A ROADMAP FOR

Sound and Music Computing

Sound Music Computing

Sound to Sense, Sense to Sound

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Version 1.0

The S2S² Consortium

Sound to Sense, Sense to Sound

The S2S^2 Consortium

Media Innovation Unit, Firenze Tecnologia, Firenze, Italy

Music Acoustics Group of the Kungliga Tekniska Högskolan in Stockholm, Sweden

Music Technology Group of the Universitat Pompeu Fabra in Barcelona, Spain

CSC - Dept. of Information Engineering, University of Padova, Italy

Austrian Research Institute for Artificial Intelligence of the Austrian Society for Cybernetic Studies in Vienna, Austria

Département d'Etudes Cognitives of the Ecole Normale Supérieure in Paris, France

Laboratoire d'Etude de l'Apprentissage et du Développement of the Université de Bourgogne in Dijon, France

Institute for Psychoacoustics and Electronic Music of the Universiteit Gent in Ghent, Belgium

Laboratory of Acoustics and Audio Signal Processing of the Helsinki University of Technology in Espoo, Finland

Vision, Image Processing & Sound Laboratory of the University of Verona, Italy

Laboratorio di Informatica Musicale of the University of Genova, Italy

Coordinator	Nicola Bernardini
Editors	Xavier Serra Marc Leman Gerhard Widmer
Main Contributors	Giovanni De Poli Roberto Bresin Vesa Välimäki Davide Rocchesso Alain De Cheveigné Daniel Pressnitzer Antonio Camurri Emmanuel Bigand
Additional Contributors	Federico Avanzini Damien Cirotteau Cumhur Erkut Werner Göbl Fabien Gouyon Philippe Lalitte Henri Penttinen Pietro Polotti Rainer Typke Gualtiero Volpe

Executive Summary

Music is an important aspect of all human cultures. Music is meant to give new experiences, to give sense and meaning to life, to console and to promote social coherence and personal identity in and across very diverse social and ethnic groups. Rooted in the biology of every human being, music is a core occupation of our technological society. By 2020, music will have become a commodity as ubiquitous as water or electricity. Its content and the activities surrounding it will promote new business ventures, which in turn will bolster the music and cultural/creative industries. Sound and Music Computing (SMC) will provide the core technologies for this ongoing revolution in electronic music culture. Its major research contribution to advances in the field will be to bridge the semantic gap, the hiatus that currently separates sound from sense. This contribution will stimulate fruitful interaction between culture, science and industry.

Sound and Music Computing (SMC) research can be traced back to the 1950's, when a handful of composers, together with engineers and scientists, began exploring the use of the new digital technologies for the creation of new music and multimedia content. This new field of research had a profound impact on the development of culture and technology in our post–industrial society. Since then SMC has not only made great advances in a variety of areas that range from digital signal processing to cognitive musicology, but has also contributed to many successful technological applications, ranging from the synthesis engines of digital musical instruments to the audio CD, MP3 and polyphonic ringtones.

Today, SMC research is Europe's most advanced multidisciplinary approach to music and multimedia. By combining scientific, technological and artistic methodologies it aims at understanding, modelling and producing sound and music using computational approaches. SMC focuses on how cultural content can be integrated with ICT and other innovative technologies.

A recent study of the economic impact of the cultural and creative sector in Europe[1] revealed that its annual turnover (€654 billion in 2003) is larger than that of the motor industry or even ICT Manufacturers. This sector, of which the music industry is a major part, contributed 2.6% of EU GDP in 2003, slightly more than the contribution of the chemicals, rubber and plastic products industry combined. The sector's growth in 1999–2003 was 12.3% higher than that of

[1] KEA Study http://www.kernnet.com/kea/Ecoculture/ecoculturepage.htm

the general economy and in 2004, about 5.8 million people worked in it, equivalent to 3.1% of the total employed population in EU25. In view of the European Council's Lisbon agreement of March 2000, that the EU by 2010 should become 'the most competitive and dynamic knowledge–based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion", reinforced coordination of activities and European Commission policies impacting on the cultural and creative sector should be given a high priority.

The main objective of this SMC roadmapping project is to identify, characterise and propose strategies for tackling the key research challenges that this growing and diversified domain will be facing in the next ten to fifteen years. This Roadmap should help overcome the present fragmentation of Europe's efforts in the area of SMC by establishing a common agenda and ensuring consolidation, integration and exploitation of research results from European initiatives and projects. Hence, this project is clearly positioned at the strategic science and research roadmapping level: the expected result is not a roadmap focused on a particular product or technology (the most common type of roadmap), but rather the definition of a strategic programme for SMC.

This Roadmap is targeted at the whole SMC community. It should be specially useful to researchers in both academia and industry, giving them a wide perspective on their own research work. It should also be relevant to educators and policy makers, informing them of the key issues that should be emphasised in training and taken account of when making funding decisions.

This SMC Roadmap includes three scenarios illustrating how our everyday life could change by 2020 if the challenges were met, a definition of the field, a description of the research, educational, industrial, and social/cultural contexts, a state of the art overview identifying the current key research issues and a strategic pathway proposal with five challenges: *to design better sound objects and environments*, *to understand, model, and improve human interaction with sound and music*, *to train multidisciplinary researchers in a multicultural society*, *to improve knowledge transfer*, and *to address social concerns*.

This document is the result of two years of work by the $S2S^2$ Consortium. Innovative working methodologies and procedures were used. These included the concentration of the efforts of a board of senior researchers directly involved in the $S2S^2$ Consortium, the creation of an advisory board to gather consensus and qualified advice from the SMC community at large, and finally the running of several iterative cycles of internal and public review.

Preface

Over the past 50 years, music and technology have forged such a strong connection that all aspects of the economic chain, from production to distribution and consumption, have become digital. The real sound and sense for music is situated at the end–points of this chain, when musicians play, or when listeners search for and enjoy music as active consumers. All the rest is electronically encoded, virtual, and difficult to access. But it works! Music has become a major e–commerce commodity, paving the way for new business models and innovative applications in mobile technology and many other fields.

Music is the language of our emotions, of social bonding, of personal development and intellectual enrichment. But access to technology will be the major means by which this language can be fully explored. Indeed, the next revolution is about the connection between sound and sense; that is, the connection between encoded physical energy in technology and the human subjective experience. New technology is needed to close this huge gap. This new technology will impact on how people normally have access to music at all levels of the digital economic chain. It will revolutionise how people deal with music, transforming recording and broadband technology for sound and music into a vast, world–wide, all–penetrating musical instrument that all humans can easily access. This revolution will be taken up by the dynamic forces that drive music, which in turn will lead to new developments and opportunities in the cultural and creative industries. New innovative products will foster social interaction among people and it will also create new opportunities by offering new tools for expression and communication, from content–based music information retrieval, to interactive music systems for artistic production, to sound–aware daily environments.

This revolution has a bright future, but it needs strong support and coordinated action. At this moment, Europe is playing a leading role in research that aims at bridging this gap between sound and sense. The intention of this roadmap is to set out the basic strategic directions needed to coordinate research activity in this domain.

This Roadmap is one of the results of the S2S^2 Coordination Action [2]. Apart from it being the greatest of honours for me to coordinate this Consortium — representing the top European researchers in this field — I must say that it has proved to be a most pleasurable experience. I wish to thank all my colleagues both for their herculean efforts and also for their unfailing kindness, patience

[2]The S2S^2 (Sound to Sense, Sense to Sound) project was submitted to the European Commission during the 6th Framework Programme in the Future and Emergent Technologies (FET)–Open call series and its funding has run from June 2004 to May 2007. Other notable results of the S2S^2 Action have been:

- the S2S^2: A State of the Art in Sound and Music Computing book (in press)
- the Sound and Music Computing Summer School

The S2S^2 website is the official source of information concerning the S2S^2 project.

and understanding in such a complicated endeavour.

Of course, an achievement of this size would not have been possible without the help of a much larger number of people. First of all, my deepest gratitude goes to Alexandros Bakalakos, a constant supporter of the S2S^2 Project right from its very inception. S2S^2 was supervised by two patient and understanding Project Officers from the European Commission: Anna Katrami–Betzirtoglou, from 2004 to September 2006, and Walter Van de Velde from September 2006 through to the end. The project reviewers Enrique Lopez–Poveda and Bozena Kostek made a number of invaluable suggestions which enhanced the results of the Action, including that the Roadmap itself. Xavier Amatriain was central in organising the *Academia meets the Industry* report and the workshops at the AES in Barcelona and in New York in 2005. During those workshops, the project (and this Roadmap) received many useful suggestions from the exceptional panels of experts gathered by John Strawn: Jens Blauert, Karlheinz Brandenburg, Peter Eastty, Jyri Huopaniemi, Morton Lave, William L. Martens, Rob Maher, Karsten Nielsen and Nick Zacharov. Many other good suggestions came from the meeting with another panel of experts, the Digital Music Research Network (DMRN) Roadmap Expert Panel of authors, editors and advisors: Barry Eaglestone, Eduardo Miranda, Tony Myatt Mark Plumbley and Francis Rumsey. The DMRN network (a network funded nationally by the UK Engineering and Physical Sciences Research Council — EPSRC Network GR/R64810/01) was set up in 2003 to prepare a UK Roadmap on Digital Music research[3]. Their roadmap was launched in December 2005, at just about the time when the S2S^2 roadmap was starting to be drafted, and their experience and suggestions — collected with those of Mark Sandler in a joint S2S^2–DMRN workshop held in London in February 2006 — were most helpful. The S2S^2 Action established a firm exchange relationship with other European Projects and Actions, notably the ENACTIVE[4] and the HUMAINE[5] Networks of Excellence, and the Cost287-ConGAS[6] COST-TIST Action. In particular, we wish to acknowledge the active participation of Annie Luciani and Claude Cadoz (ENACTIVE) in collaboration which led to the present Roadmap. The S2S^2 Summer School, besides establishing a solid framework for post–doctoral training and an evolving canvas for constant research upgrades, has provided another great opportunity to involve specialists within and without the SMC realm in the preparation of this Roadmap: Vittorio Gallese, Henkjan Honing, Leigh Landy, Fabien Lévy, Stephen McAdams, François Pachet, Ruggero Pierantoni, Emanuele Trucco and William Verplank. In the course of the preparation of the Roadmap, the S2S^2 Consortium created an advisory board to provide an outside perspective on the evolving draft. In addition to many already mentioned above, the advisory board comprised: Stephan Bau-

[3]http://music.york.ac.uk/dmrn/roadmap/

[4]https://www.enactivenetwork.org/

[5]http://emotion-research.net/

[6]http://www.cost287.org

mann, Roberto Casati, Chris Chafe, Perry Cook, Roger Dannenberg, Goffredo Haus, Anssi Klapuri, François Nicolas, Vincent Puig, Curtis Roads, Sylviane Sapir, Julius Smith, Leon van Noorden and Barry Vercoe.

Finally, Sandra Brunsberg copy–edited the scenario chapter, Jim O'Driscoll proof-read the whole document while Rebecka Bíró and Santos Miguel Tricio provided the graphic layout and Peter Linell and Howard White helped us to produce a correct camera–ready version.

My deepest gratitude goes to all of them.

Within this document, there is some variability in style and perspective which reflects the normal process of scientific endeavour. In addition, all contributors had to face the fact that there is a significant lack of quantitative data in this still fledgling domain, along with a difficulty in defining its boundaries. However, I hope that this document is complete and significant enough to make a difference in the way Sound and Music Computing progresses in all future endeavours.

A final point: while I have introduced this Roadmap as a result, it is really only a starting point. We are all conscious of the fact that it will be a useful reference and source of inspiration only if it is regularly edited and updated to reflect the constantly changing SMC community at large. For this reason, we will be setting up a permanent procedure for an editing cycle and the latest version of the Roadmap will always be downloadable from the location

http://www.soundandmusiccomputing.org/roadmap

Brussels, April 16 2007 Nicola Bernardini, Coordinator

Contents

CHAPTER 1

Scenarios from the Future: The Benefits of Sound and Music Computing Research

The three scenarios presented in this chapter represent visions of life after a few attainable (though not necessarily *easy*) scientific/technological targets have been hit through the removal of roadblocks, the filling in of gaps and the meeting of certain challenges as outlined in Chap.5.

The scenarios describe general environments and activities concerning our everyday life soundscapes, the professional perspective of musicians and general music appreciation. As such, there is no one–to–one correspondence between a particular scenario and any of the particular key issues identified in Chap.4. Rather, they provide hints of how the world could be if and when Sound and Music Computing research achieves the multidisciplinarity and transversality proposed in this Roadmap.

Chapter 1. Scenarios from the Future

1.1 CONTROLLABLE SOUND ENVIRONMENTS

Sensors, actuators, microprocessors, and wireless connection facilities are increasingly being embedded into everyday objects. These can be augmented with sonic features that make the environment more enjoyable, social life more interesting, and personal life more relaxed and healthy.

Grandma and me

Hi, I'm a teenager — 15 years old — and I like to wake up late, at least on Sundays. But today I decided to spend a few hours with my grandmother, so I set my alarm clock bed for 9 a.m. First, the bed tries to wake me up gently, by vibrating and making purring noises. Even though I am not sleeping anymore, I like to wait until the bed gets more nervous, when it realises I am still lying on it, and starts making harsh rhythmic movements and squeaking. I love it!

