) learn new action-effect relations, extending its interaction dataset, and (ii) rectify mistaken action-effect relations already learned, producing new interactions reproducing these mistaken relations, therefore, adding correct relations to the dataset. To achieve these goals, the robot executes an iterative process consisting of the execution of short babbling around an object, trying to produce action-effect relations allowing to reproduce more effects. Those relations that are not relevant for that purpose are discarded. During the whole process the robot continues adapting its skills to enrich its dataset, improving its affordance knowledge.

Thanks to the iterative process, A2L is able to extend its action-effect in- formation, improving its affordance knowledge, based on the adaptation of its motion primitives to the features of unforeseen environments.

Publications

Submitted publications:
2016 Maestre, C. and Gonzales, C. and Doncieux, S. Simultaneous Acquisition of Affordances and Motion Skills in Open-ended Environments through an Iterative Approach. FLEARS 2017.

Accepted publications:
2015 Maestre, C. and Cully, A. and Gonzales, C. and Doncieux, S. Bootstrap- ping interactions with objects from raw sensorimotor data: a Novelty Search based approach. IEEE ICDL and Epirob. Pages 1-6.

2015 Ecarlat, P. and Cully, A. and Maestre, C. and Doncieux, S. Learning a high diversity of object manipulations though an evolutionary-based babbling. Proceedings of the workshop Learning Object Affordances, IEEE/RSJ IROS.

2015 Legoff, L. and Maestre, C. and Doncieux, S. Visual saliency-based babbling of unknown dynamic environments. Proceedings of the workshop Learning Object Affordances, IEEE/RSJ IROS.

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PhD Thesis

PhD student: Sébastien Lefort

Supervisor(s): Marie-Jeanne Lesot (LIP6, UPMC), Elisabetta Zibetti (CHArt, Paris 8)

Laboratory: LIP6

Doctoral School: EDITE

Period: October 2014 – September 2017

1 Description

Flexible Queries for Smart Information Extraction

The aim of the thesis is to define natural interaction methods between humans and intelligent systems. It combines issues from cognitive psychology, machine learning and data base querying, so as to produce a triple conceptualization of natural language use to express queries: user personalization, adaptation to the data base content and cognitive adjustment. The thesis will formalize the notions of interpretability and linguistic imprecision, in particular for temporal and spatial terms, and propose methods to build formal representations of vocabularies, taking into account the formalized constraints and considering the use of fuzzy approaches. Methods to automatically adapt a vocabulary will be proposed and exploited in the applicative context of collaborative querying, to process issues related to plethoric or empty answers.

2 Results

After a literature review of the mental scales used to represent quantities, both in time and space, we focused on Approximate Numerical Expressions (ANE). ANEs are linguistic expressions involving numerical values and referring to imprecise ranges of values, illustrated by examples such as "*about 100*"). The applicative goal of our work if to design computational models that can be used to interpret vague database queries, such as looking for a hotel located at "*about 50km*" or to represent imprecise information such as "the patient has had fever for *approximately one week*".

The first part of the thesis deals with automatic ANE interpretation. Firstly, data have been collected by means of an empirical study using questionnaires. These data allowed us to validate the relevant factors to take into account in ANE interpretation [1]. Secondly, a computational model, using the identified factors, has been designed to predict intervals of denoted values corresponding to ANE. The model is based on a general underlying principle, stating that when interpreting an ANE, people tend to make a compromise between the range of denoted values and the cognitive salience of the endpoints of this range. The model has been experimentally validated using the collected data [2]. Thirdly, the model has been extended so as to interpret ANEs as fuzzy numbers in order to better capture the intrinsic imprecision of these expressions. The aim of the extension is to predict the support, the 0.5-cut and the kernel of the membership functions. As for the original model, it has been experimentally validated using the collected data [3, 4].

The second part of the thesis aims at examining the way human beings deal with imprecision in reasoning processes, especially in calculations. To the best of our knowledge, studies of imprecise/approximate reasoning in cognitive psychology are very rare. Our aim is a first attempt towards this goal. To do so, data corresponding to approximate products and additions (e.g., "about 20" + "about 30") have been collected. Preliminary

analyses show that people seem not to take into account the imprecisions related to the operands to estimate the imprecision related to the results [S1].

Ongoing works are dedicated to third issues. The first one consists in extending the proposed ANE interpretation models in order to learn the specificities of the applicative semantic and pragmatic context. The second issue concerns the generalization of the models in order to process more complex scales of measurement, especially the time scale-system. Finally, we will study how human beings approximate precise numerical data (e.g., "*about 100*" for 96.3) in order to propose a model that produces approximations that make sense for the users.

Publications

Published papers:

[1] Lefort, S., Zibetti, E., Lesot, M.-J., Detyniecki, M., & Tijus, C. (2017). Dimensions for automatic interpretation of approximate numerical expressions: An empirical study. 22nd International Conference on Intelligent User Interfaces (IUI'17), Limassol, Cyprus.

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Submitted paper:

[S1] Lefort, S., Lesot, M.-J., Zibetti, E., Tijus, C., & Detyniecki, M. (submitted). How fuzzy are we? An empirical comparison of human imprecise calculation and fuzzy arithmetic. *IEEE International Conference on Fuzzy Systems (Fuzz-IEEE2017)*, Naples, Italy.

PhD Thesis

Deep Learning for Image Recognition

PhD student: Rémi CADÈNE

Supervisor(s): Nicolas THOME (CNAM, LIP6), Matthieu CORD (LIP6)

Laboratory: LIP6 (research team MLIA)

Doctoral School: EDITE

Period: 2016-2019

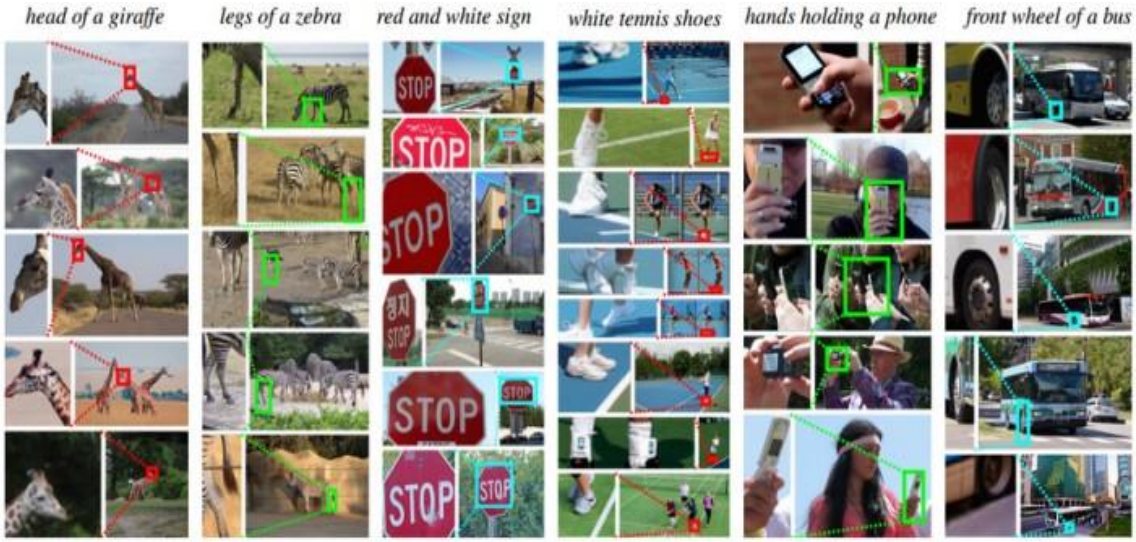
1. Description

After the huge success of deep Convolutional Neural Networks (CNNs) at the ImageNet Large Scale Visual Recognition Challenge (ILSVRC) 2012, Deep Learning nowadays appears as the dominant technique for many visual data understanding tasks. Thus, applications which were previously out of reach emerged into the Computer Vision and Machine Learning communities. In particular, tasks that combines Computer Vision and Natural Language Processing, such as Visual Question Answering or Image and Video Captioning, have dramatically increased in the past year. One of the main reasons for tackling a such difficult problem is that multidisciplinary tasks are a step towards solving Artificial Intelligence.

2. Goal

The goal of this PhD thesis is to further study such deep architectures for unified image and textual representations.

Firstly, we aim at exploring multi-modal embeddings, with the goal to learn a joint representation from heterogeneous modalities, e.g. image and text. A particular interest will be given to training schemes based on aligning representations in the joint space. From this perspective, several applications will be addressed: Visual Query answering -- Tag-to-image and image-to-tag search -- Image-to-caption search on large-scale multimodal collection -- Dense Captioning [JKF16]. For now, I am focusing on the Visual Question Answering task.



A second aspect of this thesis is go deeper toward alignment between image and text modalities, especially by incorporating spatial information. Basically, we aim at matching image and text regions based on their semantics. In this context, having precise annotations for large scale datasets in not a viable solution, due to the expensiveness of the labeling. To overcome this issue, weakly supervised learning strategies dedicated to automatically selecting relevant visual and textual locations from coarse annotations will be studied [DTC16].

