Sciences and Technologies of Music and Sound (STMS)

UMR 9912

ircam Centre Pompidou

cnrs

SORBONNE UNIVERSITÉ

MINISTÈRE DE LA CULTURE

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Recent Highlights

In 2019 and 2020, the laboratory's excellence has led to several awards

- *Best paper award at the International Computer Music Conference:* **José Miguel Fernández,** Musical Representations team, for his work on "AntesCollider", a library for the control of dynamic processes in real-time sound synthesis in Antescofo.
- *Best paper award Web Audio Conference 2019:* **Benjamin Matuszewski,** researcher in the Sound Music Movement Interaction team, for his article "Soundworks – A Framework for Networked Music Systems on the Web – State of Affairs and New Developments".
- *"Vie & Société" award in the International Sound Design Competition:* **Marion Voillot,** doctoral student in the Sound Music Movement Interaction team (in collaboration with the CRI-Paris, université Paris-Descartes).
- *2020 Jeune Chercheur en informatique musicale award from the AFIM:* **Paul Lascabettes,** for the work carried out during his Master's degree.

Organization and Cooperation in Several Public Events

- ***Lullaby Experience*** by Pascal Dusapin in collaboration with the Musical Representations team. World premiere: Frankfurter Positionen, Frankfort, Germany. February 2-3, 2019. French premiere: Le CENTQUATRE-Paris, June, 21-2019.
- ***Biotope*** by Jean-Luc Hervé. 2019-2020: Centre Pompidou, Zadkine Museum, La Villette, Nuit blanche, "fearful acoustic system" in collaboration with the Sound Music Movement Interaction team.
- **The European project Vertigo** (H2020 ICT36-2016) coordinated by the Research/Creation Interfaces department aims, within the framework of the STARTS initiative (Science, Technology and the ARTS) initiated by the DG Connect of the European Commission, to coordinate at the European level the collaboration of artists in R&D projects, notably through an important residency program, the development of a collaborative web platform and the annual public presentation of works: The Living Factory (Vertigo Forum 2019); AI and Artistic Creation (Vertigo Forum 2020).
- International festival **ImproTech Paris-Athina** co-organized by IRCAM, performances using DYC12 technologies.
- **Spectralisms** Conference 2019, second edition in Paris during ManiFeste.
- Open houses: **"Studio 5, Live"**
- **Sound Design Days,** November 28-29, 2019
- Conference **Sheng** (mouth organ) with Collegium Musicæ (Sorbonne Université)
- **Several webinars** including one organized during the cultural week France-Atlanta by the French Embassy in Atlanta and our American partners (CNMAT – UC Berkeley, Georgia Tech, and New York University).

Publication

Un siècle d'écrits réflexifs sur la composition musicale. Anthologie d'auto-analyses, de Janáček à nos jours, **Nicolas Donin** editor, Droz, 2019.
This book highlights a selection of unpublished, rare, or inaccessible texts in French, taken from personal diaries, contributions to journals, interviews with journalists and scientists, and academic works.

International Actions

- Signature of a collaboration agreement with the C-LAB (2020-2027) to create the **Taiwan Sound Lab.**
- Creation of the **international network ACTOR** on orchestration with McGill University in which IRCAM is a major partner alongside 19 other institutions.
- Artist-in-residency program with **Georgia Tech, Atlanta.**

Renewal of the scientific council focused in 2019 on two main themes—AI and sound design—with a modified body (9 new members including 4 women and the participation of external experts) and a new theme scheduled for spring 2021.

Musical research and artistic residencies are now an integral part of the joint research unit.

Renewal of the IRCAM Forum online: forum.ircam.fr

Creation of **Ircam Amplify** on July 1, 2020, a subsidiary of IRCAM.

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Projects in the Joint Research Unit UMR STMS 2019 — 2020

4 ERC Projects

ERC REACH: Raising Co-Creativity in Cyber-Human Musicianship, European Research Council Advanced Grant, Principal Investigator **Gérard Assayag,** 2021-2025. The REACH project aims to understand, model, and develop musical co-creativity between humans and machines through improvised interactions, allowing musicians of all educational levels to develop their skills and increase their individual and social creative potential. REACH investigates «shared musicality» at the intersection of the physical, human and digital spheres, as an archetype of distributed intelligence. The goal is to produce models and tools to better understand and encourage human creativity in a context where it is increasingly intertwined with computation.

ERC COSMOS: Computational Shaping and Modeling of Musical, European Research Council Advanced Grant, Principal Investigator **Elaine Chew,** 2019-2024. COSMOS proposes an integrated research program aimed at improving our understanding of both a musician's interpretative act and the listener's perception of this performance.

ERC POC HEART.FM: Maximizing the Therapeutic Potential of Music through Tailored Therapy with Physiological Feedback in Cardiovascular Disease, European Research Council Proof of Concept, Principal Investigator **Elaine Chew,** 2020-2022. The Proof-of-Concept project, HEART.FM, is an app development initiative to deliver tailored music therapy with physiological feedback.

ERC POC ACTIVATE: Augmenting the Value of Conversations with Voice Transformations, Principal Investigator **Jean-Julien Aucouturier,** 2020-2021. This Proof-of-Concept project is to promote technologies for the real-time transformation of voices from the ERC CREAM project (2014-2019) led by Jean-Julien Aucouturier, in applications for controlling emotional characteristics in spoken conversation.

4 ANR Projects

ANR MERCI: Mixed Musical Reality with Creative Instruments (2019-2023). The main objective of this project is to create the scientific and technological conditions for the emergence of mixed reality musical systems, allowing improvised human-machine interactions based on the interrelation of creative digital agents and the active acoustic control of musical instruments.

ANR RASPUTIN: Room Acoustic Simulations for Perceptually Realistic Uses in Real-Time Immersive and Navigation Experiences (2018-2022). This collaborative fundamental research project at the intersection of "digital sciences and technologies" and "psychology", that aims at reducing the cognitive complexity of navigation for the blind in a new interior environment through digital simulations and explorations using virtual reality with 3D audio. These explorations are also mental exercises that make it possible to create cognitive maps of these environments not yet physically explored.

ANR HAIKUS: Artificial Intelligence Applied to Augmented Acoustic Scenes (2019-2023). The objective of the HAIKUS project is the joint exploitation of artificial learning and audio signal processing methods to solve acoustic problems encountered in augmented reality applications.

ANR ARS: Analysis and tRansformation of Singing style (2020-2023). The project has two main objectives. The first is to develop new approaches to investigate singing style in professional musical performances. The second is to develop algorithms for high-quality modifications in expressive singing that maintain the same style.

Key figures

7
research teams
work in various scientific fields related to music: acoustics, signal processing, modeling, control, computer science, design, psychology, musicology.

110
contributors
(researchers, engineers, technicians, coordinators), & 40 internships and guest researchers per year.

30 %
of staff
are of foreign nationality.

200
publications per years
50 of which appear in scientific journals or as chapters in books.

90
annual partnerships
with 60 labs and public organizations and 30 with private companies.

22
software environments
developed and distributed to

20 000
professional users
via IRCAM Forum (software user group).

A Word from the Director

The research activities hosted at IRCAM are part of the Sciences and Technologies of Music and Sound (STMS) joint research unit (UMR 9912) bringing together IRCAM, the CNRS, Sorbonne University, and the French Ministry of Culture.

The new five-year term (2019-2023) aims to address several challenges: the integration of artistic research into university structures and the growing importance of art-science themes (with, for example, the creation of PhDs in the arts); the restructuring of the Parisian research landscape; the legibility and increased attractiveness of the unit; the evolution of the French innovation ecosystem and the renewal brought about by new methods of artificial intelligence.

The research activity at STMS is carried out by seven teams and is divided into three structuring axes: the sound workshop, the musical body, and creative dynamics.

The joint research unit relies on IRCAM's IRM department (Innovation and Research Means, under the direction of Hugues Vinet) for contractual and innovation aspects, with, in particular, the creation by IRCAM of a new development tool: the subsidiary Ircam Amplify. This subsidiary will allow a broader diffusion of the technologies emerging from our laboratory.

Finally, I am pleased to report that since the beginning of this five-year term, STMS has welcomed 4 new ERC projects, as well as 4 new ANR projects, a remarkable result that testifies to the incredible energy and vitality of the laboratory.

Brigitte d'Andréa-Novel

Director of the Joint Research Unit UMR 9912, November 2020

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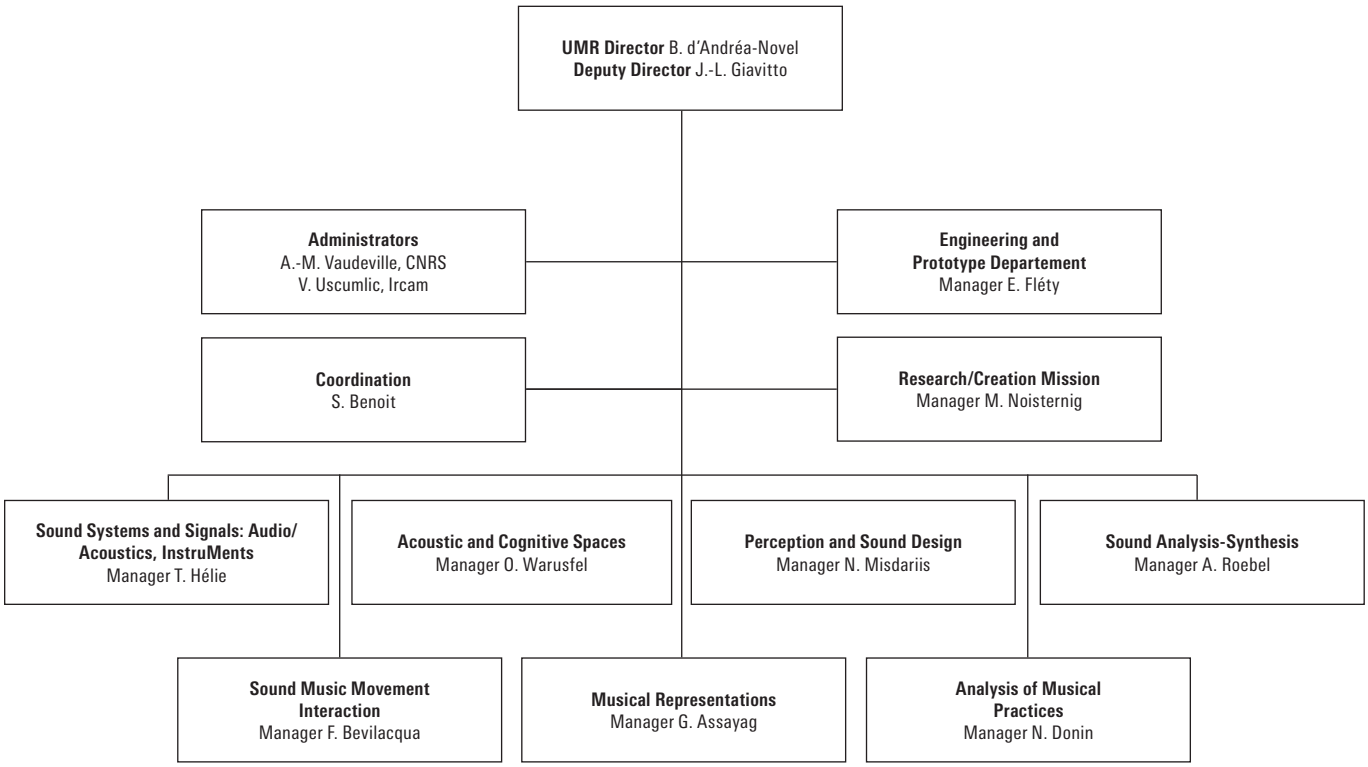
The Laboratory

Organizational chart



Mission Statement

The fundamental principle of IRCAM is to encourage productive interaction among scientific research, technological developments, and contemporary music production. Since its establishment in 1977, this initiative has provided the foundation for the institute's activities. One of the major issues is the importance of contributing to the renewal of musical expression through science and technology. Conversely, specific problems related to contemporary composition have led to innovative, theoretical, methodological, and applied advances in the sciences with ramifications far beyond the world of music. Focused on artistic production, in all its particularity and sensitivity, this highly original research dynamic addresses modes of representation and of extended manipulation of sound and music, thus eliciting scientific and technological applications that touch an increasingly wide-ranging public including sound and music professionals, industrial concerns, academics, music devotees, etc. Central to the interaction between research and musical production is the development of software tools for musicians, composers, performers, and musicologists using the models and prototypes created by the research teams in various music-related domains including information technology (e.g. languages, human-computer interaction, real-time, and databases), signal processing, acoustics, auditory perception and cognitive psychology, and musicology.

The work carried out in the STMS joint research lab (Science and Technology of Music and Sound) is supported by the CNRS, the French Ministry of Culture, and Sorbonne Université.

Research, the source of innovation, seeks to expand our knowledge of music related issues. Because of its essentially cross-disciplinary character, a great deal of research is carried out in collaboration with laboratories in France and abroad, academic institutions, institutional partners, and private partners. The integration of graduate and post-graduate students enables research training. The skills developed at IRCAM can be applied to domains beyond the musical arena and are frequently included in projects carried out with industrial partners or in the context of French, European, or multinational research projects.

The development pole seeks to adapt the knowledge, models, and prototypes produced by the research teams into software environments. The principle applications are used to create tools that assist musical creation by putting in place open and programmable environments, adaptable to a variety of aesthetic approaches and that allow for the continued integration of models and their updates. This configurable design makes it easier to develop simplified versions of the software programs intended for the general public: Ircam Tools (for audio professionals), IrcaMax (for live electronic music), IrcamLab (for a broad range of users). Central to software development is the design and evaluation of specific human-computer interaction interfaces and the permanent integration of the rapidly evolving technology from the computer industry. The IRCAM Forum—an IRCAM software user group—encourages the distribution of the institute's software within an international community of music and sound professionals (e.g. composers, multimedia and visual artists, sound engineers and designers, researchers, teachers, etc.) with an estimated 20,000 users since its beginnings. The IRCAM Forum also provides companies with licenses for either internal use or distribution purposes. These licenses can apply to either complete applications (e.g. the Max program, used by tens of thousands worldwide, is licensed to the company Cycling '74 in California) or to specific functional models (e.g. audio analysis and processing, indexing, spatialization, synthesis) that are included in commercial environments.

Organization and fields of study

The laboratory is structured in **seven teams** defined by their fields of study and theoretical approaches:

1. Sound Systems and Signals: Audio/Acoustics, InstruMents uses applied mathematics (signal, system, control, differential geometry, digital analysis), physics and mechatronics to explore, understand, reproduce, or invent multi-physical systems that produce sound signals (musical instruments, voices, etc.).
2. Acoustic and Cognitive Spaces focuses on acoustics, signal processing, cognitive listening psychology, and neurosciences for the capture, analysis, and reproduction of sound fields as well as the understanding of the notion of spatial perception in multisensory contexts.
3. Sound Perception and Design addresses the perception of vocal, musical, and environmental sounds, their emotional treatment, and sound design applications via psychoacoustics, physiology, musical cognition, and neurosciences.
4. Sound Analysis & Synthesis studies digital sound signals using sound signal processing theories and techniques, statistics, learning, and shape recognition to extract various characteristics, to synthesize sounds according to specified attributes, or the transformation of sounds based on compositional or other needs.
5. Sound Music Movement Interaction focuses its research on embodied interaction between humans and sonic and musical medias: motion capture, reactive real-time programming, learning, tangible and multimodal interfaces, sound synthesis techniques.
6. Musical Representations investigates the formal structures of music and creative environments for composition, analysis, and human-machine interaction using architectural and language approaches, algebraic formalizations, and artificial intelligence techniques such as learning optimization.
7. Analysis of Musical Practices develops interdisciplinary musicology taking into account historical, sociological, anthropological, psychological, and philosophic points of view favoring the use of creative tools, often in connection with other teams at IRCAM.

The laboratory's scientific project relies on the 7 teams, organized around **3 fields of interaction:**

- **Sound Workshop**
- **The Musical Body**
- **Creative Dynamics**

• SOUND WORKSHOP

Here, sound is understood as a physical phenomenon (mechanical, acoustic) as well as digital data involving mathematical and computer science (signal processing) techniques to process data audio streams and musical or multimedia scenes.

Digital audio signals are addressed in as sources and fields. We characterize or synthesize digital audio sources with the accuracy, subtlety, and quality required to meet the demands of contemporary creation. Our research focuses on the specificities of the musical signal and has led us to develop more precise models employing physics, biomechanics, perception and cognition, and even symbolic musical data. The extraction of more a symbolic, semantically pertinent description and the control of models via high-level qualitative data (e.g. prosody in the case of the synthesized singing voice) are two of the laboratory's objectives in this domain. As for sound fields, our studies aim at understanding their spatial representations and couple them with time/frequency representations, at capturing them in high resolution, and at reconstructing them realistically.

• THE MUSICAL BODY

The domain focused on here is that of music and sound, perceived and produced by humans who interact with an environment, a machine, or other human beings. Sound is not reduced to a simple vibration, but becomes a vehicle enabling interaction produced by a biological body and operating on individuals and behaviors. This domain is addressed through four issues—gesture, voice, the spatial perception of sound and its multi-sensorial integration—while examining the connections among sonic or musical contents and emotional valency.

• CREATIVE DYNAMICS

While music is a phenomenon produced and perceived by a body that capitalizes on physical objects and organizes a sound world, it is also thought, imagined—or dreamt— and occasionally formalized before being realized. The question of creativity emerges today as a scientific[1] issue and a useful working paradigm for the conception of intelligent systems. Contrary to what a superficial analysis of the new directions taken by AI[2] could suggest, the challenge seems to be more about mentoring and companionship than imitation: what ideas and tools are necessary to inspire, guide, and assist an artist in their creative process and make the machine a partner? We are therefore opposed to an approach that aims at replacing humans, making autonomous machines and that which aims at augmenting human capacities. We can therefore talk about *augmented intelligence*.

In the artistic field, the first approach could possibly lead to understanding mechanisms that are replaced, but the second offers novel creative dimensions that could radically renew the science-music relationship. Using one of our major assets—our intimacy with musical creation—the laboratory's work endeavors to apprehend and document composers' creative process; to formalize, analyze, calculate, and produce symbolic musical structures in interaction with the creators' goals; to develop new tools for writing that address contemporary issues of notation; and to capture systems that assist collective creation.

These three fields ensure the legibility of our research and cover all our activities, they cross the physical and digital dimensions of the sound and musical world as well as its perception and production by humans in connection with issues surrounding creation and creativity. Among these research subjects, we can cite a few examples of subjects we intend to investigate more thoroughly in the upcoming years:

- Multiphysical modelling
- Expert expressive gesture
- Cyber physical & human systems
- The contribution of neurosciences, cognitive sciences, and connections with health
- AI and musical creativity
- New dimensions of musical notation

Despite the diversity of the projects carried out, the laboratory has a strong identity and visibility in terms of the subjects of its studies and its scientific position. **Three important principles characterize the laboratory's scientific policy contribute to this state of affairs**, compensate for the small number of researchers, and enable the laboratory to produce prominent scientific contributions and develop innovative tools.

1. RESEARCH-CREATION AFFILIATION

The first principle is the affiliation of research themes with contemporary musical creation through interaction[3]. This affiliation ensures a large diffusion of research findings. Research-creation interaction is supported by several recurrent mechanisms. We will cite four.

- The joint laboratory teams participate in IRCAM's artistic productions, be it directly or via the activity of computer music designers who serve as a means of transmission among artists, prototypes, and tools developed in the laboratory. Their role is essential in adapting the long time necessary for research to the inevitably sorter time available for artistic productions.
- Artistic residency projects provide an opportunity for the teams to interact with an artist who has proposed a research project and is in residence at IRCAM for a period that can extend from 1 to 3 months. These projects, removed from production contexts and constraints, make it possible to anticipate emerging needs and forecast new developments. Since 2012, 49 residents have been selected via an annual international call on the ULYSSES[4] platform. The majority of the artists in residence are not French, and half the projects involve at least two research teams.
- Created in 2013, the system of "Doctorate in Art" enables the development of interaction over a long period with an artist working full-time on their thesis. This type of doctoral program makes it possible to combine artistic practices and academic approaches with research and creation.
- Finally, research/creation interactions are grounded in encounters with individuals with unique issues. In order to develop a more open dialogue with the community of composers, and to systematically identify emerging themes IRCAM tested in 2017 during days set aside for encounters and discussions. These days, entitled "Méridien" will be renewed.

1. See the new international conferences "Digital Intelligence (#DI)", "Musical MetaCreation (MUME)", "International Conference on Computational Creativity (ICCC)", in which the joint research laboratory has participated regularly since their creation. See also the European initiative FET "Creative ICT" that supported 5 projects in 2016.
2. Like the Magenta project developed by Google: " [how to develop] algorithms that can learn how to generate art and music, potentially creating compelling and artistic content on their own" https://goo.gl/MF5foi
3. This model of interaction, in which IRCAM was a pioneer, is now recognized and used with, for example, the H2020-ICT project Vertigo (Adding socio-economic value to industry through the integration of artists in research and open innovation processes) begun at the end of 2016, coordinated by IRCAM: http://vertigo.ircam.fr/
4. http://www.ulysses-network.eu

2. A BACK-AND-FORTH BETWEEN FINALIZED APPLICATIONS AND ACADEMIC REFLECTIONS

The second principle that characterizes the scientific strategy of the joint research laboratory is that of consistently validating theoretical reflections through developments used beyond the teams and, vice versa, substantiate applicative developments via an epistemological or theoretical reflection. In this dialogue, the software or hardware application is used in the laboratory as a necessary tool for experimentation. The prototypes developed by the researchers are often developed within the framework of collaborative projects, meaning they are used by our partners as well as in artistic productions, associating laboratory results with the demands of a composer and their experienced ears. Beyond experimentation and via IRCAM's artistic projects, these tools reach a broader public through the IRCAM Forum[1] that provides transversal coordination at IRCAM (over 20,000 professional members worldwide).

3. AN IMPORTANT PRESENCE IN FRANCE AND ABROAD

The third principle is that of a laboratory with a strong presence in high-level French and international research scenes, in all the scientific communities with which its teams are connected. This point is covered in the following paragraph.

1. https://forumnet.ircam.fr

Institutional Links

The joint research laboratory relies on the natural, diverse connections among its research teams, but also relies on the presence of its members at the heart of regional, national, and international communities. Proof of this can be seen in the large numbers of invitations extended to the laboratory's researchers (seminars, guest speakers) and in their participation in steering committees or in seminars and conferences they have either initiated or organized.

On a national level, the joint research laboratory at IRCAM is the only laboratory in the 2016-2020 Culture-CNRS framework agreement in the field of music[1].

On a regional level, the laboratory is a partner in the **ATIAM** Master's program (Acoustics, Signal Processing, and Computer Science Applied to Music) hosted and organized by IRCAM as a part of the Master's degree in Sciences and Technology at Sorbonne Université in collaboration with Télécom ParisTech. The laboratory is also a partner in the **Sound Design** Master's degree organized with the EPCC – École supérieure des beaux-arts Tours Angers Le Mans, l'université du Maine and l'ENSCI – Les Ateliers. These two programs are unparalleled in France. Abroad, these programs are usually part of a "Music Technology" class in a music school, intended for music students. Members of the laboratory also teach occasionally in other Master's degree programs (Grenoble, Strasbourg, Marseille).

The joint research laboratory hosts the doctoral schools in its domain from Sorbonne Université, particularly EDITE (Paris doctoral school for computer science, telecommunications, and electronics), SMAER (mechanical sciences, acoustics, electronics, and robotics) and ED3C (brain, cognition, behavior).
A new doctoral school was launched with the new academic year in 2014 via the ComUE Sorbonne Universités and the Idex SUPER: Doctorate in Music – Research and Composition.
IRCAM is a founding member[2] of the **Collegium Musicæ**, an institution that structures the activities of the ComUE in the field of music. Three themes are covered: analysis and creation, instruments and performers, and archives and heritage.

The joint research laboratory participates in two LabEx (**laboratories of excellence**):

- The LabEx SMART[3] that focuses on human-machine interaction, bringing together 5 laboratories from Sorbonne Université as well as Télécom ParisTech and the LUTIN (laboratory on uses associated with the Cité des sciences et de l'industrie).
- The LabEx CAP[4] via the Analysis of Musical Practices team. CAP studies the arts, creation, and heritage to understand and accompany contemporary societal mutations in the context of cultural and economic globalization.

The laboratory is also associated with the Fondation Sorbonne Université **Excellence Chair**, MouVIE, on mobility and standard of living in urban areas, supported until 2020 by PSA/Renault.

On an international level, the joint research laboratory maintains connections with today's most prestigious international research centers on computer music such as CCRMA at Stanford University, CNMAT at UC Berkeley, the MIT Medialab in Boston, CIRMMT at McGill University, or in with the MTG at the UPF Barcelona, the SPA department at Aalto University in Helsinki, and C4DM at Queen Mary University (guest researchers, doctoral exchanges, organization of common projects[5]). The laboratory has also connected with other large universities through workshops organized at the universities of Singapore, Columbia, NYU New York and Abu Dhabi, Campinas, Sao Paulo, Shanghai, and at EPFL.

1. See https://goo.gl/jmr9BE Two other joint research laboratories host programs supported by the French Ministry of Culture. The ministry is not a co-tutor of either of these laboratories. The LaBRI is host to the "Studio de création et de recherche en acoustique musicale (SCRIME)" and the LAM is home to the program for documents and sound archives as well as the work of the GIS-SPADON.
2. Along with 8 other major actors in education and musical research: IReMus, Institut de recherche en musicologie (UMR 8223 - CNRS - Paris-Sorbonne - BnF - MCC) ; LAM, Lutheries, Acoustique, Musique - Institut Jean le Rond d'Alembert (UMR 7190 - CNRS – Sorbonne Université – ministère de la Culture) ; Musée de la musique, Cité de la musique - Philharmonie de Paris : Centre de recherche sur la conservation (USR 3224 - CRCC - LRMH - ECR Musée de la musique) ; Unité systématique et catégorisation culturelles (UMR 7206 - CNRS - MNHN - Paris 7) ; Pôle Supérieur Paris-Boulogne-Billancourt (PSPBB) ; Chœur & Orchestre Sorbonne Universités (COSU) ; UFR Musique et musicologie (Paris-Sorbonne) ; UFR d'Ingénierie (Sorbonne Université).
3. The SU laboratories at LabEx SMART are ISIR, the LIP6, the laboratoire Jacques Louis Lions, the L2E and STMS: http://www.smart-labex.fr/
4. The LabEx CAP http://labexcap.fr/ covers 17 university and higher-education (from: EHESS, EPHE, CNAM, ENC, ENSCI, ESCP Europe, ENSAPLV, INHA, INP, IRCAM, LCPI ParisTech, the université Paris 1 Panthéon-Sorbonne) and 8 museums and national establishments (BnF, Musée du Louvre, Centre Pompidou, musée du quai Branly – Jacques-Chirac, Musée des Arts décoratifs, Musée des Arts et Métiers, Sèvres – Cité de la céramique, La Cité de l'architecture et du patrimoine).
5. These projects are funded in a variety of ways. For example, the bilateral contract and INRIA international funding, a Fullbright scholarship, an international Canadian program, European projects, etc.

Innovation and Research Means

At the heart of societal and economic issues crossed with those of culture and information technologies, the research hosted by IRCAM are presented in the international research landscape as an interdisciplinary benchmark for sciences and technologies as they relate to sound and music in the context of society's new needs and uses. This mediation assumes a wide range of forms according to the targets and spheres of activity and is supported by the department of Innovation and Research Means at IRCAM. This department oversees IRCAM's supervision of the joint research laboratory as well as IRCAM's internet and information technology teams.

Distinctive to IRCAM is this gathering of a broad spectrum of scientific and technological skills that find applications in numerous fields centered on the production and diffusion of music and sound, digital arts, cultural industries, and throughout the fields with a sonic dimension: sound design (automotive, transportation, urban environments), multi-modal interfaces, virtual and augmented reality, simulation, etc. With several decades of experience in the management of innovation and collective creativity, IRCAM is consulted concerning these themes (innovation, marketing, human resources, communication, etc.) on a regular basis by large groups.

IRCAM's art-innovation model has been extended to all technological and artistic fields in the framework of the European Commission's STARTS[1] (Science, Technology, and the Arts) initiative. After its coordination of the European project VERTIGO-STARTS Residencies that organized 45 artist residencies in connection with technological research projects throughout Europe, IRCAM now participates in the STARTS Ecosystem and MediaFutures projects by applying the methodology of the STARTS Residencies for the prefiguration of innovative media using large databases.

This model is presented during the annual Forum Vertigo[2], an interdisciplinary symposium held at the Centre Pompidou during the Mutations/Creations event, bringing together artists, researchers, engineers, and actors of innovation focusing on current issues in artistic creation in its relationship with sciences and technologies.

Unique to IRCAM, professional technological development within the institute's research teams leading to the production of directly transferrable finalized, functional, optimized modules is a part of IRCAM's culture. More generally, this development activity can be found throughout a variety of realizations adapted to different targets. Over a dozen software environments are developed by the teams (see Part 4), perfected incrementally in rhythm with the latest advances in research, used by other departments at IRCAM for artistic productions or training (composers, computer music designers, sound engineers, musicians, dancers, etc.), and disseminated by the IRCAM Forum to an international community of over 20,000 professional users. Applications with simplified uses can be found in a range of software bouquets: IrcamLab with Plugivery, Ircam Tools with Flux::, IrcaMax with Ableton.