I get up and go into the living room. It's a mess after last night's party. You know, mum and dad are on vacation, so ... Chairs are everywhere; chips and peanuts all over the floor. I play some of my favourite hip–hop music while I put things back in place and prepare for the day. Different MCs and DJs are embodied in different pieces of furniture. I know it sounds retro, but it is so cool to move DJ Grandmaster Flash while I am moving that old armchair around. While I move through the house, the music seamlessly follows me through the objects I pass. When I leave home, I put on my headset and keep riding the beat. The headset doesn't cut me off from the environment,though. When I catch sight of a strange bird singing, I look at it and put my hand to my ear. This gesture activates acoustic zooming, and I can appreciate the bird song in isolation. But then I am distracted by the sight of a friend of mine chatting to a girl. Instinctively, I steer my acoustic zoom towards them, but I realize she is wearing one of those new active jackets that can create an acoustic shield around you. I wonder what they are talking about.

I reach my grandma's house. She became almost deaf about five years ago, but she is really brave and decided to get an implant of powerful bionic ears. In recent years, she has become more and more worried about the bad things that could happen to her. That's why my dad bought her a new door. As we leave the house and she closes the door, she proudly explains that the complex sound of the lock tells her that the lights are switched off, the gas is turned off, the fish are fed, and the window in the living room has been left wide open. I'm sure she left it open on purpose, but we go back in and close it anyway.

We are going to the Fred Astaire club today. Grandma is wearing brand new Mike shoes. She feels much more confident about herself in these shoes, because they give her bionic ears some sonic feedback about equilibrium so she's not afraid of falling while she moves around. Before we go into the club she wants to check on her health, which is promptly sonified through her bionic ears. Everything sounds fine, so we go in just as the show's starting. There are a dozen over–eighties there, wearing Mike shoes, tap dancing, and clearly having a good time. Their subtle, gentle movements trigger a massive and diverse set of rhythms. Who knows — it may even be cooler than hip hop!

On the way back home, grandma tells me how different the town was when she was a child. There was even a working water mill. Fortunately, we can both enjoy its sound. Both my cheap headset and her bionic ear can induce selective silence and let the lost sounds of the town emerge from history. That makes her remember even more. It's fun being with grandma.

1.2 MUSIC INSTRUMENTS FOR ALL

In 2020, many sound devices will have a general purpose computer in them and will include quite a number of real–time interaction capabilities, sensors and wireless communication. Basically, any sound–producing device will be able to behave like a personalised musical instrument. Music making will become pervasive and many new forms of communication with sound and music will become available. Music content will be inherently multimodal and music making available to everyone: music from all to all.

How I became a professional musician

A year ago I bought the new wearable mobile device from SMC Inc. With it I was able to listen to my favourite songs and interact with them in ways not possible with the previous generation of devices. Now I was able to change many aspects of the songs by gestural and vocal control. Some of my friends were really good at it, and I started to improve my skills by practising on my home multimedia system. This system includes Jeeves, a virtual musical assistant, which observes and analyses my body movement, my singing and my musical abilities in general. Jeeves teaches me how to express myself in the style of famous musicians, from The Beatles to cellist Yo–Yo Ma. After a period of training, I was ready to play and jam with other users over the Internet and get advice from more expert users or their virtual musical assistants. After a couple of months, I started to get a good reputation in the community. One day, a group of users asked me to join them in person at a discotheque. In that discotheque we were able to use our mobiles to plug into a music role in the overall show. People took all kinds of roles; some were projected as visual characters on the surrounding space and walls, some were projected into moving lighting, others, like me, were controlling the expressivity of the music being played. Since I was a beginner, I took a simple role as the controller of the timbral aspects of the drum. Another person took control of the drum sticks. We had to dance to coordinate the rhythm in this shared drum set with the other visual and musical roles. This experience felt much more physical and exciting than being at home with my multimedia system. In the discotheque I had the feeling of being part of a community and of real teamwork. The various haptic devices in my clothes heightened my aural and visual perception and interaction with friends.

I met these new friends many times; I practised a lot in discotheques and at home. I developed my own style and developed good skills in controlling virtual instruments, with Jeeves evolving with me and my community. I could control expression and lead my friends in improvisations and jam sessions. One day Jeeves asked me: "Could I please change my name to Madonna? I feel that my background knowledge has changed". I realised that was true and changed her name.

Today I am a professional musician: an MJ (Music Jockey). Madonna and I prepare the shows on the authoring system at home. I design the structure, framework, roles, and musical material to be used. In my shows, I sometimes improvise with acoustic instrument players. I collect data on my sound device by monitoring their movements and performance choices. I can also monitor and analyse all the events in the show and the behaviour of everyone involved in it, including the audience. My virtual musical assistant Madonna wants to change her name again. Now she would like to be called Karajan.

1.3 PERSONALISED MUSIC DEVICES

Current portable mp3 players — despite their simplicity — have already radically changed human music-listening behaviour. Now, the first web–based music information systems which provide contextual information about music simply by connecting already existing services (such as Wikipedia, CDDB, lastFM,etc.), without the utilisation of any musical expertise, are beginning to emerge. Based on current trends in SMC research, we predict that such systems are likely to further develop in the direction of multi–modal, interactive, open and adaptive systems that support both beginners and experts from different cultures in accessing music and music–related information.

My new music friend

I take my expert music companion with me anywhere, anytime, because I love music. The companion doesn't just play music. It gives me a lot of other information about the music — from 'practical' things such as transcriptions of instruments and harmonies, to animated visualisations of the structure of the music, contextual information such as style, historical and cultural relations, and the relationship of the piece to other, related pieces and styles.

My device is easy to use. I can talk to it, or I can shake it to show it the kinds of rhythms I like. It is aware of the music being played on radio stations and available in music databases world–wide, and it finds new music that I like in a particular situation. I can point it at music being played by a street band, and it will tell me what it is. It understands my intentions and learns my musical preferences. Sometimes it will surprise me, teaching me something new about music and my taste. And by the way, having had nano–sized loudspeakers (painlessly) implanted in my ears, I listen to my music without bothering with bulky headphones and earplugs.

My music companion also helps me out in social contexts. When I am desperately looking for a date, my companion alerts me there's a dance party around the corner for people with a similar interest in Brazilian music. When I get to it, my companion contacts the DJ system and sends it some of my favourite pieces (rare Brazilian stuff). The girl in the corner just goes "Wow".

My music companion is no longer an isolating device that runs playlists; it's a friend that enhances my musical abilities, reflects my personality and helps me to socialise.

CHAPTER 2

Definition of The Field

Sound and Music Computing (SMC) research approaches the whole sound and music communication chain from a multidisciplinary point of view. By combining scientific, technological and artistic methodologies it aims at understanding, modelling and generating sound and music through computational approaches.

The central focus of the research field is *sound and music*. Sound is the resonance of objects and materials. Music is the intended organisation of sounds for particular uses in social and cultural contexts. The sound and music communication chain covers all aspects of the relationship between sonic energy and meaningful information, both from sound to sense (as in musical content extraction or perception), and from sense to sound (as in music composition or sound synthesis). This definition is generally considered to include all types of sounds and human communication processes except speech. Speech research has its own aims and methodologies and is outside the SMC field.

The other elements contained in the definition statement above can be briefly explained as follows:

The *multidisciplinary point of view* relates to the use of various research methodologies and disciplines from the natural and human sciences. SMC also includes various research goals and approaches that deal with cross–modality, such as the relationship between perception and action and the integration of different senses involved in human–machine–human interaction (hearing, vision, movement, haptics, etc.), both in individual and social contexts.

Scientific and technological methodologies refer to empirically–based and modelling–based approaches that draw upon advanced tools for measuring and processing information. *Artistic methodologies* refer to approaches that explore human experience and expression.

Understanding refers to our knowledge of the mechanisms that underlie how people deal with sound and music in terms of its content and experience.

Modelling refers to the representation of knowledge through algorithms and tools.

The resulting models are used both in applications that aim at scientific understanding (e.g. simulation of perceptual processes) and also in applications that aim at practical understanding (e.g. in sound–aware objects, music information retrieval systems, music production companions).

Production refers to the creative use of algorithms and tools to develop new content in which sound and music are communicated, as in sound environments, interactive artistic works and sonic design.

Computational approaches refer to the core processing which allows the development of tools linking sonic energy with subjective experience. Computing is the shared practice that connects scientific understanding, the development of technological equipment and content–based creation.

2.1 DISCIPLINES INVOLVED

The disciplines involved in SMC cover both human and natural sciences. Its core academic subjects relate to musicology, physics (acoustics), engineering (including computer science, signal processing and electronics), psychology (including psychoacoustics, experimental psychology and neurosciences) and music composition.

Musicology

All research that deals with musical meaning formation, musical content description, and associated mediation technologies in particular sociocultural contexts. It comprises the study of how musical content can be described and how the subjective and sociocultural background of users plays a role in the production, distribution and consumption of music.

Physics

Acoustics is the science concerned with the production, control, transmission, reception and effects of sound as a physical phenomenon. The branch of acoustics of special interest to the SMC community is music acoustics. It includes the acoustics of musical signals (such as in expressive music performance), musical instruments and singing voices.

Engineering

This includes all the research in computer science and engineering, signal processing and electronics that deals with music information representation, processing and communication. It comprises multimedia information systems, artificial intelligence, audio signal processing, robotics, sensors and interface technology.

Psychology

This includes all research into music–related behaviour and brain processes, including the roles of perception, cognition, emotion and motor activities. Psychology is here understood to cover the whole domain from psychoacoustics to experimental psychology to neurosciences.

Music Composition

This concerns all research that has a focus on musical content creation. It includes creating music as a score, as an interactive artistic event, as a sound installation, as a soundtrack, and as any form of organised sound event which communicates information.

2.2 AREAS OF APPLICATION

Most SMC research is of the applied kind and thus possible applications have an important role in the definition of the field. Current areas of application include digital music instruments, music production, music information retrieval, digital music libraries, interactive multimedia systems, auditory interfaces and augmented action and perception (e.g. bionic ears, digital prosthesis and multi–modal extensions of the human body).

Digital music instruments

This application focuses on musical sound generation and processing devices. It encompasses simulation of traditional instruments, transformation of sound in recording studios or at live performances and musical interfaces for augmented or collaborative instruments.

Music production

This application domain focuses on technologies and tools for music composition. Applications range from music modelling and generation to tools for music post–production and audio editing.

Music information retrieval

This application domain focuses on retrieval technologies for music (both audio and symbolic data). Applications range from music audio–identification and broadcast monitoring to higher–level semantic descriptions and all associated tools for search and retrieval.

Digital music libraries

This application places particular emphasis on preservation, conservation and archiving and the integration of musical audio content and meta–data descriptions, with a focus on flexible access. Applications range from large distributed libraries to mobile access platforms.

Interactive multimedia systems

These are for use in artistic, entertainment and infotainment applications. They aim to facilitate music–related human–machine interaction involving various modalities of action and perception (e.g. auditory, visual, olfactory, tactile, haptic, and all kinds of body movements) which can be captured through the use of audio/visual, kinematic and bioparametric (skin conduction, temperature) devices.

Auditory interfaces

These include all applications where non–verbal sound is employed in the communication channel between the user and the computing device. Auditory displays are used in applications and objects that require monitoring of some type of information. Sonification is used as a method for data display in a wide range of application domains where auditory inspection, analysis and summarisation can be more efficient than traditional visual display.

Augmented action and perception

This refers to tools that increase the normal action and perception capabilities of humans. The system adds virtual information to a user’s sensory perception by merging real images, sounds, and haptic sensation with virtual ones. This has the effect of augmenting the user’s sense of presence, and of making possible a symbiosis between her view of the world and the computer interface. Possible applications are in the medical domain, manufacturing and repair, entertainment, annotation and visualisation, and robot teleoperation.

2.3 ACADEMIC SUPPORT

Academic support for the SMC field has not yet reached a mature state. There are a number of related academic societies, conferences and journals, but only a few of them have a clear focus on SMC issues, reflecting the fact that SMC is not a well- established academic field. Nevertheless, the situation has improved in the last decade, especially in Europe. Below we list the major international academic societies, journals and conferences related to SMC. A more complete list can be found in Appendix B.