Finally, to push forward the relaxation of annotations, unsupervised learning methods will be explored. In particular, we want to extend recent work on ladder network [RVH+15], where the reconstruction scheme is questioned by not asking to the internal representation to do the job alone, but adding skip connections coming from the input. One interesting option would be to explicitly model specific representations for each example, which are irrelevant for a given supervised task. Basically, the idea of the training scheme is to separate the extraction of invariant representations, useful for the supervised task, and variant features (i.e. specific to each example), needed to reconstruct each training sample. The underlying assumption is that the explicit decomposition of variant and invariant features drives the learning towards more effective (robust) representations.

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PhD Thesis

Deep Neural Networks and Multimodal Semantic Role Labeling for Question Answering
PhD student: Eloi Zablocki
Supervisors: Patrick Gallinari, Benjamin Piwowarski, Laure Soulier (LIP6, UPMC)
Laboratory: LIP6
Doctoral School: EDITE
Period: October 2016: September 2019

1 Description

1.1 Context

The purpose of this thesis is to study the expression of time and space in language data. The chosen approach is to exploit visual and perceptual input (images and videos) coupled with text for learning multi-modal semantic representations for the recognition of objects and actions and their spatial and temporal relations. Those multi-modal representations can be used for several tasks as Semantic Role Labeling and Question Answering. Our goal is to use visual modality to help understand language. Indeed, contextual world knowledge and common sense are essential to understand linguistic expressions and relations referring to objects, actions and events. However, this knowledge is hard to extract from text alone because it is prone to complex formulations and to ambiguities. While text provides a versatile semantic description of situations and events, perceptual visual information grounds this information in the physical world. The methodology we employ is based on recent representation learning techniques (deep neural networks) for text and visual data.

1.2 Objectives

Based on an exploration of the state of the art techniques and approaches, two main questions emerge:
- How to automatically create text representations (in the form of single-word or multi-word embeddings) that integrate perceptual knowledge for spatial and temporal relations? This is a representation learning problem.
- How to use those newly created semantic representations to improve machine reasoning and understanding of human language, e.g. in the case of Question Answering and Semantic Role Labeling? This is an integration problem.

2 Results

After a thorough review of recent techniques and state-of-the-art algorithms, we found an interesting approach to the representation learning problem, where only a weak supervision signal is given about the link between image and text. We are currently experimenting a method for learning aligned semantic representations between the visual and textual modalities, when the alignment supervision is only given for some words (concrete objects). When we validate this experimental study, we want to assess the advantage of this approach versus more traditional ones that are limited by the number of aligned data needed for training.

Post-Doctoral Program

Post-doc

Gabriel Arnold (ISIR)

Context and objectives

Upper-limb amputees using a myoelectric prosthesis benefit from efficient motor control of the prosthesis but suffer from the absence of a tactile and proprioceptive feedback when using the prosthesis. They must compensate for these absences by visual strategies. For example, before performing a motion of the prosthesis to grasp an object, they should look at the prosthesis to determine its starting position. In order to reduce the cognitive load induced by the use of the prosthesis, a technological solution consists in providing an artificial sensory feedback giving proprioceptive information on the position and orientation of the prosthesis.

The aim of this project is to identify the optimal learning conditions for the integration of the artificial proprio-tactile feedback. The following questions are addressed:

1. Does the integration of the proprio-tactile feedback benefit from a previous learning of the feedback on the healthy limb?
2. Is there a transfer of learning from the healthy limb to the prosthesis?
3. What is the role of vision during the learning of the proprio-tactile feedback?
4. Which spatial reference frames are involved?

Progress of work

A device coupling a myoelectric prosthesis to a tactile wristband has been developed. A wristband of 6 vibrators, with a 30°-space between vibrators, is placed around the arm (not amputated) above the prosthesis replacing the amputated forearm. The tactile wristband is connected to the prosthesis and the vibrators activate according to the orientation of the prosthesis relative to the rest of the arm (prono-supination movement) and the opening of the grip. The orientation of the prosthesis is spatially encoded: the activated vibrator indicates the position of the thumb. The opening of the grip is encoded by the intensity of vibration: the more closed the grip, the more intense the vibration.

A learning protocol is under preparation. The benefit of learning the proprio-tactile feedback on the healthy limb will be assessed by comparing a group of participants learning the feedback on the healthy arm before using it on the prosthesis to a group of participants learning directly the feedback with the prosthesis. The role of vision will be assessed by comparing a group of participants who can view the movements of the arm and prosthesis during learning to a group of participants who cannot watch the movements. After learning, the appropriation of the proprio-tactile feedback will be evaluated in an object grasping task, on the healthy arm and on the prosthesis (for all groups), which will evaluate the learning transfer from the healthy arm to the prosthesis.

The spatial references that are adopted will be studied later, evaluating in particular the effects of the body configuration during the use of the prosthesis. For example, the appropriation of the proprio-tactile feedback will be assessed under different conditions of the prosthesis orientation relative to the rest of the body.

Post-doc

Giovanna Varni (ISIR)

Mohamed Chetouani (ISIR) and Chloé Clavel (Telecom-ParisTech)

During this year, my research activity mainly focused on:

1) Investigating, through computational approaches, interpersonal dynamics in human-human dyadic interaction. More specifically, the focus was done on emotional interdependence;
2) Developing computational tools to automatically quantify such phenomena. Concretely, some methods for the SyncPy open-source library (https://github.com/syncpy/SyncPy) were developed.

Interpersonal dynamics was identified as one of the four facets of dynamics human-human interaction is grounded on [1]. Although the interest on automated analysis on human-human interaction has recently grown, computational methods able to catch the complexity of the interaction and all its nuances are still missing. Furthermore, HCI research community needs such a kind of knowledge in order to enhance the social and affective behavioral strategies conceived for synthetic agents as virtual humans and robots.

I investigated *cross-modal* interpersonal dynamics of *emotional interdependence* in face-to-face human conversational dyadic interactions where the roles of the two partners were established in advance. A cross-modal analysis, that is an analysis explicitly taking into account the interleaving of the different communication modalities, was explored. It is expected to more comprehensively reflect the real nature of human interaction that is cross-modal per se. Emotional interdependence, that is the interplay of emotional responses during interaction [2], is a key phenomenon that should be addressed both to have a better understanding of the human-human interaction and to improve the quality of experience of a user when she interacts with a machine.

Face and semantics are the modalities that were taken into account in my study. Data were from the SAL-SEMAINE corpus [3]. This corpus grounds on the Sensitive Artificial Listener (SAL) technique and it includes emotionally-colored recordings consisting of dialogues between an operator and a user. Following the SAL paradigm, the operator can be a person simulating a machine or a real machine, whereas the user is always a human partner. In my study, the focus was only done on the Solid SAL scenario where the operator is a human acting one among 4 roles different in personality. The roles are: Poppy (cheerful and outgoing), Prudence (pragmatic), Spike (aggressive), and Obadiah (pessimistic). The dialogues were non-scripted in terms of sentences to allow for the most spontaneous interaction possible.

The focus of my study was on examining and measuring to which extent the emotions of one partner - the sender or leader- influence the emotions of the other partner- the receiver or follower- across conversational time. In other words, the emphasis was on one partner's emotional behavior eliciting an emotional response in the other one.

Two research questions (RQs) were addressed:

RQ1 investigating whether and to which extent a cross-modal approach provides more insights and reflects more comprehensively than an intra-modal one emotional interdependence, which is cross-modal per se;

RQ2 exploring to which extent each of the two known mechanisms explaining the dynamics of emotional interdependence, *primitive contagion* [4] and *more conscious emotional comparison process* [5], intervene during interaction.

Figure 1 illustrates the methodology conceived to answer these research questions.

Facial expressions polarity and sentiment time series were automatically extracted from the videos and the transcripts of the corpus, respectively. For each partner three time series were extracted: positive, negative and

objective polarity time series. Cross-recurrence plots (CRPs) and cross-recurrent quantification analysis (CRQA) [6] were computed from these time series and also of from their cross-modal combination. Such a cross-modal combination was obtained by filling up the silent instants of time of the sentiment polarity time series (when a partner was not speaking) with the coincident instants of time of the facial expression polarity time series (facial expression polarity was extracted as a continuous flow). Therefore, each resulting cross-modal time series is a succession of sentiment and facial expression polarity.