Services provided by the teams at IRCAM for private partners are eligible for fiscal advantages through the French Ministry of Research and Further Education's research tax credit (CIR). Connections with industry can be found in numerous collaborations: French and European R&D projects, research findings in the joint research laboratory (20 currently underway, 1/3 of which are coordinated by the joint research laboratory), research services, co-tutoring of CIFRE dissertations, accompaniment of start-ups (Phonotonic, Mogees, Niland [bought by Spotify in 2017], Antescofo, and HyVibe are the most recent examples), capital holding, and licensing. In 2019, IRCAM created a subsidiary—**Ircam Amplify**[3]—with the support of the Banque des Territoires and private investors, representing a new dynamic to boost the commercial diffusion of the institute's technologies and expertise.

1 starts.eu
2 vertigo.ircam.fr
3 ircamamplify.com

Research Collaborations and Recent Partners

3D for All Kft (Hongrie)
A-Volute
Ableton (Allemagne)
Acapela
Arkamys
Arte
Artipolis
Artshare (Belgique)
Athena Research Center (Grèce)
Athens Technology Center (Grèce)
b<>com
Bass Nation (Finlande)
Bayerischer Rundfunk (Allemagne)
BBC (Royaume-Uni)
Bmat (Espagne)
Buffet-Crampon
Cabrilog (France)
Centre de psychiatrie et neurosciences (Inserm-université Paris Descartes)
Centre de recherche de l'Institut du cerveau et de la mœlle épinière (UMR 7225)
Centre hospitalier universitaire de Nice
Centre interfacultaire des sciences affectives (Suisse)
CHU La Conception-Marseille
CHU-Liège (Belgique)
CNES
CNMAT-UC Berkeley
CNRS Telecom ParisTech
Conservatoire national supérieur de musique et de danse de Paris
CTEL
Culture Tech
Dassault Systèmes
Deezer
Deutsches Forschungszentrum für Künstliche Intelligenz (Allemagne)
Dualo
Dubbing Brothers
École de musique Schulich (Canada)
École polytechnique fédérale de Lausanne (Suisse)
ECR-Musée de la musique
EHESS
elephantcandy (Pays-Bas)
Ellinogermaniki Agogi (Grèce)
EMI
EMPAC (États-Unis)
Ensad
esba TALM
Eurecom Sophia Antipolis
Eurescom
FINCONS SpA
Flux::
Flying Eye (Allemagne)
France Télévisions
Fratelli Piacenza SpA (Italie)
Fraunhofer (Allemagne)
GENESIS (Genesis Acoustics)
Goldsmiths' College (Royaume-Uni)
Grame
Haute École de musique de Genève (Suisse)
HearDis! Corporate Sound GmbH (Allemagne)
I3S
ID Scenes
Inova+ (Portugal)
Inria
Inserm-Sorbonne Université-faculté de médecine
Institut Jean Le Rond d'Alembert (Sorbonne Université)
Instituts de recherche technologique
INTEGRAL Markt - und Meinungsforschungsges.m.b.H. (Allemagne)
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ISAE SUPAERO
ISIR
IUAV (Italie)
Kainos (Royaume-Uni)
Kantar Media
KTH (Suède)
Laboratoire de neurophysique et physiologie (UMR 8119, université Paris-Descartes)
Laboratoire des sciences, des procédés et des matériaux de l'université Paris-13
LaBRI
LAGEP
Lambde Limited (Roli)
LATMOS
Libelium Comunicaciones (Espagne)
LIMSI
LMA
Lovemonk S.L. (Espagne)
LPL
LRI
Magix (Allemagne)
Maha
Makemusic
Mathematics for more (Espagne)
Mogees
Musée du Quai Branly – Jacques-Chirac
Musimap (Belgique)
Niland
No Design
Nokia (Finlande)
Novelab
Novespace
Open University (Royaume-Uni)
Orange
Orbe
OSU Ecce Terra
Parisson
Parrot
Pathé
Philharmonie de Paris
Phonotonic
Playground (Suède)
Plux – Wireless Biosignals SA
PSA Peugeot Citroën
Qwant
Radio France
Reactable Systems (Espagne)
Renault
Sigma-Orionis
Sky-Deutschland (Allemagne)
SNCF
Somethin'Else Sound Directions Ltd (Royaume-Uni)
Soundtrack Your Brand (Suède)
StreetLab
Stromatolite Innovation Lab (Royaume-Uni)
Stupeflix
Supelec
Technicolor
Technische Universität Berlin (Allemagne)
Technische Universität Wien (Autriche)
Testaluna (Italie)
Trinity College Dublin (Irlande)
Trinnov-Audio
Ubisoft
UC Limburg (Belgique)
Universal (Royaume Uni)
Universal Music Publishing Classical
Université Ben Gurion (Israël)
Université de Bretagne occidentale
Université de Fribourg (Suisse)
Université de Gênes (Italie)
Université de Thessalonique (Grèce)
Université de Zaragoza (Espagne)
Université Kiel(Allemagne)
Université McGill (Canada)
Université Pompeu Fabra (Espagne)
UVI Sounds and Software
Velti (Grèce)
Vi-live
Vizion'r
Xtranormal

2

The Teams

SOUND SYSTEMS AND SIGNALS: AUDIO/ACOUSTICS, INSTRUMENTS

Head Researcher: Thomas Hélie

ACTIVITIES

—

The team Sound Systems and Signals: Audio/Acoustics, InstruMents creates theoretical, technological, and experimental tools based on multiphysic systems and the sound signals they produce. The team is interested in exploring, understanding, reproducing, and inventing sound objects in audio, acoustics, focusing on musical instruments and the production of the human voice.

More precisely, the objectives are to model, simulate, identify, and optimize these systems (voice, musician/instrument, loudspeakers, audio electronic effects, etc.) using physics to reveal and benefit from their intrinsic structures. The team creates methods for analysis, transformation, control, and simulation of sounds as well as tools to assist conception in virtual, real, or hybrid paradigms.

This global approach, "systems and signals" creates a synergy in the conception of these tools, connecting—not merely juxtaposing—several disciplines and scientific fields: physics, theory of systems and control, differential geometry, numerical analysis, signal processing, computer science, electronics, mechatronics, and robotics.

Target applications concern scientific, artistic, educational, and healthcare domains.

MAJOR THEMES AND ASSOCIATED PROJECTS

—

- Physical modeling of musical instruments and voice
- Sound synthesis based on physical modeling
- Modeling physical audio systems and loudspeakers
- Experimental robotic platforms: robotic bow, robotic artificial mouth to play brass instruments, robotic apparatus at a 1:1 scale
- Identification of non-linear systems
- Control of non-linear systems
- Augmented instruments, hybrid instruments
- Animaglotte project (system of artificial animation of the larynx ex vivo, p. 33)
- Bass Holograms in Pune project[1]
- CAGIMA project (acoustic conception of musical instruments), p. 33
- Finite4Sos project[2], p. 32
- iMuSciCA project, p. 33
- Infidhem project (interconnected systems of infinite dimension for heterogenous environments), p. 32
- Ondes Martenot project, p. 29
- Sheng project[3], p. 30

SPECIALIST AREAS

—

Acoustics, mechanics, non-linear systems, automatic and control, signal theory, differential geometry, digital analysis, experimentation, mechatronics, real and virtual instrument-making, sound synthesis

COLLABORATIONS

—

Athena-RIC (Greece), Cabrilog SAS, C2RMF-Louvre, C2RMF and Louvre-Lens, CHU Liège, GdR-GDM, École Centrale Lille, GIPSA-lab, HISOMA, IJLRA-Sorbonne Université, INRAE, INRIA-Lille, INRIA-Bordeaux, IREMUS, ISAE-SUPAÉRO, LAGEP-Université Lyon-1, LaSiE-Université de La Rochelle, LEOPOLY (Hungary), LJLL-Sorbonne Univsersité, LMA-CNRS, LMD-ENS, LPL, Mines ParisTech, Musée de la musique

TEAM

—

Researchers: B. d'Andréa-Novel (Sorbonne Université), H. Boutin (Sorbonne Université), R. Caussé (emerita), T. Hélie (CNRS), D. Roze (CNRS) – **Engineers:** R. Piéchaud – **Doctoral Students:** R. Muller, J. Najnudel, A. Thibault, V. Wetzel, M. Wijnand – **Residents/Guests/Long-Term Collaborations:** A. Falaize, F. Krouchi, H. P. Stubbe Teglbjærg, F. Silva, J.-E. Sotty

1 https://forum.ircam.fr/article/robert-piechaud-ircam/ https://pune.afindia.org/events/bass-holograms-a-musical-encounter-between-the-fkbass-an-augmented-bass-with-integrated-technology-and-the-rudra-veena/

2 https://anr.fr/Projet-ANR-15-CE23-0007

3 Collegium Musicae, https://www.iremus.cnrs.fr/fr/evenements/sheng-lorgue-bouche-des-dizaines-de-sons-des-centaines-de-musique

ACOUSTIC AND COGNITIVE SPACES

Head Researcher: Olivier Warusfel

ACTIVITIES

—

The Acoustic and Cognitive Spaces activity of research and development centers on the reproduction, the analysis/synthesis, and the perception of sound spaces. The main team's scientific disciplines are signal processing and acoustics for the elaboration of spatialized audio reproduction techniques and methods for the analysis/synthesis of a sound field.

In parallel, the team devotes a large percentage of its time to cognitive studies on multisensorial integration for a rational development of new sonic mediations based on body/hearing/space interaction. The scientific activities described below are combined with the development of software libraries. These developments build on the team's expertise, and its academic and experimental research activities and are the major vector of our relationship with musical creation and other application domains.

The work carried out spatialization techniques are concentrated on models based on a physical formalism of the sound field. The primary objective is the development of a formal framework for the analysis/synthesis of the sound field using spatial room impulse responses (SRIR). The SRIRs are generally measured using spherical arrays featuring several dozen transducers (microphones and/or loudspeakers). The principal application concerns the development of convolution reverberators using these high spatial resolution SRIRs to faithfully reproduce the complexity of a sound field.

Binaural Spatialization techniques using headphones is also a focus of our attention. The evolution of listening practices and the democratization of interactive applications tend to favor listening with headphones through smartphones. Taking advantage of this sonic immersion, binaural listening has become the primary vector of tridimensional listening. Based on the exploitation of head-related transfer functions (HRTFs), it is the only approach that currently ensures a precise and dynamic reconstruction of the perceptual cues responsible for auditory localization. It has become the reference tool for experimental research in connection with spatial cognition in a multisensorial context and for virtual reality applications.

These 3D audio spatialization techniques associated with a tracking system that captures the movements of a performer or a member of the audience, constitute an organologic base essential for addressing questions on "music, sound, and multimedia interaction". They offer an opportunity to reflect on the "cognitive foundation" related to the feeling of space, in particular on the coordination necessary among various sensory modalities for the perception and cognition of space. More specifically, we wish to highlight the importance of the processes of integration between idiothetic cues (related to our motor actions) and the acoustic cues (localization, distance, reverberation, etc.) used by the central nervous system to create a spatial representation of the perceived environment.

On the musical level, our ambition is to provide models and tools that enable composers to include sounds in a given space throughout the compositional process: from writing to performance. This contributes to making spatialization a parameter of musical writing. In the arts, this research also applies to post-production, to interactive sound installations, and to dance via the questions related to sound/space/body interaction.

MAJOR THEMES AND ASSOCIATED PROJECTS

—

- Sound Spatialization: Hybrid reverberation and spatial room impulse responses (SRIR), p. 26; SRIR analysis-synthesis, p. 27; Synthesis of sound fields via high-density spatial networks, p. 28; WFS and HOA systems in the Espace de Projection, p. 34; Binaural listening, p. 35; Distributed spatialization, p. 34, 35; ORPHEUS project, p. 35; HAIKUS project and augmented reality, p. 37
- Cognitive Foundations: auditory spatial cognition, p. 39; Multisensory integration and emotion, p. 45; Entrecorps project; Music and cerebral plasticity, p. 39; Perception of distance in augmented reality, p. 39
- Creation / Mediation: audio rendering of spaces in the RASPUTIN project, p. 36; Urban and landscape composition, p. 52; Audio study of the Dendara temple, p. 27
- Software: Spatialisateur, p. 75; OSCar, p. 73; Panoramix, p. 74; ADMix Tools, p. 64

COLLABORATIONS

—

AALTO (FIN), ARI-ÖAW (Wien, AUT), HEGP (FR), HISOMA (FR), IFAO (FR), IRBA (FR), LAM-IJLRA (FR), LORIA (FR), McGill (CAN), MPIA-IJLRA (FR), Radio France (FR), RPI (Troy, US), RWTH Aachen (Ger), Univ. Lille (FR), AmadeusAudio(FR), Flux:: (FR)

TEAM

—

Researchers: M. Noisternig, I. Viaud-Delmon (CNRS), O.Warusfel – **Engineer:** T. Carpentier (CNRS) – **Postdoctoral Researchers:** David Poirier-Quinot – Doctoral Students: V. Martin, P. Massé, F. Zagala, A. Moreau – **Residents/Guests/Long-Term Collaborations:** L. Hobeika, N. Schütz, C. Suied, M. Taffou

SOUND PERCEPTION AND DESIGN

Head Researcher: Nicolas Misdariis

ACTIVITIES

—

The team's project combines research in sound perception and cognition with research and applications in sound design. It implements art/science relations, on the one hand, by contributing to musical and sound research with scientific questions of a perceptive and cognitive nature ('from sound to subject' theme), and on the other hand, by placing the problems of applied sound creation in the field of design research ('from subject to sound' theme).

The applicative component allows the development of research-project or research-action type activities, within the framework of doctoral theses or industrial collaborations (Renault, Krug, SNCF, etc.) that combine the scientific and technological "knowledge" of the team's researchers with the artistic "know-how" of the composers who systematically work alongside them (e.g. A. Cera, S. Gaxie, A. Sigman, R. Rivas).

Finally, the team's work method is rounded out by an essential educational dimension. The team's involvement in the DNSEP Sound Design at the TALM-Le Mans School of Art and Design allows them to contribute to the training and development of the discipline. This involvement includes the supervision of an annual practical workshop that brings together sound design and design students to discuss a real-life case presented by an industrial or institutional partner (City of Le Mans, Ile-de-France Region, RATP, Maison de la Radio, Sainte-Anne Hospital, etc.).

The research carried out on the 'from sound to subject' theme first of all—and historically—concerns environmental sounds; a singular object that provides access to several levels of cognitive representation in connection with distinct listening modes (reduced, causal, semantic listening). They are implemented at different temporal scales (from the event to the final sound scene), at different degrees of complexity (from pure sound to complex sound), and aim as much at characterizing low-level perceptive mechanisms (loudness, auditory salience...) as at understanding higher-level cognitive processes involving the recognition, identification, categorization, memorization, or emotional processing of sound information. The team' s research on the memory and emotional aspects has also been (re) opened—notably through an ERC project—to vocal and musical problems, by combining signal analysis and transformation technologies with the study of sound clues that can induce emotions, reactivate representations in memory, and even guide social behavior.

The research carried out on the theme 'from subject to sound' expands the category of environmental sounds to that of sound artefacts—resulting from human transformation, of artificial origin—and raises the question of their conception (design) but also their reception (perception). They therefore focus on the discipline of sound design, considered as an object of study and research in its own right, by integrating it into the field of design research, a broader conceptual framework that is more established from a historical and epistemological point of view. This desire to make sound design interact with design, and to acquire its own knowledge, methodologies, and tools, is inspired by the approach of design sciences formalized in particular by Nigel Cross (2006). This approach is deployed on dimensions relating to the participants, procedures, and products of the discipline; it is complemented, moreover, by a particular consideration of the modalities of reception of sound design 'objects' (artifacts), which leads to the issue of perceptual evaluation.

MAJOR THEMES AND CURRENT PROJECTS

—

- Perception, representation, and description of sounds
- Loudness of multi-source sounds
- Vocal imitation and identification
- Timbre acoustics and semantics: SpeaK, p. 57
- Perception/cognition of complex sounds
- Local/global perception
- Inverse correlation and mental representation: CREAM, p. 43
- Vocal and musical cognition and emotion
- Social cognition and vocal identity: CREAM, p. 43; ACTIVATE, p. 40
- Emotional vocal feedback: Reflets, p. 41
- Inverse correlation and prosody: CREAM, p. 43; SEPIA, p. 40
- Roughness of sound and emotion: CREAM, p. 43
- Cognition and musical creativity: GRIAMI, p. 55
- Sound design and interaction
- Analysis of sound design practices: APDS, p. 57
- Sound signals, human-machine interfaces: Symbioz, p. 43
- Multimodal sound design, sonification
- Sound environments: KRUG, p. 44
- Sound design for health
- Sound conception tools: SpeaK, p. 57; Skat-VG, p. 51; KRUG, p. 44

SPECIALIST AREAS

—

Experimental psychology, data analysis (numerical, verbal), acoustics, psychoacoustics, psychology and cognitive neurosciences, sound design, design

COLLABORATIONS

—

LMA (CNRS), Ec. Centrale Nantes (LS2N), Ec. Nat. Sup. d'Architecture Lyon (LAURE), CNAM (Cedric), Univ. Toulouse (MSHS / PETRA), Sorbonne Université (Inst. Jean le Rond d'Alembert), Université Paris 1 Panthéon-Sorbonne (ACTE), Université de Strasbourg, EPFL (Lausanne), TU Delft (Fac. Industrial Design Engin.), ENS Ulm (LSP), CAP (Université Lyon 1), GHU Paris Psychiatrie & Neurosciences (Neuro Sainte-Anne et Lab-ah), Hôpital Cochin (APHP), Hôpital Pitié-Salpétrière (APHP), CHU Lille, Univ. de Tours (INSERM), ENAC, Centrale Supélec (FAST), INT La Timone, ICM, Université de Tokyo, McGill University (Canada), KTH (Suède), Lunds universitet (Sweden), ZHdK (Suisse), ENS Paris Saclay (CRD), ENSCI Les Ateliers, Music Unit, Alta Voce, Groupe Renault, PSA Peugeot Citroën, Maison KRUG, Actronika, SNCF, LAPS-Design, Région Île-de-France, RATP, Radio France (Maison de la Radio), Ville du Mans

TEAM

—

Researchers: J.-J. Aucouturier (CNRS), M. Ayari (Université de Strasbourg), O. Houix (ESAD TALM Le Mans), M. Liuni, N. Misdariis, P. Susini – **Postdoctoral Researchers:** P. Arias – **Doctoral Students:** C. Richards, V. Rosi, T. Souaille (co-dir. LS2N), N. Guerouaou (co-dir. CHU Lille), E. Pruvost-Robieux (co-dir. GHU Neuro Ste-Anne) – **Residencies/Artistic collaborations:** A. Cera, R. Rivas, N. Schütz, A. Tocher, J. Acheson

SOUND ANALYSIS & SYNTHESIS

Head Researcher: Axel Roebel

ACTIVITIES

—

The Sound Analysis & Synthesis team carries out research and development activity in sound analysis, transformation, and synthesis of sound signals.

The analysis of sounds includes methods enabling the permanent extraction or automatic structuring of diverse sorts of information given off by the signal, such as the fundamental frequency or the spectral evolution determining the pitch and timbre of a perceived sound. Information outside what is strictly musical is also taken into consideration, notably concerning industrial acoustics, sound design and multimedia as well as the automatic indexing of recorded sounds. The methods used are based on signal processing, statistical analysis, learning techniques and deep learning, recognition techniques, but also on knowledge of auditory perception.

Techniques of transformation and synthesis are initially created to respond to the needs of musicians in the production of new sounds and new music. A typical example of this is the computer synthesis of a virtual choir for an opera. However, the work is frequently applied to the fields of mobile telecommunications, video games, film, and virtual reality. Analysis and synthesis are based on the design of signal models (modeling the effects of sounds produced in terms of signals) as well as on models in the form of deep networks learned from large databases that are often generated or augmented using signal models. These models are realized in the form of libraries and software (Mac OS x, Windows and Linux), specifically designed for professional and non-professional users, musicians, but also sound engineers, acousticians, and enthusiasts.

Analysis and synthesis is based on the conception of both signal models (the modeling of sound effects produced via their signals) and physical models (the acoustical modeling of the source of sound production).

These models are integrated into pieces of computer software for PC or Macintosh (Mac OS X, Windows, or Linux) equipped with graphical interfaces specifically designed for musicians, but adaptable for sound engineers, acousticians and amateurs.

SPECIALIST AREAS

—

Signal processing, statistics, information theory, learning techniques, digital analysis, modeling

MAJOR THEMES AND CURRENT PROJECTS

—

- Signal models: processing with a vocoder, p. 29
- Sound characterization: automatic indexing; Skat-VG, p. 51; AI4Media, p. 26
- Analysis, transformation, and synthesis of the voice, conversion of speakers: Chanter; theVoice, p. 42; ARS, p. 38
- Analysis of sound scenes: ROUTE
- Software: SuperVP, p. 76; Audiosculpt; IRCAMLab TS, p. 67; ISiS Singing Synthesis

COLLABORATIONS

—

Aristotle University of Thessaloniki (Greece), Athens Technology Center (Greece), bmat (Spain), Centre for Research and Technology Hellas (Greece), Flux::Audio, France Télécom R&D / Orange, Frauenhofer Gesellschaft ICMT (Germany), ISIR/Sorbonne Université, LAM/Sorbonne Université, LIA (Université d'Avignon), MICC University Florence (Italy), PSA (Paris) , Sony Music France, Stupeflix, UMG, University of Huddersfield (United Kingdom), Uni. Lumière Lyon 2

TEAM

—

Researchers: R. Mignot, N. Obin (Sorbonne Université), A. Roebel – **Engineers:** F. Cornu – **Postdoctoral Researchers:** E.-L. Benaroya, D. Wolff – **Doctoral Students:** F. Bous, M. Farès, R. A. Ferro Mendes, H. Foroughmand, A. Lavault, C. Le Moine Veillon, Y. Teytaut

SOUND MUSIC MOVEMENT INTERACTION

Head Researcher: Frédéric Bevilacqua

ACTIVITIES

—

The Sound Music Movement Interaction team (previously known as the Real-Time Musical Interactions team) carries out research and development on interactive systems dedicated to music and performances.

Our work relates to all aspects of the interactive process, including the capture and analysis of gestures and sounds, tools for the authoring of interaction and synchronization, as well as techniques for real-time synthesis and sound processing. These research projects and their associated softwares (MuBu for Max, CataRT, Soundworks), are generally carried out within the framework of interdisciplinary projects that include scientists, artists, teachers, and designers and find applications in creative projects, music education, movement learning, or in medical domains such as physical rehabilitation guided by sound and music.

MAJOR THEMES AND CURRENT PROJECTS

—

• Modeling and Analysis of Sounds and Gestures

This theme covers the theoretical developments concerning the analysis of the sound and gesture data, or more generally, multi-modal temporal morphologies. This research concerns diverse techniques for audio analysis, the study musicians' gestures or dancers. See gesture analysis and recognition, augmented instruments, p. 31; EmoDemos, p. 42

• Interactive Sound Synthesis and Processing

This focuses essentially on synthesis and sound processing methods based on recorded sounds or large collections of sound (corpus-based concatenative synthesis, p. 30)

• Interactive sound systems based on gesture and new instruments

This theme focuses on the design and development of interactive sound environments using gestures, movements, and touch. Interactive machine learning is one of the tools developed in this framework (see ELEMENT, p. 41; Rapid-Mix, p. 58; Skat-VG, p. 51)

• Collective musical interaction and distributed systems

This theme addresses questions of musical interactions from a few users to hundreds. It concerns the development of a Web environment combining computers, smartphones, and/or embedded systems making it possible to explore new possibilities for expressive and synchronized interactions (see distributed systems, p. 46; CoSiMa, p. 44; WAVE p. 58)

NATIONAL AND EUROPEAN PROJECTS

—

• ELEMENT, p. 41
• CoSiMa, p. 44
• EmoDemos, p. 42
• ABC DJ
• SkAT-VG, p. 51
• Rapid-Mix, p. 58
• WAVE, p. 58

SPECIALIST AREAS

—

Interactive sound systems, human-machine interaction, motion capture, modelling sound and gesture, real-time sound analysis and synthesis, statistical modeling and interactive machine learning, sound signal processing, distributed interactive systems

COLLABORATIONS

—

Arizona State University (USA), Atelier des feuillantines, BEK (Norway), CNMAT Berkeley (USA), ENSAD, ENSCI, GRAME, HKU (The Netherlands), Hôpital Pitié-Salpêtrière, IEM (Austria), ISIR-CNRS et LIB Sorbonne Université, Little Heart Movement, Mines-Paris Tech, Mogees (United Kingdom/Italy), No Design, Motion Bank (Germany), Pompeu Fabra University (Spain), UserStudio, université de Genève (Switzerland), LIMSI-CNRS université Paris-Saclay, LRI-CNRS université Paris-Saclay, Georgia Tech (USA), Legacy Lab (Taiwan), NOTAM (Norvège), Orbe.mobi, PLUX (Portugal), ReacTable Systems (Spain), UCL (United Kingdom), Univers Sons/Ultimate Sound bank, universtié Paris 8, Université Nanterre, Universidad Carlos III Madrid (Spain), université de Gênes (Italy), université McGill (Canada), TU Berlin (Germany), ZhDK (Switzerland)

TEAM

—

Researchers and developers: F. Bevilacqua, R. Borghesi, J.-P. Lambert, W. Liu (CNRS), B. Matuszewski, D. Schwarz – **Doctoral Students:** V. Paredes**,** I. Peyre, M. Voillot – **Residencies/Guests/Long-term collaborations:** B. Caramiaux (CNRS), J. Françoise (CNRS), S. Fdili Aloui, A. W. Liu, M. Suarez Cifuentes, M. A. Magalhaes, L. Bianchi

MUSICAL REPRESENTATIONS

Head Researcher: Gérard Assayag

ACTIVITÉS

—

The Musical Representations team works on the formal structures of music and creative environments for composition and musical interaction. This work finds application in computer-assisted composition (CAC), performance, improvisation, performance and computational musicology. Reflection on the high-level representation of musical concepts and structures supported by original computer languages developed by the team, leads to the conception of models which can be used for musical analysis and creation for composition, performances, and improvisation.

On the musicology side, tools for representation and modeling enable a truly experimental approach that significantly rejuvenates this discipline. On the creation side, the objective is to design musical companions that interact with composers, musicians, sound engineers, etc. throughout the musical workflow. The software developed has been distributed to a large community of musicians, materializing original forms of thought connected to the particular characteristics of the computer supports they represent (and execute): the final score, its score's different levels of formal elaboration, its algorithmic generators, its sonic productions, making live interaction possible during a performance, even when improvising.

The team integrates symbolic interaction and artificial creativity throughout its work on the modeling of improvisation and the integration of new open and dynamic compositional forms. This research allows advances in artificial intelligence, with models of listening, generative learning, synchronization, and lays the foundation for new technologies of creative agents who can become musical companions with artificial musicality ("machine musicianship"). This prefigures the cooperative dynamics inherent in cyber-human networks and the emergence of forms of human-machine co-creativity.

The team has a long history of collaborations with composers and musicians both from IRCAM and elsewhere. Archives of this work can be found in three volumes of the OM Composer's Book, guaranteeing its international dissemination and continuity.

MAJOR THEMES AND CURRENT PROJECTS

—

- Computer-assisted composition: computer-assisted composition, OpenMusic, p. 71
- Orchestration: computer-assisted orchestration, p. 53; ACTOR, p. 55; Orchid*, p. 72
- Control of synthesis and spatialization, writing for time: computer assisted composition, p. 47; writing synchronous time; OpenMusic, p. 71; Antescofo, p. 65
- Mathematics and music, p. 56
- Computer languages for creation: OpenMusic, p. 71; Antescofo, p. 65
- The dynamics of improvised interaction, co-creativity: DYCI2, p. 54; MERCI, p. 49; REACH, p. 48; OMax & co, p. 70
- Creative artificial intelligence: ACIDS, p. 50
- Studies on musical structures in performance: COSMOS, p. 36
- Studies in connection with therapy: HEART.FM, p. 37

SPECIALIST AREAS

—

{Composition, analysis, performance, improvisation, orchestration} assisted by computer, creative artificial intelligence, musical computer languages, musical mathematics, real-time synchronous languages, executable notations, interaction architectures, computer (co)creativity

COLLABORATIONS

—

Bergen Center for Electronic Arts (NO), CIRMMT/ McGill University (USA), City University London, Conservatoire national supérieur de musique et danse de Paris, Columbia New York, CNMAT/UC Berkeley, Electronic Music Foundation, Gmem, Grame Lyon, HEM Genève, École normale supérieure, EsMuC Barcelona, Harvard University, Inria, Sorbonne Université, université de Strasbourg, université Paris-Sud Orsay, UCSD San Diego, Yale University, University of Minnesota, Barts Heart Centre, University College London, GREAM Strasbourg, Institut Pasteur, Jardin des Sciences Strasbourg, Università degli studi di Padova, EHESS, HyVibe, University of Tokyo, Geidai University of the Arts, université de Kyoto, Metropolitan University Tokyo, STEGI Onassis Cultural Center, University of Athens, University of Pennsylvania

TEAM

—

Researchers: C. Agon (PR Sorbonne Université), G. Assayag (DR IRCAM), E. Chew (DR CNRS), P. Esling (MC Sorbonne Université), J.-L. Giavitto (DR CNRS), K. Haddad (CR IRCAM, composer), J. Nika (CR IRCAM), M. Malt (PAC, associated composer), G. Bloch (MC U. Strasbourg, associated researcher) – **Postdoctoral Researchers, Engineers:** L. Fyfe (CNRS), A. Chemla Romeu-Santos, C. Guichaoua – **Guest Researchers/ Residencies:** M. Andreatta (DR CNRS, U. Strasbourg) A. Vinjar (Residence IRC), B. Gatinet (Residence ANR MAKIMOno), C. Malherbe (associated composer), M. Stroppa (associated composer) – **Doctoral Students:** T. Bazin (CIFRE Sony CSL), A. Bitton, A. Caillon, T. Carsault, C. Douwes, M. Prang, A. Ratoci, D. Cabanzo, J. M. Fernandez (thesis in compostion), J.-F. Ducher, M. Fouilleul, D. A. Bedoya Ramos, P. Lascabettes, N. Devis (SCAI thesis).