2.3.1 Academic societies

International Computer Music Association (ICMA); International Musicological Society (IMS); Acoustical Society of America (ASA); European Acoustics Association (EEA); Institute of Electrical and Electronics Engineers (IEEE); Association for Computing Machinery (ACM); Audio Engineering Society (AES); European Society for the Cognitive Sciences of Music (ESCOM); Society for Music Perception and Cognition (SMPC) and Electroacoustic Music Studies Network (EMS)

2.3.2 Journals

Computer Music Journal; Journal of New Music Research; EURASIP Journal on Audio; Speech; and Music Processing; IEEE Signal Processing Magazine; IEEE Signal Processing Letters; IEEE Transactions on Audio; Speech and Language Processing; IEEE Multimedia Magazine; Journal of the Acoustical Society of America; Acta Acustica; united with Acustica; Journal of the Audio Engineering Society; Musicae Scientiae; Music Perception; Psychology of Music; Leonardo Music Journal; Computing in Musicology; Perspectives of New Music and Organised Sound

2.3.3 Conferences

International Computer Music Conference (ICMC); International Conference on Music Information Retrieval (ISMIR); International Conference on Digital Audio Effects (DAFx); International Conference on New Interfaces for Musical Expression (NIME); International Conference on Music Perception and Cognition (ICMPC); Sound and Music Computing International Conference (SMC); ACM Multimedia; Meeting of the Acoustical Society of America; AES Conventions and International AES Conferences; International Conference on Music and Artificial Intelligence (ICMAI); IEEE International Conference on Acoustics; Speech and Signal Processing (ICASSP); IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA); International Conference on Computer Music Modelling and Retrieval (CMMR); Stockholm Music Acoustics Conference (SMAC); International Conference on Auditory Display (ICAD); International Conference of the European Society for the Cognitive Sciences of Music (ESCOM); International Conference for Human–computer Interaction (HCI); Conference on Interdisciplinary Musicology (CIM) and Electroacoustic Music Studies Network's conference

CHAPTER 3
Contexts

Having defined the SMC field in the previous chapter the next issue we want to address is the various contexts in which the field can be situated. Four of these may be identified. First, there is the research context; that is, the state and trends of related disciplines and what influence they might have on SMC. Secondly, current trends in higher education are of relevance because they will determine the context in which future SMC researchers are educated. Third, the industrial context has a big impact on the direction of SMC research, so an understanding of the industries that will most benefit from it, and of trends in the ICT sector generally, is vital. Finally, SMC research has an obvious link to culture and has, or might have, relevant social implications, so we need to view current cultural and social trends in relation to it.

3.1 CONTEXT 1: RESEARCH

This section aims to identify the major research trends within which SMC is to be situated. The focus is on trends in ICT, the cognitive sciences and the humanities. Given the broad scope of SMC, this section devotes special attention to the rise and importance of multidisciplinary research [9, 11, 12].

Trend 1: Rapid progress in ICT

In recent decades, progress in SMC has been driven by revolutionary developments in information technology. The transitions from analogue to digital data processing and from wired to wireless mobile data–communication have been key components in this development. The relentless rate of annual to biennial doubling of storage capacity, bandwidth and data–crunching computing power has been unprecedented in history, leading to fundamental transformation of all aspects of the production–processing–distribution–consumption chain of sound and music content. In no other field has an entire processing chain been digitalised and made available on broadband networks and mobile devices on such a massive scale. In this development, technological progress has had a direct empowering influence both on scientific knowledge and on end applications, which in turn have impacted on the development of new technologies. In the context of this development, a number of consequences for research can be identified [1, 2, 3, 4].

> *Statement 1: The rate of increase in storage capacity, bandwidth and data–crunching computing power is leading to fundamental transformations in all aspects of the music chain.*

First, the increasing capacity of data storage and transfer supports the accumulation of, and easy access to, ever–larger volumes of data. A resulting benefit is better access to *knowledge*, e.g. online access to vintage publications, supplementary data, new publication formats, etc. This accessibility is empowering to the scientist. At the same time, like the invention of printing, it has an effect on the embodiment of knowledge itself, shifting the centre of gravity of knowledge from brain, to book and onward to database.

A second effect is the shift towards *data intensive* methodologies that involve gathering or compilation of large volumes of data. This allows a focus on data intensive *phenomena*, phenomena that are either intrinsically complex, or else accessible only as patterns within multiple or complex observations. In the field of music studies, an enquiry might call for the processing of a large library of musical scores or a large database of audio data. A few years ago such a quest might have remained untouched for lack of access to the data, or no room to store it in the computer, or no time to wait for the computer to give an answer. By the same token, a topic once respectable for its technical difficulty might suddenly become trivial. In ways such as these, Information Technology affects the focus of science.

A third consequence is the shift away from analytical and theoretical approaches towards a reliance on computer models and simulations. This approach, which can be observed in fields as diverse as pure mathematics (computational proofs), statistics (Montecarlo methods, bootstrap) biology (DNA sequence alignment), linguistics and speech engineering (data–driven methods), has engendered a degree of unease and debate [10]. Does a proof that only a computer can follow really contribute to our understanding? Similar unease met the invention of algorithmics, infinity, or proof by induction. In similar vein, does a drum machine qualify as a musician? Is 'jazz improvisation' by a computer really either jazz or improvisation?

A fourth consequence is the development of 'machine–embedded knowledge' such as that gathered by machine–learning techniques. Arguably these techniques come closer to delivering the promises of 'intelligence' than has Artificial Intelligence itself. With them, intelligence is attained less by artifice of man than that of machine. At the confluence of statistical estimation techniques and neural network theory, machine learning harnesses the computer to compile and extract regularities from massive quantities of data. The 'knowledge' thus obtained, usually impossible to describe to a human brain and useless without a computer, is nonetheless empowering for web search, spam filtering, or musical content indexing and retrieval. As models of brain processing, machine–learning techniques may eventually provide a bridge between information technology and neurosciences. Particularly relevant to music technology are new techniques of signal processing related to machine learning.

In summary, progress in information science and technology is fuelling a drive towards data– and computation–intensive approaches to knowledge acquisition and problem solving, particularly in domains relevant to SMC. These have deep implications for the nature of scientific and technological knowledge and how it is brought to bear on our needs.

> *Statement 2: Information technology is profoundly reshaping the methodologies and scope of scientific inquiry and technological development.*

Trend 2: Cognitive science: from musical mind to brain

Cognitive sciences [5] focus on how humans interact with their environment, mostly from the viewpoint of perception and action. Developments in this research domain have had a huge impact on SMC. In fact, studies on musical memory, learning and all activities related to music perception and action, such as extraction of high–level information from musical stimuli or gestural sound control, can be considered the basic constituents of SMC applications.

The cognitive science of music (as practised in, for example, cognitive musicology, experimental music psychology or the neurosciences of music) has as its focus the semantic gap that exists between our daily meaningful experiences with sound and music on the one hand, and the encoded physical energy of sound and music on the other. When dealing with music, we call upon content and meaning, whereas the encoded physical energy is just a way of storing information in a technological device. How are the two connected? How can we access the encoded information by means of meaningful actions? Research in cognitive science aims at providing new insights into this semantic gap problem.

Several different approaches to solving this problem can be distinguished.

A first approach starts out from the premise that the human mind is embodied [13]. Rather than trying to solve the semantic gap problem by looking at formal structures and higher–level or low–dimensional representational spaces, the relation between human meaning and encoded physical energy is here seen as being mediated by the human body. For example, if an ambiguous musical rhythm is presented, then it is assumed that the motor system of the human body engenders the anticipatory mechanisms (called emulation) that allow a disambiguated auditory perception of it. Action is here seen as a crucial component for auditory perception, with action and feedback mechanisms being considered at different processing levels, from feedback mechanisms in the auditory periphery (e.g. the role of outer hair cells in attenuation) to the role of intended actions in perception. The embodied viewpoint may revolutionise how we think about ICT development in that it calls for new technologies that mediate between the human mind and its musical environment, based on a multi–sensory approach to SMC.

> *Statement 3: The embodied viewpoint calls for new technologies to mediate between the human mind and the environment.*

A second research direction is concerned with the methodologies for acquiring knowledge about the semantic gap problem. In the last decade, these methodologies have been extended from behavioural to brain research. Knowledge about the brain is progressing rapidly and at multiple scales which include molecular, synaptic, cellular, cell assembly, and regional and functional anatomy as revealed by brain imaging. Today our tools include molecular biology techniques for probing the membrane and synaptic properties of neurons, physiological recording techniques to observe entire neuronal assemblies, non–invasive imaging techniques to probe activity within the human brain, computational tools to gather and process the resulting data, and theoretical tools to make sense of the complexity of what is observed. Some recent studies in neurophysiology include the use of awake preparations (often coupled with behavioural studies), multiple unit recordings, simultaneous invasive and non–invasive brain imaging techniques (to calibrate one with respect to the other), selective brain cooling, optical imaging and the coupling of one of these with genetic engineering or biochemical manipulations to probe specific stages in processing. Research in brain imaging includes the use of higher magnetic fields for structural and functional MRI (magnetic resonance imaging), increased numbers of channels in EEG (electroencephalography) or MEG (magnetoencephalography), simultaneous recording of fMRI and EEG, or EEG and MEG, and use of pre–surgical supradural or intracortical recordings from patients to obtain 'close up' snapshots of brain activity. An important facilitating factor in these developments is progress in hardware and software techniques for handling and interpreting the massive data sets produced by brain imaging. In short, there is presently a rapid development of different technology–driven methodologies that provide new insights into how the brain is involved in the semantic gap problem.

> *Statement 4: New technology–driven methodologies are providing new insights into the human brain.*

A third major research effort in theoretical neurosciences is about a tight interaction between signal processing and machine learning techniques on the one hand, and models of neural processing on the other. A common goal is to find techniques that can harness the extreme *complexity* of relevant patterns in data (for example databases of environmental, speech or musical sounds) or the structures and mechanisms observed within the brain. The computer here is used as an aid to harness a degree of complexity of which our brains cannot otherwise easily comprehend. One promising angle of enquiry is the use of data–driven *development* of the processing mechanism (natural or artificial) under the drive of the data patterns that it is to process, as an alternative or complement to more traditional engineering techniques.

On the practical side, one can speculate on possible future benefits from the neurosciences. An example of such a hypothetical breakthrough might be the possibility of 'downloading' entire cognitive or perceptual processing mechanisms to software. This could result from a combination of progress in recording techniques, theoretical neurosciences and machine learning. Another hypothetical breakthrough (heralded by the well–established cochlear implant and recent experiments with animal models and impaired humans) could be the widespread development of brain–machine interfaces (BMI). This could result from a combination of progress in interface hardware (e.g. miniaturised electrode arrays), signal processing (to factor out 'noise') and machine learning (to translate between the different codes used by brain and machine). All this research is likely to have a huge impact on the SMC field. Examples are hearing aids that allow their users to listen to music or an intracortical implant that would allow a quadriplegic to play the piano.

> *Statement 5: Cognitive and neurosciences offer a rapidly expanding window on the human mind and brain, thereby providing new possibilities for solving the semantic gap problem.*

Trend 3: From subjective experience to cultural content in the Humanities

Research in the humanities is focused on signification practices; that is, on how human being make sense of their environment and give meaning to their lives. The humanities view this signification practice from a subjective and experiential point of view. Therefore, research of this kind includes anthropology, area studies, communications, cultural studies and media studies. The humanities not only provide insights into these aspects but also train people in the skills necessary for practitioners (e.g. in music playing, painting). Traditionally, research methodologies in the humanities are based on analytic, descriptive, critical or even speculative and imitation approaches, although recent approaches also involve quantitative and empirical studies [14, 15, 16]. In the cultural and creative industries, the humanities can provide the content needed to develop a significant partnership between culture and technology.

Several research efforts in the humanities address this issue.

A first approach has adopted the belief that subjective factors in (related to gender, education and social and cultural background) play a central role in how people deal with technology. Knowledge of these factors needs to be incorporated into music information retrieval technologies. Humanities research provides the necessary analysis of the social and cultural context in which technological applications will function.

> *Statement 6: Subjective factors play a central role in how people deal with technology.*

A second research approach is concerned with what is sometimes called 'medialogy'; that is, an approach which combines technology and creativity to design new processes and tools for art, design and entertainment. It involves insight into the creative processes, thoughts and tools needed for media–productions and other arts to exist. Clearly, medialogy is at the crossroads of the human sciences, the creative arts and technology. As such, it is a central pillar of the creative industries.

A third research approach is concerned with the transformation of the cultural sector into the digital domain. This involves the digitalisation of a large part of our cultural heritage. From the humanities point of view, the preservation and archiving of cultural heritage poses huge challenges with respect to issues such as the authenticity of documents, flexible multi–language access and the provision of proper content descriptions of objects from multifarious cultures.

> *Statement 7: The digitalisation of a large part of our cultural heritage is opening up completely new challenges.*

A fourth key topic in the humanities concerns the role of embodiment, an area of research which is clearly connected with the study of embodiment in cognitive science. It is thanks to the humanities that this topic has become a genuine research topic on the agenda of empirical sciences that deal with perception, action and the use of tools and technologies. Indeed, some aspects of embodiment, involving emotions and the gesture related to them, can be straightforwardly explored and used in artistic and cultural applications. Even if our knowledge about these processes is limited, we can still use them in applications. These typically human skills, which often require intensive learning, have been studied and described for centuries from a humanistic point of view, often from entirely different cultural perspectives. Accordingly, the humanities provide a rich source of theories, concepts and traditions that are highly revealing and inspiring for new empirical studies and technological applications. One example is the Laban theory of effort, which provides a speculative but very valuable insight into choreography and expressive moving. This theory can be straightforwardly related to music perception, leading to the interesting approach of gesture–based music retrieval. Another example is phenomenology and how it is currently being integrated into a neuroscientific approach to empathy and social cognition.