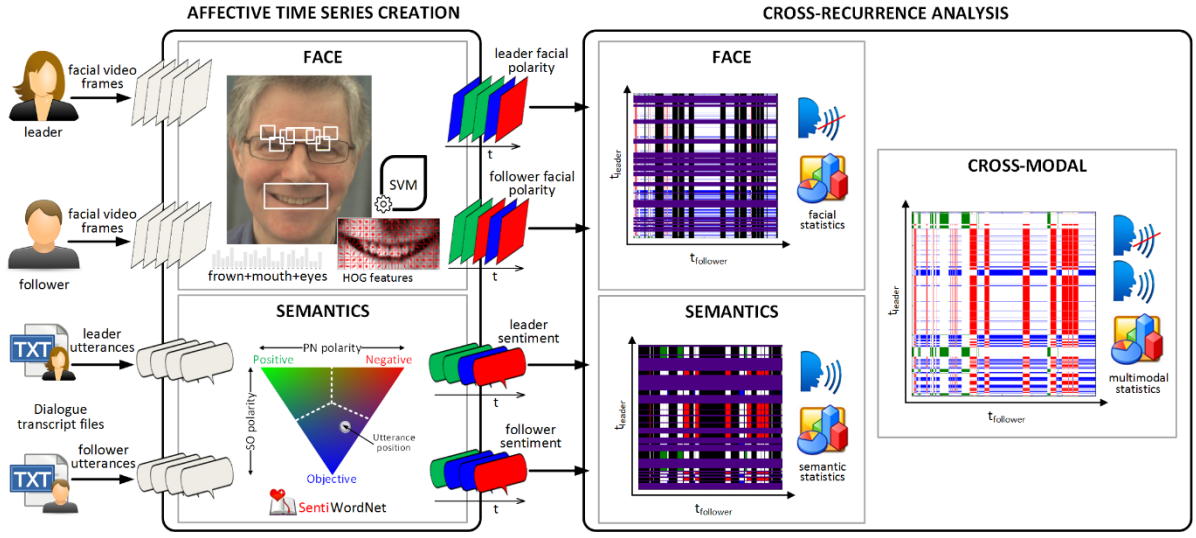

Figure 1

The analysis was carried out at two different temporal levels (short-term and long-term) to explore in a computational way how the two mechanisms responsible for emotional interdependence (*primitive contagion* and *more conscious emotional comparison process*) contribute. Short-term was defined according to the dynamics of each modality, whereas long-term included the analysis over the whole interaction. Primitive contagion is a very fast and automatic mechanism: it was here addressed by a short-term analysis. It consisted in the computation of the τ-Cross-Recurrence Rate (cRRτ) from the Cross-Recurrence plots. Emotional comparison process develops in a longer time than primitive contagion: it was here addressed by a long-term analysis. It consisted in the computation of the Cross-Recurrence Rate (cRR), the Average diagonal length (L) and entropy (E) of diagonal lines from the Cross-Recurrence plots.

RQ1

The results showed that adopting a cross-modal approach increases the detected amount of emotional interdependence and its stability over time both at long and at short time.

Long-term

A pair of paired sign tests using Bonferroni adjusted α=.025 per test were run to verify whether there was a difference in the median of the cRR values when intra-modality (semantics or face) vs cross-modality was adopted, independently from the valence expressed by the operator. The tests concerned only the positive and negative valence, objectivity was assumed playing exactly the same role for each character. In both the cases, cross-modality elicited a statistically significant ($p<.025$) median increase in the cRR compared to intra-modality. When cross-modality was tested vs semantics the median increase was equal to 6.0% and 4.8% for positive and negative valence, respectively; when cross-modality was tested vs face the median increase was

equal to 6.7% and 5.3% for positive and negative valence respectively. It is important to stress that these increases refer to the medians without taking into account the valence played by the operator.

A pair of paired Wilcoxon tests using Bonferroni adjusted α=.025 per test were run to check possible differences due to intra-/cross-modality approach in the stability of the emotional interdependence. These tests revealed that cross-modality guaranteed a more stable interdependence with respect to the adoption of the face modality only ($V=0$ $p<.001$ both for negative and positive valence with an increase in the median of 1.7s and 1.6s, respectively). Regarding semantics, no significant difference occurred. A similar analysis was carried out on E to test if changes in the emotional interdependence structure appear. The paired t-tests showed that cross-modality produced a greater number of changes in the structure of the patterns than intra-modality except for the positive valence of semantics ($t=-3.0$, $p<.001$, $t=-5.9$, $p<.001$; $t=-7.3$, $p<.001$ for the negative valence of semantics and the negative/positive valence of face, respectively).

Short-term

A pair of paired sign tests using Bonferroni adjusted α=.025 per test were run on the maxima of positive and negative $cRR\tau$ to verify whether differences occurred between intra-modality and cross-modality. These tests involved only the maxima occurring at statistically significant times, that is all the maxima for semantics and cross-modality and only 13 maxima for facial. Using a cross-modal approach increases the maximum of the cross recurrence of 4.7% (positive valence) and 4.6% (negative valence) for semantics and of 6.1% (positive valence) and 6.8% (negative valence) for facial, respectively. However, there was not statistical significance ($p>.025$) for the positive valence of the facial modality.

RQ2

In average, the only short-term analysis allows to grasp the 55.8% (Obadiah), 63.1% (Poppy), and 66.6% (Spike) of the emotional interdependence. These results are relevant for a twofold reason. First, at the best of our knowledge, this is the first attempt to provide a quantitative measure of how the emotional interdependence due to primitive contagion concurs to explain the whole phenomenon of emotional contagion. Then, these results are promising towards the design and the development of machine able to deal with affective interaction in real-time.

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Publications

G. Varni, I. Hupont, C. Clavel, M. Chetouani, *Computational Study of Emotional Interdependence in Dyadic Interactions – Toward a dynamic emotional planner for virtual agents*, IEEE Transactions on Affective Computing (In Preparation).

Post-doc

Adrien Ugon (LIP6)

1 Aim of the project

The AEP (Automated Embedded Polysomnography) projects aims at designing a network of autonomous and smart sensors able to record polysomnographic data and process them in a distributed embedded system to support their interpretation and generate high level information that can be used for the diagnosis.
The expert system is based on international sleep medicine practice guidelines published by the American Academy of Sleep Medicine and follows the principle of symbolic fusion. Information extracted from different sources is formalized by a symbolic representation and combined by applying fusion strategies and rules.
The project partners are:
— LIP6 - UPMC (Adrien ugon, Amina kotti, Jean-Gabriel Ganascia, Patrick Garda, &
Andrea Pinna)
— Unité de pathologies du sommeil, La Pitié-Salpêtrière, AP-HP (Carole Philippe)
— LIMICS - UPMC, INSERM (Karima Sedki, Brigitte Séroussi & Jacques Bouaud)

2 A new database

During the AEP project, a new database was acquired containing 131 polysomnographic recordings : 101 recordings from subjects suspected to suffer from a Sleep Apnea Syndrome (with different severity degrees) and 30 recordings from 10 healthy subjects having spent 3 consecutive nights at the hospital and recruited for research purpose thanks to the project.
All the recordings were scored by an expert according to the AASM guidelines, with the addition of comments on the curves that may be useful in understanding the reasons why a decision was taken. In particular, some of the sleep events that are used to score sleep stages visually, and that are usually not mentioned, were highlighted to be used in a learning or evaluation process.

3 A better way to consider time and sleep architecture in decision process

Most of existing approaches in decision process are based on a segmentation of recordings in 30-seconds windows called epochs. This segmentation avoids a good consideration of sleep dynamic and sleep architecture and results in inappropriate transitions. To address this issue, sleep was considered as a continuous process where the current state depends on the previous state and of events occurring currently or very recently. Decision is thus taken in a short-time window reflecting more compliantly the transitions. A sleep event, specific of a specific stage B, occurring in the stage A, may be without any impact on the decision if, in the guidelines, the transition from stage A to stage B is not based on the occurrence of this sleep event.

4 Automatic extraction of sleep events

To be compliant with AASM guidelines, it is necessary to extract, with a good quality, all sleep events that should be taken into account in the decision process. New algorithms were thus defined so that all events are more precisely delimited in time. This precision is required to take appropriate decision in short-time windows. All sleep-events algorithms are based on the extraction of attributes that reflect its definition in the AASM guidelines. Algorithms were defined for the extraction of following sleep events : system disconnection, EEG alpha rhythm, low amplitude mixed frequency EEg activity, EEG Slow wave activity, sleep spindles, K complexes, Eye blinks, Rapid Eye Movements, Slow Eye Movements, High Chin Muscle Tone, Low chin Muscle Tone.

5 Automatic decision on short-time windows

In the AASM guidelines, the decision that should be taken locally depends directly on criteria combining sleep events occurring simultaneously or with an acceptable delay. Indeed, each sleep event has its own influence period that allows to take the occurrence of some events into account in the decision process, even a few seconds after their end. In addition, some of the criteria requires that several events occurs simultaneously, or quasi simultaneously.

After having formalized all the rules from the AASM guidelines, criteria were defined so that the decision is taken faithfully.
Thus the whole local decision system consists of a « package » of transition functions from a given sleep state to a new one (or to remain in the same sleep state). All transition functions assemble criteria with logic inference rules to take the decision. When all the criteria are met, this results in a transition of the local sleep state.

6 Automatic decision at the epoch level

The decision at the epoch level consists of assembling the local decisions of all short-time windows in the epoch. Regarding to the AASM guidelines each of the 5 sleep stages defined (W, N1, N2, N3, R) needs to be present with a minimum percentage to be assigned to the epoch.

7 Integration of preferences to solve conflicts

Some of the rules in the AASM guidelines are priority rules. A given pattern meeting criteria of two different sleep events will be assigned only one of them by applying the priority rule. This was formalized by integrating preferences in the inference rules to take a decision. These preference rules are applied at the sleep event extraction level and at the automatic decision at the epoch level, when two sleep stages are sufficiently locally present to be assigned to the epoch.