ANALYSIS OF MUSICAL PRACTICES

Head Researcher: Nicolas Donin

ACTIVITIES

—

The Analysis of Musical Practices team carries out research on the works and scholarly practices that form IRCAM's heart: composition, improvisation, performance. To this end, the team is developing an empirical and technological musicology, whose goal is to describe (or even to modify) knowledge outside of the realm of music analysis, through novel methods of data collection. The goal is to characterize the phenomena under examination without reducing them a priori to their apparent structure (formalizable procedures, canonical texts), but in addressing them in all their dynamic, creative, contextualized, social, and cultural complexities.

These works are disseminated through publications and colloquia within the various scientific communities concerned (musicology, history, philosophy, cognitive sciences, sociology, genetic criticism); they are also the subject of other forms of dissemination: short documentary films, teaching at universities and to a wider public, computer developments, conference-performances, etc.

MAJOR THEMES AND ASSOCIATED PROJECTS

—

- Analysis of individual and collective creative processes
- Joint improvisation and action
- History of musical and scientific practices and their interaction
- Interpretation of mixed and electroacoustic music
- History and aesthetic of avant-garde music
- Sound Studies
- Musicology and Human and Social Sciences & SHS
- MICA, p. 52
- Wasabi, p. 46
- Musical temporality and spatiality of "la conscience morbide", p. 61
- Talking music, p. 62
- Instruments of Improvisation, p. 62
- History of musical acoustics in France, p. 60
- Tuning the world

COLLABORATIONS

—

Centre de recherches sur les arts et le langage (EHESS, CNRS), CIRMMT/ McGill University (United States), Conservatoire national supérieur de musique et de danse de Paris, Oxford University Faculty of Music, Haute École de musique/conservatoire de Genève, Institut des textes et manuscrits modernes (CNRS-ENS Ulm), OICRM/université de Montréal

TEAM

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The Projects

C1. Sound Workshop

AI4Media

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Team Involved: Sound Analysis & Synthesis
Funding: H2020, European Commission
Calendar: September 2020—August 2024
Partners: 30 partners coordinated by CERTH

Faced with the rapid evolution of the media as well as multimedia and audiovisual fields, AI4Media aspires to develop artificial intelligence tools for these domains. For example, in the combat against disinformation led by European democracies, AI4Media aspires to offer media analyses that detect the most up-to-date information, fake news, and validate information for journalists. The project is also interested in artistic applications and assistance in the creation of video games; the work carried out by IRCAM's Sound Analysis-Synthesis team is in this domain. Using advanced artificial intelligence techniques, we will develop a new approach to realistic sound synthesis of musical instruments. This method will make it possible to produce high quality musical content from MIDI scores. This can be used for artistic or video game applications in addition to supervised learning of models for automatic analysis of audio recordings: tempo estimation, key detection, chord recognition, automatic transcription, source separation.

Hybrid reverberation and spatialized impulse responses

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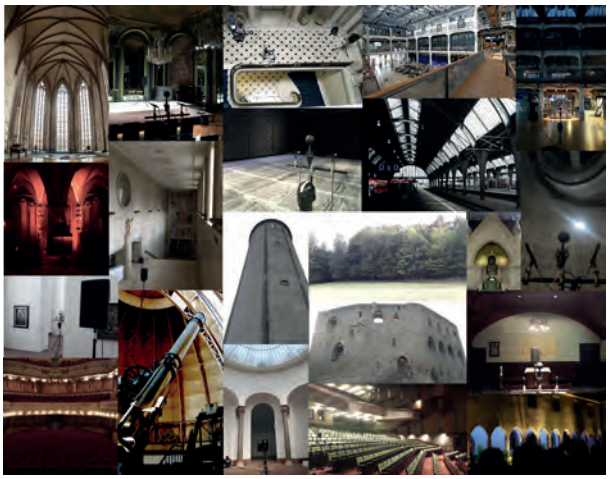
Team Involved: Acoustic and Cognitive Spaces

Most artificial reverberators use either feedback delay networks (FDN) or convolution reverb. These approaches differ in their computation cost, the "authenticity" of the results, the flexibility of use and adaptability vis-à-vis the system used for audio rendering. For several years, the Acoustic and Cognitive Spaces team has explored a "hybrid" approach. Using measured room impulse responses (RIR), the early reflections are reproduced by convolution while the later part of the reverberation is synthesized by a FDN that approximates the energy decay relief (EDR) of the RIR. The transition from one mode to the other occurs at the so-called "mixing time" and the FDN is calibrated to guarantee the continuity of the EDR, assuring audio rendering that is perceptively indistinguishable from the original IRR.

This hybrid technique has been extended to spatial room impulse responses (SRIR), measured with spherical microphone arrays (see photo) in order to recreate the spatial distribution of the room reflections.

During Pedro Garcia-Velasquez and Augustin Muller's 2017 residency in artistic research, their artistic work focused on the notion of "sound places" leading to the creation of a library of 3D SRIR for acoustic simulation of remarkable sites. Rather than catalogue the fingerprints of concert halls with fairly homogenous acoustics, this library favors more atypical places both in terms of their acoustic signature as by their evocative power.



© P. Garcia-Velasquez, A. Muller

Assortment of remarkable sites used for 3D acoustic fingerprints.

DRIR AnalysisSynthesis

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Team Involved: Acoustic and Cognitive Spaces
Partners: Aalto University (Helsinki, Finland)

The analysis and processing of directional room impulse responses (DRIR) is a central theme in the team. The work focuses on the modeling and resynthesis of the late reverberation sound field. In this context, a robust denoising process has been developed to exploit the team's DRIR database. When the late reverberation tail exhibits diffuse field properties (plane wave incoherence, isotropic spatial power distribution), denoising via resynthesis can be carried out in a spherical harmonics domain, the spatial representation at the root of the HOA format. The domain of spherical harmonics preserves the incoherent spatial nature of the diffuse field (thanks to the orthogonality of the decomposition base). The exponential energy decay is then modeled component by component and frequency by frequency, during which the noise threshold is simultaneously detected. This frequency-dependent noise floor may be then replaced by a synthesized incoherent tail parameterized by the DRIR energy decay envelope.

In the framework of a collaboration with Aalto University a study is devoted to the analysis of the directivity of the late field in the case where it is not entirely diffuse, i.e. where the plane waves are incoherent but the spatial power distribution is anisotropic. In this case, the spatial symmetry of the spherical harmonics cannot preserve anymore the spatial distribution of the reverberation tail. An alternative approach has been proposed based on plane-wave decomposition of the SRIR. The number of the plane waves is limited by the spherical harmonics order to allow for an exact reconstruction. The spatial distribution of the plane waves is chosen by maximizing the angular difference between their steering directions (so that their signals are as independent as possible) and minimizing the overall directivity variance over the sphere. The denoising process is then applied in each direction which preserves the spatial incoherence and directivity of the reverberation tail. The following steps of this project are devoted to the extraction of high level DRIR descriptors in order to allow for the development of a collection of spatial transformations potentially interesting for artistic applications exploiting DRIRs (cf. Urban and Landscape composition p. 52).

Acoustic study of the Temple of Dendara

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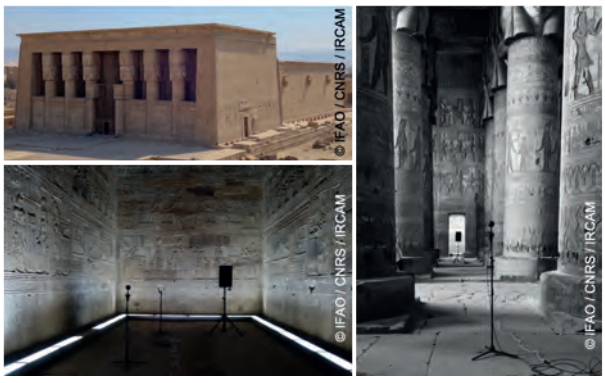
Team Involved: Acoustic and Cognitive Spaces
Partners: HISOMA, IFAO

The CNRS and the IFAO (French Institute of Oriental Archaeology) have undertaken, in collaboration with IRCAM, the archaeo-acoustic study of the main temple of Dendara (project directed by Sibylle Emerit, researcher in the CNRS HiSOMA laboratory and former member of the IFAO). Located in Upper Egypt, and built between the end of the Ptolemaic period and the beginning of the Roman period, this temple is dedicated to Hathor, goddess of music, love, and inebriation. Epigraphic and iconographic studies attest to the importance of sound activity in this temple, whether through textual references or through the omnipresence of representations of deities or dancers and musicians worshipping Hathor through their songs and instrumental manifestations (tambourines, harps, sistra lutes) that adorn the walls and columns of various spaces. This is the first time that such a study—at the crossroads of anthropology, archaeology, architecture, music, and acoustics—has been devoted to an Egyptian temple. At stake is the understanding of how the ancients perceived and interpreted sound phenomena through the analysis of the vocabulary dedicated to sounds, through the study of musical instruments and the observation of sites in which rich sound events took place. Architectural studies generally focus on the visual dimension of the built environment and more rarely on its acoustic dimension with the exception of ancient Greek and Roman theaters. In this project, IRCAM's mission is to conduct an acoustic characterization of the different spaces of the temple by measuring spatial room impulse responses. These responses, recorded by a high-spatial resolution microphone array (EM32 microphone from MHAcoustics®) will be used later to calibrate a 3D numerical model, currently under development, which will allow to complete the study by considering architectural elements that have now disappeared (doors of the sanctuary and the various chapels, peristyle courtyard).



Acoustic study of the temple of Dendara. Measurement in the naos (below) and the pronaos (right).

Sound field synthesis with high-density loudspeaker arrays

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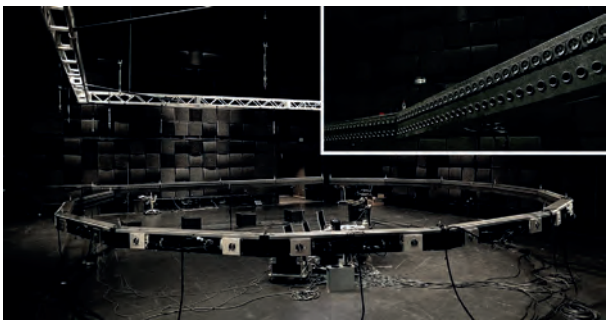
Team Involved: Acoustic and Cognitive Spaces
Partners: EMPAC (Troy, NY, United States)

Sound field synthesis with high-density loudspeaker arrays (HDLAs) remains one of the main research topics for the Acoustic and Cognitive Spaces team, which naturally finds its applications in musical production. It also represents an outstanding vehicle for the promotion of our developments and the numerous collaborations with other research institutions and prestigious musical creations.
As a part of a research collaboration with Rensselaer Polytechnic Institute, the concert hall in the Curtis R. Priem Experimental Media and Performing Arts Center (EMPAC) was equipped with a large scale HDLA. This new system consists of a linear 512-loudspeaker array (16 modules of 31 loudspeakers associated with a subwoofer) for Wave Field Synthesis (WFS) and a dome of 100 loudspeakers for Higher-Order Ambisonics (HOA). The distance in between the loudspeakers of the WFS array is 5.8 cm. Different geometric layouts were tested; each making it possible to take full advantage of different methods of sound field synthesis. For example, positioning two arrays on top of each other and offsetting them by half the on-center distance between drivers results in a horizontal distance of 2.9 cm between speakers and a total array length of 15 m. In doing so the aliasing frequency can be shifted up to around 6 kHz, which results in a striking impressive holophonic sound field reproduction. Arranging the speaker modules in a circle, on the contrary, allows for a 2D HOA reproduction of orders up to N=250.
The independently controlled loudspeakers are driven by a cluster of computers that compute the sound field synthesis in real-time. One of the major issues in this project was the implementation of multi-zone sound field control.



WFS – HOA system for spatial audio rendering in the Curtis R. Priem Experimental Media and Performing Arts Center at Rensselaer Polytechnic Institute de Troy (US). The system consists of 16 linear arrays of loudspeakers spaced at 5.8cm, configured here for bi-dimensional HOA diffusion.

FuturePulse

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Team Involved: Sound Analysis & Synthesis
Funding: H2020 ICT-19-2017
Calendar: September, 2017 — August, 2020
Partners: Bmat (coordinator, Spain), Athens Technology Center (Greece), Musimap (Belgium), Playground (Sweden), Bass Nation (Finland), Soundtrack Your Brand (Sweden)

Music is one of the fastest evolving media industries, currently undergoing a transformation at the nexus of music streaming, social media and convergence technologies. The availability of huge music catalogues and choices has rendered the problems of recommendation and discovery as key in the competition for audience, while the continuous access to multiple sources of music consumption have resulted in a dynamic audience, characterized by a highly diverse set of tastes and volatility in preferences which also depend on the context of music consumption. To serve the increasingly complex needs of the music ecosystem, FuturePulse will develop and pilot test a novel, close to market, music platform in three high-impact use cases:

- Record Labels
- Live Music
- Online Music Platforms

The project will help music companies leverage a variety of music data and content, ranging from broadcasters (TV, radio) and music streaming data, to sales statistics and streams of music-focused social media discussions, interactions and content, through sophisticated analytics and predictive modelling services to make highly informed business decisions, to better understand their audience and the music trends of the future, and ultimately to make music distribution more effective and profitable.
IRCAM's role in the project consists of the adaptation and perfection of the institute's technologies for indexing, enabling automatic extraction of information from musical recordings.

Vocoder Treatments

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Team Involved: Sound Analysis & Synthesis

Research on vocoders for the transformation of music and speech is one of the team's key topics. At the beginning (since 1995), research was focused on the phase vocoder, one of the most powerful techniques for sound analysis and transformation. These studies are the basis of the SuperVP software, which makes it possible to transpose, stretch or shorten sounds, filter them almost without limitation, and more. By the same token, the level of sound quality of the transformed signals is extremely high when applied to speech. Numerous improvements and extensions have been introduced, for example:

- Estimation of the spectral envelope via «true envelope»;
- Transposition with spectral envelope preservation;
- Transposition of the voice with «shape invariant» model;
- Generalized cross synthesis which enabling the synthesis of hybrid sounds;
- The detection and separate processing of time-sinusoidal, non-sinusoidal, and transient time-frequency zones.

These different modules of analysis, synthesis, and processing are used in several software programs on the market today. Starting in 2009 a new type of vocoder, based on the management of glottic impulses was imagined. Resulting from our research, the vocoder PaN «Pulse and Noise» has been integrated into the ISiS vocal synthesis software (available via the IRCAM Forum).
Since 2017, the success of deep learning techniques in the field of speech synthesis has motivated a new research direction on speech transformation with neural vocoders, which is currently being studied in particular in the ARS project, p. 38.

Ondes Martenot

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Team Involved: Sound Systems and Signals: Audio/Acoustics, Instruments
Funding: Collegium Musicæ
Partner: ECR-Musée de la musique

This project has a dual focus: museums and science
The objective for museums in this project concerns the automatic generation of documentation for instruments and simulation code for "non-invasive listening"—important for preserving playable virtual forms—in addition to electronic cloning of ancient technological components as programmable analog components that can be inserted in circuits, an important factor for the preservation of instruments in a non-virtual form.
The scientific objective focuses on physical models of old non-linear electronic components, simulation in real-time with guaranteed passivity of electronic circuits, and automatic generation of documentation and simulation code (work based on Port-Hamiltonien systems—PHS—a very productive formalism for multi-physical systems). It also focuses on the conception of programmable analogical electronic components and the creation of a general methodology applicable to Ondes Martenot and other families of analogical audio circuits.
We made an ergonomic facsimile of the Ondes Martenot n° 169, dating from 1937, intended to show the operation and sound of the instrument to museum visitors. The numerical simulation of the period triode tubes, in the stages of the electronic circuit (heterodyne oscillator, mixer and amplifiers), is based on the PHS formalism.
The digital model is embedded in a real-time digital processor and connected to a user control interface: MIDI keyboard and ribbon position sensor for the pitch, hand pressure control key (Touch, Expressive E) for the sound level. The next steps are to design facsimiles of the original «diffusers».
A measuring bench is currently being developed to characterize the voltage and current responses of the triode lamp models used in the different generations of Ondes Martenot, as well as their ageing. This study will allow to virtually control the degradation of these electronic components and thus to simulate the sound of the instruments at different stages of their life.
This project involves the Musée de la musique, whose approach aims to develop innovative tools for the conservation of its collections and the dissemination of heritage.

SHENG – Mouth Organ

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Team Involved: Sound Systems and Signals: Audio/Acoustics, Instruments
Calendar: 2019—2021
Partners: Collegium Musicæ, Iremus, TPMC

The sheng (mouth organ) is an instrument with a long history, whose repertoire is divided between the traditional and the contemporary. In order to foster and encourage future creations, a team of researchers (France, Germany, Austria, China, Taiwan, Japan) is working, within a project led by the Collegium Musicæ Institute of Sorbonne University, on the history, the different models of mouth organ, the repertoire, the acoustic study, the gestural analysis of improvisation, the combination of fingerings, the notation, and to explore this historical instrument which lends itself surprisingly well to modernity. This research will be accompanied by a series of seminars.

Corpus-based concatenative synthesis

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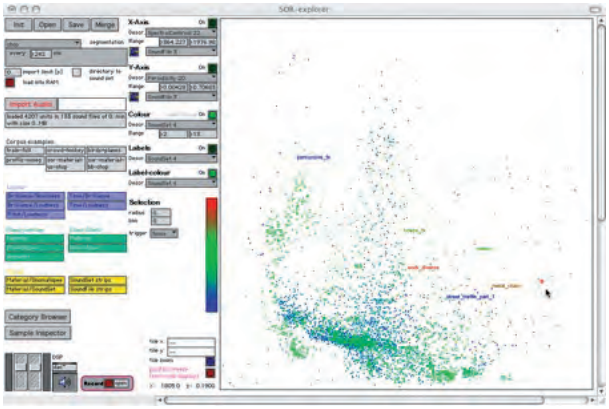
Team Involved: Interaction, Sound, Music, Movement

Corpus-based concatenative synthesis uses a database of recorded sounds, segmented and indexed by characteristics such as pitch or timbre. From this database, called a corpus, we can choose, via a selection algorithm, the segments from the database that best suit the musical sequence that we would like to synthesize by concatenation. The selection is based on the characteristics of the recording obtained through signal analysis and match, for example, the pitch, energy, or roughness. The habitual methods for musical synthesis are based on a model of a sound signal, but it is very difficult to establish a model that conserves the entirety of the details and delicacy of the sound. However, concatenative synthesis—that uses real recordings—preserves these details.

When this new approach of concatenative synthesis by corpus is used in real-time, it enables an interactive exploration of a sound database and a granular composition that targets specific sound characteristics. It also makes it possible for composers and musicians to reach new sounds. If the target position of the synthesis is obtained by an audio signal input, we can talk about "audio mosaicing". Corpus-based concatenative synthesis and audio mosaicking via spectral similarity are carried out using the MuBu library of modules optimized from Max in the CataRT system. This system makes it possible to display a 2D projection of the descriptor space that can be browsed using a mouse, external controllers, or the analysis of an audio signal. CataRT, like a library of modules for Max, a device for Ableton Live, or a standalone application, is used for musical composition, performance, and in various sound installations.

Example of concatenative synthesis



Example of a concatenative synthesis display.

Augmented Instruments

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Teams Involved: Interaction, Sound, Music, Movement and
Sound Systems and Signals: Audio/Acoustics, Instruments

These instruments are specifically adapted for mixed acoustic and electronic music. This work is carried out in close collaboration with composers and performers, the goal being the integration of this technology in their works. These developments are also a part of IRCAM's research into instrumental gesture. This project began with the development of the augmented violin, which then took off due to the interest of various composers. We are now working on all the string quartet instruments, certain percussion instruments, and the piano.
Various computer techniques are also developed to analyze, recognize, and follow instrumental gestures. For example, a vocabulary of musical elements such as game modes or musical phrases can be defined by the composer, and serve as a basis for interaction with sound processes such as synthesis or spatialization.
Finally, it should be noted that augmented instruments are used in musical creations but also in educational applications.

Augmented Instrument-making

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Team Involved: Sound Systems and Signals: Audio/Acoustics, Instruments

This project is at the heart of the research on musical instruments. Prototypes of musical instruments, or components of musical instruments, that can be used in concert have been produced in this project. Work carried out includes a broadening of the range of mutes for brass instruments, studying a system for the automatic tuning of a kettledrum, the creation of a clarinet mouthpiece with a variable volume, and the creation of a bow and mouthpiece instrumented via several sensors. In addition, IRCAM has designed and owns an instrumentarium of SmartInstruments (guitars, string quartet, bass clarinet, brass mutes) equipped with sensors and actuators with acoustic properties that a musician or composer can modify, and can diffuse sounds from a variety of sources without an external loudspeaker. This led to the realization of COALA, an embedded low-latency active control system for SmartInstruments.

Augmented Violin
© Florian Kleinefenn

INFIDHEM

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Interconnected inFInite-Dimensional systems for Heterogeneous Media

Team Involved: Sound Systems and Signals: Audio/Acoustics, Instruments
Funding: ANR / DFG
Calendar: February 2017–January 2020
Partners: Deutsche Forschungsgemeinschaft, ISAE SUPAERO (Toulouse), LAGEP (Lyon), Kiel University

Motivated by recent technological progress in mechanical, aeronautical, energy systems and chemical engineering and novel computational tools, the analysis and control of infinite-dimensional systems became a field of major interest during the last decades. The basic concepts of classical systems theory have been progressively generalized to infinite-dimensional systems with contributions stemming from the mathematical as well as from the engineering community.
More recently, scientists became interested in understanding systems composed of distributed-parameter subsystems (described by systems of partial differential equations, PDEs) which interact in networks. Most of the existing literature on modeling, system analysis and control, deals with networks of homogeneous systems such as trusses of elastic rods or the heat conductivity properties of metal foams.

Finite4SoS

Finite Time Control and Estimation for Systems of Systems

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ANR Project

Team Involved: Sound Systems and Signals: Audio/Acoustics, Instruments
Funding: SEAM
Calendar: September 2015—December 2019
Partners: Inria Lille - Nord Europe, Sorbonne Université, CRISTAL École centrale Lille, université du Littoral Côte d'Opal

Systems of Systems (SoS) are composed with interconnected dynamical subsystems with communication facilities, the natures of which lead to different mathematical models: ordinary differential equations, differential inclusions, time delay systems, partial differential equations. Information technology revolution has become a reality together with its new challenges. One of them being the need to manage such SoS with communication facilities, while requiring the best achievable performances. Finite4Sos aims at developing a new promising framework to address control and estimation issues of SoS subject to this model diversity, while achieving robustness as well as severe time response constraints. The key ingredients are: finite-time concepts, which will help in managing severe time constraints; homogeneity and time-varying feedback, which are the main tools for achieving the finite-time property for both convergence and input-to-state stability for each class of system. These concepts will help for both cascade and feedback connections (feedback homogenization will preserve the finite-time property).

iMuSciCA

www.imuscica.eu/

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Team Involved: Sound Systems and Signals: Audio/Acoustics, Instruments
Funding: European Commission Call H2020 ICT-22-2016
Calendar: January 2017 — June 2019
Partners: Athena Research Center (coordinator, Greece), UC Limburg (Belgium), Ellinogermaniki Agogi (Greece), 3D for All Kft (Hungary), Cabrilog (France), Mathematics for More (Spain), University of Fribourg (Switzerland)

iMuSciCA is an educational project that intends to improve the acquisition of scientific skills in secondary-level education. iMuSciCA offers new learning methods using innovative "discovery" technologies—both personalized and collaborative—in order to make certain scientific subjects, in particular math and physics, more appealing. The joint research laboratory brings its skills in virtual instrument making via Modalys, giving life to 3D instruments created by students. Some of these instruments feature parameters that can be tested and modified (geometry, material, etc.) in real-time.
The iMuSciCA environment, implemented through a collaboration among different industrial and educational partners, will be tested and assessed during a pilot program with a large number of students and teachers in three European countries: Belgium, France, and Greece.

Animaglotte

Artificial System of Ex Vivo Animation of the Larynx

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Team Involved: Sound Systems and Signals: Audio/Acoustics, Instruments
Calendar: 2018—2019
Partners: LPL-CNRS (coordinator), LMA-CNRS, CHU La Conception-Marseille, CHU-Liège

The human voice has an extremely variable range of acoustic characteristics depending on whether it is a whispered, sung, spoken or pathologically effected voice. To produce these different types of voices, humans use the length of the vocal folds and their level of contact (delineating the glottis).
Our project develops a mechanized system of ex vivo animation for human larynxes excised post-mortem. Following measures taken in vivo of the dynamic (amplitude and speed) of the glottis' movements, we aim to reproduce them via an artificial mechanical controller.

CAGIMA

Global Acoustic Conception of Reed Musical Instruments, In Tune and Homogeneous

http://cagima.ircam.fr

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Teams Involved: Sound Systems and Signals: Audio/Acoustics, Instruments, Sound Analysis & Synthesis
Funding: ANR - programme blanc
Calendar: December 2011 — November 2015
Partners: Laboratoire de mécanique et d'acoustique de Marseille, Laboratoire des sciences, des procédés et des matériaux de l'Université Paris 13, and Buffet Crampon
Coordinator: LMA Marseille-CNRS

The Cagima project focused on flaws found in reed instruments in tuning, homogeneity of emitted sounds, and timbre from both the perspective of the musician and also that of the instrument-maker who endeavors to satisfy the specific demands of each musician. The project's ambition was to replace the historical incremental approach used by instrument-makers with a rational and global approach that aimed to design new "logical" instruments that minimized the identified flaws. This was a large step forward for the methodology and technology of instrument making. To begin, the constraints of sound production that are imposed by an instrument on a musician were evaluated via the measurement of a specific gesture (e.g. pressure in the mouth, pressing on the reed with a lip, configuration of the vocal tract) and were correlated to the acoustic flaws of the instruments in order to suggest novel methodologies for the general design for the bore and the lateral holes of reed instruments. For this, the study of global criterion was at the heart of this project; their understanding led to the fabrication of playable prototypes of musical instruments.

WFS and Ambisonic Systems in the Espace de projection

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Team Involved: Acoustic and Cognitive Spaces
Funding: Programme Sesame (Conseil général d'Île-de-France), CNRS, IRCAM, ANR, Sorbonne Université

The Wave Field Synthesis (WFS) technique is a type of holophonic reproduction process that enables, by analogy with visual holograms, to capture or synthesize a sound scene while preserving the direction and depth information of its components. This approach, initiated by the University of Delft, goes well beyond the limits of conventional systems in terms of reproduction fidelity in a wide listening zone. While traditional stereophonic techniques (e.g. stereo, 5.1) are a kind of trompe-l'œil and can only be truly appreciated when one is positioned at the sweet-spot of the system, the goal of holophonic technology is to reproduce a sound field in which listeners can move freely while maintaining a coherent perception of the localization of the sound sources (parallax effect).
The Ambisonics technique consists of representing the sound field as an angular distribution of sound pressure expressed through its decomposition on the spherical harmonics (an ensemble of periodic functions of the space that form an orthonormal basis). Capture and reproduction are based on concentric transducer arrays composed of microphones (or loudspeakers, respectively) mounted on the surface of a sphere and that sample the space. Encoding and decoding operations are used to switch from the transducers' domain to the domain of the spherical harmonics. The higher the order of decomposition into spherical harmonics, the better the spatial resolution. This is called Higher Order Ambisonics (HOA). The Ambisonics formalism is very powerful and allows a certain independence between the reproduction system (number and spatial distribution of the loudspeakers) and the encoding/decoding format. It also enables efficient spatial morphing operations on 2D or 3D sound scenes, such as rotation, spatial warping and beam forming (directional virtual microphone).