In short, the humanities offer a very rich background from which the problem of the semantic gap can be addressed. Its focus on specific topics such as the human subject, embodiment and social and cultural interaction, along with its often descriptive analytic approach, is highly valuable from the perspective of content creation.

> *Statement 8: The humanities offer the cultural background and content for SMC research.*

Trend 4: The rise of multidisciplinary research

Scientific research is currently witnessing two opposing, though intimately related, approaches. On the one hand, it continues to differentiate into more and more specific and narrowly circumscribed sub–fields owing to the accelerating accumulation of ever more specific knowledge. At the same time, new multidisciplinary research fields are emerging within academia, for example in the life sciences, neurosciences and earth sciences. Understanding the complex phenomena facing mankind — from climate change to new epidemics to global economic and social developments — requires the integration of expertise from many fields.

The growing importance of multidisciplinarity is being increasingly recognised in research funding agencies and educational organisations. According to a report recently presented at the OECD Global Science Forum Workshop [6] "[t]he increasing multidisciplinary nature of research [...] is an important overall trend in science policy. For example, during the past four years, the fraction of interdisciplinary research at the United States National Science Foundation has increased significantly". The current *NIH Roadmap for Medical Research* issued by the U.S. National Institutes of Health (NIH) [6] states that "the traditional divisions [...] may in some instances impede the pace of scientific discovery". In response to this, the NIH is establishing "a series of awards that make it easier for scientists to conduct interdisciplinary research". As early as the year 2000, The National Sciences and Engineering Research Council of Canada (NSERC) set up a special Advisory Group on Interdisciplinary Research (AGIR) with a mandate to study how multidisciplinary research could be better supported by NSERC [7]. In 2003, the National Science Foundation promoted a study on the convergence of technologies [8] which concluded that: "In the early decades of the 21st century, concentrated efforts can unify science based on the unity of nature, thereby advancing the combination of nanotechnology, biotechnology, information technology, and new technologies based in cognitive science". Similarly, research funding institutions all over the world are beginning to recognise the need to give special attention to multidisciplinary research funding.

Of course, the fundamental importance of multidisciplinary research is also acknowledged by the European Commission. In the field of ICT, which is of direct relevance to SMC, the "Future and Emerging Technologies" (FET) programme is explicitly targeted towards innovative, multidisciplinary work — in the chapter dedicated to FET, the ICT work programme of FP7 calls for "interdisciplinary explorations of new and alternative approaches towards future and emerging ICT–related technologies, aimed at a fundamental reconsideration of theoretical, methodological, technological and/or applicative paradigms in ICT", one of the goals of FET being to "[help] new interdisciplinary research communities to establish themselves as bridgeheads for further competitive RTD" (ICT Work Programme 2007, p.53).

SMC is *by definition* an multidisciplinary field, ranging from the natural sciences like physics and acoustics through mathematics, statistics and computing, all the way to physiology, psychology and sociology. The global trend towards the recognition of multidisciplinarity should help SMC establish itself more confidently as an encompassing discipline that studies a phenomenon of central relevance to humans in all its necessary breadth. In addition, the emergence of new multidisciplinary fields of research and application is producing new points of contact for SMC.

A prime example of such contact is the current rise of the so–called *creative industries (CI)*. While the notion “creative industries” refers to a sector of the economy, its current upsurge (also in terms of public awareness) also leads to new opportunities for creative multidisciplinary research at the intersection of art, design and technology. SMC can and will play an important role here.

The case of the creative industries also highlights once more — if that were needed — the close ties between scientific research and the *arts*. Artistic visions coupled with creative application ideas are likely to drive SMC research in more ways than can currently be envisioned, resulting in entirely new environments, devices and cultural services.

> *Statement 9: Multidisciplinary research is increasingly seen as a necessity and an asset, and special programmes for fostering and funding it are being developed. SMC can take advantage of this and should actively seek alliances with other disciplines, including the arts.*

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3.2 CONTEXT 2: EDUCATION

The education context of SMC is quite complex, mainly due to its multidisciplinary nature and the consequent difficulty of fitting it into the traditional, discipline–oriented focus of most university level studies. There are almost no specific undergraduate degrees in SMC and the possibilities for an SMC specialisation are centred at the graduate level, where multidisciplinarity is more common.

Below, we summarise the relevant trends in higher education in Europe, and identify those most related to SMC at each of the three university education levels: Undergraduate, Master's and PhD.

Trend 1: The new European Higher Education Area

The EU drive towards the creation of an open European higher education area (EHEA) is both a reaction to and a reinforcement of the profound changes which have occurred in recent years: universities are educating larger numbers of students, from a wider range of backgrounds and with a wider range of skills, on entry; students are more mobile, spending parts of their education in other countries. This drive, initiated with the Bologna Process [5], is creating a framework that enables closer cooperation between higher education institutions in Europe, facilitates student and staff mobility and increases the attractiveness of European higher education in the world. In the following paragraphs, we discuss these trends and their significance for the design of new curricula in Sound and Music Computing.

Improving quality in the curricula is seen as one of the keys to greater recognition of qualifications across Europe, and this viewpoint is being taken by many universities as an opportunity to update and add more flexibility into their programmes [1]. These changes will definitely be beneficial for multidisciplinary fields like SMC; in fact many institutions explicitly praise the new freedom to design multidisciplinary Master's programmes, as well as programmes in emerging areas of science and knowledge. The wave of reform wave in European higher education seems to be going even further and deeper than the Bologna reforms themselves.

A second key ingredient in curricular reform is the link between higher education and employment. The Bologna Declaration particularly calls for undergraduate degrees to be relevant to the labour market. There is in general a growing push towards shorter study cycles, and many EU countries have already adopted the two–cycle qualification structure based on the Bachelor's and Master's distinction [4]. Employability is also seen as an important criterion in the design of new degrees in SMC. The music/multimedia industry at large is in the middle of important changes and is trying to adapt to the new markets and exploring the potential of SMC technologies (see the IndustrialContext section). New curricula in SMC have the opportunity to address these emerging labour markets.

A major recent change in higher education has been the increase in student mobility. A considerable part of overall mobility is supported through the EC's Erasmus–Socrates programme [7], established in 1987, which seeks to reinforce the European dimension of higher education by encouraging transnational cooperation between universities and boosting European mobility. The figures for mobility reflect a steady improvement, but remain below what the Commission considers necessary [3]. Moreover, the EU still attracts less talent than its competitors. [2]. SMC research in Europe has a successful track record involving excellence spread over several centres which have gained world leadership through complementarity and coordination supported by EC funding. This excellence has to be exported to the higher education domain, in order to attract students, scholars and researchers from other world regions.

> *Statement 1: New trends of higher education in Europe give more possibilities for designing curricula in SMC.*

Trend 2: Discipline oriented undergraduate education

The tradition of undergraduate education is very much discipline oriented. A student has to choose a curriculum aimed at developing a number of specific competences in a particular discipline plus a few general academic and professional competences. However there are curricula in Europe that are more multidisciplinary or that allow a student a wider choice of itineraries, thus permitting the design of 'custom made' curricula. With respect to research, the involvement of undergraduate students in such activities as a normal part of their curriculum is still very exceptional.

Given that there are many academic disciplines integral to SMC research (for a detailed discussion see the content areas listed in Appendix A), the education given in all the undergraduate degrees supporting these disciplines are of interest to any future SMC researcher. Thus a student wanting to become an SMC researcher might choose an undergraduate degree related to musicology, physics, computer science, electrical engineering, psychology, music composition, etc... Within most of the undergraduate programmes that support these disciplines, there are specific courses that might be of very great relevance to SMC. But in most cases it really depends on the professor responsible for the course and the special focus given to it.

> *Statement 2: Numerous paths, embedded in different well–established undergraduate degrees, can be designed to approach an multidisciplinary field such as SMC.*

The music conservatories are a special case of higher education institutions in the context of SMC. Traditionally, they have a strong professional orientation and thus might not provide the necessary background for a musician wanting to follow a research career. This situation has been slowly changing, due both to the transformations taking place in the music profession and also, in Europe, to the inclusion of the conservatories into EHEA [6]. Slowly, the conservatories are converging with the university system. It is now becoming quite common for a conservatory to offer a degree with a strong technological component. There are, for example, conservatory degrees in sound recording, tonmeister, sonology, music technology, electroacustic music, etc... Most of these degrees remain professionally oriented but very much related to SMC. Conservatories are also slowly incorporating the idea of research as one of their institutional aims and are designing curricula which are closer to the university model.

> *Statement 3: New conservatory degrees are a model for professionally oriented undergraduate curricula in SMC.*

Apart from the traditional university degrees and the case of the music conservatories, there are quite a number of multidisciplinary undergraduate programmes related to SMC, especially in the US and Great Britain. In the Anglo–Saxon system, it is much easier for universities to establish multidisciplinary programmes or even to allow student–centred curricula with individual academic pathways. However, there is an ongoing discussion among academics and researchers about the type of undergraduate education best suited to preparation for a research career in an multidisciplinary field like SMC— a strongly discipline oriented undergraduate degree or an multidisciplinary programme.

The adoption of a common system of credits, such as the ECTS system, plus the existence of funding programs like Erasmus to support mobility have had a big impact on undergraduate education. They have led students to become familiar with other approaches to a given field and have given them the opportunity to take courses not offered in their 'home' university. The Erasmus programme has also facilitated the creation of networks of universities with complementary undergraduate degrees in a given discipline, so that experiences among faculty members can be shared and the curricula opportunities for students are widened. Due to the variety of disciplines and methodological approaches involved in the SMC field, it is not easy to find educational institutions with an extensive coverage of all of them. It is thus very useful for an undergraduate student wanting to get a wider view of the field to take courses in different centres.

> *Statement 4: Undergraduate degrees with multidisciplinary contents encourage student mobility.*

Trend 3: multidisciplinary studies at Master's level

The objective of a Master's programme is academic or professional specialisation or an introduction to research activity. A research Master's serves as the bridge between undergraduate programmes, which are mainly courses based, and PhD studies focused on elaborating a research thesis. These Master's degrees are generally developed by universities by taking advantage of existing research strengths and therefore tend to reflect the research focus of university departments and faculty. Universities have a large degree of autonomy in setting up and modifying their Master's programmes, much more so than at undergraduate level. These programmes can therefore be more easily adapted to universities' educational and research strategies.

Research Masters used to be common in Great Britain but rare in continental Europe. But as part of the Bologna process, most European universities are now integrating PhD courses into Master's programmes and creating new Master's degrees [1]. Many programmes continue the traditional discipline oriented focus, thus offering a clear continuity from undergraduate studies, but they tend to have a greater degree of flexibility. The students have a greater choice of optional courses and, since the research thesis is a major part of the programme, they are able to work independently under the supervision of a tutor.

> *Statement 5: It is becoming easier for university faculties and research groups to introduce a student enrolled in a Master's programme into any given research field.*

In the last few years there has been a proliferation of multidisciplinary Master's programmes. Many of the key current research issues require multidisciplinary approaches and researchers need to be trained appropriately. multidisciplinary education requires collaboration between institutions and thus there is a clear trend toward promoting it. Collaborations between departments of the same university, between universities of the same country and between universities of different countries are becoming commonplace. At the European level, the Erasmus Mundus [8] is a co–operation and mobility programme which supports European top–quality Master's courses and enhances the visibility and attractiveness of European higher education in third countries. It also provides EU–funded scholarships for third country nationals participating in these Master's Courses, as well as scholarships for EU–nationals studying at partner universities throughout the world.

Until recently, Master level studies were typically offered exclusively at universities. It is a challenge for music institutions to offer musicians, in addition to instrumental training and practice, a reflective environment that nourishes innovation and creativity paired with the extension of knowledge and artistic understanding [6]. It becomes equally interesting when attempts are made to bridge the gap between theoretical research and musical practice. A great effort is being made by the European conservatories to develop Master's programmes and PhD studies and thus to incorporate research into their educational and institutional aims. It might take some time before this happens.

> *Statement 6: The multidisciplinary nature of SMC research can find the right educational framework at the Master's level.*

Trend 4: The Professionalisation of PhD studies

Doctoral studies have traditionally been based on independent research undertaken by the doctoral candidate who draws upon the advice and guidance of a supervisor, supposedly on the model of a Master/apprentice relationship. This type of arrangement has long been the norm. For non traditional fields like SMC, it has had the advantage that a student is able to do a PhD just by finding an appropriate faculty member with sufficient knowledge of the chosen topic and a willingness to guide and support the student through the programme.

However, as a result of the changing context, PhD studies have recently come under scrutiny. Among the new challenges faced by universities in relation to doctoral education, it is worth mentioning the following desiderata [10]:

- to review the structure of training for researchers and integrate doctoral programmes into the Bologna Process;
- to deal with increased competition, from outside and within Europe;
- to increase and strengthen co–operation with businesses and to contribute more effectively to technological innovation;
- to find a new balance between basic and applied research;
- to enhance the employability of researchers by including in their training both core skills and wider employment–related skills.