8 Conclusion

The AEP reached two objectives:
1. Acquiring a new database of polysomnographic recordings scored compliantly with international guidelines in sleep medicine.
2. Defining a new way of interpreting automatically polysomnographic curves to generate a hypnogram on the basis of medical knowledge formalized from the international guidelines and following the principles of symbolic fusion. To take into consideration the sleep architecture, the decision process is divided into three steps: (1) extraction of sleep events (delimited in time) (2) decision on short-time windows using criteria fusing sleep-events with time period consideration (3) decision at the epoch level

Decision conflicts are solved by integrating preferences in inference rules in step (1) and (3). By applying the algorithm on the recordings of the new database, it is possible to conduct an evaluation. The analysis of wrong decisions allows to enrich the model by adding new knowledge at any step of the decision process.

Références

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Post-doc

Marine Taffou (STMS)

New approaches for the evaluation and the treatment of emotional disorders: Virtual reality, multisensory integration and affect (STMS)

In the past twenty years, medical applications of virtual reality technology to psychotherapy and rehabilitation have addressed a variety of pathologies including emotional disorders. In the framework of the postdoctoral program of the labex SMART, we explored the advantages of virtual environments involving both visual and auditory stimulations for the evaluation and treatment of fear of crowds. Fear of crowds is a symptom found in several emotional disorders like agoraphobia, social phobia, fear of falling and in fear associated with ageing. Moreover, this symptom has both auditory and visual emotional components. Previous work has shown that controlling the sensory presentation of the stimuli delivered to patients during exposure enable mastering the gradation of their emotional impact (Taffou et al., 2013). We further explored this effect by studying the influence of the sensory presentation of crowds on their emotional impact as a function of their spatial location around the user. This investigation has relied on the development of technical environments allowing the manipulation of both the visual and auditory dimensions and has involved the specific expertise of the Acoustic and Cognitive Spaces team (STMS) in 3D sound rendering.

We first characterized what is considered as a crowd in our auditory-visual virtual environment. We invited participants to be immersed in our interactive virtual environment containing virtual humans (humanoids). The setup comprised a tracking system, headphones with binaural rendering and a large screen with passive stereoscopy. They were successively presented with groups of humanoids, which increased in numerosity (from 8 to 128). These groups of humanoids could be presented through the auditory channel, the visual channel or both channels. Participants were asked to judge the size of the group of humanoids and to rate their discomfort related to the stimulus. The results showed that the groups of 96 and 128 humanoids are considered as crowds in our virtual environment (Taffou, Ondrej, O'Sullivan, Warusfel and Viaud-Delmon, 2016). This study also suggested that numerosity perception might involve different processes according to the sensory channel that is solicited. We further investigated this potential effect by conducting an experiment that enabled to more appropriately test the impact of crowds' sensory presentation on the perception of humanoids numerosity. In this experiment, we used a head-mounted display and headphones to present small videos of groups of humanoids of different numerosities (from 8 to 96) through the auditory channel, the visual channel or both channels. This setup enabled the repetition and the randomization of the presentation of the different stimuli. Participants were instructed to judge the size of the groups of humanoids and to rate their discomfort related to the stimuli by means of visual analogue scales. The results confirmed that sensory presentation has an influence on numerosity judgment processes (Taffou, Hobeika, Viaud-Delmon, in preparation).

In a second study, two groups of participants (sensitive or non-sensitive to the fear of crowds) were exposed to an auditory-visual virtual environment containing crowds of 96 humanoids in different places of the scene. They explored this virtual environment and reported the intensity of their discomfort when they were at a far and at a close distance from a virtual crowd. The sensory presentation of the crowds could be only visual, only auditory or auditory-visual. The results showed that auditory-visual presentation of crowds amplified the negative emotional experience induced in participants sensitive to the fear of crowds (Taffou, Ondrej, O'Sullivan, Warusfel, Dubal, Viaud-Delmon, 2015). Nevertheless, this effect was observed only when participants were at close distance from the crowds. When at a farther distance, sensory presentation had no influence on participants' emotional experience. These findings suggest that the spatial location of the feared stimulus interacts with the sensory presentation to modulate the emotional experience induced in the perceiver (Taffou, Ondrej, O'Sullivan, Warusfel, Dubal, Viaud-Delmon, 2016).

The findings of these studies depict auditory-visual virtual reality as a promising tool for the treatment of fear of crowds and suggest that manipulating spatial location and sensory presentation of feared situations is a good

way to modulate patients' affective reaction during virtual reality based exposure therapy for emotional disorders.

Publications within the postdoc program Labex SMART:

Taffou, M., Ondrej, J., O'Sullivan, C., Warusfel, O., Dubal, S., & Viaud-Delmon, I. (2016). Multisensory aversive stimuli differentially modulate negative feelings in near and far space. *Psychological Research*, 1–13. https://doi.org/10.1007/s00426-016-0774-1

Taffou, M., Ondrej, J., O'Sullivan, C., Warusfel, O., & Viaud-Delmon, I. (2016). Judging crowds' size by ear and by eye in virtual reality. *Journal on Multimodal User Interfaces*, 1–9. https://doi.org/10.1007/s12193-016-0228-5

Taffou, M., Ondrej, J., O'Sullivan, C., Warusfel, O., Dubal, S., & Viaud-Delmon, I. (2015). Auditory-visual virtual environment for the treatment of fear of crowds. In *Proceedings of the Virtual Reality International Conference: Laval Virtual*. Laval.

In preparation :

Taffou, M., Hobeika, L., Viaud-Delmon, I. (in preparation). Multisensory numerosity judgments for auditory and visual crowds.

Scientific communications within the postdoc program Labex SMART:

EBBS-EPBS joint meeting, September 12-15, 2015, Verona, Italy.

Taffou, M., Ondrej, J., O'Sullivan, C., Warusfel, O., Dubal, S., & Viaud-Delmon, I.

Multisensory fearful stimuli amplify negative feelings in the space near the body.

16th International Multisensory Research Forum, June 13-16, 2015, Pisa, Italy.

Taffou, M., Ondrej, J., O'Sullivan, C., Warusfel, O., Dubal, S., & Viaud-Delmon, I.

Auditory-visual fearful stimuli amplify negative feelings as a function of their distance to the perceiver.

Journée Intelligence Artificielle Embarquée, April 14th, 2015, Pontoise, France.

Taffou, M.

Intégration multisensorielle et Emotion.

Virtual Reality International Conference, April 8-10, 2015, Laval, France.

Taffou, M., Ondrej, J., O'Sullivan, C., Warusfel, O., Dubal, S., & Viaud-Delmon, I.

Auditory-visual virtual environment for the treatment of fear of crowds.

Training Program

Master Program

In 2015, we set-up an educational committee composed of Labex direction, representatives of UPMC masters (Computer Science: Engineering), Polytech and Cogmaster. The role of this committee is (i) to communicate SMART calls to students and teachers, (ii) to identify lectures, projects and training sessions related to SMART topics. SMART plans to take part of the committees that will elaborate future master accreditation.

SMART also proposed funding for Master Training periods (up to 6 months) in 2015 and 2016. During this period, we recruited 32 master interns (Master students are from various institutions: UPMC (Computer Science, Engineering), Polytech, EPHE, EPITA, ENSTA, Cogmaster, MVA, Tsinghua University (China), Politecnico di Torino…

French-American Doctoral Exchange Seminar (FADEx) 2016: Cyber-Physical Systems

The FADEx (French-American Doctoral Exchange) Seminar was created in 2014 by the Office for Science and Technology of the Embassy of France in the United States. This program aims to enhance scientific exchanges between American and French Ph.D. students working in the same field of research in order to encourage the development of French-American collaborations in the future. This program also serves as an opportunity for American students to better understand the French research system.

SMART Labex co-organized the 2016 edition from July 4th to 8th, with Embassy of France in the United States, CNRS, SIF, INRIA, IRISA, LIP6 and two other Labex namely CominLabs (Rennes) and PERSYVAL-Lab (Grenoble).

The main topic of this seminar was Cyber-Physical Systems.

The program included visits in Grenoble, Paris and Rennes. Twenty students have been selected from the on-going call (10 from each country). SMART organized lab visits, demonstrations and invited two keynote speakers: Robert Plana (Director Innovation and Ecosystem at GE Digital) and James Crowley (LIG).