IRCAM was able to acquire and install a WFS and HOA system in the Espace de Projection with the support of the Île-de-France Région, the CNRS, and Sorbonne Université. The system inaugurated in 2012 is made up of a horizontal ring of 264 loudspeakers placed at regular intervals around the stage and the audience for WFS sound diffusion and of a dome of 75 loudspeakers for three-dimensional Ambisonic sound diffusion. This equipment is used to experiment with new methods of spatialization for musical creation and for scientific experiments with virtual reality and spatial cognition. Elements from this system are mobile and can be used outside the Espace de Projection. The system has been used in this way for numerous musical creations, theatrical performances, and sound installations (*Operspective Hölderlin* by P. Schoeller; *Le Père* by M. Jarrell; *Mimesis* by M. Garcia-Vitoria; *La Tragédie du Roi Richard II* based on W. Shakespeare's work and directed J.-B. Sastre at the Cour d'honneur du Palais des papes in Avignon; *Mon Cœur parle tout seul* by D. Ghisi and D. Janneteau; *Disenchanted Island* by O. Neuwirth and T. Rosner; *Pocket of Spaces* by N. Barett and The OpenEnded Group).

This system is currently unavailable due to asbestos removal in the Espace de projection. The room is scheduled to reopen in 2022.

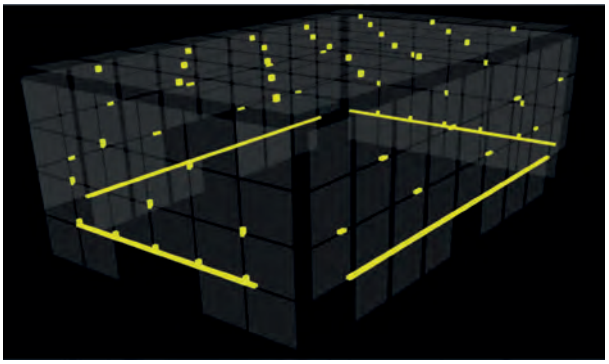

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Diagram of the installation of the sound diffusion system in the projection space.

© Centre Pompidou – Photo H. Véronèse

The HOA system installed in the Grande salle at the Centre Pompidou for the performance of *Pocket of Spaces* by N. Barrett and The OpenEnded Group.

Binaural listening

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Team Involved: Acoustic and Cognitive Spaces

Personal devices (smartphones, tablets, etc.) have multiple functions and are the main vehicle for distributing musical contents today. As the audience drifts towards these new devices, binaural listening over headphones is gaining ground and symbolizes the very notion of personal experience by theoretically giving access to the reproduction of three-dimensional sound scenes. This binaural reproduction is based on the dynamic filtering of the sound sources by Head-Related Transfer Functions (HRTF) previously measured on the head of a listener or of a dummy head. However, the individual dependency of these HRTFs has limited their general public use to date.

As part of the BiLi project (FUI funding), the HRTF measurement system in IRCAM's anechoic chamber received a major hardware and software upgrade that significantly increases the spatial resolution compared to the available databases. The new spatial sampling (1680 directions) allows a decomposition into high order spherical harmonics, useful for various post-processing steps (spatial interpolation, HOA / binaural transcoding).

The sharing of HRTF databases within the international community has motivated the standardization of an exchange format. Resulting from an international collaboration, the AES69 SOFA (Spatially Oriented Format for Acoustics) format, approved by the Audio Engineering Society's standardization body, allows the storage of spatial acoustic data such as HRTFs or Spatial Room Impulse Responses (SRIRs). IRCAM has set up an OPenDAP (Open-source Project for Network Data Access Protocol) server that hosts various HRTFs databases in SOFA format and to which client applications (web applications, Matlab, etc.) can send download requests (a specific HRTF, a complete head, etc.).

Work on the individualization of HRTFs is continuing, notably in the field of HRTF estimations that do not require either acoustic or morphological measurements. Some methods exploit available databases to guide the user in the selection of the most appropriate set of HRTFs (RASPUTIN project, p. 36). A proposed new approach is based on the use of deep learning methods (HAIKUS project, p. 37) and blind analysis on binaural signals recorded with in-ear microphones under unsupervised conditions (reverberant environment, any signals, sources and moving listener).

ORPHEUS

Object Based Broadcasting

orpheus-audio.eu

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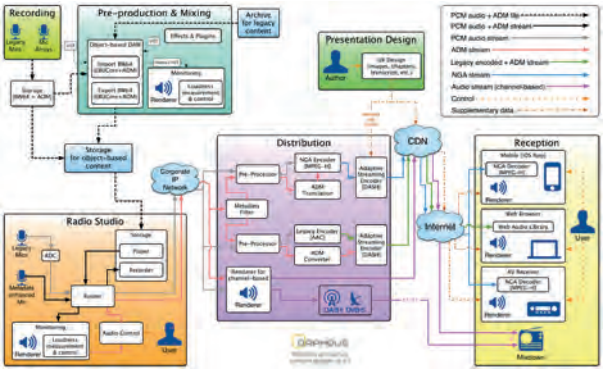
Team Involved: Acoustic and Cognitive Spaces
Funding: H2020-ICT-2015
Funding Calendar: December 2015—May 2018
Partners: Fhg IIS, BBC, Bayerischer Rundfunk, IRT, b ‹› com, Magix, Trinnov-Audio, ElephantCandy, Eurescom

Object-based media is a promising approach for creating and deploying interactive, personalized, scalable and immersive content, by representing it as a set of individual assets (video and/or audio) together with metadata describing their temporal and spatial relationships and associations. This allows media objects to be assembled in groundbreaking ways to create new user experiences, offering various levels of inter- action: adjustment of the balance between objects in the foreground and the background, spatial navigation, non-linear media usage, adaptation to listening contexts (public broadcast, home listening, headphone listening while moving, etc.).

The ORPHEUS project aims at developing and validating the whole audio production chain, from studio to listener, making it possible to create, transmit, and receive "object" contents on different platforms (audio-video receiver, smartphone, web browser). This chain relies on the Audio Definition Model (ADM) recommended and defined by several international authorities (European Broadcast Union and International Telecommunication Union).

At the heart of this research partnership, IRCAM focuses more specifically on aspects connected to the characterization, synthesis, and transmission of the effects of reverberation. IRCAM developed a software suite dedicated to recording, to reading, and rendering of ADM audio contents (see ADMix Tools in software, p. 64).



Architecture of treatment for the creation, broadcast, and reception of audio contents in object-based format.

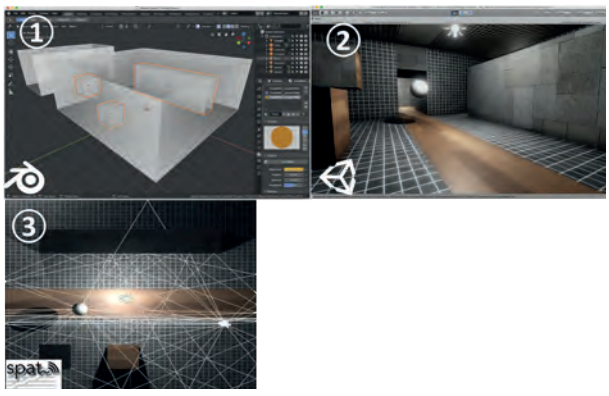
C2. The musical body

RASPUTIN

—

Team Involved: Acoustic and Cognitive Spaces
Funding: ANR, programme AAP 2018
Calendar: November 2018—April 2022
Partners: IJLRA (Sorbonne Université / CNRS), université Paris Descartes, Novelab

RASPUTIN is a collaborative fundamental research project (PRCE) at the intersection of «digital sciences and technologies» and «psychology», that aims at reducing the cognitive complexity of navigation for the blind in a new interior environment through digital simulations and explorations using virtual reality with 3D audio. These explorations make it possible to mentally create cognitive maps of these environments not yet physically explored.
The main technical challenge of the project is to generate a realistic audio rendering of a building (auditory virtual environment) in real-time using, on the one hand, the spatialization library Spat~ and, on the other hand, the Evertims library for the simulation of acoustic propagation in a digital model that describes the architectural parameters of a building.
Three components are essential to the creation of realistic and interactive auditory virtual environments: the creation/editing of scenes (audio-visual), the quality and computing cost of the simulations performed and the management of interactions between the user and the elements of the scene. To focus our efforts on acoustic simulation, we have articulated Evertims around existing scene graphs. The module now works in conjunction with Blender and/or Unity, the former serving as a scene editor, the latter as a graphical rendering and interaction engine.
The ability of the module to produce realistic auditory virtual environments will be tested through listening tests and objective comparison to a reference. The computer developments developed in this project can also be applied to different artistic fields using virtual reality techniques or for the prefiguration of sound installations (urban and landscape composition, p. 52), archaeological study (Temple of Dendara, p. 27), and cultural mediation.



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Steps for the audio rendering of a room using the Evertims module in Spat~.
1) Creation of the 3D model in Blender. 2) Management of the scene (sources and listener) in Unity. 3) Simulation and sound rendering in real-time (Spat~).

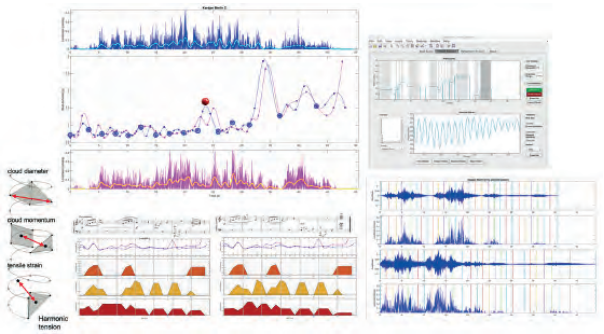
COSMOS

Computational Shaping and Modeling of Musical Structures
cosmos.cnrs.fr

—

Team Involved: Musical Representations
Funding: European Research Council Advanced Grant;
Principal Investigator: Elaine Chew (2019 – 2024)

That music performance is a creative act is no longer a disputed fact, but the very nature of this creative work remains elusive. Taking the view that the creative work of performance is the making and shaping of music structures, and that this creative thinking is a form of problem solving, COSMOS proposes an integrated program of research to transform our understanding of the human experience of performed music, which is almost all music that we hear, and of the creativity of music performance, which addresses how music is made.
COSMOS uses data science, optimization, and analysis as well as citizen science to study musical structures as they are experienced and created in performance. The project investigates unusual sources such as arrhythmic cardiac data.
The research themes are as follows: i) to find new ways to represent, explore, and talk about performance; ii) to harness volunteer thinking (citizen science) for music performance research by focusing on structures experienced and problem solving; iii) to create sandbox environments to experiment with making performed structures; iv) to create theoretical frameworks to discover the reasoning behind the structures perceived and made; and, v) to foster community engagement by training experts to provide feedback on structure solutions so as to increase public understanding of the creative work in music performance.
The citizen science platform developed in COSMOS enables the general public to annotate and deconstruct the structures created in musical performances, and to explore the space of possible musical interpretations. Mathematical tools and techniques to characterize variations and patterns in interpreted music and electrocardiographic sequences will expand the tools available to music information researchers, mathematicians, musicologists, music educators, music psychologists, and music therapists. Applications of the COSMOS platform and tools will include artistic projects, public engagement events and music science communication.



HEART.FM

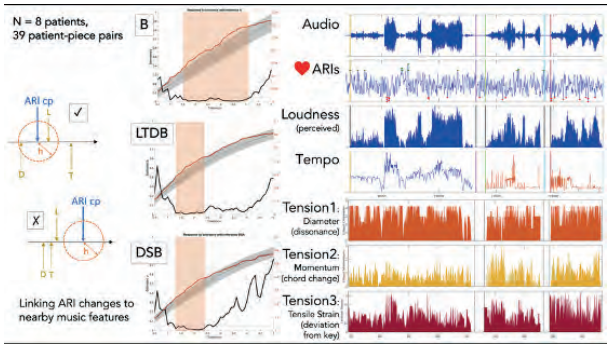
Maximizing the Therapeutic Potential of Music through Tailored Therapy with Physiological Feedback in Cardiovascular Disease

—

Team Involved: Musical Representations
Funding: European Research Council Proof of Concept Grant
Calendar: December 2020—May 2022
Partners: University College London, CNRS Innovation

Heart.FM Is a proof of concept project connected to Cosmos.

Cardiovascular diseases are the number one cause of death globally. Hypertension is the main risk factor for heart disease, thus reducing blood pressure in patients is essential. Music has the potential to regulate heart rate and blood pressure. However, current music listening therapy methods are labor-intensive and rely on professional therapists' intuition, or fail to address the subjectivity and specificity essential for individual music reaction.
The EU-funded HEART.FM project is developing a mobile app to democratize access to personalized medical music interventions based on physiological feedback. The project will exploit advances in wearable ECG monitors and portable blood pressure sensors, delivering music therapy based on individual users' physiological feedback corresponding to emotionally notable moments in their listening experience.



HAIKUS

Artificial Intelligence Applied to Augmented Acoustic Scenes

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Team Involved: Acoustic and Cognitive Spaces
Funding: ANR AAP19
Calendar: December 2019— May 2023
Partners: MPIA (CNRS-SU), LORIA (INRIA, Univ. Lorraine)

Applications using augmented acoustic reality are receiving attention in a broad range of fields including artistic creation, cultural mediation, communication, and entertainment. Audition is a key modality to understand and to interact with our spatial environment, and plays a major role in augmented reality applications. Embedding computer-generated or pre-recorded auditory content into a user's real acoustic environment creates an engaging and interactive experience that can be applied to video games, museum guides or radio plays. The major challenge of audio processing in augmented reality applications lies in the ability to seamlessly integrate these sound events into the real environment without any perceptual auditory or visual discrepancy. The spatial should constantly adapt to the acoustic conditions of the real environment according, for instance, to the movement of the sound sources or of the listener.
The objective of the HAIKUS project is the joint exploitation of machine learning and audio signal processing methods to solve acoustic problems encountered in augmented reality applications. Machine learning methods will be applied for the automatic identification of the acoustic channels between the sources and the listener. The seamless integration of virtual sounds in the real environment requires the estimation of the room or site's acoustic parameters enabling automatic adaptation of the reverberation process applied to virtual sources. The challenge is therefore the blind estimation of the acoustic parameters (reverberation time, direct-to- reverberant energy ratio) or the geometry of the room (volume and shape of the rooms, wall absorption) based on simple observation of the reverberant audio signals from real sound sources present in the room. The listener's adhesion to the augmented acoustic scene is based on a realistic and congruent evolution of the acoustic cues with their movement in the scene and the movement of the virtual sources. This requires the inference of plausible rules for modifying spatialization parameters, or the implementation of room impulse response interpolation techniques, according to the relative movements of the sources and the listener.
Interactive virtual sound scenes are generally rendered in binaural format over headphones. Convincing binaural rendering requires the use of individual head related transfer functions (HRTFs) that must be personalized for each listener, ideally requiring complex measurement in an anechoic chamber with perfectly calibrated audio signals. We propose the blind estimation of the listener's HRTFs based on binaural 'selfies', i.e. binaural signals recorded in real environments and non-supervised conditions (everyday environment, unknown and moving audio sources).

ARS

Analysis and tRansformation of Singing Style

ars.ircam.fr

—

Team Involved: Sound Analysis & Synthesis
Funding: ANR Révolution numérique: rapports aux savoirs et à la culture (CE38)
Calendar: January 2020— June 2023
Partners: Institut d'Alembert (Sorbonne Université), Passages XX-XXI (université de Lyon), Flux:: audio

Singing style is an important attribute of singing performance with strong effects on the subjective perception and reception of music. Recently, musicologists have started to study singing style in popular music, where at the same time digital singing style effects have become so popular that today the majority of popular music productions will make use of one of the few effect plugins that are available on the market today. In this context the ARS project aims to establish a mutually beneficial interdisciplinary collaboration between musicologists studying singing performance (humanities), engineers working on singing voice transformation (digital sciences), and developers specialized in software for professional audio.
ARS has two central objectives: The first one is to establish new means to study singing style in real music performances. The second one aims to develop algorithms for high quality expressive singing style modification. From the long list of style related singing characteristics, the ARS project will concentrate on features related to personal style that is stylistic effects a singer might choose in a performance to create an interpretative effect. This includes the modification of intonation-, and intensity contours, as well as the voice characteristics including but not limited to: rough, growl, breathy, belting, and the vocal tract configuration implying a singer's formant.

MoVE

Modeling of Speech Attitudes and Application to an Expressive Conversational Agent

—

Team Involved: Sound Analysis & Synthesis
Funding: 2019 Paris Region PhD doctoral research allowance "Ph2D" supported by the Région Île-de-France
Calendar: September 2019—September 2022
Partners: PSA

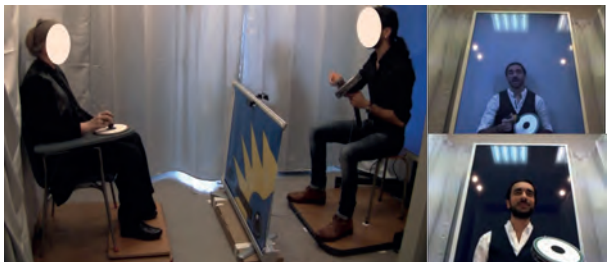
In a context where personal assistants and interactions with machines are becoming a part of our daily realities, voice has become the privileged modality of interaction with the machine. Voice synthesis has made enormous progress in recent years, particularly through the use of deep learning and large multi-speaker databases. However, there are two principal limitations. The first is low expressivity: the agent's behavior is still often monomodal (voice, such as seen in the assistants Alexa or Google Home) and remains very monotonous, which greatly reduces the acceptance, length of time, and quality of interactions. The second limitation is that the agent's behavior is poorly, or not at all, adapted to the speaker and to the situation, which reduces their understanding of the information and reaction time to the information transmitted.
The MoVE project will develop neural learning algorithms to adapt the speech style of a synthetic voice to a specific interaction situation, with, for example, a focus on the attitudes of the synthesized voice (cordial, smiling, authoritative, etc.). The improved adaptation of the voice style will result in a better understanding of the information communicated by the agent and will reduce human reaction time to the information provided (e.g. in an emergency situation).

Music and Neuroplasticity

—

Team Involved: Acoustic and Cognitive Spaces
Partners: université de Lille

This work, conducted in collaboration with the Université de Lille, focuses on the cognitive effects of music in pathological aging. Alzheimer's disease is a neurodegenerative disease that affects the cognitive, emotional, and social functioning of individuals. Given the limited efficacy of pharmacological approaches, non-drug treatments and in particular musical interventions are frequently proposed to overcome these difficulties. However, the factors that explain their effectiveness are not clearly identified. The aim of this project is to evaluate the factors influencing the socio-emotional and motor engagements of Alzheimer's patients during musical activity, as well as their ability to synchronize their movements with the musical rhythm. For this purpose, Alzheimer's patients and matched control participants performed a sensorimotor synchronization task, which consisted of tapping with their hand to the rhythm of a metronome or music in the presence of a musician. The musician performed the synchronization task with the patient. The musician was physically present in front of the patient (live condition), or virtually present through a pre-recorded video projected in real size in front of the patient (video condition). The results show the importance of the musical context and social interactions in the synchronization performances, but also in the social, emotional, and motor involvement of participants with Alzheimer's. These results open promising therapeutic perspectives, including the possibility of complementing current care with regular musical activities through the use of video recordings and mobile technology.



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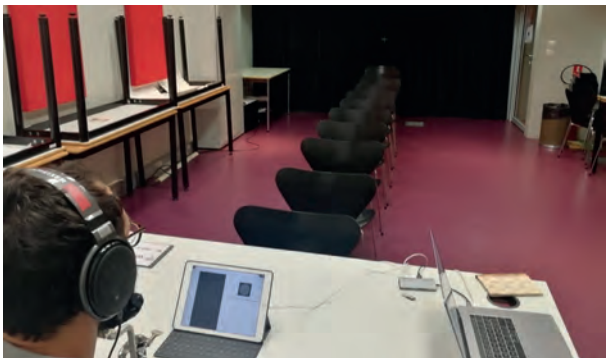
Experimental system.
[Left] The participant taps the tablet in response to the rhythm of the auditory sequences (music or metronome). Opposite, the musician also taps a tablet with his or her hand to the rhythm of the auditory sequences. [Right] Manipulation of social presence: the musician's performance could be pre-recorded and played on a full-size screen (above), or live (below).

Perception of Auditory Distance in Augmented Reality

—

Team Involved: Acoustic and Cognitive Spaces

This work is part of a larger study on modeling and spatial perception in the context of auditory augmented reality. In this context, where the real environment is enhanced by a set of virtual sound events, an important issue is to ensure the coherence of the spatial perception of these virtual sound events and the real sound sources, or visual anchors, present in the room. Ensuring this coherence requires, in particular, the choice of a model to render the sound distance effect and access to information on the acoustic properties of the room.
In a first step the objective was to evaluate the performance of a model, informed by a single directional impulse response (DRIR) measured in the real environment, to control the apparent distance from a virtual source. Within this model, the sound distance effect is rendered by the modification of the energy of different time segments of the reference DRIR. The extrapolated impulse responses are then used in a convolution rendering engine to place the virtual source at different distances from the listener. The performance of the model was evaluated using a perceptual test protocol in which the participant was placed in an audio only augmented reality situation in which he or she had to judge the distance of a virtual sound source. Visual anchors (chairs) were also present to help scaling the judgment. Model performance was conducted by comparison with reference binaural impulse responses measured in the test room for each specific distance tested. Statistical analysis of the results, collected from 40 participants over two sessions, demonstrates the perceptually equivalent performance of this model compared to the reference measurements. The criteria judged in the analysis are the average perceived distance, inter-subject and intra-subject variability.



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Test protocol for the perceptual evaluation of auditory distance models in an augmented reality setting. © IRCAM-Centre Pompidou

ACTIVATE

Augmenting the value of conversations with voice technologies

Projet ERC

—

Team Involved: Sound Perception and Design
Funding: ERC Proof of Concept
Calendar: 2020— 2022
Partners: Altavoce SAS, CNRS Innovation

Project ACTIVATE aims to bring to market real-time voice transformation technologies based on ERC CREAM's research in emotion neuroscience, which can augment the value of spoken conversations by adding business-relevant control on emotional expressivity. For instance, in the context of a call-center conversation, our real-time transformation may make an angry client's voice 10% less aggressive, reducing employee fatigue at the end of the day, or make an operator's voice 10% more trustworthy augmenting customer satisfaction after the call.

ACTIVATE is a collaboration between researchers and business developers and will:
1. Conduct market analyses and interviews of industrial players to identify relevant conversational situations in which the technologies can be tested.
2. Identify precise conversation outcomes that have market value.
3. Measure the impact of the voice transformation on these outcomes in a simulated test environment that is near the desired configuration in terms of performance and user performance.
4. Use these results to estimate the value of a minimally-viable product to be taken to market by partner startup Altavoce (http://www.altavoce.tech).
ACTIVATE aims to capitalize on the socio-economic insights provided by ERC CREAM.

SEPIA

Sensory and Emotional Processing in Autism spectrum disorders

Projet ANR Programme blanc

—

Team Involved: Sound Perception and Design
Funding: ANR Programme Blanc (Neurosciences intégratives et cognitives)
Calendar: 2020—2024
Partners: Unité Imagerie et Cerveau (iBrain, Inserm U1253), université de Tours

The SEPIA project combines the expertise of the Sound Perception and Design team in innovative techniques in psychoacoustics with that of the Imaging and Brain Unit at Inserm/université de Tours (Dr. Marie Gomot) in the neuroscientific study of Autism Spectrum Disorders (ASD).
The diagnosis of autism requires the combined presence of social communication disorders and repetitive and limited behaviors. Yet few studies of ASDs include the socio-emotional and perceptual domains. Therefore, it remains to be established whether the difficulties of ASDs are related to specific emotional deficits, sensory peculiarities that would be even more pronounced for social stimuli, or both.
Using the vocal smile as a model, each major step of the Perception-Representation-Action loop will be explored in the same patients: children and adults. At the perceptual level, the neural correlates of encoding auditory regularity to emotional stimuli will be studied using electrophysiology (EEG), while series of smiling or neutral repeated voices will be presented to participants. Mental representations of the prototypical auditory smile and motor and autonomic mimicry will be studied through the collection of behavioral (reverse correlations) and physiological (facial electromyography, pupilometry) data respectively, as participants listen to and judge smiling and non-smiling vocal expressions.
This project will make it possible to dissociate perceptual and emotional processes, and to determine at what level physiopathological processes can intervene, thus offering a new mechanistic insight into the socio-emotional difficulties of ASDs.

REFLETS

Facial and Linguistic Emotional Retroaction in Traumatic Stress States

ANR PROJECT "AAP GENERIQUE 2017"

—

Team Involved: Sound Perception and Design
Funding: ANR, programme blanc « Technologies pour la santé »
Calendar: October 2017— September 2021
Partners: CentraleSupélec (Rennes, France – coordinateur), UMR 8257 Cognac-G (CNRS Paris-Descartes/Service de Santé des Armées), Hôpital militaire Percy et Institut de recherche biomédicale des Armées (France), Dynamixyz (France), HumanEvo (France), Chanel (France)

The project REFLETS (Rétroaction Émotionnelle Faciale et Linguistique et États de Stress Traumatique) focuses on improving the care of those suffering from post-traumatic stress syndrome (PTSD) using a technological system that reacts with the sufferer's capacity to perceive and regulate their emotions. The project is based on technologies recently developed at IRCAM on the manipulation, in real-time, of indicators of smiles in the spoken voice and at CentralSupélec on the video manipulation of visual cues of a smile on a face.
The project focuses on three different disciplines. In the domain of information sciences, the project aims to develop "emotional mirror" technology in which the participant can see and hear themselves, but their emotional tone is manipulated algorithmically (in practice, participants will see and hear themselves with a smile while they express themselves using a neutral tone). In the domains of psychology and cognitive neurosciences, REFLECTS aims at studying mechanisms for perception of oneself and metacognition involved in this paradigm of false feedback. Preliminary studies have already established that hearing oneself speak with a more joyful tone has a positive effect on the speaker's emotions (Aucouturier et al., PNAS 2016). Finally, from a clinical point of view, the project intends to test the therapeutic impact of this type of system to treat patients suffering from deficiencies in self-perception and emotional control (alexithymia) in post-traumatic troubles. The project will lead to clinical trials on a group of PTSD patients selected in collaboration with the Percy Military Hospital.

ELEMENT

Stimulate Movement Learning in Human-Machine Interactions

element-project.ircam.fr

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Team Involved: Interaction, Sound, Music, Movement
Funding: ANR, projet AAP
Calendar: November 2018—October 2021
Coordinator: IRCAM
Partners: LRI, LIMSI-CNRS

The majority of interactions based on movement offer "intuitive" interfaces and trivial gesture vocabulary. While they facilitate the adoption of the system, they also limit the possibility of more complex, expressive, and truly embodied interactions. The ELEMENT project proposes to shift the focus from intuitiveness/naturalness towards *learnabiliy*. Our project addresses computational problems of methodology and modelling.
Firstly, we must create methods to design movement vocabularies that will be easy to learn and compose in order to build rich and expressive phrases of movements. Secondly, we must design computational models capable of analyzing users' movements in real-time to provide diverse feedback mechanisms and multimodal guiding (for example visual and auditive).
This project raises three fundamental research issues:
1. How do we conceive movements and gestures, formed with components easy to learn while supporting techniques for complex interactions beyond simple commands?
2. How do we account for the sensory-motor learning with computational modeling of movement and interaction?
3. How do we optimize the feedback systems and computer guides in order to facilitate the acquisition of skills?
The long-term objective is to encourage innovation in multimodal interaction, from non-verbal communication to interaction with digital medias in creative applications.

theVOICE

Vocal Design for Creative Industries

—

Team Involved: Sound Analysis & Synthesis
Funding: ANR, programme Société de l'information
et de la communication (DS07)
Calendar: January 2018— June 2021
Partners: LIA (Laboratoire d'informatique d'Avignon), Dubbing Brothers

TheVoice addresses voice design for the production of contents in the field of creative industries (films, series, documentaries). This is a particularly important field in terms of industrial possibilities while extremely demanding in terms of quality. The project stems from a simple observation: the production of voices is carried out exclusively by humans in a field that is practically entirely digital. The scientific and technological objectives of the project are to model the "vocal palette" of actors in order to create recommendations of voices by similarity as well as the creation of artificial voices capable of reproducing the vocal identity of an actor. The project will change today's uses through the production and industrialization of new technologies for the creation of natural and expressive vocal contents. The consortium, supported by a major player in the industry of creation of digital contents and made up of renowned research laboratories, aims to consolidate its position of excellence in digital research and technologies "made in France" as well as the promotion of French culture abroad.

EmoDemos

Musical Interactions, Empathy, and Development
Musical learning in the Demos project as seen through cognitive sciences.

—

Team Involved: Interaction, Sound, Music, Movement
Funding: Philharmonie
Calendar: janvier 2018 – juin 2019
Partners: Centre interfacultaire des sciences affectives – université
de Genève (coordinator), université de Gênes, Philharmonie de Paris

The main objective of the EmoDemos project was to understand how orchestral practice as proposed by DEMOS:
a) strengthens sensorimotor skills,
b) develops essential executive functions
c) how this collective practice promotes the emergence of so-called «soft skills», cognitive and emotional skills that are central to establishing a relationship and becoming a member of a group.
The methods implemented in this study sought to characterize this cognitive and emotional development throughout the years of DEMOS training. In this context, the ISMM team implemented a series of pilot tests designed to measure certain skills related to collective practice, such as synchronization, imitation or sharing, through scenarios of collective musical interactions.

CREAM

Cracking the Emotional Code of Music

cream.ircam.fr

—

Team Involved: Sound Perception and Design
Funding: ERC Starting Grant program 335536
Calendar: October 2014— September 2019
Partners: Centre de recherche de l'Institut du cerveau et de la moelle épinière (CRICM UMR7225).