PhD students doing multidisciplinary research are more diverse than their disciplinary counterparts. They may have any one of a wide range of subject backgrounds and may sometimes have have followed more than one educational pathway. The backgrounds of students doing research in SMC ranges from music to mathematics, from psychology to electrical engineering. What they have in common is the aim of bridging disciplines to develop new and multidisciplinary knowledge. There is general agreement [9] that this type of multidisciplinary research should conform to the following:

- Consistency with established knowledge in multiple separate disciplinary antecedents: how the work stands *vis à vis* what researchers know and find tenable in the disciplines involved.
- Balance in weaving together perspectives: the extent to which the work hangs together as a generative and coherent whole.
- Effectiveness in advancing understanding: the extent to which the integration of disciplinary perspectives advances the goals that have been set and the methods used.

> *Statement 7: The traditional model of a Master/apprentice relationship in PhD studies is evolving in a much more complex education environment, especially for multidisciplinary fields like SMC.*

The need for more structured PhD studies in Europe and the relevance of such studies to the Bologna Process have been highlighted repeatedly in recent years. In particular, joint PhD programmes can be amongst the most attractive features of the EHEA. But for the time being, interested students are still confronted with a variety of national and institutional structures that are not easily comparable.

> *Statement 8: Joint SMC PhD programmes at the EU level can be built by exploiting excellence spread over several centres with complementary competencies.*

Attention to employable skills and competencies in doctoral programmes is increasing. There is a clearly growing trend towards the professionalisation of PhD studies, involving the inclusion of coursework and training in transferable skills aimed at facilitating the flow of doctoral students into the wider job market. Students are becoming employed researchers within well–structured research groups and funded within well–focused research projects. Within this context, PhD students represent major academic and financial investments and contribute to much of the original research in universities. The role of supervisors seems key to the success or failure of multidisciplinary PhD projects [11]. There is clear evidence that the disciplinary background, interest and motivation of the supervisor have much influence on research outcomes, both in terms of its quality and also whether PhD studies are completed on time (or at all).

However the added–value of a PhD for employment outside the areas of research in universities, research institutes and R&D functions in industry remains somewhat limited. Central and East European countries especially, as well as South European countries, experience a continuing lack of interest on the part of employers outside the academy in hiring PhDs. The situation is almost reversed in the US, where a significant and ever growing number of PhDs are attracted to private sector employment in which remuneration is higher than in the academy [10].

Statement 9: multidisciplinary PhD programmes avoid a focus which is too narrow and provide a broad spectrum of knowledge that also qualifies their graduates for careers outside the academy.

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3.3 CONTEXT 3: INDUSTRIAL

Sound and Music Computing has always been an applied research field quite close to the music industry, thus close to the industries that create, perform, promote and preserve music. These industries involve: composers; performers and ensembles; publishers, record producers, manufacturers, labels and distributors; managers and agents; instrument makers; and some others. But right now SMC technologies have a much broader impact and are present in most of the industries that sit at the nexus of cultural, entertainment, leisure and fast moving consumer goods.

A recent study of the economic impact of the cultural and creative sector in Europe [10] revealed that the annual turnover of the sector (€654 billion in 2003) is larger than that of the motor industry or even ICT Manufacturers. This sector, of which music industry forms a major part, contributed 2.6% of EU GDP in 2003, slightly more than the contribution of the chemicals, rubber and plastic products industries combined. The sector’s growth in 1999–2003 was 12.3% higher than that of the general economy and in 2004, about 5.8 million people worked in it, equating to 3.1% of the total employed population in the EU25. In view of the European Council’s Lisbon agreement of March 2000, that the EU by 2010 should become ‘the most competitive and dynamic knowledge–based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion”, reinforced coordination of activities and policies impacting on the cultural and creative sector within the EU should be given a high priority.

The industries that relate to SMC are in the middle of important changes and most are trying to adapt to the new markets and exploring the potential of SMC technologies. From the writings and presentations of industry experts, we can identify seven major trends.

Trend 1: Towards a knowledge-based economy

Modern economies are increasingly based on the production, distribution and use of knowledge and information. Knowledge is now recognised as the driver of productivity and economic growth.

From the OECD report [1] it is clear that this long–term trend towards a knowledge–based economy is continuing. Science, technology and innovation have become key contributors to economic growth in both advanced and developing economies. Investment in knowledge (comprising expenditure on R&D, software and higher education) in the OECD area reached around 5.2% of GDP in 2001, compared to around 6.9% for investment in machinery and equipment. The share of knowledge–based "market" services is continuing to rise and now accounts for over 20% of OECD value added. The share of high and medium–high technology manufacturing fell to about 7.5% of total OECD value added in 2002, compared to about 8.5% in 2000.

Statement 1: Music related activities are part of the new knowledge economy and they should take advantage of the continuing growth of this sector.

Trend 2: A Global economy

Economies have expanded beyond national borders. Production in particular has been expanded by multinational corporations to many countries around the world. The global economy includes the globalisation of production, markets, finance, communications and the labour force.

From the OECD report [1] we learn that this is not a new phenomenon per se, but that it has become more pervasive and driven mainly by the use of information and communication technologies (ICT). In the knowledge economy, information circulates at the international level through trade in goods and services, direct investment and technology flows and the movement of people.

According to the American National Science Board [4] the globalisation of R&D, S&T, and S&E labour markets is continuing. Countries are seeking competitive advantage by building indigenous S&T infrastructures, attracting foreign investments and importing foreign talent. The location of S&E employment is becoming more internationally diverse and those who are employed in S&E have become more internationally mobile.

Statement 2: Both the production and consumption of music related goods is now globalised and international cooperation is more important than ever.

Trend 3: The development of the ICT sector

In the final decade of the twentieth century, the almost simultaneous arrival of mobile phones and the Internet not only changed the face of communications but also gave impetus to dramatic economic growth. We now speak of the Information and Communication Technologies sector to refer to the agglomeration of the communications sector, including telecommunications providers and the information technology sector, which ranges from small software development firms to multinational hardware and software producers.

Chapter 3. Contexts

According to the i2010 report [2] ICT accounts for a quarter of EU GDP growth and 40% of productivity growth. The digital convergence of the information society and media services, networks and devices is finally becoming an everyday reality: ICT will become smarter, smaller, safer, faster, always connected and easier to use, with content moving to three- dimensional multimedia formats.

Roberto Saracco [3] points out that any economic indicator ties together progress and communications infrastructure, and that the dissemination and progress of culture go hand in hand with the possibility of interacting and sharing ideas, thus putting telecommunications at centre stage.

The American National Science Board [4] reports that the number of industrial researchers has grown along with rapidly increasing industrial R&D expenditures. Across OECD member nations, employment of researchers by industry has grown at about twice the rate of total industrial employment. For the OECD as a whole, the full–time equivalent number of researchers more than doubled in the two decades from 1981 to 2001, from just below 1 million to almost 2.3 million. Over the same period, the number of researchers in the United States rose from 0.5 million to nearly 1.1 million.

According to the KEA report [10] the ICT sector is central to European growth and competitiveness and has been identified as a pillar of the European Lisbon Strategy. It accounts for 5.3% of EU GDP and 3.4% of total employment in Europe. In the period 2002–2003 it was responsible for more than a quarter both of productivity growth and of the total European R&D effort.

Damon Darlin [7] predicts that flat–screen televisions will get bigger and that MP3 players and cell phones will get smaller. And almost everything will get cheaper. But the biggest trend expected is that these machines will communicate with one another.

According to the OECD report [8], digital music and other digital content are also drivers of global technology markets, both to consumer electronics manufacturers and PC vendors. The increase in revenues from hardware in the PC and consumer electronics branch resulting from the availability of online music, authorised or not, is potentially greater than the revenues currently generated by paid music streaming or downloads.

> *Statement 3: The growth of the ICT sector and the innovations coming out of it will be the main driving forces for the music related industries.*

Trend 4: The interdependence of the cultural & creative sector and ICT

The cultural and creative sector generates significant economic performance in other non–cultural sectors, thereby indirectly contributing to economic activity and development, and in particular in the ICT sector.

Culture contributes directly to the economy by providing products for consumption, namely the cultural goods and services embodied in books, films, music sound recordings, concerts, etc. But the recent growth of the creative media, according to the KEA report [10], is due to the growing diffusion and importance of the Internet. The impact of this development on media consumption has been huge in recent years and will be the major factor for this sector in the future. At the same time, creative content is a key driver of ICT uptake. The consultancy firm PriceWaterhouseCoopers estimates that spending on ICT- related content will account for 12% of the total increase in global entertainment and media spending until the year 2009.

The development of new technology depends to a large extent on the attractiveness of content and the new networks are no exception. The development of mobile telephony and networks is based on the availability of attractive value–added services that will incorporate creative content.

However, the KEA report [10] predicts that the roll out of broadband and the digitisation of production processes will require significant investment for the creative industries to adapt, as well as changes in its management practices. Some industries (notably music) have had to go through aggressive cost restructuring programmes and are experiencing consolidation through mergers. Without a strong music, film, video, TV and game industry in Europe, the ICT sector will be the hostage of content providers established in Asia or North America.

Statement 4: Content is a major driver of ICT development.

Trend 5: New models of exploitation of content

The new ICT technologies have opened up new possibilities for the exploitation of music. Traditionally there have been two distribution channels for media content: physical distribution and analog broadcasting (radio, TV). Now we also have: IP/Internet, Mobile communications (UMTS), Digital TV and Radio.

The OECD report [8] identify that network convergence and widespread diffusion of high–speed broadband have shifted attention towards broadband content and applications that promise new business opportunities, growth and employment. Digital content and digital delivery of content and information are becoming increasingly ubiquitous, driven by the increasing technological capabilities and performance of delivery platforms, the rapid uptake of broadband technologies — with 2004 identified as a breakthrough year for broadband penetration in OECD countries — innovative creation and use of content and improved performance of hardware and software. Through a combination of new technologies, new business relationships and innovative service offers to consumers, the market is developing rapidly in order to realise the potential of online music.

Roberto Saracco [3] predicts that in ten years' time nearly all communications (over 90% of it) will be using fixed networks, while most people will be under the impression they are using mobile networks. He observes that in the coming years we are going to see a tremendous increase in communicating entities, be they applications or objects. The amount of communication directly involving humans will keep growing but at a slower pace, fuelled mostly by the dissemination of telecommunications in developing countries.

We read in the OECD report [9] that users are becoming increasingly active, that we are entering a participatory culture not of consumers but of users. Users are increasingly active and want to express themselves.

> *Statement 5: Interactive broadband networks are revolutionising the way music is distributed and consumed.*

Trend 6: New forms of Intellectual Property protection

Traditionally, there are only two extreme positions: absolute control of a creation or complete release of the rights to it. Until recently, there was no easy way to make explicit the rights that an author gives in relation to a creation. All the initiatives that explore alternatives to the traditional copyright are called copy–left. (Creative Commons [11] is the first example of a system that offers flexible protection of intellectual rights).

David Kusek and Gerd Leonhard [5] claim that the issue of protecting intellectual property goes far beyond music and audio technologies. Nevertheless, the crisis started in the music industry. Already, music recording industry revenues are down sharply, despite an overall increase in the distribution of music. The financial crisis has caused music labels to become cautious and conservative, investing in proven artists, with less support available for new and experimental musicians. Kusek and Leonhard, in their Manifesto for the Digital Music Revolution, [5] note that the breakdown of copyright protection is even starting to impact on musical instruments. Synthesisers, samplers, mixers and audio processors can all be emulated in software. For example they estimate that at least 90% of the copies of "Reason," one of the emulation software leaders, are pirated.

Commenting on the OECD report [9] they note the existence of sharp disagreement as to whether intellectual property rights (IPR) currently strike the right balance. There are three points of view: some believe that interest- group pressure has led to excessive protection; some adopt an intermediate position, believing that recent court cases such as Grokster have clarified secondary liability and that this has been sufficient to clarify the IPR situation; a third group maintain that levels of protection and enforcement are still insufficient and should be strengthened. That same report [9] proposes a tentative work agenda that might address the following needs: first, putting intellectual property in its proper place (that is, balancing private incentive versus the public good); second, achieving new digital rights definitions which integrate old rights (e.g. fair and legitimate use) and new rights (e.g. access to orphaned and out–of- print works); finally, accommodating new models of production and distribution (Open Source, Open Format, Open Access).

According to the KEA report [10] the main beneficiaries in Europe of the digital revolution have been the telecom operators acting as Internet service providers. Broadband access spending has risen very rapidly. This growth is largely due to the availability of free content. 95% of music downloads today, for example, are unpaid for.

> *Statement 6: New models of the control and use of intellectual property rights are impacting on the music industry and opening up new possibilities for the protection and dissemination of music content.*

Trend 7: Revolution in the music business

The whole music business is going through a major revolution, the main cause of which is the development and expansion of the ICT sector.

According to the OECD report [8] the rise of online music has resulted in product and process innovation, the entry of new players and new opportunities for music consumption and revenues, involving different forms of disintermediation, and the continued strong role of some traditional market participants (especially the record labels). In the new digital model, artists, majors and publishers have so far retained their creative roles related to the development of sound recordings. Direct sales from artist to consumer or the building of an artist's career purely through the online medium are still rare. Nevertheless, the Internet allows for new forms of advertising and possibilities that lower the entry barriers for artistic creation and music distribution.