The program was as follows:

SERVICE POUR LA SCIENCE & LA TECHNOLOGIE
AMBASSADE DE FRANCE AUX ETATS-UNIS

French-American Doctoral Exchange Program

FADEx 2016 – Agenda, July 4-8, 2016
Cyber-Physical Systems

--- Monday, July 4, 2016 ---
Grenoble

Auditorium, Espace colloques au rez-de-chaussée
du **bâtiment IMAG**
(http://www.openstreetmap.org/relation/6158280)
700 avenue Centrale - Domaine Universitaire - 38401
Saint Martin d'Hères
Tram B & C - Arrêt Gabriel Fauré

9:00 am: Introduction

9:30 am – 11:15 am: Keynote Speeches
Joseph Sifakis "A Research Agenda for CPS"

Rahul Mangaram, University of Pennsylavnia
"Three Challenge Problems with CPS"

11:30 am – 12:30 pm: Panel discussion
Scientific challenges on CPS
Joseph Sifakis, Rahul Mangharam, Carlos Canudas de Wit, Claude Castelluccia

2:00 pm – 5:00 pm: Students Presentation
Chairs: Nicolas Halbwachs, Nicolas Marchand

Chuchu Fan, University of Illinois at Urbana-Champaign, "Verification of the cyber-physical systems: invariance and conformance"

Ayman Aljarbouh, Université de Rennes, "Accelerated Simulation of Hybrid Systems (Language and Compilation)"

Achin Jain, University of Pennsylvania, "Data Predictive Control for Cyber-physical Systems"

Berk Celik, Université de Technologie de Belfort-Montbéliard, "Adaptive and anticipative energy management applications to the coupling of the smart buildings with electric vehicles by using multi-agent systems"

Imane Lamrani, Arizona State University, "Robust Controller Software Synthesis for Non-linear Safety Critical Cyber-Physical Systems"

Maëlle Kabir-Querrec, Université Grenoble Alpes, "Cybersecurity of smart-grid control systems: intrusion detection in IEC 61850 networks"

Arsalan Mohsen Nia, Princeton University, "Security and Privacy Challenges in Cyber Physical Systems"

Blazo Nastov, Université de Montpellier, "Towards V&V suitable Domain Specific Modeling Languages for MBSE: A tooled approach"

Nidhi Rastogi, Rensselaer Polytechnic Institute, "Using Information Centrality for Anomaly Detection and Attack information in Large Networks"

Aurélien Palisse, Université de Rennes, "Malware Analysis and Detection"

--- Tuesday, July 5, 2016 ---
Grenoble

Centre de recherche Inria Grenoble - Rhône-Alpes
655 avenue de l'Europe - 38 330 Montbonnot-Saint-Martin
Bus 6070 - Arrêt Inria
Accueil Salle A103

9:00 am – 10:30 am: Platform Visits
GTL/Grenoble Traffic Labs, Amiqual4Home

10:45 am – 12:45 pm: Workshop between US and French PhD students
Chairs: Alain Girault, Alain Kibangou

--- Wednesday, July 6, 2016 ---
Paris

UPMC - LIP6
4 Place Jussieu
Bâtiment 25-26
75005 Paris

Laboratoire LIP6: Bâtiment 25-26/Salle 105

9:00 am – 9:30 am: Introduction

9:30 am – 10:15 am: Keynote Speech
Robert Plana "Cyberphysical Systems: enablers for Industry 4.0"

10:30 am – 12:00 pm: FADEx Laureates' Pitch
Chuchu Fan, University of Illinois at Urbana-Champaign, **Ayman Aljarbouh**, Université de Rennes, **Achin Jain**, University of Pennsylvania, **Berk Celik**, Université de Technologie de Belfort-Montbéliard, **Imane Lamrani**, Arizona State University, **Maëlle Kabir-Querrec**, Université Grenoble Alpes, **Arsalan Mohsen Nia**, Princeton University, **Blazo Nastov**,

Université de Montpellier, **Nidhi Rastogi**, Rensselaer Polytechnic Institute, **Aurélien Palisse**, Université de Rennes, **Jared Frank**, New York University, **Yuko Sasa**, Université Grenoble Alpes, **Kapil Sharma**, University of Texas, **Christophe Viel**, Université Paris Saclay, **Jill Jermyn**, Columbia University, **Maxime Puys**, Université Grenoble Alpes, **Juhi Ranjan**, University of Virginia, **Baptiste Goupille-Lescar**, Université de Rennes, **Aditya Zutshi**, University of Colorado, Boulder, **Anas Motii**, Université de Toulouse - Paul Sabatier

12:00 pm – 2:00 pm: Visit of Labs and ISIR Platforms

2:00 pm – 2:45 pm: Keynote Speech
James Crowley "Qualities for Smart Objects"

2:45 pm – 3:30pm: Labex Presentations
Persyval-Lab (Marie-Christine Rousset), **SMART** (Mohamed Chetouani), **CominLabs** (Patrick Bouthemy)

4:00 pm – 5:00 pm: Discussions on international mobility opportunities
CNRS (Anne Doucet, INS2I, International Affairs) **Inria** (Tania Castro), **ANR** (Nazim Agoulmine, Nakita Vodjani), **Labex Smart** (Raja Chatila), **Persval-Lab** (Marie-Christine Rousset), **CominLabs** (Patrick Bouthemy)

--- Thursday, July 7, 2016 ---
Rennes

Institut de recherche en informatique et systèmes aléatoires (IRISA)
Campus de Beaulieu - 263 avenue du Général Leclerc
35042 Rennes – Salle Métivier

1:30 pm – 2:00 pm: Introduction

2:00 pm – 5:30 pm: Students Presentation
Jared Frank, New York University, "Immersive Mobile Interfaces for Enhanced Human-Robot Interaction"

Yuko Sasa, Université Grenoble Alpes, "Intelligence in a Socio-Affective perspective for a Robot: Language Primitives for a Scalable Interaction with a Smart Home's Robot"

Kapil Sharma, University of Texas, Austin, "Micro models of traffic flow with human in loop, and game theoretic analysis for predicting collisions"

Christophe Viel, Université Paris Saclay, "Determination of command control and observator for multi-agent system with reduced information"

Jill Jermyn, Columbia University, "Scaling Network Attack Detection Using Network Function Virtualization"

Maxime Puys, Université Grenoble Alpes, "Certified filters generation process for control systems"

Juhi Ranjan, University of Virginia, "Sensing Human Context using Cyber Physical Systems"

Baptiste Goupille-Lescar, Université de Rennes, "Introducing Dynamicity in High Performance Real-Time Computing Platforms for Sensors"

Aditya Zutshi, University of Colorado, Boulder, "Falsification of Safety Properties of Hybrid Systems"

Anas Motii, Université de Toulouse - Paul Sabatier, "Incremental pattern-based modeling and safety/security analysis for correct by construction systems design"

5 :30 pm – 6 :00 pm : Presentation on Drones
François Bodin

--- Friday, July 8, 2016 ---
Rennes

IRISA
Campus de Beaulieu - 263 avenue du Général Leclerc
35042 Rennes - Salle Métivier

9:00 am – 9:45 am: Keynote Speech
Benoit Caillaud "Its About Time...Time Domains in Hybrid Systems Modeling"

9:45 am – 11:00 am: Presentation of local research groups

11:30 am – 12:00 pm: Poster Session

1:00 pm – 3:30 pm: Workshop between US and French PhD students

3:45 pm – 4:45 pm: Visit of the Immersia platform

Partners

SMART PhD program

SMART set-up a cross-disciplinary PhD programme on human/machine/human interactions open to three doctoral schools EDITE: telecommunications and computer science, SMAER: signal processing, robotics and electronics and 3C: Brain, Cognition and Behavior. The SMART Doctoral Program funded 3 PhD grants in 2015 and 4 in 2016 (see description of SMART PhD theses).

Summer Schools

SMART proposed and organized a new summer school series: "The SMART School on Computational Social and Behavioral Sciences"[7]. The first edition held in Paris (August 31th –September 4th 2015) with about 100 participants. One of the objectives of this school is to gather researchers and students from the Idex Sorbonne University. The school was jointly organized with Paris 4, UTC, INSEAD and IUIS. The school has received funding from Sorbonne University and is labelled as an International School of Sorbonne University. The 2016 edition has been organized in Paris (September 5th –September 9th 2016) with a strong focus on health. This edition also received funding from CNRS and labelled as CNRS Thematic School.

The SMART School on Computational Social and Behavioral Sciences contributes to bridge the gap between the areas of social neuroscience, linguistics, psychology and sociology on the one hand, and mathematics, machine learning, artificial intelligence, social networks, autonomous agents and social signal processing on the other hand. This cross-disciplinary framework will be efficient only if regulatory and ethical issues are taken into account at the early steps of the research.

This school allows training PhD students in computational sciences, human behavior analysis, modeling and/or synthesis.

The programme is composed of (i) invited lectures, (ii) hands-on sessions, (iii) poster or pitch session, (iv) industry session with SoftBank Robotics, (v) social events.

[7] http://www.smart-labex.fr/SMART_School_on_Computational_Social_and_Behavioral_Sciences.html

Special sessions on robotics hosted by Softbank Robotics have been organized in 2015 and 2016.