The CREAM project's objective was to produce technology and knowledge that make it possible to characterize which type of musical signal sets off which type of brain mechanism of emotional induction.
Until now, research in musical cognition has focused on correlations between relatively indistinct emotional reactions and loosely controlled musical stimuli: we know that music creates emotions, but we do not know how. The CREAM project made it possible to combine current neuroscience methods with a high technical level of signal processing to create, for the first time, musical stimuli capable of selectively causing or inhibiting certain cortical circuits involved in emotional processing so they could be studied in isolation. For example, the project highlighted a phenomenon of facial imitation of the smile in speech by constructing vocal sounds with spectral characteristics reminiscent of a smile.
These new experimental control techniques make it possible to expand our current understanding of brain mechanisms of emotional induction, but also to conceive several clinical applications for therapy or diagnosis of depression or neurodegenerative illnesses. In other words, the CREAM project turns music into a real clinical technology capable of stimulating specific neuronal circuits in a non-intrusive and non-pharmacological manner.

Symbioz

Sound Design and Human-Machine Interface of an Autonomous Electric Car

—

Team Involved: Sound Perception and Design
Funding: Groupe Renault
Calendar: 2016 – 2017
Partners: Renault – department Design et Laboratoire collaboratif d'innovation (LCI)

The Renault Symbioz demo-car is a project for an autonomous electric vehicle that embodies the manufacturer's vision for 2030 in terms of new forms of mobility and new uses for the automobile. This project is the result of a collaboration between Renault's Design and Innovation laboratories and the Sound Perception and Design team associated with the sound designer Andrea Cera.
The Symbioz project involves two major issues: the design of an exterior sound signature and the design of a range of interior signage sounds.
The sound signature is activated between 0 and 30 km/h - the speed range during which an electric car is silent. Its characteristics are the result of two previous projects developed by the same team (the Trezor concept car and the Zoé series model). Its sound, powerful without being aggressive, is a hybrid between electric components and turbine, with a slight reminder of the combustion engine.
Interior signage (sound MMIs) has been developed, in an innovative way, on the basis of two major concepts:

- Exhaustiveness: the project specifications required that all driver/passenger/passenger/cabin interactions related to the operation of the Symbioz be handled. As such, the autonomous driving mode opens up an entirely new scope in terms of user experience and represents a new sound design challenge of how to communicate the car's different levels of autonomy and reassure passengers when the car is in autonomous driving mode.
- Spatialization: the project was an opportunity to develop an original concept of spatialized sound HMIs. Each sound emitted in the passenger compartment (indicators, alarms, informative sounds, etc.) is positioned in a virtual acoustic space. By moving slightly in space, these sound signals adapt to different driving modes and also become less intrusive and more natural - the changes in position resulting in subtle alterations in timbre due to phase shift and reverberation on the walls of the passenger compartment.

Symbioz's sound design work has been recognized by international professionals as «Better Sound 2018» by the Audio Branding Academy.

CoSiMa

Collaborative Situated Media

cosima.ircam.fr

—

Teams Involved: Interaction, Sound, Music, Movement and Acoustic and Cognitive Spaces
Funding: ANR, programme Contenus et interactions
Calendar: November 2013— April 2017
Partners: Orbe, EnsadLab, ID Scenes, ESBA TALM, No Design
Coordinator: IRCAM

In the past decade, we have seen a huge change in media and their relationship with bodies and space with tangible interfaces, augmented reality, and ambient Internet. As a part of this movement, the CoSiMa project explored the relationship among body, media, and space via new interfaces and tools for collaborative creation. The aim of CoSiMa was to implement a platform for publishing and disseminating medias situated in space and time, combining several sensory modalities.

The CoSiMa project is based on three complementary axes. The first axis, technological, was dedicated to the implementation of an accessible platform to implement and democratize new types of collective and collaborative musical experiences. This open source technological platform relies in particular on new Web standards (notably WebAudio API, WebSockets) to allow the public easy access—through the browser of a cell phone or a tablet, for example—to multimedia experiences in which everyone can interact collectively.

The second axis focused on exploring the new uses which these technologies have opened up to develop collective and participatory experiences in different contexts: musical creation and live performance, but also education. In particular, this research relied on numerous collaborations including artists, designers, and educators to explore and propose new ways of perceiving and interacting together.

The third and final axis focused on supporting the development of communities around these different issues, for example through the organization at IRCAM, in 2015, of the first Web Audio Conference (WAC) in collaboration with Mozilla, Google, and the W3C.

KRUG

Immersive Sound Design for an Augmented Tasting Experience

—

Teams Involved: Sound Perception and Design and Acoustic and Cognitive Spaces
Funding: Maison KRUG
Calendar: 2017 – 2018
Partners: Maison Krug – Oenological team and the Communication and Marketing team, IRCAM Production department, Amadeus

The Krug project is the fruit of a creative collaboration with one of the oldest French champagne houses (1843). It aims to create an enhanced multi-sensory tasting experience by combining sound works with champagne vintages made from elementary wines originating from different regions. Its objective is to create correspondences between the oenological characteristics of these regions and established sound properties, in order to inform the sound design and express, through sound, the singularities and similarities of the different wine-growing areas. It deploys a collaborative design methodology (co-design) that notably associates Krug's oenology experts and researchers from the Sound Perception and Design team associated with composer Roque Rivas. The project is implemented in a tasting room equipped with a multi-speaker system that makes the experience immersive by integrating the spatial dimension of sound in the composition. This part of the project is made possible thanks to the contribution of the Acoustic and Cognitive Spaces team and the IRCAM production department, which is embodied in particular by the presence of a sound engineer associated with the project (Clément Cerles) from the phase of realization of the first sound sketches, to the final phase of in situ mastering, through the various stages of design in the studio.

For sound design research, one of the main challenges of the project lies in the concept of semantic transformation and is embodied in the co-design methodology implemented.

Semantic transformation is a process of association between words related to an intention or a definition (here the «wine words», terms defining the different oenological identities,) and terms capable of expressing design ideas (here the «sound words», sound attributes allowing to design sound material). Co-design is one of the methodologies for implementing semantic transformation. It is a creative approach based on a participatory principle and on the assumption that experts in a field can also, or even more so, provide solutions to a design problem. In the project, this approach was notably based on a sound lexicon developed and adapted by the team (Speak, p. 57).

Multisensory and Emotion Integration

—

Teams Involved: Acoustic and Cognitive Spaces

Over the past twenty years, new types of exposure therapy using virtual reality technologies have been developed for the treatment and rehabilitation of emotional disorders, including phobias. Virtual Reality (VR) offers a very powerful control of the sensory and spatial presentation of stimuli, allowing better control of the emotional impact of anxiety-inducing situations to which the patient is exposed. However, in order to exploit these unique benefits of VR, more knowledge is needed about the links between the presentation characteristics of stimuli and their emotional effect.
We explored these links in virtual crowds. Fear of crowds is a symptom found in several emotional disorders (agoraphobia, social phobia, fear of falling...) and has both sensory (auditory and visual) and spatial components, making crowds an ideal stimulus for our studies.
A study was conducted on two groups of participants (with a fear of crowds or not), immersed in a visuo-auditory environment containing virtual crowds, who were asked to indicate the intensity of their discomfort. The sensory presentation of the crowds was either visual or auditory, or both visual and auditory. The results indicate that the visual-auditory presentation amplified negative feelings in participants who were sensitive to crowd fear. However, this effect was only observed when the crowd was close to the participant. This result reveals the interaction of the spatial and sensory characteristics of the anxiogenic stimulus on the emotional impact. This spatial dependence has motivated the initiation of a research component devoted to the study of peri-personal space. Humans do not perceive space in a homogeneous way: the brain codes space close to the body differently from far space. Peri-personal space (near the body) is coded by multisensory neurons. We seek to highlight the plasticity of the limits of this space according to the nature of the sound and the emotional or social context.

VR device in IRCAM's studio 4. Visual stereo is projected on a large screen.
The visual and auditory information is updated by a position tracking system.

GEMME

Musical Gesture: Models and Experiments

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Teams Involved: Analysis of Musical Practices and Interaction,
Sound, Music, Movement
Funding: ANR, programme Blanc SHS
Calendar: November 2012— June 2016
Partners: université de Nice-Sophia Antipolis
(CTEL : Centre transdisciplinaire d'épistémologie de la littérature)
Coordinator: IRCAM

In the beginning of the 21st century, gesture became a significant means of interaction with technology for the general public, and also within the musician community. While musical writing has put a strong emphasis on deconstructing and reshaping the acting body of the musician-performer for nearly 50 years, it is interesting to note that for the past 10 years there has been a strong multidisciplinary convergence on this research/creation topic, drawing the attention of composers, performers, and computer scientists as well as the domains of engineering, psychology, physiology, biomechanics, and cognitive sciences. This concept of gesture, commonly used in numerous domains, notably in the performing arts such as theater and dance, has only been the subject of embryonic research in the domain of musicology. The GEMME project offers an analysis of theoretical texts and musical works, and also carries out investigations before and after the premiere of a score: what theoretical and technical possibilities of the formalization of gestures are available to composers? What gestural procedures can they test on paper and during the performance of a work? What means of transmission of the gestural information are created not only during the collaboration between composer and performer, but also when the performance of the work is taught? This project endeavors to answer these questions via four main themes:
1. Tacit Theories of Gesture: genealogy of the compositional notion of gesture, its categorizations and periodization, the current state of the art
2. Gesture and Stage: study of a paradigmatic method—that of Kagel—where the musical idea is connected to its staged expression in the framework of musical and instrumental theater
3.Gesture and Instrument: study of a contrasting paradigmatic method—that of Lachenmann—where the composition calls upon a breakdown of the organological possibilities of sound production in relationship with a political and social criticism of expressive conventions
4.Gesture and Technology: a series of musical analyses of a group of seminal scores, from Ferneyhough's Time and Motion Study II to Luna Park by Aperghis, that offer a variety of technical and computing paradigms that formalize and/or accompany the instrumental gesture.

C3. Creative dynamics

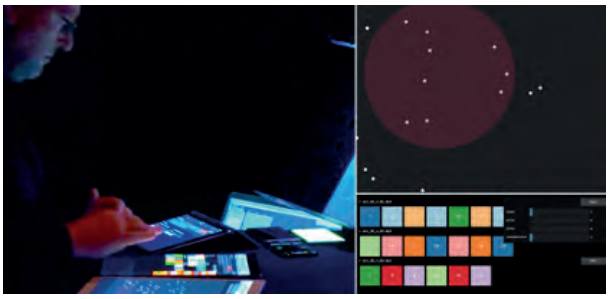
Distributed and Interactive Sound Systems

—

Teams Involved: Interaction, Sound, Music, Movement

This project, which is part of the follow-up of the CoSiMa (p 44) and Wave (p 58) projects, concerns the development of software and theoretical tools dedicated to the implementation of distributed sound and interactive systems on a large number of devices, relying in particular on the technologies. This project aims, in particular, to consider and facilitate the creation of new musical scenarios ranging from distributed spatialization (p. 34, 35) to collective interactions. In addition to the production of several pieces, concerts, and installations, this project has also opened up new perspectives for scientific research, for example, on the study of movement in situations of collective interaction (EmoDemos, p. 42).

An important aspect of this project is now focused on developing a hybrid environment that can combine computers, smartphones, and/or embedded systems, enabling new possibilities for expressive and synchronized interactions. This approach is also accompanied by important work on the implementation of tools and interfaces that make it possible to extract the complexity of these systems and therefore allow artists and researchers to appropriate and manipulate them more.



1/ The Playground application, used by the composer Garth Paine during his residency at IRCAM.

2/ *The Constellactions project* by composer Michelle Agnes Magalhaes, using the CoMo-Element application.

3/ *The Poly project* by Benjamin Matuszewski.

WASABI

Web Audio Semantic Aggregated in the Browser for Indexation

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Teams Involved: Analysis of Musical Practices, Sound Analysis & Synthesis, IRCAM Resource Center Funding: ANR, programme générique

Calendar: October 2016 — March 2021

Partners: I3S (coordinator), Parisson, Deezer, Radio France

The goal of the WASABI project is to define an optimized methodology for indexing music for the Web for large databases by linking metadata from audio analysis, Semantic Web techniques, and the analysis of textual data such as song lyrics using natural language analysis and to compare this methodology with case scenarios to develop unique services and applications using Web Audio technologies.

The project entails using algorithms to extract musical information and Semantic Web techniques to produce more consistent musical knowledge bases for streaming services and music databases. Services using Web Semantic data like LastFM, MusicBrainz, or DBPedia use the extraction of structural data, connecting works to metadata such as the producer, the recording studio name, the composer, the release year, or the subjects in the lyrics for example. The data in free text like the lyrics are also analyzed to determine the musical context of the piece. Web Audio technologies make it possible to explore these musical spaces improved with analyses such as high-level musical indexation: detecting emotion and plagiarism, detecting and characterizing the singing voice, detecting the structure and separating the different sources.

Open source software bricks and "open data" online services will be proposed at the end of the project for:

- The visualization of audio metadata and listening to unmixed tracks in a browser as well as using the latest Web Audio API technologies (mixing in real-time, audio effects)
- Automatic processing of lyrics, recognition and merging named entities, collaborative annotation and correction
- Access to a Web service with an API offering an environment in which to study musical similarities from audio and semantic analyses

These software bricks will be used in the development of formalized demonstrators with our partners and collaborators (journalists and composers), using the new Web Audio API standard making it possible to develop musical applications accessible to the general public via a Web browser.

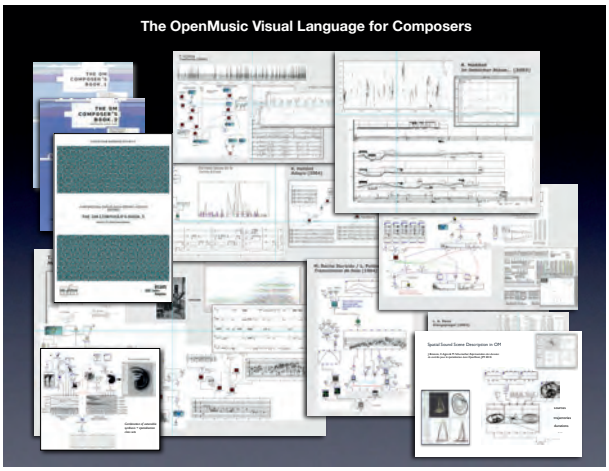
Computer Assisted Composition: Writing Sound, Time, and Space

—

Team Involved: Musical Representations

The purpose of research in computer-assisted composition (CAC) is to study and design models and computer techniques adapted to the creative process, incorporating paradigms for calculations as well as musical interactions and representations. This approach favors symbolic orientation using programming languages for artistic creation and processing harmonic, temporal, and rhythmic data in addition to other aspects that come into play in the compositional process. Our work in this domain is articulated primarily around the OpenMusic environment, a visual programming language based on Common Lisp and dedicated to musical composition. Contemporary music composers have used this environment for the past 15 years. Today, is regarded as one of the principle references in computer-assisted composition. Taught in top computer-music centers and dozens of universities in Europe and around the world, it has been downloaded by several thousand users.

OpenMusic (OM) is a visual programming environment for composition or musical analysis assisted by computer. OM offers users a range of interconnected modules associated with specific functions, making up patches that enable the creation or transformation of musical data structures. OM also offers several editors to manipulate these data in addition to libraries in specialized sound analysis and synthesis, mathematical models, the resolution of constraint problems, etc. Unique interfaces like the maquette editor let users construct structures that include functional and temporal relationships among musical objects. The expressive richness of CAC environments is largely due to the junctions between temporal and functional relations within musical structures it enables. OpenMusic is used by a large number of composers and musicologists, and is taught in leading music computer centers as well as in several universities in Europe and around the world.



Recently, a new computing and programming paradigm has been proposed based on OpenMusic, combining the existing functional/demand-driven approach with a reactive approach inspired by event-driven interactive real-time systems. The integration of execution and calculation loops of musical structures enables the activation of reactive chains in visual programs, and increases the possibilities of interaction in the CAC environment: a change or an action by the user (event) in a program or in the data that compose it, produces a series of reactions leading to its update (re-evaluation). The CAC environment is then inserted into the temporality of a larger system, and can be potentially controlled by the events and interactions produced by or in this system. This temporality can be that of the composition process, or that of performance. This project has produced the OpenSource software OM#, which is now developed independently of IRCAM.

The technologies of sound signal analysis, processing, and synthesis allow us to envisage new writing modalities that assimilate sound creation at the heart of musical composition. OpenMusic allows the integration of such technologies via a set of specialized libraries linking programs created in the CAC environment to sound processing, synthesis or spatialization processes (realized notably by IrcamTools: SuperVP, Pm2, Chant, Modalys, Spat^, but also external tools such as Csound or Faust). This convergence of the fields of sound and CAC constitutes a new approach to sound representation and processing through programs and high-level symbolic data structures.

Developed in collaboration with the composer Marco Stroppa, the OMChroma library provides the ability to control sound synthesis processes using matrix data structures.

Its extension to for the field of spatialization, OMPrisma, allows the realization of «spatialized sound synthesis» processes, involving spatialization (positions and trajectories, but also room characteristics, orientation or directivity of sound sources) at the same time as sound production. Controlled in OpenMusic through a set of graphical editors and operators, these tools offer a range in the conjoint specification of synthesized sounds and spatialized scenes. The OM-Chant project has recently brought the technology of synthesis by FOFs (formantic wave functions) back to the forefront and has made it possible to create synthesized sounds, inspired by a speech production model, in the core of CAC processes.

REACH

Raising Co-Creativity in Cyber-Human Musicianship

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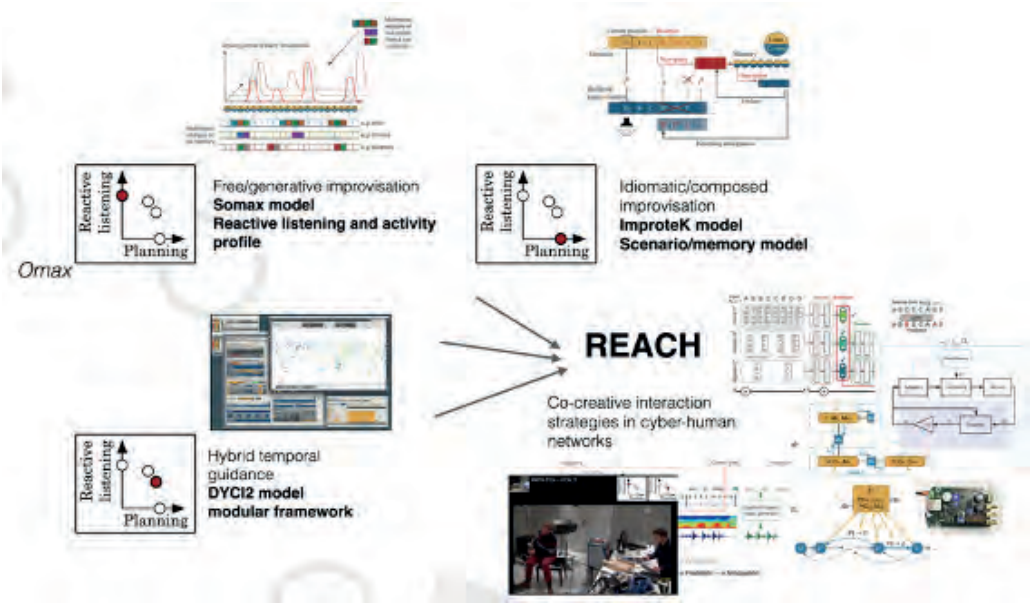
Team Involved: Musical Representations
Funding: European Research Council Advanced Grant;
Principal Investigator: Gérard Assayag (2021—2025)
Partners: CAMS / EHESS, UCSD

Digital cultures are increasingly pushing forward a deep interweaving between human creativity and autonomous computation capabilities of surrounding environments, modeling joint human-machine action into new forms of shared reality involving ««symbiotic interactions" found in the arts and, more generally, in almost any human endeavor. Co-creativity between humans and machines will bring about the emergence of distributed information structures, creating new performative situations with mixed artificial and human agents. This will disrupt known cultural orders and significantly impact human development. Generative learning of symbolic representations based on physical and human signals, as well as the understanding of artistic and social strategies of improvisation, will help us to better comprehend the dynamics of cooperation (or conflicts) inherent to cyber-human bundles.

To this end the REACH project aims at understanding, modeling, and developing musical co-creativity between humans and machines through improvised interactions, allowing musicians of any level of training to develop their skills and expand their individual and social creative potential. Indeed, improvisation is at the very heart of all human interactions, and music is a fertile ground for developing models and tools of creativity that can be generalized to other activities, as in music the constraints are among the strongest to conduct cooperative behaviors that come together into highly integrated courses of actions. REACH will study shared musicianship occurring at the intersection of the physical, human and digital spheres as an archetype of distributed (natural / artificial) intelligence, and will produce models and tools as vehicles to better understand and foster human creativity in a context where it becomes more and more intertwined with computation.

REACH is based on the hypothesis that co-creativity in cyber-human systems results from a an emergence of coherent behaviors and non-linear regimes of event and structure formation, leading to a rich co-evolution of musical forms. These phenomena result from cross-learning processes between agents involving feedback loops and complex reinforcement mechanisms. REACH will study these mechanisms in vivo and in vitro, and will produce creative tools through the convergence of methods from research in interactive computational creativity, artificial intelligence and machine learning, social sciences with the anthropology of improvised practices (collaboration with CAMS at EHESS), and instrumental mixed reality systems (collaboration with the company HyVibe).



MERCI

Mixed Musical Reality with Creative Instruments

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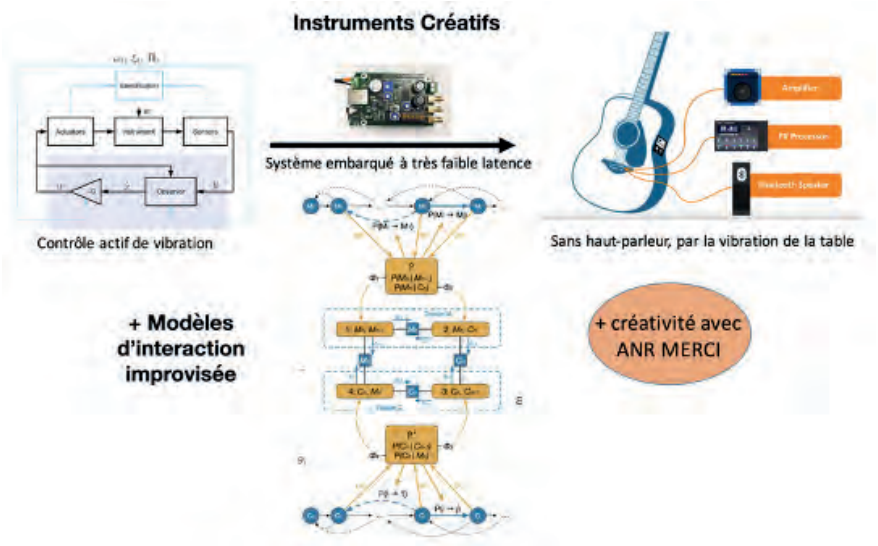
Team Involved: Musical Representations
Funding: Projet ANR
Calendar: 2020-2022
Partners: HyVibe, CAMS / EHESS

Improvisation is a major driver in all aspects of communication and action in human interaction. In its highest form, musical improvisation is a combination of structured, planned actions and unpredictable localized decisions and differences, optimizing the adaptation to the context, expressing the subject's creativity and stimulating coordination and cooperation between agents. The implementation of powerful and realistic human-machine environments for improvisation requires going beyond the software engineering of creative agents with the capacity to listen and generate audio signals. This project proposes to fundamentally renew the paradigm of improvised man-machine interaction by establishing a true continuum from co-creative musical logics to a form of «physical interreality» (a mixed reality scheme where the physical world is actively modified by human action), human subjects are immersed and engaged in tangible actions allowing for full embodiment in the digital, physical and social worlds.

The main objective of this project is to create the scientific and technological conditions for the emergence of mixed reality musical systems, allowing improvised human-machine interactions based on the interrelation of creative digital agents and the active acoustic control of musical instruments. We call these mixed reality devices creative instruments. The functional integration of creative artificial intelligence and active acoustic control into the organological core of the musical instrument, in order to promote plausible situations of physical interreality, requires the synergy of highly interdisciplinary public and private research, such as that provided by the partners. This evolution is likely to disrupt artistic and social practices and, in the long run, have a powerful impact on the music industry as well as on amateur and professional musical practices. A creative instrument will be able to constantly listen to the performance of the musician who plays it, in order to determine his/her musical orientations, and to interact creatively with him/her in an unprecedented experience of mixed musical reality where the sounds produced by the performer and those created artificially will blend together in a meaningful musical polyphony. This mixed musical reality will unfold in the melodic, harmonic, rhythmic, and orchestral dimensions of the music, with a creative musical companion located at the very heart of the instrument and acting as an artistic avatar, a creative assistant, a partner, a new incentive to learn, practice, and communicate in a musical language.

1/ The HyVibe Guitar control panel

2/ Early SmartInstrument violin prototype at IRCAM



ACIDS

Artificial Creative Intelligence and Data Science

acids.ircam.fr

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Team Involved: Musical Representations

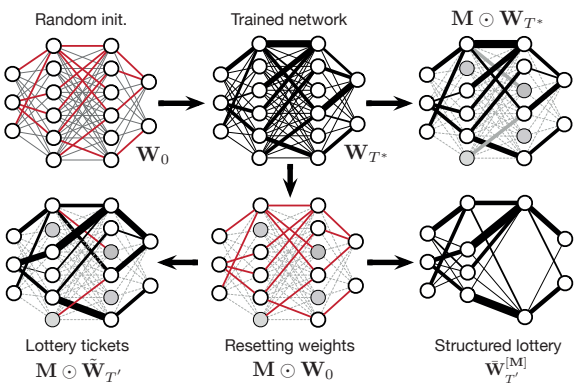
The objective of the Artificial Creative Intelligence and Data Science (ACIDS) project is to model musical creativity by developing innovative artificial intelligence and machine learning models and to provide tools for intuitive exploration of creativity. The project provides extensive theoretical, modeling, and tool experimentation activity.

The study of creativity in interactive human-AI situations is crucial for the understanding of «symbiotic» interactions. The availability of artificial intelligence models capable of demonstrating creative behaviors could give rise to a whole new category of generic creative learning systems.

Time is the very essence of music, and yet it is a complex, multi-scale, multi-faceted fact. This is why music must be examined at varying temporal granularities, as a multitude of time scales coexist (from the identity of individual notes to the structure of entire pieces). We therefore introduce the idea of learning about deep temporal granularity, which could allow us to find not only the salient features of a dataset, but also the time scale at which it behaves best.

For example, we recently developed the first Live Orchestral Piano system with automatic learning of piano/orchestra repertoires (ACTOR project), which allows you to compose music with a classical orchestra in real-time by simply playing on a MIDI keyboard. By observing the correlation between piano scores and corresponding historical orchestrations, we could deduce the spectral knowledge of composers. The probabilistic models we are studying are neural networks with conditional and temporal structures.

ACIDS encourages an interactive, user-centered model where the goal is to put the focus on the human. For example (see collaborations with the team's REACH and MERCI projects), collective human-machine interactions, including improvisation, interest us as a general model of human interactions in which decisions, initiatives, and cooperation are all at work, and constitute an ideal observation and vantage point for understanding and modeling symbiotic interaction in general.



While most current research attempts to surpass previous approaches by using more complex and cumbersome models, we encourage the need for a simple and controllable model. In addition, we believe that truly intelligent models should be able to learn and generalize from small amounts of data. One of ACIDS' core ideas is based on the assumption of multiplicity. This concept asserts that very complex information could be found in a simpler and more organized space in its original form. We therefore intend to model the high-level semantics of music through the notion of latent spaces. This could lead to an understanding of the complex characteristics of music but also to the production of understandable control parameters.

We study the relationships between different instrumental timbres, based on perceptual notations. However, they allow only a limited degree of interpretation, there is no capacity for generation and no generalization. In ACIDS we are studying variational auto-encoders (VAE) that can compensate for these limitations by regularizing their latent space during training to ensure that the latent space of the audio tracks the same topology as that of the perceptual timbre space. In this way, we bridge the gap between analysis, perception, and audio synthesis in a single system. Sound synthesizers are ubiquitous in music, and they even now completely define new musical genres. However, their complexity and parameters make them difficult to master. We have created an innovative generative probabilistic model that learns an inversable correspondence between the continuous latent auditory space of a synthesizer's audio capabilities and its parameters. We approach this challenge by using variational auto-encoders and standardizing the audio streams. Thanks to this new learning model, we can learn the principal macro-commands of a synthesizer, allowing us to travel through its multitude of organized sounds, make parameter inferences from the audio to control the synthesizer with our voice, and even tackle the learning of the semantic dimension where we find out how the commands adapt to given semantic concepts, all in a single model.

ACIDS' work is regularly used in contemporary creation, for example in the production of the voice of a synthetic opera singer (*La fabrique des monstres*, Ghisi / Peyret) or collaborations with the composer Alexandre Schubert on gestural learning and capture.