Kusek and Leonhard [5] write that ever since the invention of electricity, music and technology have worked hand–in–hand, and that technology continues to catapult music to unprecedented heights. Today, the Internet and other digital networks, despite all the legal wrangling, have made music bigger than ever before. Within ten to fifteen years, Kusek and Leonhard claim, the "Music Like Water" business model will make the industry two or three times larger than it is today. They imagine a world where music flows all around us, like water or electricity, and where access to music becomes a kind of "utility". Not for free per se, but certainly for what feels like free.

Kurzweil [6] claims music technology is about to be radically transformed. Communication bandwidths, the shrinking size of technology, our knowledge of the human brain and human knowledge in general are all accelerating.

Music will remain the communication of human emotion and insight through sound from musicians to their audience, but the concepts and process of music will be transformed once again.

> *Statement 7: The possibilities of the ICT technologies are completely reshaping the music business.*

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3.4 CONTEXT 4: SOCIAL AND CULTURAL

Music is an important aspect of all human cultures [6]. Musical activity involves a mental context of values and goals, as well as an institutional context of societal organisations and structures, and relates to all kinds of interactions with other humans, with nature and with material objects and machines Musical activity is, moreover, explorative, creative, and innovative, and can focus on expression (via art and music works), the acquisition of knowledge (via music science and research) or the development of tools to act (via music technology and industry). Besides all this, music is also meant to provide new experiences, to give sense and meaning to life, to console and to promote social coherence and personal identity in and over very diverse social and ethnic groups [3]. Rooted in the biology of every human being [9], music is a core occupation of our technological society.

A recent study of the cultural and creative industries in Europe [11] reveals that the expansion of the ICT sector depends to a large extent on the attractiveness of cultural content. Music has thereby been identified as one of the most vibrant cultural industries with a flourishing music research component embedded within a particular social and cultural context. According to [11], cultural activities can be stimulated by both bottom–up, grass–roots initiatives and also the top–down initiatives of administrations and institutes. These social and cultural strategies are beneficial to the economic environment because they:

- reinforce social integration and help build an "inclusive Europe"
- contribute to fostering territorial cohesion
- contribute to reinforcing the self–confidence of individuals and communities
- participate in the expression of cultural diversity.

Below, some particular features of the current socio–cultural context are described. These provide a background against which we can better understand trends and open problems related to SMC research.

Trend 1: Transgression and uncertainty

Classical views hold that the socio–cultural context is largely shaped by developments in science/technology, whose authority, values and practices permeate all dimensions of society and culture. However, more recent views [7] hold that, owing to the growth of complexity, unpredictability and irregularity in both science and society, this one–way influence has given way to the mutual influencing, or even transgression, of science/technology and society/culture, as well as of university, industry and government [2]. The inherent generation of uncertainties (often resulting from the quest for innovation) yield different research practices. These are reflected in an increasing number of different directions in which technology could be explored and exploited. Which directions are selected may be strongly driven by the dynamics of innovation and economic rationality. However, as this cannot be entirely planned, there is a need for values and goals which allow for uncertainty. In the context of EU research policy, [10] has defined strategic objectives which draw upon solidarity and security. These objectives are based on concepts such as a friendly business environment, the embracing of change, economic and social cohesion, responsibility for common values, justice and risk management. This approach can be adopted as a basic framework for the social and cultural values and goals of SMC research. It implies, among other things,

- respect for the diversity of social/cultural identity
- the care of cultural heritage (preservation and archiving)
- openness to cultural change and new forms of expression
- democratic access to knowledge
- a culture of participation and participation in culture

Statement 1: The uncertainty that is inherent in SMC research should be guided by the specification of social and cultural values and goals.

Trend 2: Beyond the logic of economic rationality

Socio–cultural values and goals may guide the development of SMC research by bringing forward certain requests. At this moment, for example, music information retrieval research has excelled in developing tools for common mainstream commercial music, but it has to a large extent neglected more culturally interesting musical expressions. Indeed, the social and cultural context may require SMC research to develop beyond the logic of economic rationality. Apart from commercial music, there is a broad spectrum of music traditions, with different applications in music information retrieval, interactive systems, education, archiving and entertainment, which form important components for the future eCulture (the electronic environment in which culture is produced, distributed and consumed). Society and culture require that this broad spectrum should be taken into account in research.

Governmental support should compensate for biases induced by economic rationality and support new socially and cultural valuable developments. Support for these areas may boost very innovative technologies which, once a critical mass has been achieved, can be taken up by the logic of economic rationality.

Statement 2: The (EU–)government should inject its support at the frontiers of economic rationality.

Trend 3: Local specialisation and global integration

In Europe, research in SMC is organised in terms of small dynamic institutions, often specialised in small niche areas. Owing to recent European collaboration (often with support from the EU commission), these small research units have developed complementary competences. This has resulted in a quite powerfully connected network of music research institutions. With the development of GRID–like environments, both for data and computing, this trend towards local specialisation and global integration may increase. Interestingly, this network is entirely based on competition and shifting alliances.

Statement 3: Local specialisation and global integration offers a competitive environment for SMC research.

The organisation of SMC research in Europe is that of an interconnected network of small dynamic research units with a multidisciplinary orientation. This orientation over different scientific disciplines suits the object of research, which is in itself very broad, covering issues in signal processing as well as in symbolic handling of musical information. This multidisciplinary orientation is situated within an economic rationality of production, distribution and consumption, a social rationality involving diverse players such as musicians, organisers, the mass media and the music industry, and a cultural rationality involving contexts related to high culture, low culture, cross–culture and inter–culture.

Statement 4: Research should be grounded in a multidisciplinary basis because that is the best guarantee for its embedding in the economic, social and cultural reality of our post–industrial society.

Trend 4: A Neo–evolutionary research model

Given the broad context in which audio and music manifest themselves, SMC research strategies are characterised by emergence rather than planning. This emergence, moreover, is driven by creativity and innovation. Hence it is difficult to predict what may be successful and what not. SMC's scientific paradigm is therefore close to a neo–evolutionary model [5], in which elaborate systems of peer review, assessment and evaluation leave room for strategies of variation to be pursued by smaller laboratories in different alliances.

> *Statement 5: SMC research is strongly driven by innovation, albeit in a context of emergence rather than planning.*

In this model, risk analysis is needed to consider the possible implications of research. After all, science and technology do not automatically lead to the best possible world. In developing them, it is necessary to calculate the risks, to keep an eye on the volatile and ambiguous dynamics. The co–evolution of the socio–cultural context and the scientific/technological context implies that an analysis of values and goals should become an integral part of the development of SMC [7]. The best guarantee to cope with unpredictable outcomes, or uncertainties initiated by innovation, is to allow society and culture to speak back to science and technology, hence the importance of reflection, the development of a code of ethics, the concern for democratic access and several other values that should be taken into account.

> *Statement 6: Democratic access, reflection and a code of ethics should form an integral part of SMC research.*

Trend 5: Innovation through artistic creation

Creation and innovation form the motor of SMC research. Most interestingly, they are strongly driven by the context of artistic application. In that respect, it is of interest to mention that content–based music technology has roots in the particular cultural rationality of the 1950s [1], [4]. That rationality, heavily supported by European governments of the time, led to novel developments in electronic music, of which interactive multimedia is a recent outcome. In contrast, audio–recording technology had already begun by the early 20th Century and was driven by the logic of economic rationality and the free market [8].

The trend of allying content–based music technology to economic rationality is new. But it is reasonable to assume that artistic creation remains a major factor in maintaining the former’s innovative character. There are at least two reasons why art will continue to throw up innovating challenges to SMC research:

- First of all, there is the desire for expression. If tools are used to be expressive, then one is always inclined to go beyond that what is actually possible. Indeed, recent developments in SMC research have pushed back the frontiers of sensing, multi–modal multimedia processing and gesture–based control of technologies.
- Secondly, there is the desire for social communication, and for technologies that enhance collaboration and exchange of information among communities at the semantic level. And indeed, recent developments in SMC research have pushed back the frontiers of networking into technologies that deal with semantics as well as new forms of human–human and human–machine interaction.

In short, the context of art application results in a constant drive towards human–friendly and expressive technologies of mediation.

> *Statement 7: SMC Research should include artistic creation because the latter is a major driving force for innovation, including innovation in music technology.*

In the 1950 and 1960s, numerous small music research laboratories played an important role in the development of content–based music technologies [4]. Their original focus on electronic music production has now been extended to multi–media art production. This distinctive European approach, based on small but very innovative and specialised art centres connected through electronic networks, offers a unique and rich context for innovation in music/multimedia technology. Participative technologies involving all players in the cultural domain (developers, distributors, consumers, users and artists) can contribute to the formation of a space for eCulture. This space is closely connected to research/science and technology/industry.

> *Statement 8: eCulture draws on a platform of participation in culture and on a culture of participation.*

Trend 6: Focus on the user

SMC research is characterised by its potential for use and hence by a strong willingness to respond to signals from society and culture.

The social/cultural context definitely calls for more attention to the user and the human factor in the practice of music technology. Indeed, the development of music technology should take into account a context of application and focus on different categories of users, the design of appropriate mediation technologies and the pursuit of personalised approaches.

The user can no longer be considered passive, as one that merely registers what is given as stimulus. Instead, the user is an active consumer, which implies a transgression from the domain of pure consumption into that of production and distribution. The active consumer is also a producer and distributor of music, and therefore an active contributor to what happens with music. Being an active consumer implies participation in the whole chain of production, distribution and consumption, forming part of a network of participating users.

> *Statement 9: SMC research should take into account the context of application, in which the active user/consumer occupies a central place.*

Trend 7: Ethics in research

Ethics pertains to what is morally right and wrong. In view of the growing impact of technology, this perspective needs to be addressed in SMC research. The impact manifests itself in various aspects of our social and cultural life. Examples are the personal integrity of subjects involved in experiments and exchange of data, the safeguarding of the rights of those who have invested in producing valuable content, the right to democratic access to information and so on. It is clear that new developments in SMC research should take this context of implication into account. For example, issues of IPR ownership can be a significant barrier to the conducting of large and ambitious research projects, and the new concepts being developed around this issue may therefore be of critical value. Sensor technologies are another sensitive issue. They may infringe the personal integrity of subjects and therefore the privacy and confidentiality of information. The conceptual and philosophical implications regarding human responsibility in contexts of application need consideration in SMC research.

> *Statement 10: SMC research should take into account the context of implication, assessing risks and ethical implications.*

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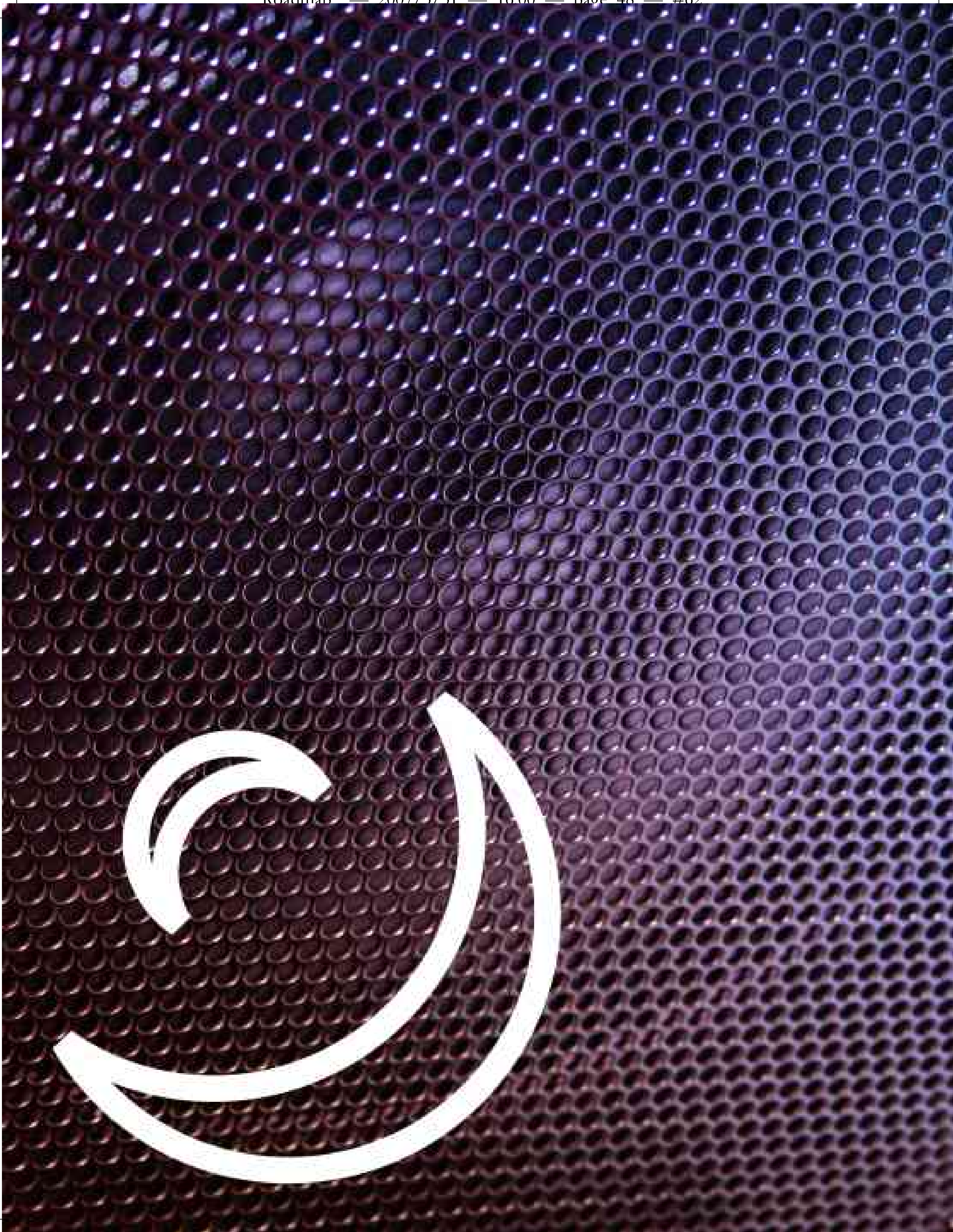

CHAPTER 4
The State of the Art

In Chapter 2 we defined the SMC field, identifying its boundaries from a substantive point of view and also from the perspective of the research community. The aim of the present chapter is to summarise the state of the art, laying special emphasis on the open issues that are currently being worked on. Faced with the great variety of research topics covered within SMC, we have tried to give our summary a coherent structure by grouping the topics into three major areas, Sound, Interaction and Music, which are further divided into sub areas.