List of speakers of 2015 edition:

- Aziz Benlarbi (L2E)
- Frédéric Bevilacqua (IRCAM)
- Antonio Camurri (UNIGE)
- Marie-José Caraty (Univ. Descartes)
- Raja Chatila (ISIR)
- Mohamed Chetouani (ISIR)
- Matthieu Cord (LIP6)
- Marco Cristani (Univ. Verona)
- Patrick Garda (LIP6)
- Daniel Gatica-Perez (IDIAP)
- Dan Istrate (UTC)
- François Jouen (EPHE)
- Mathieu Latapy (LIP6)
- Catherine Pelachaud (LTCI)
- Charles Tijus (Chart-Lutin)
- Julien Sarrazin (L2E)
- Joe Saunders (University of Hertfordshire)
- Liane Schmidt (INSEAD)
- Bjorn Schuller (Imperial College)
- Alessandro Vinciarelli (Glasgow)

List of speakers of 2016 edition:

- Benoît Bardy (EuroMov, University of Montpellier)
- Nadia Berthouze (UCL)
- David Cohen (ISIR, AP-HP)
- Thierry Chaminade (Institut de Neurosciences de la Timone, CNRS)
- Yiannis Demiris (Imperial College)
- Nathalie George (ICM)
- Vincent Guigue (LIP6)
- Vincent Hayward (ISIR)
- Dirk Heylen (University of Twente)
- Nathanaël Jarrassé (ISIR)
- Charles Lenay (CosTech, UTC)
- Gianluca Manzo (GEMASS)
- Amit Pandey (Aldebaran Robotics)
- Agnès Roby-Brami (ISIR)
- Liane Schmidt (INSEAD-Sorbonne Behavioural Lab)
- Serge Uzan (UPMC, Faculty of Medicine, AP-HP)

Examples of hands-on sessions:

- Modeling multimodal behaviors for virtual agents (LTCI) ; Catherine Pelachaud
- Testing cognition and motivation in humans (INSEAD) ; Liane Schmidt
- Getting started with ROS : Salvatore Anzalone
- Cognitive Computing: the design of Smart things (LUTIN) ; Contact: Charles Tijus
- Interpersonal synchrony: The SyncPy Library (ISIR) ; Contact: Giovanna Varni
- Automatic facial expression analysis (ISIR) ; Contact: Kévin Bailly
- Behavioural Lab (INSEAD) ; Contact: Huong Ngo
- Light Touch for balance (ISIR) ; Contact: Waël Bachta
- Artificial agents in autism (Hospital Pitié-Salpêtrière) ; Contact: Salvatore Anzalone

Projects with industry

Industry partnership

Valorisation and exploitation dimension became possible after the first phase of community creation and the production of scientific results. To this end, SMART stimulated collaborations with industrial partners by (i) organizing meetings and (ii) co-funding projects.

Industry partnership meeting:

SMART organized a first one-day meeting with industry partners on October 9, 2015, which attracted a total of 60 participants, 20 of which were external to the labex institutions and members. The event[8] included presentations and demonstrations of the labex projects and achievements, a panel as well as direct discussions. Direct contacts with interested companies were established.

Call for industry partnership projects:

In 2016, SMART proposed a specific call for industry partnership projects. The call was elaborated with relevant local partners such as DGRTT and SATT-LUTECH, which are structures in charge of valorisation and exploitation of UPMC and Sorbonne University projects. Two projects have been funded in this context:

- Intuitive Interface for Precision Manipulation between ISIR/UPMC and Percipio Robotics SA. This project aims to develop a support system as well as an associated user interface for the precision manipulation of small components, usually performed manually by tweezers.
- Social Co-Learning for Personal Robots between ISIR/UPMC and Softbank Robotics. This project aims at developing robots able to learn new tasks through human guidance and demonstration. In particular, the industrial challenge is to elevate the robot's learning capabilities from day to day interaction with people

[8] http://www.smart-labex.fr/1442332311.html

Collaborations & Dissemination

Labex Joint Workshop in Besançon

On 22th November 2916, 8 Laboratories of Excellence LabEx (ACTION, CominLabs, IMobS3, MS2T, NUMEV, Σ_LIM, UCN@Sophia and Labex SMART) met for the first time in order to share good practices and spark interLabex Syergies.

On 23th November 2016, the first inter-PIA national meeting on the theme of "Exellence in Smart systems: scientific excellence at the service of the society" took place in Besançon. 8 Laboratories of excellence (LabEx ACTION, CominLabs, IMobS3, MS2T, NUMEV, Σ_LIM, UCN @ Sophia, Labex SMART), the most advanced public research laboratories in the field of Smart Systems, gathered and organized a national meeting open to all - R & D, industrial and academic actors - to share their expertise and make known theirs projects. Organized in Besançon with the participation of the ANR (represented by its CEO, Michael Matlosz), this unprecedented symposium was organized around invited sessions (PSA Peugeot Citroën, ST Microelectronics, Legrand, Thales ...), showroom and visits to technological sites.

This symposium was an opportunity for exchanges and new partnerships to be grasped by all academic and industrial acteurs from all sectors (mobility, health, security, defense, energy, telecom, etc.), who wanted to develop the "Smart" innovations of tomorrow.

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Cooperation with other Labex within Sorbonne University

SMART, BIO-PSY and MS2T are three labex within Sorbonne Universités sharing common intersests. BIO-PSY deals with neuroscience and psychiatry; MS2T with systems of systems. These two areas have connections with SMART work on human-machine interactions. In particular, we decided to jointly focus on the notion of « behavior », of humans, of machines and during their interaction. The cooperation has been implemented two folds:

- a participation of each labex in project calls of the two others to foster cooperation among teams
- the joint proposal to the « Instituts Convergence » call of the Investments of the Future program (PIA) to create the *Interdisciplinary Behavioral Science Institute (see the section on IBSI).*

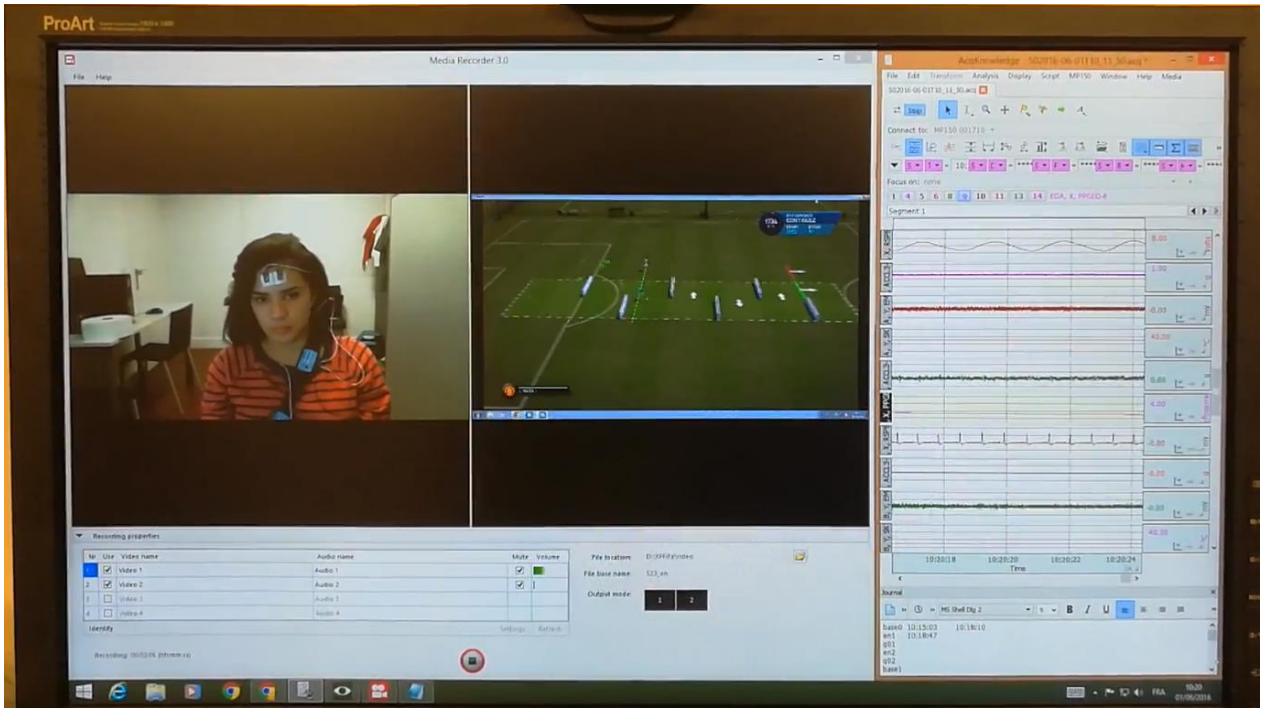
INSEAD – Sorbonne University Behavioural Lab

The INSEAD-Sorbonne University Behavioural Lab brings behavioural scientists together to work on multidisciplinary projects (including ethical issues). It provides custom-designed facilities for controlled laboratory experiments, allowing faculty and doctoral students from all academic disciplines to pursue world-class people-based research.

The Behavioural Lab is an important partner of SMART, in particular, for (i) collecting data: ethics, recruitment of participants, experiences; and (ii) training students and researchers: participation to the SMART Summer School, SMART PhD students regularly attend to technical workshops proposed by the Behavioural Lab (e.g. eye-tracking, physiological data collection…).

Example: Affective computing (LIP6, SeNSE project):

The objective of this experimentation has been to collect data for analysis of relationship between physiological signals and self-evaluation of participants playing a video game. A panel of 58 participants of different genders, ages, and skill levels, took part in this study. This experimentation has been performed at the INSEAD-Sorbonne University Behavioral Lab. The equipment consisted in a BIOPAC MP-150, a PC and the videogame FIFA'2016:



University Institute of Engineering for Health (IUIS)

SMART is taking part to the Institute of Engineering for Healthcare (IUIS, Institut d'Ingénierie pour la Santé) of Sorbonne Universités. In 2015, SMART co-organized with IUIS a joint call for projects. The EPaCE project has been selected and it is lead by V. Pasqui (ISIR/UPMC), S. Boudaoud (BMBI/UTC) and P. Thoumie (Hôpital Rotschild). EPaCE investigated biomechanical models of human posture based on the dynamics of a disturbance in the context of cerebral palsy.