SKAT-VG

Sketching Audio Technologies using Vocalizations and Gestures

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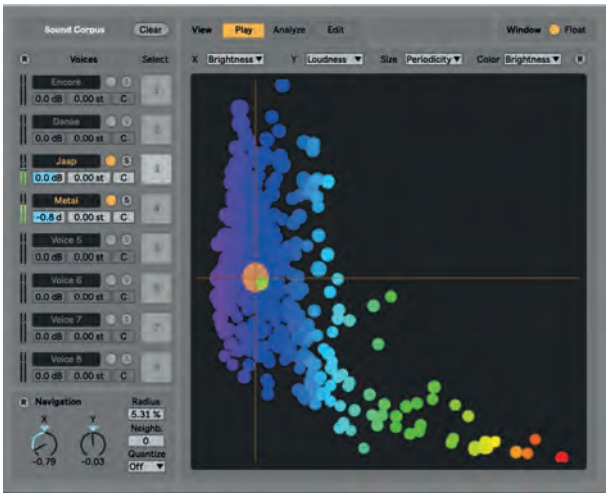
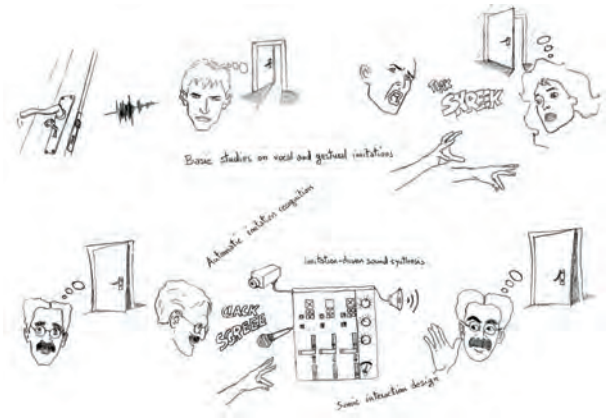
Teams Involved: Sound Perception and Design, Sound Music Movement Interaction, Sound Analysis & Synthesis
Calendar: January 2014—January 2017
Funding: Objective ICT-2011-C, FET-Open: Challenging current thinking FP7, European Commission
Partners: IUAV (Universita Iuav di Venezia), KTH (Kungliga Tekniska Högskolan), GENESIS (Genesis Acoustics)
Coordinator: IUAV (Universita Iuav di Venezia)





Sketching is a fundamental step in design activities. The SkAT-VG project explores the capacity of voice and gesture to transpose the «paper / pencil» paradigm widely used in visual design for sound design, . It aims to allow designers to use their voice and hands directly to sketch the sound characteristics of an object, facilitating the exploitation of the functional and aesthetic possibilities of sound. The heart of the project lies in a device capable of interpreting users' intentions expressed through vocal and gestural imitations, selecting appropriate sound synthesis modules, and therefore making it possible to share and refine ideas.
The main tasks of the project include case studies around sound communication, analysis of expert practices, experimental and fundamental studies on sound identification, gesture analysis, machine learning, and the development of sound sketching tools.
The objectives of the project are to extend existing knowledge in the field of sound perception through imitation, to develop automatic classification algorithms by combining the analysis of the sound signal of imitation with physiological mechanisms of voice production, to explore the effectiveness of sound and gesture sketches in the field of interactive sound design, and to develop applications for intuitive sound creation and processing, using voice and gesture.
One of the technological developments of the project is embodied in the SkataRT environment, a Max for Live software brick that permits sound synthesis by corpus, controlled by voice and gesture and articulated in 2 main steps:

- an exploration of a 2D space on which grains of sound are projected (CataRt)
- the capture of a vocal imitation, its analysis and its modeling in the form of a parameterizable sound sketch exploiting a CataRt type corpus synthesis.

This tool is intended to be tested and then integrated into the sound design work process and will also be used to investigate the question of sound prototypes.

Urban and Landscape Composition

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Teams Involved: Acoustic and Cognitive Spaces

The artistic residency of Nadine Schütz focuses on the integration of acoustic qualities and sound compositions within urban and landscape projects. The aim is to compose from, with and within the existing, a condition inherent to this type of project and to question the application of ambiences and impulse responses (IR) recorded in HOA format (MHAcoustics® EM32 microphone), as well as the associated spatialization tools throughout the different stages of the artistic project. This work was organized around the case study of the Place de La Défense, in collaboration with the landscape-urban planning team in charge of a global renovation project. In order to capture the ambient quality and significant sound events linked to the different uses of the site, several recording sessions were carried out in situ, at different times of day, days of the week and seasons. These data were evaluated in the studio to identify tracks likely to enrich urban and landscape composition methods. The IR of the Place de la Défense, a very atypical space in terms of its dimensions, gave rise to special analysis and post-processing procedures (see SRIR analysis-synthesis, p. 27).

These recordings and measurements are used to reconstruct a composition environment in the studio that reflects the key features of the existing sound environment of the work's destination site. They simulate the integration of new sound sources in this same context. They also give rise to the creation of auditory models that play the role of a dreaming thread (Leitbild) for the creation stage of the sound material, considering the technical constraints of the site and the device to be set up. The design of the device, a combination of physical structures and electroacoustic components, is an integral part of the work.

Currently, the creation-research interaction deals with the exploitation of IR descriptors as structuring composition material.

The project: cloud-shaped 'parasols' incorporate the electroacoustic device and create an intimate local acoustic atmosphere.

MICA

Musical Improvisation and Collective Action

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Teams Involved: Analysis of Musical Practices, Sound Perception and Design, Sound Music Movement Interaction
Funding: ANR, programme JCJC
Calendar: March 2018 – February 2021
Partners: Sorbonne Université, EHESS Coordinator: IRCAM

Collective improvisation is everywhere in our lives, from street protests to brainstorming sessions at work, from playing football to cooking meals. But how do we do to act together in a way that is both creative and spontaneous? The MICA project aims at analyzing such spontaneous interactions and emergent coordination through the lens of musical improvisation, with a special focus on collective free improvisation. We believe that musical practices make for a wonderful laboratory for the study of joint action and that improvisers can teach us many valuable lessons on how we can do complex things together on the fly. The project is at the crossroads between musicology, cognitive sciences and philosophy, mixing ethnographical inquiries in the field, empirical studies in the recording studio, and conceptual analysis in the armchair. Overall, the project aims at elaborating theoretical frameworks for emergent coordination and improvised joint action that are substantiated by rigorous data collection, hoping to shed light on a fundamental aspect of our social lives.

Jeanne Suzin (piano) and Basile Naudet (saxophone) during an experiment organized at IRCAM in February 2020.

Computer-Assisted Orchestration

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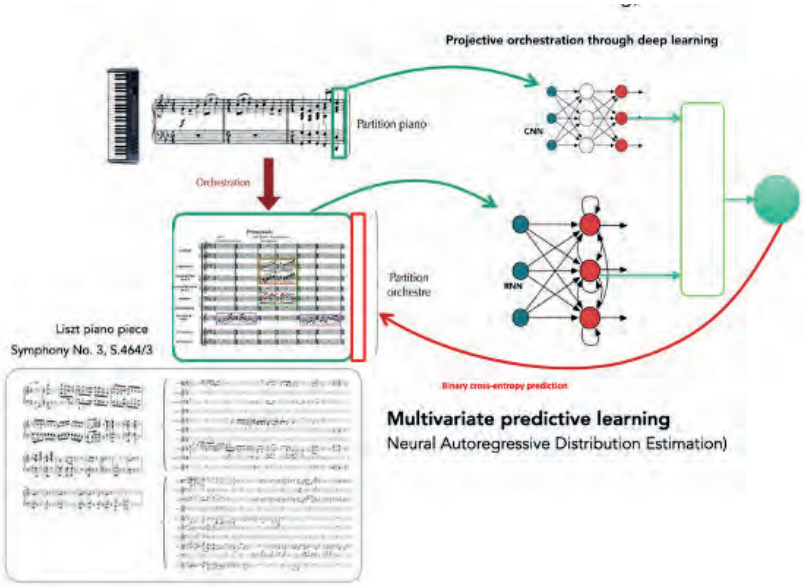
Team Involved: Musical Representations

This project addresses the question of orchestration via an automatic search of instrumentation and layering instruments approaching, depending on different acoustic similarity criteria, a target defined by the composer. Current research endeavors to make this dynamic orchestration paradigm heard, according to the targets with sonorous characteristics that vary with time.

Realized after the Orchidée software suite, Orchids is the first complete system in the Orchid* system for temporal computer-assisted orchestration and the optimization of timbre combinations. It provides an ensemble of algorithms making it possible to recreate any sound target that changes over time through a combination of instruments or samples, according to the psycho-acoustic criteria. This can help composers obtain unique timbre colors providing a multitude of effective solutions to best recreate the sound target. Through a large selection of functions, Orchids can also recreate the evolutions and abstract forms of spectral movements. Its results provide multiple orchestra scores that can be organized intuitively in order to quickly construct orchestral and musical ideas. This system provides several approximation algorithms that make it possible to conjointly optimize several timbre features. The advantages of the Orchids system lies in the fact that this approximation can be carried out separately on temporal forms, values, mean values or standard deviations (or any combination of the three) of each psycho-acoustic descriptor. In addition, users can also manually define a temporal deformation and carry out a multi-target search within several sound segments, making it possible to create full orchestral works in just a few seconds.

The new version of the Orchid* series, Orchidea, developed in the Musical Representations team in collaboration with the Haute École de musique de Genève, is based on orchids and is designed to further optimize analysis, research, and interfaces. It is now available in open-source, and offers significant optimizations and greater reliability of results.

In addition to the production of Orchid* flagship software programs, IRCAM's orchestration project has led to numerous national and international collaborations coordinated by the institute's Musical Representations team: the ANR MAKIMONO project explores the contributions of artificial intelligence and machine learning to timbral and orchestral synthesis; the Orchestration project funded by the Social Sciences and Humanities Research Council (SSHRC) with the Haute École de musique de Genève (Switzerland) has laid the foundations for a vast international project involving 19 American and European partners, and finally, the ACTOR project that explores all facets of orchestration, from modeling to education and which started in 2019.



(DYCI2) Creative Agents, Improvised Interactions, and "Meta-Composition"

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Équipe concernée : Représentations musicales

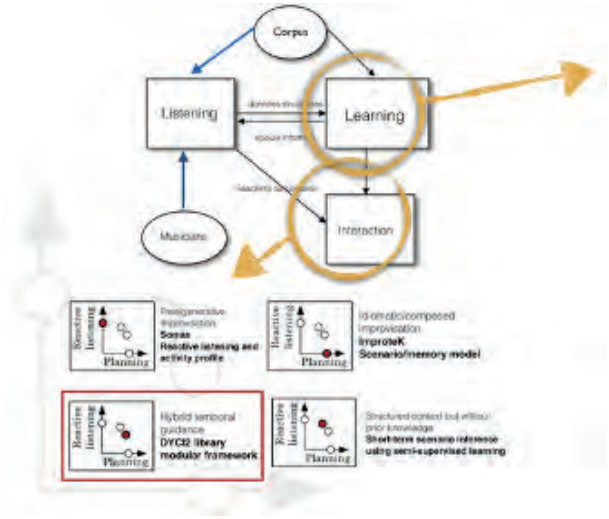
The team explores the paradigm of computational creativity using devices inspired by artificial intelligence, in the context of new symbolic musician-machine interactions or in the context of data science and knowledge extraction.

In the tradition of the OMax software program, research on learning and interactive music generation has led to the creation of several paradigms of musician-machine interaction characterized by an architecture combining artificial listening to the signal, discovery of a symbolic vocabulary, statistical learning of a sequence model and generation of new musical sequences by reactive and/or planning (scenario) mechanisms.

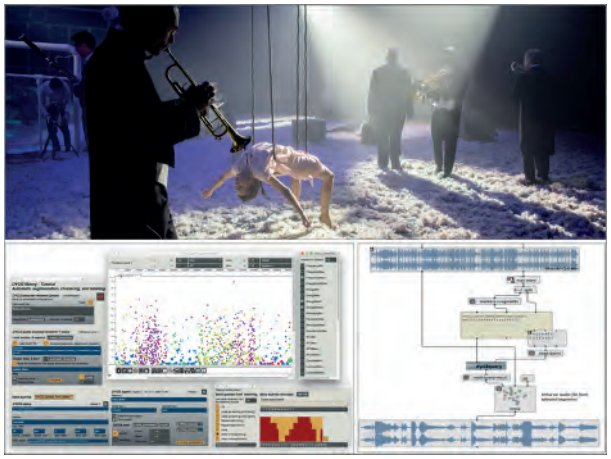
The ANR DYCI2 project (2015-2018) has given birth to DYCI2lib, a library containing a collection of generative agents and tools for smart composition and human-machine co-improvisation. These agents combine machine learning models and generative processes with reactive listening modules. This library offers a collection of "agents/instruments" embedding free, planned and reactive approaches to corpus-based generation, as well as models of short-term dynamic scenarios («meta-Djing»). This axis of research emphasizes improvised interaction, as an anthropological and cognitive model of action and decision, as a scheme of discovery and unsupervised learning, and as a discursive tool for human - digital artifact exchange, in a style and interaction modeling perspective. The objective is to constitute autonomous creative agents through direct learning resulting from exposure to the live performance of improvising human musicians, by creating a loop of stylistic feedback through the simultaneous exposure of humans to the improvised productions of the digital artifacts themselves, thus starting from a situation of human-artefact communication evolving in a complex dynamic of co-creativity.

These agents/instruments are also a part of a study on new generative paradigms «informed by AI», working, for example, on the association of generative mechanisms with modules for the extraction and inference of a harmonic grill in real-time.

After having been the foundation of large-scale productions that were validated by expert musicians (Pascal Dusapin, Bernard Lubat, Steve Lehman, Rémi Fox, Hervé Sellin, etc.) as well as workshops and festivals (Festival Improtech Paris-Athina and Paris-Philly; MassMoca, Cycling '74, etc.), the DYCI2 themes continue with the launch of the ANR project MERCI (Mixed Musical Reality with Creative Instruments) project coordinated by G. Assayag with the EHESS and the startup HyVibe with the support of the ERC Advanced Grant REACH led by G. Assayag. Setting up powerful and realistic human-machine environments for improvisation requires going beyond the software engineering of creative agents with listening and audio signal generation capabilities. This line of research proposes to radically alter the paradigm of improvised human-computer interaction by establishing a continuum from co-creative musical logic to a form of «physical interreality» (a mixed reality scheme where the physical world is actively modified) anchored in acoustic instruments.



1/ Human-computer music interaction paradigms



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2/ *Lullaby Experience* (© Q. Chevrier) - DYCI2 Library – om-dyci2 Library

GRIAMI

Group for Interdisciplinary Research on Musical and Interartistic Acts

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Team Involved: Sound Perception and Design
Funding: ITI GRIAMI, université de Strasbourg
Calendar: 2021-2024
Partners: ITI GRIAMI / EA 3402, université de Strasbourg.

This research on the musical act tries to understand how artistic activity and musical intelligence function in their plasticity through practice, learning, and oral/aural creativity, as well as how a social group establishes organizational rules and frameworks for designing particular music.
Orality is a constituent process that can condition and create improvised and spontaneous forms, whether musical or poetic (Lortat-Jacob). The immense musical terrain represented by the Mediterranean basin is a fascinating example of the transfer of cultural elements, but also of the construction of specific identities. The understanding of its mechanisms, involving processes of exchange, interaction, imitation, memorization, reproduction, implies the construction of a comprehensive anthropology of the phenomenon of listening, for which a thorough knowledge of the cognitive aspects, in the relationship that oral music establishes with memory, is essential (Chouvel).
Field investigations and psychological experiments focus mainly on the role of acculturation and the implication of cognitive patterns in listening to the listener, as well as the complex relationships of the creator (improviser, performer) to music, to common culture (the art of emotional bonding, During), and to the norms of tradition; i.e. how, and on what criteria, could the improviser be the bearer of a particular gift for the social group, and have a specific link with what is out of the ordinary and common? We are also interested in the experience and the semantic depth of everything the musician can say about his/her social practice and his/her art; diverse verbalizations, metaphorical formulations, symbolic representations, etc. It is the aesthetic experiences of the subject-actors and the performative and cognitive strategies that are acted upon that hold our attention. These are all cultural and psychological references to be collected in the field of performance, to be analyzed and reported in our «culturalized listening model».

ACTOR

Analysis, Creation, and Teaching of Orchestration

—

Team Involved: Musical Representations
Funding: Social Sciences and Humanities Research Council (SSHRC, 2019 – 2026)
Partners: over 20 American and European institutions

ACTOR is an interdisciplinary partnership involving more than 20 academic, artistic, and private-sector institutions working to develop a 21st-century approach to orchestration.
The ACTOR Partnership proposes to enhance attention to timbre and orchestration by bringing its musical use to the forefront of scholarship, practice, and public awareness with world-class artists, humanists, and scientists. This Partnership links North American and European orchestration practice and pedagogy, stimulates the development of new creativity-enhancing digital tools for learning, creating, and studying orchestration practice in concert, club, film, and video-game music, and sensitizes young audiences to the wonders and complexities of high-quality music.
ACTOR aims to transform music scholarship both through the application of novel analytical tools to uncover the untheorized mysteries in over four centuries of music and through the development of sound-based music analysis tools that can be applied to un-notated music or recordings of notated music.
ACTOR will transform research in the fields of musicology, music theory, music psychology, popular music studies and ethnomusicology where the role of timbre in music has been either ignored or only rarely addressed systematically.
ACTOR will enhance the education of composers, arrangers and orchestrators by providing technological tools for learning the associations between symbolic representations in scores and the sonic result.
ACTOR will create tools to enhance musical creativity related to timbre and orchestration in the many genres of music on stage and at home through computer-aided orchestration environments that integrate cutting-edge signal-processing and machine-learning techniques. To achieve these aims, ACTOR activities are structured into three axes of research dealing with Analysis, Technological Tool Development and Innovative Outputs in several domains. The team is responsible for the second research axis (tool development), and implements a series of studies in Artificial Intelligence and machine learning based on the analysis and generation of orchestration, such as the «Live Orchestral Piano» which automatically arranges piano sequences for large orchestras and synthesizes the result, or which can conversely reduce an orchestral score.

Mathematics and Music

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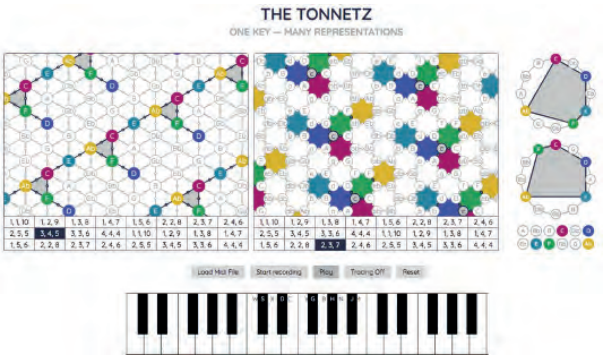
Team Involved: Musical Representations

The SMIR (Structural Music Information Research) project is an extension of the project selected by the CNRS at the time of the creation of a research director's position in the Musical Representations team by expanding the range of mathematical tools at the disposal of the computational musicologist (tools derived not only from algebra but also from topology and category theory). At the same time, it tackles the articulations between scholarly and popular music (rock, pop, jazz and chanson), in a dimension that is both theoretical but also practical and open to the dissemination of knowledge. The project benefits from the support of 4 institutions within the Society for Mathematics and Computation in Music (an international society whose activity has been federated by the Journal of Mathematics and Music): a partnership with the University of Strasbourg (in particular IRMA, the Labex GREAM, the Idex «University and City» and the Garden of Sciences), a collaboration with the Pasteur Institute (in the framework of the «Challenge - Learning Processes and Techniques 2020» financed by the Mission for Transversal and Interdisciplinary Initiatives of the CNRS), and with the University of Padua (creation of a Chair of Visiting Professor for the new doctoral scholarship «Mathematics and Music», 2020-2021). In addition, this project feeds the MaMuPhi (Mathematics, Music and Philosophy) seminar, co-organized with the École normale supérieure and the book collections: Musique/Sciences (Delatour France) and Computational Music Sciences (Springer).

The project is based on an experimental environment for computational music analysis called The Tonnetz, which relies on the functionalities of HexaChord software. Tonnetz is a web environment that makes it possible to construct spatial representations associated with harmonic progressions and to analyze them across several geometric spaces (called the Tonnetze). The environment is commonly used in schools and workshops for the general public as well as in projects for promoting knowledge such as the show «Math'n Pop».



Vertigo

starts.eu:vertigo

—

Departments Involved: IMR, General Direction, Research/Creation Interfaces, IRCAM Resource Center, Communication

Funding: European Commission, H2020 Program, Call ICT36-2016

Calendar: December 2016—May 2020

Partners: Artshare (Belgium), Fraunhofer ICT Group (Germany), Inova+ (Portugal), Culture Tech (France), École polytechnique fédérale de Lausanne (Suisse), Libelium Comunicaciones (Spain) Coordinator: IRCAM

The Vertigo project was written and selected in response to the first call during the European Commission's H2020 ICT program (Information and Communication Technologies) connected to the STARTS initiative (Science, Technology and the Arts). STARTS encourages synergies between artists and R&D projects in the field of ICT supporting innovation and Vertigo was committed to coordinating a range of actions carried out in this regard throughout Europe focusing on three complementary areas:

The organization of artistic residencies in connection with R&D projects via an annual call for propositions and selected by an international and multidisciplinary jury. A budget of 900 K€ is dedicated to supporting 3 annual cycles for a total of 45 artistic residency projects that focus on creating, via the production of unique artistic works, prototypes for innovative products using the technologies developed.

The public presentation of different actions carried out during the new, annual event at the Centre Pompidou: Mutations / Créations. This event features exhibitions, symposia, and artistic events and aims to expose and debate evolutions in artistic practices within the contemporary scientific and technological ecosystem. The theme of the inaugural edition in March 2017, presented in connection with the exhibitions "Printing the World" and "Ross Lovegrove", is "Simulated Space or Digital Forms".

In this project, a communal online platform was developed. This platform enables different parties (scientists, artists, manufacturers, business incubators, investors) to contact each other and offer support for their actions (communication, organization of specific artistic residency programs, etc.). In addition to the consortium partners, the project oversees an international network of 20 correspondents in the cultural field, including Zentrum für Kunst und Media de Karslruhe, The Victoria and Albert Museum in London, the Venice Biennale, the festival Ars Electronica in Linz, etc.

SpeaK

Sound Lexicon to Describe Sound Qualities

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Team Involved: Sound Perception and Design
Funding: Sound Perception and Design team
Calendar: 2018—2019
Collaborations: F. Voisin (development), R. Rivas (creation)

The SpeaK tool is an interface that presents a sound lexicon. The semantic descriptors of the lexicon are organized according to three main classes: timbre (dry/resonant, matte/shiny, smooth/rough, warm, round, rich, nasal, ...), general qualities (bass/treble, tonal/noisy, near/far, ...), and morphology (attack, fall, continuous/discontinuous, constant/fluctuating, ...). The SpeaK tool, in its current form, offers two principal possibilities. The first is to present a definition and a set of sound examples for each of the descriptors of the lexicon proposed by Carron et al (Journal of Design Research, 2017). The sound examples were produced by IRCAM and cover several categories of sources: musical instruments, female/male voice, elementary and complex synthetic sounds. The second possibility is to simply configure the interface to integrate new semantic descriptors and associated sounds. In this way, the lexicon can be expanded or adapted to meet the needs of a specific project. The SpeaK tool ensures a common language to meet different objectives. Within the framework of a sound design project, it can be used to accompany exchanges among different partners. It has been used at IRCAM in design projects with SNCF, Krug and by Ircam-Amplify with Sorbonne University (SU). In a educational framework, it could be used to learn how to listen and name sound qualities. The prospects for the SpeaK tool are: improving the definitions of some descriptors such as warm and round, adding a category of examples of environmental sounds, proposing signal models for each descriptor, and developing an online version.

APDS

Analysis of Sound Design Practices

—

Teams Involved: Sound Perception and Design, Analysis of Musical Practices
Funding: Labex Création – Arts – Patrimoines (CAP)
Calendar: 2018–2019
Partners: Institut ACTE (Univ. Paris 1 Panthéon-Sorbonne), Laura Zattra (independent researcher), David Fierro (independent developer)

The project focuses on sound design—a field of design and sound creation that appeared in the last third of the 20th century—and more precisely on its practices, which are deployed in fields where thinking about sound, making it, integrating it, and diffusing it proves to be relevant from a functional and/or aesthetic point of view: architecture, urbanism, digital arts, cinema, scenography, but also ecology or marketing.
The project is based on the observation that this discipline is relatively recent—formalized by R. Murray Schafer in the late 1970s, it only really developed from an institutional and professional point of view in the 2000s—and remains, to this day, ill-defined and polymorphous. It is a singularly transdisciplinary practice: the sound designer needs to understand the environment he is confronted with, he needs knowledge in acoustics, signal processing, psychology, information sciences (sound semiotics), cognitive sciences (study of context, integration and learning processes), socio-economics (culture, heritage and environment) and, of course, musical composition. At a time when research on creative practices is extending to new forms of contemporary practices and to the resulting new socio-professional figures, the project opens a reflection on the specificity of this discipline whose creative processes, unlike their products, still remain private.
Adopting an approach inspired by design research, and aiming to establish a long-term conceptual framework for the study of sound design, the project focuses on the actors of the discipline—sound designers—through the analysis of their practices from different points of view (artistic, musicological, socio-cultural, technical, ecological, scientific). Using a field methodology (questionnaires and interviews), the project makes it possible to understand the creative processes of sound design, to amass historical knowledge, and to measure current issues on artistic, technical, and scientific levels.

Rapid-Mix

Musical Tools and Modules for Digital Designers and Content Creators

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Team Involved: Sound Music Movement Interaction
Funding: Program H2020- ICT22-2014-c
Calendar: February 2015—January 2018
Partners: Universitat Pompeu Fabra, Goldsmith's College, Plux – Wireless Biosignals S.A., Reactable Systems SL, Somethin' Else Sound Directions Limited, Lambde Limited (Roli), Orbe Sarl
Coordinator: Universitat Pompeu Fabra

The goal of the European project Rapid-Mix is to develop new modes of musical interaction by including multimodal data connected to movement and the body. From a methodology point of view, the project is based on user-centered evaluations and on the quick development of prototypes (agile prototyping). Advanced techniques for signal analysis and automatic learning are also used. The transfer of these technologies to small business taking part in the project is an important aspect of the project. In this project, the joint research laboratory is responsible for the development of application prototypes and software bricks; in particular the WiFi module for motion capture (R-IoT) conceived by IRCAM and distributed by pluX.

WAVE

Web Audio: Editing/Visualization

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Teams Involved: Analysis of Musical Practices, Sound Music Movement Interaction
Funding: ANR - Contenus et interactions
Calendar: November 2012—October 2015
Partners: Eurecom Sophia Antipolis, Éditions Durand (Universal Music Publishing Classical), Vi-Live
Coordinator: IRCAM

The WAVE project aimed to formalize new means of editing, visualization, and interaction with temporal audiovisual objects online.

This project led to the design and development of software bricks concerning user interfaces and interactions, digital audio interfaces, client/server interfaces, and their data exchanges. These software bricks are the result of the analysis of expert musical practices compared to their ordinary use in web applications and standards, with the goal of offering innovative uses and services for them.

The project was based on Web standards, in order to propose coherent, accessible and innovative interfaces and new user experiences adapted to the consultation, interaction, annotation, transformation, and sharing of temporal objects to contribute to the emergence of a truly hypermedia and interactive web.

This project led to the organization of the first Web Audio Conference (WAC) at IRCAM in 2025 in collaboration with Mozilla, Google, and the W3C.

Multimedia Publishing Tools for Musicology

—

Team Involved: Analysis of Musical Practices

This research aimed to experiment with and, in some cases, standardize original multimedia publishing formats for music. It can be said that any analytical discourse on music contains, in itself, a strong «multimedia» potential since it includes text (verbal commentary) and pointers to musical data (quotes from musical examples, references to movements or passages of the works, etc.). Yet, paradoxically, it is only recently that musicologists have become interested in the new expressive possibilities of multimedia publishing (online and on media), hitherto limited to educational and cultural CD-Rom publications.

To contribute to this movement, we have followed a two-step approach. First, the experimentation consisted in carrying out various musicological analyses in a multimedia environment, gradually specifying this environment in relation to the stages of the analytical approach. This experimentation activity is concretized, on the one hand, by the development of analysis tools in collaboration with musicologists (e.g. «Charting the Score, a Score Tabulation Tool», in collaboration with Jonathan Goldman); on the other hand, by the publication of multimedia documents, on DVD-Rom (such as those attached to L'inouï, IRCAM's journal in 2005 and 2006) and in online journals such as DEMeter (University of Lille-3) or Musimédiane - an audiovisual and multimedia journal of musical analysis.

Then, through a process of comparison and abstraction, we went on to formalize the analytical operations involved. This has made it possible to standardize publication formats using text, sound and image; not only for the specific needs of musicologists but also for similar methods of publishing music that are peculiar to IRCAM's institutional projects (redesign and overhaul of the Brahms database, creation of the IRCAM Repertory, software documentation).