Fig. 4.1 depicts the relationships between the different research areas and sub areas as we see them. In it, we make a basic distinction between research that focuses on sound (left– hand side of the figure) and research that focuses on music (right–hand side of the figure). In between, there are research fields that address the interaction between the two. For each research field, there is an analytic and a synthetic approach. The analytic approach goes from encoded physical (sound) energy to meaning (sense), whereas the synthetic approach goes in the opposite direction, from meaning (sense) to encoded physical (sound) energy. Accordingly, analytic approaches to sound and music pertain to analysis and understanding, whereas synthetic approaches pertain to generation and processing. In between sound and music, there are multi–faceted research fields that focus on interactional aspects. These are performance modelling and control, music interfaces, and sound interaction design.

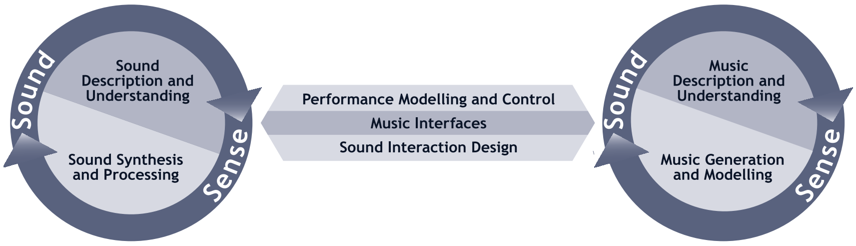

Figure 4.1.: Relations between the different SMC research areas.

4.1 SOUND

In this section we review the research on sound that is being carried out within the boundaries identified in chapter 2. From a sound to sense point of view, we include the analysis, understanding and description of all musical and non–musical sounds except speech. Then, in the sense to sound direction, we include the research that is more related to sound synthesis and processing.

4.1.1 Sound Description and Understanding

One of the basic aims of SMC research is to understand the different facets of sound from a computational point of view. We want to understand and model not only the properties of sound waves but also the mechanisms for their generation, transmission and perception by humans. Even more, we want to understand sound as the basic communication channel for music and a fundamental element in our interaction with the environment. Sound serves as one of the main signals for human communication and its understanding and description requires a notably multidisciplinary approach.

Traditionally the main interest of SMC researchers has been musical sounds and thus the understanding of the sound generated by musical instruments and the specific transmission and perception mechanisms involved in the music communication chain. In recent years, this focus has been broadened and there is currently an increased interest in non–musical sounds and aspects of communication beyond music. A number of the methodologies and technologies developed for music are starting to be used for human sound communication in general and there is increasing cross–fertilisation between the various sound related disciplines.

There has been a great deal of research work on the analysis and description of sound by means of signal processing techniques; extracting features at different abstraction levels and developing source–specific and application–dependent technologies. Most of the current research in this domain starts from frequency domain techniques as a step towards developing sound models that might be used for retrieval, synthesis or recognition applications.

Also of importance has been the study of sound–producing physical objects. The aim of such study is to understand the acoustic characteristics of musical instruments and other physical objects which produce sounds relevant to human communication. Its main application has been the development of physical models of these objects for synthesis applications [4, 5, 10], so that the user can produce sound by interacting with the models in a physically meaningful way.

However, beyond the physical aspect, sound is a communication channel that carries information. We are therefore interested in identifying and representing this information. Signal processing techniques can only go so far in extracting the meaningful content of a sound and in the past few years there has been an exponential increase in research activity which aims to generate semantic descriptions automatically from audio signals. Statistical Modelling, Machine Learning, Music Theory and Web Mining technologies have been used to raise the semantic level of sound descriptors. MPEG–7 [11] has been created to establish a framework for effective management of multimedia materials, standardising the description of sources, perceptual aspects and other relevant descriptors of a sound or any multimedia asset.

Most research approaches in sound description are essentially bottom up, starting from the audio signal and trying to reach the highest possible semantic level. There is a general consensus that this approach has clear limitations and does not allow us to bridge what is known as the semantic gap. The current trend is towards Multimodal Processing methods and top–down approaches based on Ontologies, Reasoning Rules, and Cognition Models. For example, collaborative tagging by users is being increasingly used to attach semantic information to pictures.

Key Issues

Perceptual versus motor-based models

Perceptual systems are usually studied separately from motor systems, but there are strong arguments in favour of merging the two, or at least for including the dimension of action within the study of perception. It has been argued, for example, that visual information is not accrued by sampling successive 2D patterns from the retina, but rather from the interplay between sensory changes and eye, body and environmental movements. The structure of three–dimensional space can be ‘learned’ from the cross–correlation between movement and sensory information. It has even been claimed that perceptual information is, to some degree, stored internally in the form of ‘potential actions’. The technological counterpart in robotics is the joint development of sensory and motor functions, or the ‘calibration’ of delicate control mechanisms based on sensory feedback [9].

Sound source recognition and classification

The ability of a normal human listener to recognise objects in the environment from only the sounds they produce is, with regard to characteristics of the acoustic environment and of other competing sound sources, extraordinarily robust. In contrast, computer systems designed to recognise sound sources function precariously, breaking down whenever the target sound is degraded by reverberation, noise, or competing sounds. Robust listening requires extensive contextual knowledge, but the potential contribution of sound– source recognition and classification to the process of auditory scene analysis has largely been neglected by researchers building computational models of the scene analysis process [12].

Sound search and retrieval based on content

Audio content analysis and description makes various new and advanced audiovisual applications and services possible. Search engines or specific filters can use the extracted description to help users navigate or browse through large collections of data. Digital analysis of an audio file may be able to discriminate between speech, music and other entities or identify how many speakers are contained in a speech segment, what gender they are and even who exactly is speaking. Spoken content may be identified and converted to text. Music might be classified into categories, such as jazz, rock and classical (although this is problematic because such categories are user-dependent and perhaps cannot be unequivocally defined). Often it is possible to identify a piece of music even when performed by different artists — or an otherwise identical audio track when it is distorted by coding artefacts. Finally, it may be possible to identify particular sounds, such as explosions, gunshots, etc. [13]

4.1.2 Sound Synthesis and Processing

Sound synthesis and processing has been the most active research area in SMC for more than 40 years. Quite a number of the research results of the 60s and 70s are now standard components of many audio and music devices and new technologies are continuously being developed and integrated into new products. The sounds of our age are digital. Most of them are generated, processed, and transcoded digitally. Given that these technologies have already become so common and that most recent developments represent only incremental improvements, research in this area has lost some of its prominence in comparison to others in SMC. Nonetheless, there remain a number of open issues to be worked on and some of the new trends have the potential for huge industrial impact.

With respect to sound synthesis, most of the abstract algorithms that were the focus of work in the 70s and 80s were not related to a sound source or its perception (e.g., FM and waveshaping) and are considered obsolete. The 1990s saw the emergence of computational approaches to sound synthesis. These aimed either at capturing the characteristics of a sound source, known as physical models [4, 5, 15], or at capturing the perceptual characteristics of the sound signal, generally referred to as spectral or signal models [3]. The technology transfer expectations of the physical models have not been completely fulfilled. Their expressiveness and intuitive control — advantages originally attributed to this kind of model — did not help commercial music products to succeed in the market place. Meanwhile, synthesis techniques based on spectral modelling have met with competitive success in voice synthesisers, both for speech and singing voices, but to a lesser extent in the synthesis of all other musical instruments. A recent and promising trend is the combination of physical and spectral models such as *physically informed sonic modelling* [2] and *commuted synthesis* [4, 5].

The new corpus–based concatenative methods for musical sound synthesis, also known as mosaicing, have attracted much attention recently [14]. They make use of a variety of sound snippets in a database to assemble a desired sound or phrase according to a target specification given in sound descriptors or by an example sound. With ever–larger sound databases easily available, together with a pertinent description of their contents, these methods are increasingly used for composition, high–level instrument synthesis, interactive exploration of a sound corpus and other applications. In sound processing, there are a large number of active research topics. Probably the most well established are audio compression and sound spatialisation, both of which have clear industrial contexts and quite well defined research agendas. Digital audio compression techniques allow the efficient storage and transmission of audio data, offering various degrees of complexity, compressed audio quality and compression itself. With the widespread uptake surge of the mp3, audio compression technology has spread to mainstream audio and is being incorporated into most sound devices. These recent advances have resulted from the understanding of the human auditory system and the implementation of efficient algorithms in advanced DSP processors. Improvements to the state of this art will not be easy but there is a trend towards trying to make use of our new understanding of human cognition and of the sound sources to be coded.

Sound spatialisation effects attempt to widen the stereo image produced by two loudspeakers or stereo headphones, or to create the illusion of sound sources placed anywhere in three dimensional space, including behind, above or below the listener. Some techniques, such as ambisonics and wave–field synthesis, are readily available and new models are being worked on that combine signal–driven, bottom–up processing with hypothesis–driven, top–down processing [1].

Digital sound processing also includes the techniques used for audio post–production and other creative uses in music and multimedia applications [7]. Time and frequency domain techniques have been developed for transforming sounds in different ways and in a number of other applications. But the current trend is to move from signal processing to content processing; that is, to move towards higher levels of representation for describing and processing audio material.

There is a strong trend towards the use of all these signal processing techniques in the general field of interactive sound design. Sound generation techniques have been integrated in various multimedia and entertainment applications (sound effects and background music for gaming), sound product design (ring tones for mobile phones) and interactive sound generation for virtual reality or other multimodal systems. Old sound synthesis technologies have been brought back to life and adapted to the needs of these new interactive situations. The importance of control has been emphasised, and source–centred and perception–centred modelling approaches have been expanded towards *interactive sonification* [6].

Key Issues

Interaction-centred sound modelling

The interactive aspects of music and sound generation should be given greater weight in the design of future sound synthesis techniques. A challenge is how to make controllability and interactivity central design principles in sound modelling. It is widely believed that the main missing element in existing synthesis techniques is adequate control modelling. Feature and expressive content extraction from human gestures, from haptic (for example pressure, impacts or friction–like interactions on tangible interfaces) to movement (motion capture and analysis) to voice (extraction of expressive content of the voice or breath of the performer), should become the main paradigm for new research in sound generation. This development also opens the field to multisensory and cross–modal interaction research. Besides the analysis and coding of the expressivity of the human body 'playing', the consequent problem concerns how to exploit the extracted contents in order to model sound. Effective sound generation needs to achieve a perceptually robust link between gesture and sound. The mapping problem is in this sense crucial both in musical instruments (see also Section 4.2.1) and in any other device/artefact involving sound as one of its interactive elements.

Modular sound generation

Sound synthesis by physical modelling has, so far, mainly focused on accurate reproduction of the behaviour of musical instruments. Some other efforts have been devoted to everyday sounds or to the application of sophisticated numerical methods for solving wave propagation problems. A seductive dream has been that of a toolkit for constructing sounding objects from elementary blocks such as waveguides, resonators and nonlinear functions. The dream has faced a number of intrinsic limitations in block–based descriptions of musical instruments. In general, it is difficult to predict the sonic outcome of an untested connection of blocks. However, by associating macro–blocks to salient phenomena, it should be possible to devise a constructivist approach to sound modelling. At the lowest level, blocks should correspond to fundamental interactions (impact, friction, air flow on edge, etc.). The sound quality of these blocks should be tunable, based on properties of both the interaction (e.g., pressure, force) and the interactants (e.g., size and material of resonating object). Higher–level, articulated phenomena should be modelled on top of lower–level blocks according to characteristic dynamic evolutions (e.g., bouncing, breaking). This higher level of sound modelling is suitable for tight coupling with emerging computer animation and haptic rendering techniques, as its time scale is compatible with the scale of visual motion and gestural/tactile manipulation. In this way, sound synthesis can become part of a more general constructivist, physics–based approach to multisensory interaction and display.