Several physician and medical staff actively participated to SMART projects (five). The focus of the 2016 edition of the SMART School was on health. Several speakers and students were medical doctors and health-care workers participated. Two hands-on sessions were also focusing on applications to health: light touch at ISIR and artificial agents in Autism at the Pitié-Salpêtriere Hospital.

SMART Events

Events 2015-2016

- 13th December 2016: Seminar "Automated Extraction and Sonification of Motion Qualities"
- 7th December 2016: Seminar "Embodied Affect in Autonomous and Social Robots"
- 23th November 2016: National Symposium Inter-Labex "Excellence in Smart Systems"
- 7th July 2016: Seminar "The Active Hands Platform: An automated guidance system for supporting individuals with cognitive impairments during ADL performance"
- 6th July 2016: Seminar "Beware of computers bearing smiles: A review of research into machines that understand and shape human emotion"
- 6th July 2016: French American Doctoral Exchange, Paris
- 31st May 2016: Seminar "The Nature of Unintentional Movements"
- 31st May 2016: 2nd UPMC Symposium of Computational Neurosciences: "Multi-scale mechanisms in neurosciences: interactions between experimentation and modelling"
- 22th April 2016: SMART issues a new call for industry partnership projects/ Appel à projets SMART-entreprises
  16th & 17th April 2016 : Robotic event, Cité des sciences

- 12th Avril 2016, Colloquim Sorbonne Universités with Aude Billiard:

- 12th January 2016: PhD defense Mohamed Hamza Kaaouachi
- 17th December 2015: PhD defense Aurelie Garnier
- 16th December 2015: Seminar Stacy Marsella
- 09th October 2015: Industry partnership meeting
- 21th September 2015 : The First International Workshop on ENgagement in HumaN Computer IntEraction (ENHANCE Workshop)
- 18th March 2015 : Seminar "Psychological Well-being of "ANSHIN" in Human-Robot Interaction"
- 18th March 2015 : Seminar "Micro Robotics and Its Application in Bio Science"
- 4th March 2015: Seminar "EyesWeb XMI: the multimodal and multimedia research platform"
- 2th-3th March 2015: Workshop on Movement, Sound and Learning

SMART Publications

Books

2016

[2] **Human Behavior Understanding, 7th International Workshop, HBU 2016, Amsterdam, The Netherlands, October 16, 2016, Proceedings** (M. Chetouani, J. Cohn, A. Salah), volume 9997, 2016. [bibtex]

2015

[1] **Proceedings of the 1st Workshop on Modeling INTERPERsonal SynchrONy And infLuence, INTERPERSONAL@ICMI 2015** (M. Chetouani, G. Varni, H. Salam, Z. Hammal, J. Cohn), *(ISBN 978-1-4503-3986-5 ACM 2015, ed.)*, 2015. [bibtex]

Book Chapters

2016

[3] **Evaluating Social Attitudes of a Virtual Tutor** (Florian Pecune, Angelo Cafaro, Magalie Ochs, Catherine Pelachaud), *Chapter in (David Traum, William Swartout, Peter Khooshabeh, Stefan Kopp, Stefan Scherer, Anton Leuski, eds.)*, Springer International Publishing, 2016. [bibtex]

[2] **Multimodal Detection of Engagement in Groups of Children Using Rank Learning** (Jaebok Kim, Khiet P. Truong, Vicky Charisi, Cristina Zaga, Vanessa Evers, Mohamed Chetouani), *Chapter in (Mohamed Chetouani, Jeffrey Cohn, Albert Ali Salah, eds.)*, Springer International Publishing, 2016. [bibtex] [pdf] [doi]

[1] **Fostering user engagement in face-to-face human-agent interactions** (Angelo Cafaro Sabrina Campano Chloé Clavel, Catherine Pelachaud), *Chapter in Toward Robotic Socially Believable Behaving Systems (A. Esposito, L. Jain, eds.)*, volume Volume I: Modeling Social Signals, 2016. [bibtex]

Refereed Articles

2016

[36] **Performance Assessment of IR-UWB Body Area Network (BAN) based on IEEE 802.15.6 Standard** (H. Liu, J. Sarrazin, T. Mavridis, L. Petrillo, Z. Liu, P. De Doncker, A. Benlarbi-delai), *In Antennas and Wireless Propagation Letters, IEEE*, volume PP, 2016. [bibtex] [doi]

[35] **Fully Automatic Analysis of Engagement and Its Relationship to Personality in Human-Robot Interactions** (H. Salam, O. Celiktutan, I. Hupont, H. Gunes, M. Chetouani), *In IEEE Access*, volume PP, 2016.[bibtex] [doi]

[34] **Dynamics of Non-verbal Vocalizations and Hormones during Father-Infant Interaction** (O. Weisman, M. Chetouani, C. Saint-Georges, N. Bourvis, E. Delaherche, O. Zagoory-Sharon, D. Cohen, R. Feldman), *In IEEE Transactions on Affective Computing*, volume 7, 2016. [bibtex] [pdf] [doi]

[33] **Millington Effect and Propagation Enhancement in 60-GHz Body Area Networks** (T. Mavridis, C. Leduc, L. Petrillo, J. Sarrazin, M. Zhadobov, R. Sauleau, A. Benlarbi-Delai, P. De Doncker), *In Antennas and Propagation, IEEE Transactions on*, volume PP, 2016. [bibtex] [doi]

[32] **Grounding the detection of the user's likes and dislikes on the topic structure of human-agent interactions** (Caroline Langlet, Chloé Clavel), *In Knowledge-Based Systems*, Elsevier, volume 106, 2016. [bibtex]

[31] **Implementing and evaluating a laughing virtual character** (Maurizio Mancini, Beatrice Biancardi, Florian Pecune, Giovanna Varni, Yu Ding, Catherine Pelachaud, Gualtiero Volpe, Antonio Camurri), *In Transactions on Internet Technology (TOIT), Special Section on Affect and Interaction in Agent-based Systems and Social Media*, 2016. [bibtex]

[30] **Interpretation of approximate numerical expressions: Computational model and empirical study**(Sébastien Lefort, Marie-Jeanne Lesot, Elisabetta Zibetti, Charles Tijus, Marcin Detyniecki), *In International Journal of Approximate Reasoning*, volume , 2016. () [bibtex] [pdf] [doi]

[29] **Perception of emotions and body movement in the Emilya database** (Nesrine Fourati, Catherine Pelachaud), *In IEEE Transactions on Affective Computing*, volume July, 2016. [bibtex]

[28] **Affective Interaction with a Virtual Character Through an fNIRS Brain-Computer Interface** (Gabor Aranyi, Florian Pecune, Fred Charles, Catherine Pelachaud, Marc Cavazza), *In Front. Comput. Neurosci.*, volume 10, 2016.[bibtex]

[27] **The Effects of Interpersonal Attitude of a Group of Agents on User&Rsquo;s Presence and Proxemics Behavior** (Angelo Cafaro, Brian Ravenet, Magalie Ochs, Hannes H\?ogni Vilhjálmsson, Catherine Pelachaud), *In ACM Trans. Interact. Intell. Syst.*, volume 6, 2016. [bibtex]

[26] **The complexity of data aggregation in static and dynamic wireless sensor networks** (Quentin Bramas, Sébastien Tixeuil), *In Information and Computation*, volume, 2016. () [bibtex] [pdf] [doi]

[25] **The Next 700 Impossibility Results in Time-Varying Graphs** (Nicolas Braud-Santoni, Swan Dubois, Mohamed-Hamza Kaaouachi, Franck Petit), *In International Journal of Networking and Computing (IJNC)*, volume 6, 2016.[bibtex]

[24] **Wideband Off-Body Measurements and Channel Modeling at 60 GHz** (T. Mavridis J. Sarrazin A. Benlarbi-Delaï L. Petrillo, P. De Doncker), *In IEEE Transactions on Antennas and Propagation*, 2016. [bibtex]

[23] **Judging crowds' size by ear and by eye in virtual reality** (Marine Taffou, Jan Ondrej, Carol O'Sullivan, Olivier Warusfel, Isabelle Viaud-Delmon), *In Journal on Multimodal User Interfaces*, volume -, 2016. [bibtex] [pdf] [doi]

[22] **Multisensory aversive stimuli differentially modulate negative feelings in near and far space** (Marine Taffou, Jan Ondrej, Carol O'Sullivan, Olivier Warusfel, Stéphanie Dubal, Isabelle Viaud-Delmon), *In Psychological Research*, volume May, 2016. [bibtex] [doi]

[21] **Trust as indicator of robot functional and social acceptance. An experimental study on user conformation to iCub answers** (I. Gaudiello, E.i Zibett, S. Lefort, M. Chetouani, S. Ivaldi), *In Computers in Human Behavior*, volume 61, 2016. [bibtex]

[20] **Interaction and behaviour imaging: a novel method to measure mother-infant interaction using video 3D reconstruction** (C. Leclerc, M. Avril, S. Viaux-Salevon, N. Bodeau, C. Achard, S. Missonnier, M. Keren, R. Feldman, M. Chetouani, D. Cohen), *In Translational Psychiatry (Nature Publishing Group, ed.)*, volume 6, 2016.[bibtex] [doi]