The challenges are related to documentary engineering: to use a well-defined format (to facilitate data processing) but one that is not too restrictive for the authors; to be able to integrate visual and sound musical examples; to make several types of publication possible (Online, in CD-Rom or DVD-Rom format, but also in paper version). To do this, and given the quantity of orders involved in these projects, it is impossible to rely on manual formatting of the data provided by the authors for each publication. It is therefore necessary to use a tool dedicated to these types of publications that integrates the previously listed constraints. This was the purpose of our involvement in the RIAM Ecoute project («Author environment for instrumented music listening, management of sound archives and their multimedia publication») and in the RNTL Scenariplatform project.

The entire process has already made it possible to establish a publication format for musical analysis, initially tested in a model of online courses for the European project MusicWeb (2003), then in a scientific publication on performance analysis (2005) and, finally, formalized during the design of a series of CD-Roms associated with the Musique Lab2 project (2006-2007) within the framework of an association between IRCAM and the Provence-Alpes-Côte d'Azur region. The CD-Roms produced, one on Webern's Variations op. 27 and the other on P. Leroux's Voi(rex), offer two levels of reading of the work:

- The first one introduces the work by giving the score to be read as you listen, with some contextual elements added during the reading;
- The second proposes several analytical notes on the work, each of which points, by means of hypermedia links, to key passages of the score annotated by the author using the Music Lab annotation software. The entire content is produced by the author himself using the Scenari-CHaIN authoring tool and the Musique Lab software suite.

History of Musical Acoustics in France

—

Team Involved: Analysis of Musical Practices

Over the past decade, a considerable amount of work has been carried out on the history of the relationship between music and science. Most studies in this field have focused on the production of knowledge and dialogues among scientific laboratories, instrument makers' workshops, instrument makers, and learned societies, particularly in Germany, England, and the United States. This project extends and develops this work by considering the complex history of the relationship between music and science in France and its colonies from the late 18th century to the present day, and by examining the broader implications of these exchanges for social life as a whole.

This research is being carried out within the framework of two collective projects:

1. The Powers of Sound. Music and Science in France from the Revolution to the First World War
2. The Manufacture of Musical Acoustics in Paris Since 1945

Désiré-Magloire Bourneville and Paul Regnard, *Iconographie photographique de la Salpêtrière (service de M. Charcot)*. Paris: aux bureaux du 'Progrès médical', 1876, vol. 3, p. 204

The Powers of Sound. Music and Science in France from the Revolution to the First World War:

Focusing on France, this project directed by Fanny Gribenski and Jillian Rogers (Indiana University Jacobs School of Music) deals with the relationship among music, science, and power in France throughout the 19th century. The highly centralized nature of the French musical, scientific, and political systems makes it a good entry point to consider the intertwining of music and science, as well as the intermingling of these two fields with multiple institutions, networks of protagonists, and instruments. The project analyzes different moments in the co-production of musical and scientific practices and shows how their interactions were shaped by military, religious, industrial, social, or environmental contexts in France and abroad. In addition to extending the field of investigation of the relationship between music and science, this research is based on a detailed and nuanced examination of the circulations of power around sound through meticulous archival work. Through this double reconfiguration of the scale of investigation, this project offers a new framework for understanding the development of musical and scientific practices, while underscoring the broader importance of these relationships to social, political, and cultural history.

In December 2020, we organized a study day with the authors of articles for a special issue of the journal to be published in 2022. In the coming years, we will continue these reflections over the long term, from the modern era to the present day.

Temporality and Spatiality of Morbid Consciousness

—

Team Involved: Analysis of Musical Practices

Two main axes articulate this research.

One concerns the understanding of morbid consciousness in the musical work. In the analysis of works by Barraqué and Zimmermann—others will follow—we aim neither at a psychoanalysis of the musician, as in many studies on Robert Schumann or Hugo Wolf, nor at a psychiatric reading of music, establishing a diagnosis and making musical analysis and clinical analysis undivided, but at foundation, at the leitmotif of biography, experience, aesthetics, and philosophy of art, in order to describe their world, its temporality and its own spatiality, as well as their manifestation of language and silence, but also to highlight the structure of their form of existence and to study the constituent elements of these worlds.

Th s axis has involved research in the history of psychiatry, in its daseinsanalytical aspect, and more generally, the history of medicine, which has led to the critical edition, with extensive commentary, of essays by Danilo Cargnello and Giovanni Morelli, as well as to papers by Laurent Feneyrou in the context of the seminar at the French School of Daseinsanalysis and at the Institute of Humanities at the Lausanne University Hospital.

Centered on the temporality of Bernd Alois Zimmermann's works (*Les Soldats, Requiem pour un jeune poète, Ich wandte mich und sah an alles Unrecht das geschah unter der Sonne*...), philosophical research is necessary, mainly on his biblical, musical, and musicological sources (*Traité d'harmonie* by E. Pound, "*…comment passe le temps*" by K. Stockhausen, théories by M. Hauptmann) and philosophical (St. Augustine, Husserl, and Heidegger in addition to various representatives of German neo-Kantian and phenomenological philosophy, explicitly mentioned by Zimmermann), with a view to a line-by-line exploration of the essay Interval and Time, as well as of the composer's main articles relating to this theme.

The second axis in this project focuses on the critical edition of previously unpublished early works by Jean Barraqué, published by Bärenreiter, directed by Laurent Feneyrou, Michael Töpel, Aurélien Maestracci, and Frédéric Durieux.

After the *Sonata for violin*, first heard at the Théâtre des Bouffes du Nord on November 30, 2009 as part of the Festival d'Automne in Paris (Caroline Widmann, violin), after the premiere of pièces pour piano (1947-1950) (Nicolas Hodges, piano) and the Quatuor à chordes (Quatuor Diotima) as part of the Musica festival in Strasbourg on October 5, 2011, the Ultraschall festival in Berlin featured, in January 2012, new premieres: *Ecce videmus eum*, for mixed a cappella choir (RIAS Kammerchor, conducted by Hans-Christoph Rademann), *La nature s'est prise aux filets de ta vie*, for flute, bass clarinet, drum, suspended cymbal, choir, solo contralto, and piano (RIAS Kammerchor and Kammerensemble Neue Musik Berlin, conducted by Hans-Christoph Rademann), *Three Melodies* (1948), *the Little Song for Gravigny* (1948), *Two Mélodies sur des poèmes de Paul Valéry* (1948-1949), *La Porte ouverte* (1949), *Les nuages s'entassent sur les nuages* (1950) and the first of the *Trois Mélodies* (1950) (Anja Petersen, soprano, Nicolas Hodges, piano), whose complete series was premiered in Geneva, November 20, 2016, as part of the Contrechamps season (Christina Daletska, contralto, and Stefan Wirth, piano). More substantial scores followed: the ballet for the Melos orchestra, premiered in Cologne, June 24, 2017 (WDR Sinfonieorchester Köln, conducted by Jean-Michaël Lavoie) and the Stage Music premiered in Vienna, November 6, 2017 (ensemble sirene, conducted by François-Pierre Descamps).

Barraqué's final never-before-seen work, *La Nostalgie d'Arabella*, is scheduled to be premiered in Paris, February 3, 2021 (Ensemble Cairn, conducted by Guillaume Bourgogne). These works are also expected to be the subject of a recording. This editorial work is accompanied by the publication of articles (scientific articles, Barraqué's entry in the Brahms database, prefaces to the scores, popularization notices, etc.).

Talking Music

—

Team Involved: Analysis of Musical Practices

In view of the works and creations that often preceded them, writings by composers are crucial to understanding music of the 20th century. With Charles Baudelaire the demand of the artist rationalizing their art and discovering its obscure laws was born, "It is impossible that a poet does not contain a critique." Biographical, critical, theoretical, aesthetic, genealogical, paving the paths of a work still in the making or indulging in analytical introspection, the writings of composers constantly renew concepts and methods of musical discourse.
Sometimes threatened by the dispersal of archives and the deterioration—if not disappearance—of manuscripts and typescripts in their original language, as well as magnetic tapes of interviews, the publications imagined, willingly exhaustive, situate each of the articles and propose a critical apparatus (historical, biographical and bibliographical references, index of works, catalogs...), thus placing at the disposal of musicians, music lovers, institutions and concert halls a set of documents properly gathered, translated and annotated.
Laurent Feneyrou has recently edited writings by André Hodeir and Niccolò Castiglioni following the publication of writings by Jean Barraqué, Giacomo Manzoni, Luigi Nono, Louis Saguer, Salvatore Sciarrino, and Frédéric Durieux. More collections are in progress.

Instruments of Improvisation

—

Team Involved: Analysis of Musical Practices

This project extends the work previously carried out within the «Music & Hacking» project. It aims at analyzing the multiple material transformations, adjunctions or inventions that musicians exert on their instruments, considered as means of artistic singularization, ergonomic optimization, institutional circulation or cognitive extension. Nearly fifty filmed interviews were conducted with instrumentalists with varied improvisational practices (free improvisation, jazz, baroque music, traditional music). Every musician was interviewed in their workshop, instrument «in hand», to allow the finest possible exploration of their lutherie practices. This work will lead to the writing of a book, and will be accompanied by the realization of a web-documentary.

Pascal Battus playing with his "Surfaces rotatives"

ALCOLL

—

Team Involved: Analysis of Musical Practices
Funding: Sorbonne Université, programme Emergences
Calendar: September 2017 – July 2018
Partners: IReMus

The project "Analyze the Collective in the Process of Musical Creation", ALCOLL, aims at understanding the creative process in music beyond the supposed opposition between the individual and the collective (and between musicology and the humanities and social sciences). Who is who in a given musical work? What is unique and what is general? What is specific to participation or to a creative action? This is what the ALCOLL project endeavors to measure by reexamining data by observing situations of musical creation (composition, improvisation, performance), the organization of seminars, and the realization of a ethnographical survey.

4

The Software

ADMix TOOLS

—

Design and Development: Acoustic and Cognitive Spaces Team

The ADMix tool suite, developed during the research project ORPHEUS (European Union's Horizon 2020 research and innovation program, p. 35), can be used for recording (ADMix Recorder) and reproduction (ADMix Renderer) of object audio contents.

The object format follows the audio definition model (ADM) defined by international standardization bodies (European Broadcast Union and International Telecommunication Union). ADM data is typically stored in .wav audio files (BW64) in which a <axml> chunk embeds the metadata. The association of audio channels and the metadata is defined in the <chna> chunk.

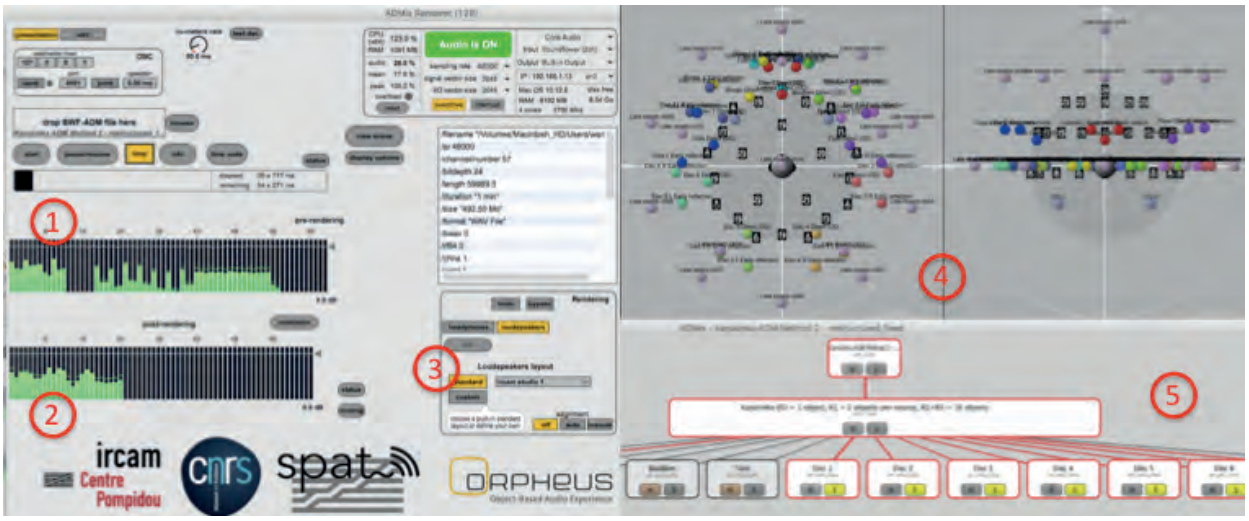
ADM elements can be of different types: DirectSpeakers, HOA, binaural, Matrix, or Objects. DirectSpeakers elements make it possible to create a multi-channel bed for standard loudspeaker setup (stereo, 5.1, etc.). HOA elements are used to store a sound scene encoded as High Order Ambisonics. Objects are the most generic elements and are defined by their time dependent 3D position and gain.

An ADM file can further contain multiple audio "programs" that each exploit all, or a part, of the audio tracks and are associated with different metadata sets. This functionality can e.g. be used to transmit contents in different languages, where only the dialogues in the selected language are played while the musical components and ambient sounds are shared by all programs. Another application of multi-program contents could consist of transmitting a single sound scene, mixed and rendered according to different listening positions.

In practice, the ADMix Recorder can connect with any digital-audio work station in order to convert automation tracks to ADM metadata. Communication between the DAW and ADMix is established via the ToscA plugin, and relies on the OSC communication protocol. ADMix Renderer is based on the Spat^ library and makes it possible to render contents on 2-or-3D reproduction systems, over headphones or any loudspeaker setup.

Configuration

The ADMix tool suite, downloadable from the IRCAM Forum website, is available for Mac OSX and Windows.



Main window of ADMix Renderer.
1) Meters corresponding to different objects in the audio file;
2) Meters of different output channels created depending on the rendering mode;
3) Choice rendering system (binaural with headphones or standard or ad hoc loudspeakers configurations;
4) Instantaneous visualization of the position of different objects;
5) Graph of the sound scene and activation of objects (mute/solo).

Antescofo

http://antescofo-doc.ircam.fr/

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Design and Development: Musical Representations, the MuTant project and the start-up Antescofo

Antescofo is a modular score following system as well as a synchronous programming language for musical composition. The module allows for automatic recognition of the player's position and tempo in a musical score from a real-time audio stream coming from a performer, thus making it possible to synchronize an instrumental performance with computer generated sounds. Antescofo brings together the description of instrumental and electronic parts of a work in a single score via a synchronous language designed for mixed music, with the goal of increasing the expressivity of the process of writing in real-time in a format adapted for the musical language. After changing the score, Antescofo is able to follow the position and tempo of the musicians in real-time and synchronizes the programmed actions for the computer-music portion of the score (setting off and controlling the electronic parts). Antescofo uses a polyphonic audio stream as input. Antescofo is also used as a programmable sequencer to control the processes of sound synthesis and complex spatialization in real-time.

Applications

Interactive musical works, automatic accompaniment, mapping gestures/sound synthesis, spatialization control, music education

Main Features

- Recognition in real-time of the position and tempo of the polyphonic audio stream in a score
- Writing the electronic components of a score in relative, absolute, and rational time
- Management of events and continual chronometric time
- Interactive sequencing of multimedia scores
- Conversion of MIDI and MusicxML scores
- OSC communication, input/output in JSON format

Platform

Antescofo is a library of objects for Max (IRCAM/Cycling'74) that can be used with Mac OSX or Windows XP. Antescofo is also available as a PureData object for Max OSX, Windows, and Linux.

CataRT

—

Design and Development: Sound Music Movement Interaction Team

Concatenative corpus-based synthesis uses a database of recorded sounds and a selection algorithm that makes it possible to choose the segments of the database in order to synthesize by concatenation. The selection is based on the characteristics of the recording such as the pitch, energy or spectrum that are obtained by automatic analysis and segmentation of the signal.

Using this new approach to sound synthesis, the CataRT system enables an interactive exploration of a sound base in real-time and a targeted granular composition with specific sound characteristics. This makes it possible for composers and musicians to reach new sounds, and for sound designers to quickly explore the variability and nuances of a large sound corpus. CataRT exists as a standalone application, a device for Ableton Live or as modular system implemented in Max with the MuBu extensions. Interaction relies on a simple interface made up of a 2D projection of the sound segments according to their descriptors, through which the musician can navigate and thereby select and play grains by geometric proximity. This navigation can be controlled by a mouse, external controllers (multi-touch pads, joysticks, cameras), or by the analysis of the audio signal.

Applications

Interactive musical and fixed or interactive multimedia works, sound design, synthesis of environmental textures, new instruments, searches in sound databases

Main applications

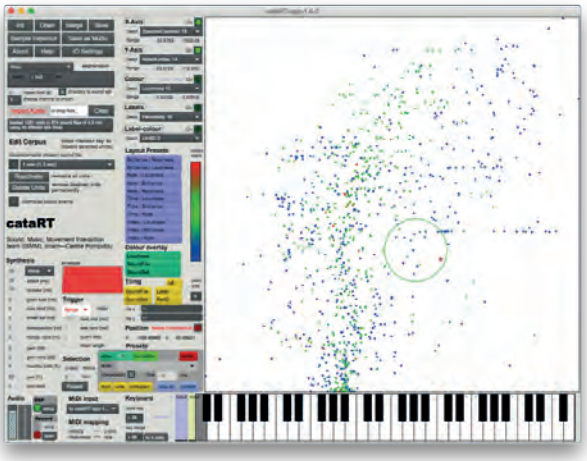
- Audio import with segmentation and automatic analysis
- Analysis, visualization, and sound interaction
- Analysis data export
- Composition via interactive navigation in a descriptor space
- Mixing and juxtaposition of massive amounts of sound samples
- Flexibility of granular synthesis
- MIDI compatibility
- Efficient interactive browsing of events or particularities in several or in long recordings, parasite noise separation

Platform

- Application Version: Mac OS 10 or higher. Collection for Mx 7 runtime or higher.
- Max4Live Device Version: Ableton Live 10 or higher
- Modular Version: Mac OS 10.10 or higher or PC Windows with Max 7 or higher and the MuBu package

Audio File Formats

- Up to 32-bit/192 kHz integer and floating point: AIFF, AIFC, WAV, FLAC, AAC, MP3
- SDIF files for importing segmentation markers from AudioSculpt (application version)
- MIDI files for importing segmentation and pitch annotation (application version)
- Text files for importing segmentation and label annotation. Audacity, for example. (application version)



IRCAM Lab TS

—

Design and Development: Sound Analysis & Synthesis Team

TS is a standalone software application for sound transformation and time stretching that uses SuperVP and elements of the AudioSculpt 3 interface.

Applications

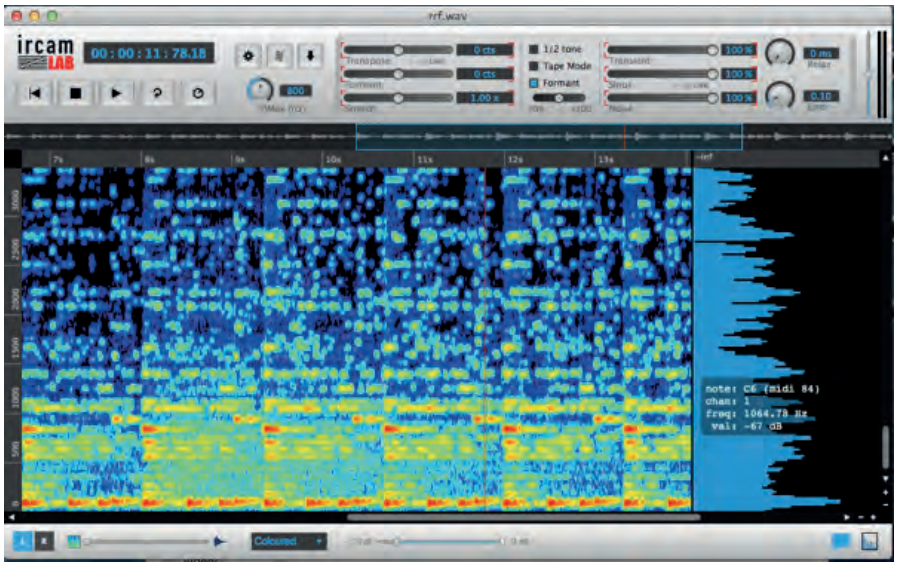
Composition, sound design, post-production, teaching

Main Features

- Visualization – display of the sonogram, waveform, and spectrum. Interactive zoom from the temporal signal to sample, linear and logarithmic sonogram. FFT, LPC, and True Envelope analysis
- Compression/Expansion – modification of the length of a sound without changing its pitch or timbre and preserving the quality of the attacks and transitions. Presets for different transposition modes with the possibility of adjusting the max FO and spectral envelope
- Remix – remix the transient, sinus, or noise components of the sound signal
- Control – audio playback with standard controls. Results can be recorded in real-time or offline by modifying the parameters. Possibility of piloting and automation via a MIDI controller

Platform

Macintosh on MacOSX (10.5 or higher). Compatible with AIFF/AIFC, WAV, and other formats via the libsndfile library



MAX

The world standard for real-time sound interaction

—

Max (formerly Max/MSP) is a visual programming environment for building real-time musical and interactive applications. It is currently the world's leading software program for interactive sound installations. Max is a bundling of Max (IRCAM/Cycling '74) for real-time control of interactive musical and multimedia applications through MIDI, of MSP, a large set of objects for real- time analysis, synthesis, and processing of audio signals, and of Jitter, a set of video, matrix, and 3D graphical objects for the environment. Max was developed for musicians, sound designers, and researchers who want to develop interactive real-time programs. Cycling '74 (United States) develops Max under an exclusive license from IRCAM.

Composition

Generation of musical structures using mathematical or random models.

Live Performance

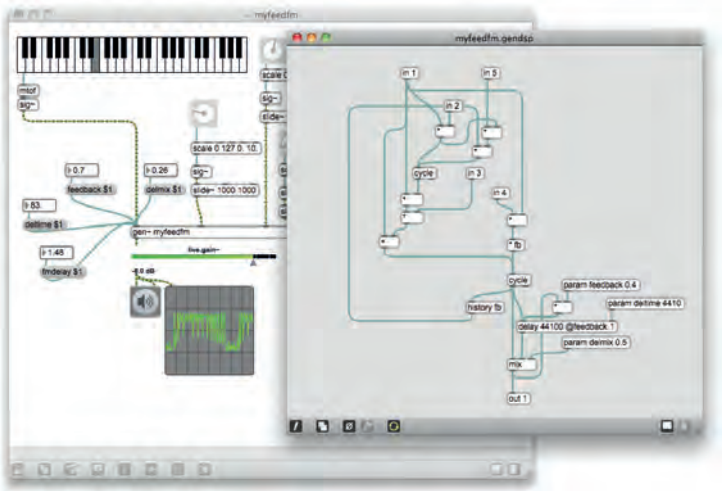
Production of mixed works in which the electronic part reacts according to the instrumental performance using incoming instrumental capture, incoming MIDI signals, or direct modification of the instrumental sound as source material. Controlling the diffusion of sounds and audio files in time Max acts as a sampler. The dynamic control of complex programs that pilot musical signals, video, and lighting effects is also possible.

Audio Post-Production

Virtual control of several external devices such as the mixing console, direct-to-disk system, and synthesizers.

Real-Time Video Processing

A library of objects for video processing (Jitter) is included with the software. It provides users low-level control and the ability to program several applications.

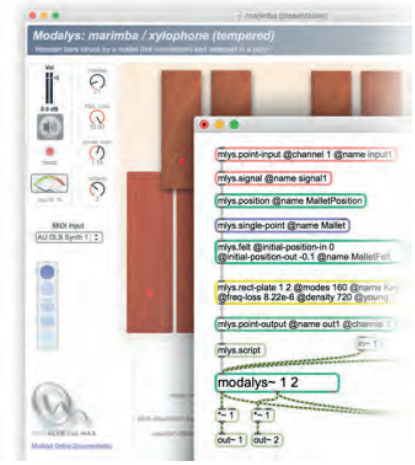


MODALYS

—

Design and Development: Sound Systems and Signals : Audio/Acoustics, Instruments Team

Modalys is an environment that lets users create unheard of virtual instruments based on simple physical objects such as strings, plates, tubes, membranes, plectrum, bows, or hammers, and making them interact. It is possible to construct objects with complex forms using a three-dimensional mesh or resulting from measurements. Modalys brings these virtual instruments to life by calculating how they vibrate when played. By combining different physical, resonating objects and by specifying the type of interaction (striking, rubbing, mouthpiece, bow, etc.), the user creates a virtual instrument and then decides how it will be played. OpenMusic and Max communicate directly with the Modalys synthesis engine via intuitive graphical interfaces.



Applications

- Musical composition: contemporary, techno, electro, etc.
- Sound design: natural work on sound quality (metallic, woody, etc.)
- Education: modal theory in practice
- Cinema & video: sound design
- Scientific research & development: comparison of theoretical and measured modes

Main Features

Modalys' synthesis engine makes it possible to hear virtual instruments made from simple physical objects or 3D mesh. The user can make an instrument and then decide how it will be played. To do this, the user must define the following in four steps:

- Objects which simulate the physical structures (tubes, strings, membranes, plates, complex inexistent forms, plectrums, reeds, hammers) which are calculated according to the default values given by the system or can be modified by the user
- Access to the objects (points on the object on which an action will take place)
- Connections which make it possible to define playing modes: hitting, blowing, bowing, etc.
- Controllers that will describe how the parameters of a connection will evolve over time

Use

Chosen by a large number of composers and sound designers, Modalys for Max is the incarnation of Modalys in the real-time environment Max, used to construct sophisticated instruments graphically using strings, plates, membranes, tubes with any type of materials (metal, wood, diamond, etc.), size (unlimited), and interactions: hitting, plucking, rubbing, blowing, etc. This interface can be controlled live from Modalys in real-time. Modalys for Max requires Max 5 or higher (including 7) and is available for Mac OS X (10.6 or higher) and Windows (7 or more recent). Modalys can also be used from ModaLisp, a textual programming interface that can be used to construct and play an instrument with a script. Using this approach, the user writes and executes Lisp programs to obtain the desired musical result. IRCAM's musical programming software, OpenMusic, also based on Lisp, enables a musical or graphical control of the models, for instance from a score and/or temporal envelopes.

For a scientific approach to model synthesis, Modalys can easily be used with MatLab through dedicated libraries.

Platform

Mac OSX 10.6 or higher, Window 7 or higer (Modalys for Max only)

MuBu for Max

—

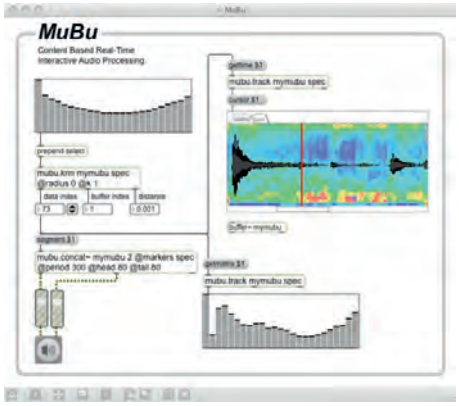
Design and Development: Sound Music Movement Interaction Team

MuBu (for "multi-buffer) is a set of modules for real-time multimodal signal processing (audio and movement), automatic learning, and sound synthesis via descriptors. Using the multimodal MuBu container users can store, edit, and visualize different types of temporally synchronized channels: audio, sound descriptors, motion capture data, segmentation markers, MIDI scores. Simplified symbolic musical representations and parameters for synthesis and spatialization control can also be integrated.
MuBu integrates modules for interactive automatic learning for recognition of sound or motion forms. MuBu also includes PiPo (Plugin Interface for Processing Objects) for signal processing.
The development of the MuBu and PiPo modules is the result of the experience acquired during the development of the FTM & Co libraries as well as development carried out on software components during research projects such as the MuBu, ZsaZsa, and RTA libraries.

Applications
Musical works and interactive multimedia projects, interactive sound synthesis, music, dance

Main Features
- Multi-buffer with a graphical interface
- Recording data streams and sequences
- Processing data streams and data store in the multi-buffer
- K-NN unit selection
- Concatenative synthesis, granular synthesis, PSOLA
- Additive synthesis

Platform
Logiciel Max, MacOSx, Windows



OMax

—

Design and Development: Musical Representations Team

Omax is an environment for improvisation with a computer that analyzes, models, and re-improvises in real-time the performance of one or several musicians, in audio or in MIDI formats.
OMax is based on a computer model called "Oracle Factors", a graph that connects all the motives and their variations and provides a map to the music's structure, leading to a large number of stylistically coherent variations. Omax bases its recognition on either notes (pitch following) or on timbres (spectral following).

Applications
Improvisation with a computer, interactive musical works, automatic accompaniment, human-machine co-creativity

Main Features
Modular architecture that makes it possible to allocate improvisers, players, and to connect them as you like (e.g. several players connected to the same improviser can create a cannon with a rhythmic increase).
Real-time visualization of knowledge models, multiple selection functions, focalization on the visual representation. Generation of characteristics according to formal, motivational, or energy criteria.

Omax offsprings : from reactive listening to "meta-composition", SoMax, Improtek, DYCI2
- SoMax is a stand-alone agent capable of generating coherent musical content based on knowledge extracted by learning a corpus. SoMax focuses on instantaneous listening and implicit guidance operated by the human musician to navigate in a reactive and self-coherent way, in order to produce accompaniment, counterpoint or co-improvisation.
- ImproteK is a human-machine musical improvisation system guided by a formalized temporal scenario (harmonic grid, composition, etc.) in collaboration with EHESS.
- DYCI2lib, the more recent creation, is a library of generative agents and tools for smart composition and human-machine co-improvisation. These agents combine machine learning models and generative processes with reactive listening modules. This library offers a collection of "agents/instruments" embedding free, planned and reactive approaches to corpus-based generation, as well as models of short-term dynamic scenarios ("meta-Djing"). The declination of the library for the OpenMusic environment, OM-DYCI2 specializes in the large-scale offline generation of "meta-composed" material.

Platform
Recent versions of Mac OSX, Max, and Python

OpenMusic

—

Design and Development: Musical Representations Team

OpenMusic (OM) is a visual programming environment for creating computer aided composition applications. OpenMusic offers users the possibility of graphical construction for processing procedures or generation of musical data with the assistance of numerous graphical modules and predefined functions, assembled in visual programs. Programs can then be integrated within each other, producing structures that are more and more elaborate. Today, OpenMusic is taught in the world's major computer-music centers and several universities in Europe, Asia, and the United States.

Main Features

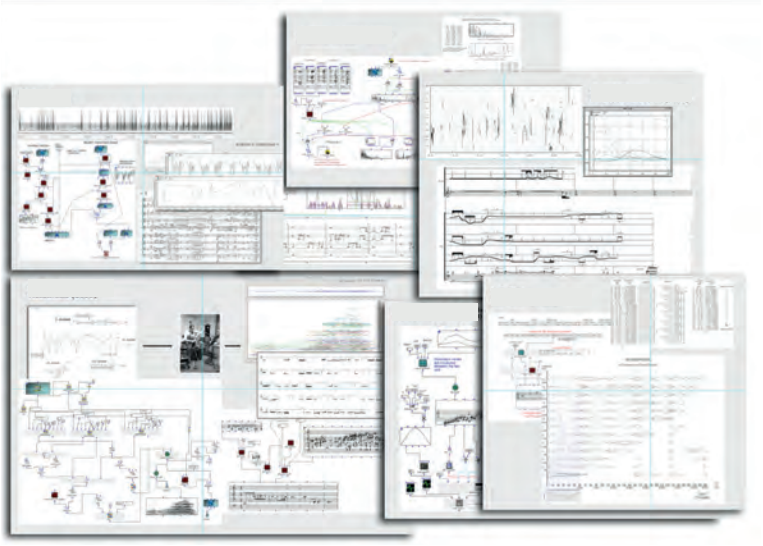
- Graphical construction of functional programs (abstractions/ application modes, higher-order functions, conditional structures, iterations, etc.)
- High-level functions for the creation and transformation of musical structures (e.g. pitch, rhythm, etc.)
- Algorithmic data manipulation in MIDI, audio, and SDIF formats, communication with OSC
- Graphical editors: score editing functions for traditional and proportional music notation (with import and export to main software programs), 2D and 3D curves, and breakpoint functions
- Mathematical tools for analysis and composition
- "Maquettes": a graphical editor that makes it possible to give a temporal and hierarchical form to visual programs

Specialized Libraries

Spectral music, musical constraints, musical algorithms, rhythmic structures, stochastic or chaotic probabilistic generators, sound synthesis, spatial synthesis (Spat~), sound control and processing (super-vp, additive, singing, csound), etc.

Technical Features and Platforms

Programming based on Common Lisp / LispWorks
(http://www.lispworks.com/)
Available for MacOS, Windows and Linux environments



OpenMusic software for composition (Assayag, Agon, Bresson, Haddad)

Orchid*

—

Design and Development: Musical Representations Team

IRCAM's computer-assisted orchestration software, developed by the Musical Representations team, proposes instrumental mixtures as a solution to an orchestration problem consisting of imitating an acoustic target as perceptually as possible.

Orchid* is divided into three instances of Orchids developed within the team: Orchidee, Orchids and Orchidea.

- Orchid / Orchidée, the first version, set the ground rules of the genre in terms of imitative orchestration functionalities, and methods with the prediction of audio descriptors of the mixtures, multi or mono objective optimization by genetic algorithm for the search of orchestral solutions, static (single target) or sequential (by segmentation) orchestration of the target. Orchidée was available as a standalone or Max interface toolbox interacting with the orchestration engine.
- Orchids extended the field from multi-objective optimization in a descriptor space to time-series optimization and opened the way to continuous dynamic orchestration of complex and evolving spectral morphologies and proposed a robust standalone interface.
- Orchidea, the most recent version, is based like the others on genetic research for single or multi-objective optimization and descriptor prediction, and also offers either a standalone version or a toolbox and GUI in Max. Orchidea refines and optimizes the analysis and prediction of descriptors, the search for solutions and the quality of sequences for sequential orchestration, and makes the user interface more fluid. Orchidea is an IRCAM/HEM collaboration, which will continue through an Ircam / Berkeley collaboration, as well as with independent developers such as Daniele Ghisi (Bach). Therefore, Orchidea will remain open source.

*Orchid** is a complete system for temporal computer-assisted orchestration and timbral mixture optimization. It provides a set of algorithms and features to reconstruct any time-evolving target sound with a combination of acoustic instruments, given a set of acoustic and perceptive criteria. It can help composers to achieve unthinkable timbral colors by providing many efficient sets of solutions that best match a sound target. With an extended set of features, Orchid* can also reproduce spectral evolutions by analyzing the temporal dynamic. Its results provide multiple orchestral scores that can be arranged in an intuitive way in order to perform a fast sketching of musical ideas. Orchid* can use several databases of instrumental sounds but can also be extended in an unlimited way, including with synthesized sounds, by simply importing its own sound bank.

Applications

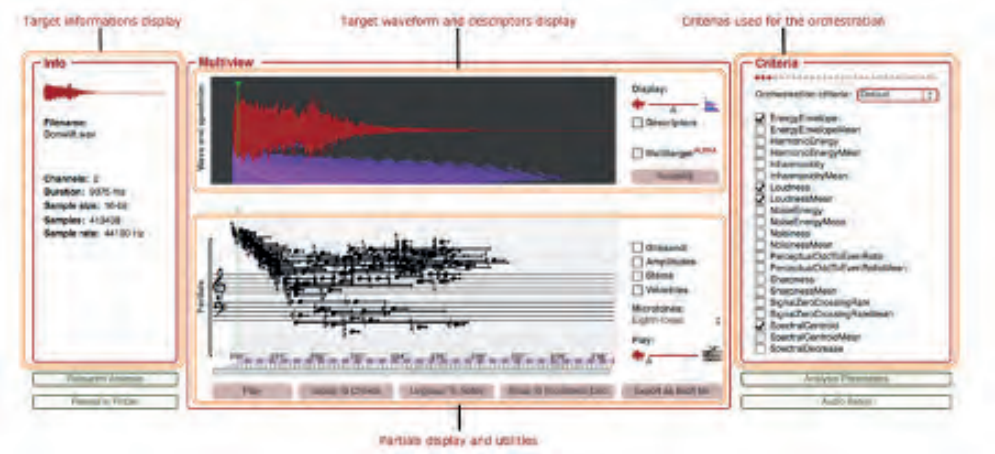
Orchestral composition, re-orchestration, timbral writing, music education

Main Features

- Generation of new combinations and orchestral combinations by optimization of a target
- Possibility of timbral writing through orchestral mixtures and optimization of the temporal evolution
- Definition of abstract targets and temporal evolution of spectral descriptors
- Simple interface enabling the spatialization of an orchestra or efficient work of the model of an orchestral work
- Simple extension of a knowledge base and efficient temporal searches
- Interaction and exports towards several systems of musical notation

Platform

Mac OSX



OSCar

—

Design and Development: Acoustic and Cognitive Spaces Team

OSCar is a plugin that makes it possible to send and receive the automation parameters of a digital audio workstation towards or from other applications using the OSC protocol. Its application typically concerns the production of object-oriented spatialized mixes independently of the host software constraints.

Main Features

OSCar can be inserted into a DAW (digital audio workstation) for each track you want to spatialize. The OSCar plugin does not affect the audio signals: its function is to provide a certain number of parameters that can be automated. In order to ensure compatibility with a wide range of digital audio workstations, it is suggested to limit the numbers of parameters per track to 32. During playback, active automation tracks are read by OSCar and the corresponding OSC messages are sent over UDP. When the automation tracks are armed for recording, OSCar accepts incoming OSC packets from remote applications and data can be written in the sequencer tracks. Each OSCar instance has an ID that can be adjusted by the user. This ID can be used to format the OSC messages sent and received by OSCar. Their syntax is as follows: "/track/ID/ParameterName ParameterValue" (e.g. "/track/3/azimuth 135.0"). For the sake of simplicity, the parameters in OSCar are all double precision floating-number points. Other types of data that can be included in an OSC message (such as integer numbers or text strings) are not currently supported.

OSCar is not connected to a particular spatialization or synthesis engine. In other words, the automation parameters are generic. By default, these 32 parameters are called param1, param2, and so on. The labels of the parameters can be modified. This is carried out via an XML mapping file that can be loaded into OSCar (see illustration).

The XML mapping file makes it possible to specify the automation scale for each parameter: inside the DAW environment, OSCar scales up the tracks in a [0 – 1] floating point range towards the [min – max] domain selected by the user. This scaling affects data output and the inverse scaling is applied to input data.

Platform

OSCar was developed with the JUCE framework. JUCE offers a plugin wrapper that makes it possible, using a common base code, to generate plugins in different formats (VST, AudioUnits, etc). Therefore, OSCar is available for MacOSX and Windows in VST3, AU, and AAX formats. OSCar is distributed by the IRCAM Forum.

PANORAMIX

—

Design and Development: Acoustic and Cognitive Spaces Team

Panoramix is a mixing and post-production workstation for 3D-audio contents. This tool offers a comprehensive environment for spatializing sound materials recorded with different microphone systems: main tree, spot microphones, Higher Order Ambisonics capture. Several 3D spatialization methods (VBAP, HOA, binaural) can be combined and mixed simultaneously in different formats. Panoramix also provides conventional features found in other mixing tools (equalizer, compressor/expander, grouping parameters, routing of input/output signals, etc.), and it can be controlled entirely via the Open Sound Control protocol.

Architecture

Like a traditional mixing desk, the panoramix interface is designed as vertical strips which are organized in two main categories: input tracks and busses. Tracks are used to process signals from a recording session. Panoramix supports several input formats: mono (typically from a spot microphone or an electronic track), multi (a multi-track is basically a grouping of several mono tracks), SMA (used to process recordings from a spherical microphone array like the EigenMike ®), or tree (used to process a main microphone tree)

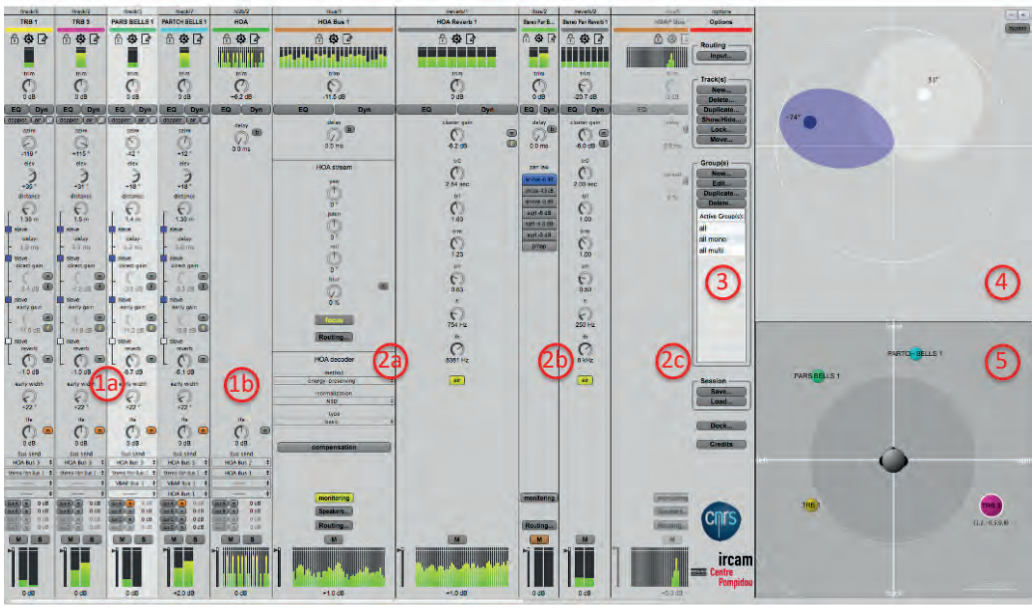
Three types of busses are available: a panning bus, a reverb bus, and the LFE (low frequency enhancement) bus.

The purpose of the panning bus is threefold: 1) it allows for the summation of multiple input tracks, 2) it determines the spatialization technique (VBAP, HOA, or binaural) being rendered, 3) it provides various settings for the encoding and decoding of the signals (e.g. HOA decoder settings or HRTF attributes in the case of binaural reproduction). The reverberation busses create and control the late/diffuse sections of the artificial reverberation. The current version implements a feedback delay network. Finally, all the output signals from all the busses are collected in the master strip and then sent to Panoramix's physical outputs or bounced to disk. While each session only has one master track, it is possible to create mixes in several formats simultaneously.

Platform

Panoramix can be downloaded from the IRCAM Forum web-site and is available for the Mac OS, Windows, and Linux environments.

The panoramix station console window 1a) Mono input channel; 1b) HOA input channel; 2a) Panning and HOA reverberation bus; 2b) Stereo bus; 2c) VBAP bus; 3) Session options (management of groups, import/export presents, etc.; 4) Module to create focus groups in HOA; 5) Geometric positioning interface



SPAT~

—

Design and Development: Acoustic and Cognitive Spaces Team

Spat~ is a library dedicated to real-time sound spatialization. Originally designed as a library, it enables musicians and sound engineers to control the spatial sound processing for various sound rendering systems. Applications range from reproducing sound in a home setting (with headphones, a stereo system, or 5.1) to concert situations (2D or 3D loudspeaker layout) to holophonic and interactive sound installations.

Applications

- Concerts and Real-Time Spatial Sound Processing
  Composers can map a particular room effect or sound position to each note or musical event in their score by using a score-following program. The Spat~ can be controlled via a sequencer, a score-following program, or by using a high-level control dedicated to composition (OpenMusic).
- SimulationandVirtualReality
  Spat~ can be added to each track of a mixing console or virtual mixing environment, enabling intuitive control of the position of each sound source and the effect of a virtual room.
- Simulation and VirtualReality
  Spat~ is well suited for immersion through binaural rendering when wearing headphones. The effect is even more impressive if the system is associated with a head-tracking system. The sound sources maintain their localization according to the user's navigation.
- Ambisonics Reproduction
  Numerous modules are dedicated to the generation, processing, and decoding of HOA (Higher Order Ambisonics) streams: encoders for MH acoustics® EM32 and Zylia® ZM1 spherical microphones, beam forming synthesizing directional virtual microphones in the HOA domain, non-linear sound field distortions (compression or expansion towards the poles or the equator), etc.
- Holophonic Reproduction
  Spat~ has been adapted to the holophonic reproduction system (WFS), facilitating the reconstruction of an acoustic sound field while preserving the consistency of spatial characteristics in an extended zone for the audience. For interactive installations, this reproduction mode enables natural spatial sensations to be retrieved during the exploration of the sound scene.

Technical Features

Perceptual Controls: azimuth and elevation, distance, source presence, room presence, running and late reverberance envelopment, frequency balances.

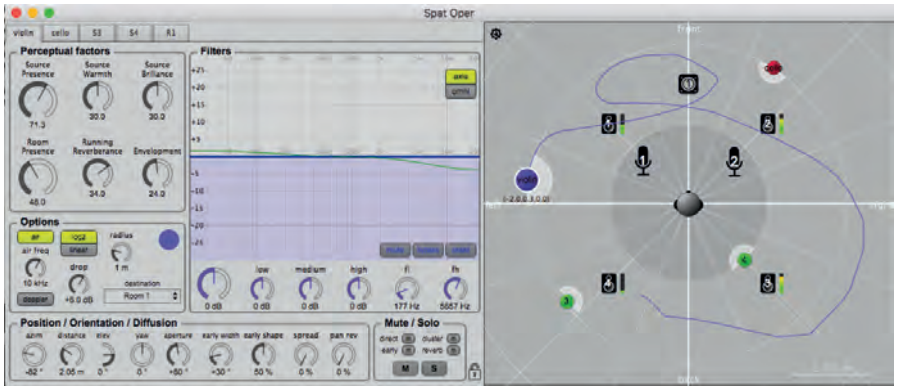
Low-Level DSP Controls: equalization, Doppler effect, air absorption, multi-channel reverberation, source direction according to of the reproduction system (e.g. binaural, transaural, stereo, 3/2 stereo, 4 to 8 HP multi-track, VBAP for 3D loudspeaker configurations, Ambisonics and Higher Order Ambisonics (HOA), Wave Field Synthesis (WFS).

Platform

Spat~is a library of objects for Max that runs on Mac OS or Windows. This library is also the core of Spat Revolution, an autonomous multi-channel mixing and sound spatialization station, developed in collaboration with the company Flux ::.

Technology and Partners

France Télécom, Cycling'74, Flux::



Gesture and Temporal shape following

—

Design and Development: Sound Music Movement Interaction Team

Several Max objects are available to follow temporal morphologies from Markov models.
The voicefollower^ object shows in real-time the temporal progression of a performance in comparison with an audio recording. This enables the synchronization of a number of sonorous or visual processes with a pre-recorded text. This object was tested in a theatrical context with spoken and singing voices.
The motionfollower^ object is similar to the voice follower^ (they both use a similar interface) but functions with gestural parameters, like those that come from sensors. This makes it possible to follow augmented instruments or a beat with a motion sensor.
The gf object (for gesture follower), included in the MuBu modules, enables the recognition and following of the temporal evolution of gestural and/or sound morphologies, comparing them with recorded examples

Applications

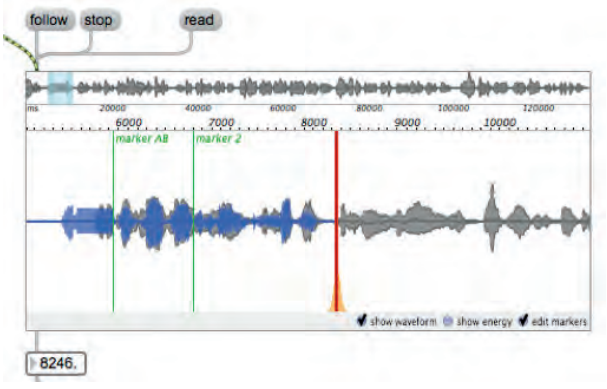
Interactive musical and multimedia works, music, dance, gesture control of sound synthesis

Main Features

- Synchronization between gestures and digital media
- Continual gesture recognition from the beginning of the movement
- Similarity measurements between continual temporal morphologies

Platform

Logiciel Max, MacOSx, Windows



Voice follower~ in Max

SuperVP, TRaX and Libraries

—

Design and Development: Sound Analysis & Synthesis Team

SuperVP is a signal-processing library that is based on an implementation of a sophisticated phase vocoder algorithm. The library can be used to perform a large number of signal transformations with outstanding sound quality (time stretching, transposition of pitch and spectral envelope, denoising, noise-sinusoids-transient remixing, amplitude scaling of the spectral envelope, generalized cross synthesis, source filter cross synthesis, etc.) and provides access to an extensive set of parameters that offer complete and fine grained control over the different algorithms. In addition to sound transformation algorithms, the library includes a large collection of signal analysis algorithms (F0, onsets, spectrogram, re-assigned spectrogram, spectral envelope, etc.). One of the by- products of SuperVP is the VoiceForger library that offers a large number of real-time SuperVP processing and provides high-level access (see the Sample Orchestrator, Vivos, and Affective Avatars projects).
The TRaX tools have been designed so that the majority of the library parameters have been condensed in a set of high-level user parameters that enable an intuitive control of the application.

Main Features

Signal Transformation:

- Time Stretching/Compression: with and without preservation of transients, special mode with waveform preservation for speech transformation
- Transposition: independent transposition of pitch and spectral envelope, sample rate transformation (re-sampling)
- Denoising: interpolation of multiple noise keys and independent processing of sinusoidal noise
- Noise-Sinusoids-Transient Remixing: detection of sinusoidal, noise and transient components with independent mixing controls
- Envelope Transformation: estimation of the spectral and time envelope with independent mixing controls
- Cross synthesis: phase vocoder or source filter based cross synthesis with various controls

Signal Analysis:

- Spectrogram: Short-time Fourier transform (STFT) with and without reassignment
- Spectral Envelope: LPC, True Envelope
- Fundamental Frequency (F0): precise analysis with very low CPU usage, specialized instrument presets for various instruments (i.e. violin, flute, xylophone, vibraphone)
- Attacks: versatile algorithm for the detection of note onsets and other transients
- Voiced/Non-Voiced: detection of the cut-off frequency boundary

Technical Characteristics and Platform

The library can be controlled on different levels of abstraction. It supports file and memory based sound input/output as well as real-time control of many parameters. The library is used in a wide variety of environments. There is a command line application using file based sound input/output that gives access to all available sound transformations and analysis. It is used for example in the AudioSculpt and OpenMusic applications (see OM-SuperVP). In Max, objects enable sound transformation and analysis in real-time; the TRaX application is based on these objects. The library is programmed in C + + using advanced optimized methods, such as SIMD operations (SSE2, SSE, AltiVec) found in today's processors. The library runs on Mac OSX operating systems, Windows XP, and Linux on Intel and PowerPC. Its multithread implementation makes it possible to exploit the calculated capabilities of the multi- core and computer processors.

Technologies and Partners

MakeMusic (SmartMusic), Flux::, Univers Sons, Xtranormal, Voxler, MXP4, etc.

The Snail-Absolute Tuning

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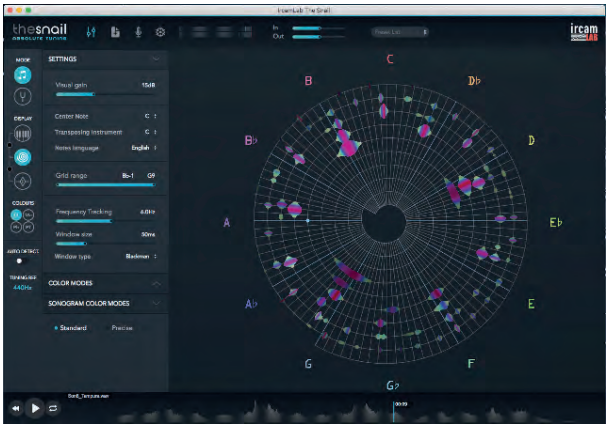
Design and Development: Sound Systems and Signals: Audio/Acoustics, Instruments

The Snail-Absolute Tuning est un analyseur fréquentiel de sons qui repose sur une représentation originale à alignement chromatique.
Comparée aux analyseurs standard, cette représentation permet de visualiser simplement les zones actives par activation lumineuse (comme sur un spectrogramme) et d'organiser la disposition des fréquences par notes sur une échelle tempérée, accordée sur un diapason.



Applications

Visualisation musicale du signal, pédagogie, accordage.

Fonctions principales

- Visualisation :
  Affichage de l'abaque de The Snail-Absolute Tuning (chromatique) simplifiée pour une lecture musicale du son.
- Interface :
  Paramétrage du moteur d'analyse. Réglages des différents modes de visualisation : phase, spectre ou snail (tuner). Réglage de la région fréquencielle visible en note MIDI. Réglage du diapason.

Platform

Macintosh on MacOSX (10.6 or higher), iOS (iPad). Compatible with all audio files (all formats supported by the native MacOSX library) or signal input via the audio input of the equipment used.

The Ircam Forum

ircam.fr forum

IRCAM is committed to serving artists, designers, sound engineers, researchers, entrepreneurs, teachers, and students by offering them access to its latest technologies and enabling them to showcase their work.

Sound synthesis, voice processing, computer-assisted composition, real-time interaction, sound spatialization, gesture control, and new instruments: hundreds of technological components derived from the latest advances technology at IRCAM and by forum members are made available for musical creation, live performances, digital arts, and sound production.

The IRCAM Forum community has been growing by leaps and bounds over the last few years and has nearly **20,000 members worldwide,** mainly professionals and students.

The Online Collaborative Platform forum.ircam.fr

A completely new version of the Forum's platform was launched in 2019. In addition to the already existing functions of Ircam software distribution and communication, it gives members the opportunity to publish their own work and offers a new approach to content publication and exchanges in the form of projects combining different technological bricks, articles, events and discussion forums by grouping all this information into thematic collections.

The IRCAM Forum facilitates the collective development of new ideas, promotes the transmission of practices, the archiving and indexing of knowledge, and provides an overview of the tools and innovations available in the fields of music and sound.

IRCAM Forum Workshops

Organized once a year at IRCAM in the presence of our research teams, the Forum Workshops are the annual meeting for the Forum community: three days of conferences, workshops, demonstrations and sharing on music and sound, in a multidisciplinary spirit. The 2021 edition features a new organization with a reinforced online dimension due to the current health crisis, making this event available to all who wish to attend.

Forum Workshops: Hors des Murs

Organized in collaboration with an international network of universities, research centers and cultural institutions, these events are hosted once a year by our partners abroad include conferences, workshops and artistic performances (Seoul 2014, São Paulo and Buenos Aires 2015, Taipei 2016, Santiago de Chile 2017, Shanghai 2019, Montreal 2020-21).

The IRCAM Forum Offer

Registration to the IRCAM Forum is free of charge, providing users with a large number of software programs for experimental uses. Paid annual subscriptions—Premium Individual and Premium Institutional memberships—provide more comprehensive user rights, particularly for professional production and teaching, while offering exclusive access to a range of software and discounts on training courses and commercial software collections.

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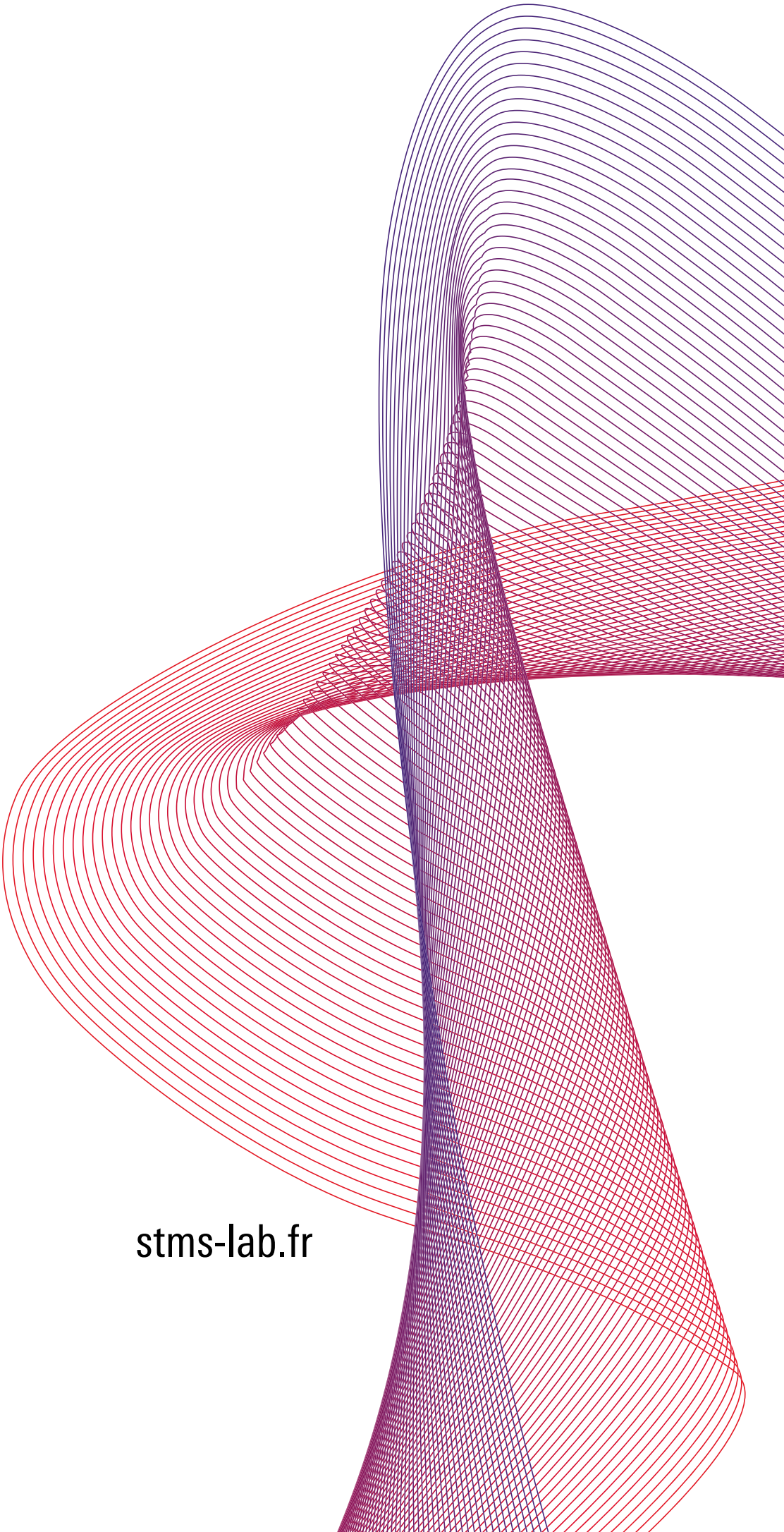

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