[19] **Robots Learn to Recognize Individuals from Imitative Encounters with People and Avatars** (S. Boucenna, D. Cohen, A. Meltzoff, P. Gaussier, M. Chetouani), *In Scientific Reports (Nature Publishing Group, ed.)*, volume 6, 2016. [bibtex] [pdf]

[18] **A CMOS Buried Quad p-n Junction Photodetector Model** (T. Courcier O. Tsiakaka A. Karami A. Alexandre-Gauthier O. Romain V. Aimez P.G. Charette P. Pittet G.N. Lu S. Feruglio), *In IEEE Sensors Journal*, volume 16, 2016.[bibtex]

2015

[17] **Statistical On-Body Measurement Results at 60 GHz** (Luca Petrillo, Theodoros Mavridis, Julien Sarrazin, Aziz Benlarbi-Delai, Philippe De Doncker), *In IEEE Transactions on Antennas and Propagation*, Institute of Electrical and Electronics Engineers (IEEE), volume Volume : 63, 2015. [bibtex] [pdf] [doi]

[16] **Modeling choice and reaction time during arbitrary visuomotor learning through the coordination of adaptive working memory and reinforcement learning** (Guillaume Viejo, Mehdi Khamassi, Andrea Brovelli, Benoît Girard), *In Frontiers in behavioral neuroscience*, Frontiers Media SA, volume 9, 2015. [bibtex]

[15] **A 2D Infrared Instrumentation for Close-Range Finger Position Sensing** (F. Gonzalez, Fl. Gosselin, W. Bachta), *In IEEE Transactions on Instrumentation and Measurement*, volume 64, 2015. [bibtex]

[14] **A neural mass model with direct and indirect excitatory feedback loops: identification of bifurcations and temporal dynamics.** (A. Garnier, A. Vidal, C. Huneau, H. Benali), *In Neural Computation*, volume 27, 2015.[bibtex]

[13] **Compensating for age limits through emotional crossmodal integration** (Laurence Chaby, Viviane Luherne-du Boullay, Mohamed Chetouani, Monique Plaza), *In Frontiers in Psychology*, volume 6, 2015. [bibtex] [pdf] [doi]

[12] **Near-Body Shadowing Analysis at 60 GHz** (T.; Petrillo L.; Sarrazin J.; Benlarbi-Delai A.; De Doncker P. Mavridis), *In IEEE Transactions on Antennas and Propagation*, volume 63, 2015. [bibtex] [pdf] [doi]

[11] **Robotic prosthetics: beyond the technical performance. A study of socio-anthropological and cultural phenomena influencing the appropriation of technical objects interacting with the body.** (N. Jarrassé, M. Maestrutti, G. Morel, A. Roby-Brami), *In IEEE Science and Society*, volume 34, 2015. [bibtex] [pdf]

[10] **Contextual modulation of value signals in reward and punishment learning** (S. Palminteri, M. Khamassi, M. Joffily, G. Coricelli), *In Nature Communications*, volume 6, 2015. [bibtex] [doi]

[9] **Evaluating the Engagement with Social Robots** (S. M. Anzalone, S. Boucenna, S. Ivaldi, M. Chetouani), *In International Journal of Social Robotics*, volume 7, 2015. [bibtex]

[8] **Open Challenges in Modeling, Analysis and Synthesis of Human Behaviour in Human-Human and Human-Machine Interactions** (A. Vinciarelli, A. Esposito, E. André, F. Bonin, M. Chetouani, J.F. Cohn, M. Cristani, F. Fuhrmann, E. Gilmartin, Z. Hamml, D. Heylen, R. Kaiser, M. Koutsombogera, A. Potamianos, S. Riccardi G. Salah A. A. Renals), *In Cognitive Computation (Springer)*, volume 7, 2015. [bibtex]

[7] **Automatic measure of imitation during social interaction: a behavioral and hyperscanning-EEG benchmark** (E. Delaherche, G. Dumas, J. Nadel, M. Chetouani), *In Pattern Recognition Letters*, volume 66, 2015.[bibtex] [pdf]

Refereed Conference Papers

2016

[78] **Modeling the dynamics of individual behaviors for group detection in crowds using low-level features** (O. A. I. Ramírez, G. Varni, M. Andries, M. Chetouani, R. Chatila), *In 2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 2016. [bibtex] [doi]

[77] **Robots learning how and where to approach people** (O. A. I. Ramírez, H. Khambhaita, R. Chatila, M. Chetouani, R. Alami), *In 2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 2016. [bibtex] [doi]

[76] **Using Temporal Association Rules for the Synthesis of Embodied Conversational Agents with a Specific Stance** (Thomas Janssoone, Chloé Clavel, Kévin Bailly, Gaël Richard), *In International Conference on Intelligent Virtual Agents*, 2016. [bibtex]

[75] **Towards a Wireless Smart Polysomnograph Using Symbolic Fusion** (Adrien Ugon, Brigitte Seroussi, Carole Philippe, Jean-Gabriel Ganascia, Patrick Garda, Karima Sedki, Jacques Bouaud, Andrea Pinna), *In Stud Health Technol Inform*, volume 221, 2016. (\textbfBest paper award) [bibtex]

[74] **Decision System Integrating Preferences to Support Sleep Staging** (Adrien Ugon, Karima Sedki, Amina Kotti, Amina Seroussi, Carole Philippe, Jean-Gabriel Ganascia, Patrick Garda, Jacques Bouaud, Andrea Pinna), *In Studies in Health Technology and Informatics*, IOS Press, volume 228, 2016. [bibtex] [pdf] [doi]

[73] **Reconnaissance des stades de sommeil à l'aide d'☐™un outil de support à la décision basée sur les connaissances et la pratique des experts** (Adrien Ugon, Amina Kotti, Karima Sedki, Carole Philippe, Brigitte Seroussi, Jacques Bouaud, Jean-Gabriel Ganascia, Patrick Garda, Andrea Pinna), *In Actes de la conference IC, Atelier IA & Santé*, 2016. [bibtex]

[72] **Improving the scoring of N2 sleep stage by adding background waves knowledge in the recognition of sleep spindles** (Adrien Ugon, Brigitte Seroussi, Carole Philippe, Amina Kotti, Jean-Gabriel Ganascia, Patrick Garda, Karima Sedki, Jacques Bouaud, Andrea Pinna), 2016. [bibtex]

[71] **Nouvelle technique d'analyse automatique des polysomnographies : approche symbolique avec intégration de préférences** (Amina Kotti, Adrien Ugon, Karima Sedki, Brigitte Seroussi, Patrick Garda, Jacques Bouaud, Andrea Pinna, Isabelle Arnulf, Carole Philippe), 2016. [bibtex]

[70] **BANZKP: A Secure Authentication Scheme Using Zero Knowledge Proof for WBANs** (Nesrine Khernane, Maria Potop-Butucaru, Claude Chaudet), *In 13th IEEE International Conference on Mobile Ad Hoc and Sensor Systems, MASS 2016, Brasília, Brazil, October 10-13, 2016*, 2016. [bibtex] [pdf] [doi]

[69] **Sequence-based multimodal behavior modeling for social agents** (Soumia Dermouche, Catherine Pelachaud), *In Proceedings of the 18th ACM International Conference on Multimodal Interaction, ICMI 2016, Tokyo, Japan, November 12-16, 2016*, 2016. [bibtex]

[68] **The Effects of Interrupting Behavior on Interpersonal Attitude and Engagement in Dyadic Interactions**(Angelo Cafaro, Nadine Glas, Catherine Pelachaud), *In Proceedings of the 2016 International Conference on Autonomous Agents & Multiagent Systems, Singapore, May 9-13, 2016*, 2016. [bibtex]

[67] **Benchmarking Energy-Centric Broadcast Protocols in Wireless Sensor Networks** (Quentin Bramas, Sébastien Tixeuil), *In Networked Systems - 4th International Conference, NETYS 2016, Marrakech, Morocco, May 18-20, 2016, Revised Selected Papers*, 2016. [bibtex] [doi]

[66] **Distributed Online Data Aggregation in Dynamic Graphs** (Quentin Bramas, Toshimitsu Masuzawa, Sébastien Tixeuil), *In 36th IEEE International Conference on Distributed Computing Systems, ICDCS 2016, Nara, Japan, June 27-30, 2016*, 2016. [bibtex] [pdf] [doi]

[65] **Non-☐"Contact Estimation at 60 GHz for Human Vital Signs Monitoring Using a Robust Optimization Algorithm** (J. Sarrazin G. Valerio D. Istrate T. Zhang), 2016. [bibtex]

[64] **Impact of Random Body Movements on 60-GHz Doppler Radar for Real-Time Monitoring of Vital Signs**(G. Valerio J. Sarrazin D. Istrate T. Zhang), 2016. [bibtex]

[63] **Antenna Radiation Efficiency Considerations in Body Area Networks** (F. Sarrazin S. Razafimahatratra G. Valerio M. Casaletti L. Petrillo P. De Doncker J. Sarrazin, A. Benlarbi-Delaï), 2016. [bibtex]

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[61] **Interprétation floue des expressions numériques approximatives** (Marie-Jeanne Lesot Elisabetta Zibetti Charles Tijus Marcin Detyniecki Sébastien Lefort), 2016. [bibtex] [pdf]

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