Physical modelling based on data analysis

To date, physical models of sound and voice have been appreciated for their desirable properties in terms of synthesis, control and expressiveness. However, it is also widely recognised that they lack the ability to fit with real observed data due to the high number of parameters involved, the fact that control parameters are not related to the produced sound signal in a trivial way and, in some cases, the radical non–linearities in the numerical schemes. All these issues make the parametric identification of physics–based models a formidable problem. Future research in voice and sound physical modelling should thus take into account the importance of models fitting real data, both in terms of system structure design and also of parametric identification. Co–design of numerical structures and identification procedures may also be a possible path to complexity reduction.
It is also desirable that from the audio–based physical modelling paradigm, new model structures emerge which will be general enough to capture the main sound features of broad families of sounds (e.g. sustained tones from wind and string instruments, percussive sounds) and to be trained to reproduce the peculiarities of a given instrument from recorded data.

Audio content processing

Currently, a very active field of research is Auditory Scene analysis [8], which is conducted both from perceptual and computational points of view. This research is conducted mostly within the cognitive neurosciences community. But an multidisciplinary approach to it would allow the translation of its fundamental research advances to many practical applications. For instance, as soon as robust results emerge from this field, it will be possible to approach (re)synthesis from a higher-level sound-object perspective and we should be able to identify, isolate, transform and recombine sound–objects in a flexible way. The use of spectral models manipulation and synthesis is based on *features* emerging from audio analysis. The use of auditory scene representations for sound manipulation and synthesis could be based on *sound objects* captured from the analysis. This possibility offers great prospects for music, sound and media production. With the current work on audio content analysis, we can start identifying and processing higher–level elements in an audio signal. For example, by identifying the rhythm of a song, a time–stretching technique can become a rhythm–changing system, and by identifying chords, a pitch shifter might be able to transpose the key of the song.

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4.2 INTERACTION

In this section we review a variety of research topics that address interaction with sound and music. Music Interfaces is quite a well–established topic which deals with the design of controllers for music performance. Performance Modelling and Control is an area that has been quite active in the last decade. It has focused on the study of the performance of classical music but more recently is opening up to new challenges. The last topic covered under the Interaction heading is Sound Interaction Design. This is a brand new area that opens up many new research problems not previously addressed within the SMC research community.

4.2.1 Music Interfaces

Digital technologies have revolutionised the development of new musical instruments, not only because of the sound generation possibilities of the digital systems but also because the concept of 'musical instrument' has changed with the use of these technologies. In most acoustic instruments, the separation between the control interface and the sound–generating subsystems is fuzzy and unclear. In the new digital instruments, the gesture controller (or input device) that takes the control information from the performer(s) is always separate from the sound generator. The controller component can be a simple computer mouse, a computer keyboard or a MIDI keyboard, but with the use of sensors and appropriate analogue to digital converters, any control signal coming from the outside can be converted into control messages intelligible to the digital system. The elimination of the physical dependencies has meant that all previous construction constraints in the design of digital instruments have been relaxed. [15]

A computer–augmented instrument takes an existing instrument as its base and uses sensors and other instrumentation to pick up as much information as possible from the performer's motions. The computer uses both the original sound of the instrument and the feedback from the sensor array to create and/or modify new sounds. Augmented instruments are often called hyper–instruments after the work done at MIT's MediaLab [16] to provide virtuoso performers with controllable means of amplifying their gestures, suggesting coherent extensions to instrumental playing techniques.

The field of musical controllers is rich and diverse. An example of its vitality can be found in the annual conference New Interfaces for Musical Expression (NIME). The design of new musical controllers is now more accessible than ever before. The wider and ever increasing availability of sensing technologies enables virtually any kind of physical gesture or external parameter to be tracked and digitised into a computer. The broad accessibility of devices, such as video cameras and analog–to–MIDI interfaces, provides a straightforward means for the computer to access sensor data. This wealth is yet to be reflected in the commercial market.

One of the new paradigms of digital instruments is the idea of collaborative performance; of instruments that are intended to be performed by multiple players. In this type of instrument, performers can take an active role in determining and influencing not only their own musical output but also that of their collaborators. These music collaborations can be achieved over networks such as the Internet, and the study of network or distributed musical systems is a new topic on which much research is being carried out [17].

Most current electronic music is being created and performed with laptops, turntables and controllers that were not really designed to be used as music interfaces. The mouse has become the most common music interface and several of the more radical and innovative approaches to real–time performance are currently found in the apparently more conservative area of screen–based and mouse–controlled software interfaces. Graphical interfaces may be historically freer and better suited to unveiling concurrent, complex and unrelated musical processes. Moreover, interest in gestural interaction with sound and music content and in gestural control of digital music instruments is emerging as part of a more general trend that has led in recent years to an increasingly important role for research on gesture analysis, processing and synthesis. This growing importance is demonstrated by the fact that the Gesture Workshop series of conferences recently included sessions on gesture in music and the performing arts. On the one hand, research on gesture enables a deeper investigation of the mechanisms of human–human communication. On the other hand, gesture processing capabilities can open up unexplored frontiers in the design of a novel generation of multimodal interactive (music) systems.

Key Issues

Designing innovative multimodal music interfaces

A key target for designers of future interactive music systems is to endow them with natural, intelligent and adaptive multimodal interfaces which exploit the ease and naturalness of ordinary physical gestures in everyday contexts and actions. Examples are tangible interfaces (e.g., see [14]) and Tangible Acoustic Interfaces (TAIs), which exploit the propagation of sound in physical objects in order to locate touching positions. TAIs are a very promising interface for future interactive music systems. They have recently been enhanced with algorithms for multimodal high–level analysis of touching gestures so that information can be obtained about how the interface is touched (e.g., forcefully or gently, head-on or glancing).

Integration of control with sound generation

The separation between gesture controllers and output generators has some significant negative consequences, the most obvious being the reduction of the 'feel' associated with producing a certain kind of sound. Another frequent criticism is the inherent limitations of MIDI, the protocol that connects these two components of the instrument chain. However, there is a more basic drawback concerning the conceptual and practical separation of potentially new digital instruments into two separated components. This is that it becomes hard — or even impossible — to design highly sophisticated control interfaces without a profound prior knowledge of how the sound or music generators will work. Generic or non–specific music controllers tend to be either too simple, mimetic (imitating traditional instruments) or too technologically biased. They can be inventive and adventurous, but their coherence cannot be guaranteed if they cannot anticipate what they are going to control [15].

Feedback systems

When musicians play instruments, they perform certain actions with the expectation of achieving a certain result — a musical performance. As they play, they monitor the behaviour of their instrument and, if the sound is not quite what they expect, they will adjust their actions to change it. In other words, they have effectively become part of a control loop, constantly monitoring the output from their instrument and subtly adjusting bow pressure, breath pressure or whatever control parameter is appropriate. The challenge is how to provide the performer of a digital instrument with the appropriate feedback to control the input parameters better than that provided by mere auditory feedback. One proposed solution is to make use of the musician's existing sensitivity to the relationship between an instrument's 'feel' and its sound with both haptic and auditory feedback [18]. Other solutions rely on visual and auditory feedback [15].

Designing effective interaction metaphors

Beyond the two previous issues, which concern the musical instrument paradigm, the design of structured and dynamic interaction metaphors, enabling users to exploit sophisticated gestural interfaces, has the potential to lead to a wide series of music and multimedia applications beyond the musical instrument metaphor. The state–of–the–art practice mainly consists of direct and strictly causal gesture/sound associations, without any dynamics or evolutionary behaviour. However, research is now shifting toward higher–level indirect strategies: these include reasoning and decision–making modules related to rational and cognitive processes, but they also need to be grounded in strong perceptual, cognitive and emotional bases. Music theory and artistic research in general can feed SMC research with further crucial issues. An example is expressive autonomy; [19] that is, the degree of freedom an artist leaves to a performance involving an interactive music system.

Mobile music

Combining music and mobile technology promises exciting future developments. Devices such as mobile phones, Walkmans and mp3 players have already reshaped the general music experience of listeners. With new properties such as ad hoc networking, Internet connection and context–awareness, mobile music technology offers countless new artistic, commercial and socio–cultural opportunities for music creation, listening and sharing. Through the use of these new technologies, new forms of interaction with music lie ahead.

Weakness of the new interfaces

The possibilities offered by digital instruments and controllers are indeed endless. Almost anything can be done and much experimentation is going on. Yet the fact is that there are not that many professional musicians who use them as their main instrument. No recent electronic instrument has reached the (limited) popularity of the Theremin or the Ondes Martenot, invented in 1920 and 1928 respectively. Successful new instruments exist, but they are not digital, not even electronic. The most recent successful instrument is the turntable, which became a real instrument in the early eighties when it started being played in a radically unorthodox and unexpected manner. It has since then developed its own musical culture, techniques and virtuosi. For the success of new digital instruments, the continued study of sound control, mapping, ergonomics, interface design and related matters is vital. That is, what is needed is lower–level and focused research which tries to solve independent parts of the problem. But clearly these studies are insufficient and we require integral studies and approaches which consider not only ergonomic but also psychological, philosophical and above all, musical issues, even if these are, by definition, non–systematic.

4.2.2 Performance Modelling and Control

A central activity in music is *performance*, that is, the act of interpreting, structuring, and physically realising a work of music by playing a musical instrument. In many kinds of music — particularly so in Western art music — the performing musician acts as a kind of mediator: a mediator between musical idea and instrumental realisation, between written score and musical sound, between composer and listener/audience. Music performance is a complex activity involving physical, acoustic, physiological, psychological, social and artistic issues. At the same time, it is also a deeply human activity, relating to emotional as well as cognitive and artistic categories.

Understanding the emotional, cognitive and also (bio–)mechanical mechanisms and constraints governing this complex human activity is a prerequisite for the design of meaningful and useful music interfaces (see section 4.2.1) or more general interfaces for interaction with expressive media such as sound (section 4.2.3). The research in this field can be seen as ranging from studies aimed at *understand-*

ing expressive performance to attempts at *modelling* aspects of performance in a formal, quantitative and predictive way.

Quantitative, empirical research on expressive music performance dates all the way back to the 1930s, to the pioneering work by Seashore and colleagues in the U.S. After a period of neglect, the topic experienced a veritable renaissance in the 1970s, and music performance research is now thriving and highly productive (a comprehensive overview can be found in [1]).

Historically, research in (expressive) music performance has focused on finding general principles underlying the types of expressive 'deviations' from the musical score (e.g., in terms of timing, dynamics and phrasing) that are a hallmark of expressive interpretation. Three different research strategies can be discerned (see [2, 11] for recent overviews on expressive performance modelling): (1) acoustic and statistical analysis of performances by real musicians — the so-called analysis-by-measurement method; (2) making use of interviews with expert musicians to help translate their expertise into performance rules — the so-called analysis–by–synthesis method; and (3) inductive machine learning techniques applied to large databases of performances.

Studies along these lines by a number of research teams around the world have shown that there are significant regularities that can be uncovered in these ways, and computational models of expressive performance (of mostly classical music) have proved to be capable of producing categorically musical results. These achievements are currently inspiring a great deal of research into more comprehensive computational models of music performance and also ambitious application scenarios.

One such new trend is quantitative studies into the individual style of famous musicians. Such studies ate difficult because the same professional musician can perform the same score in very different ways (cf. commercial recordings by Vladimir Horowitz and Glenn Gould). Recently, new methods have been developed for the identification of music performers and their style, among them the fitting of performance parameters in rule–based performance models, and the application of machine learning methods for the identification of the performance style of musicians. Recent results of specialised experiments show surprising artist recognition rates [3].

So far, music performance research has been mainly concerned with describing detailed performance variations in relation to musical structure. However, there has recently been a shift towards high–level musical descriptors for characterising and controlling music performance, especially with respect to emotional characteristics. For example, it has been shown that it is possible to generate different emotional expressions of the same score by manipulating rule parameters in systems for automatic music performance [10].

Interactive control of musical expressivity is traditionally the task of the conductor. Several attempts have been made to control the tempo and dynamics of a computer–played score with some kind of gesture input device. For example, [12] describes a method for interactively controlling, in real time, a system of performance rules that contain models for phrasing, micro–level timing, articulation and intonation. With such systems, high–level expressive control, for example of the communicated emotional content, can be achieved. Dynamically controlled music in computer games is another important future application.

Visualisation of musical expressivity, though perhaps an unusual idea, also has a number of useful applications. In recent years, a number of efforts have been made in the direction of new display forms of expressive deviations in music performance. Langner and Goebl [13] have developed a method for visualising an expressive performance in a tempo–loudness space: expressive deviations leave a trace on the computer screen in the same way that a worm does when it wriggles over sand, producing a sort of 'fingerprint' of the performance. This and other recent methods of visualisation can be used for the development of new multi–modal interfaces for expressive communication, in which expressivity embedded in audio is converted into visual representation, facilitating new applications in music research, music education and HCI, as well as in artistic contexts. A visual display of expressive audio may also be desirable in environments where audio display is difficult or must be avoided, or in applications for hearing–impaired people.

For many years, research in Human–Computer Interaction in general and in sound and music computing in particular was devoted to the investigation of more cognitive, abstract aspects. In the last ten years, however, a great number of studies have emerged which focus on emotional processes and social interaction in situated or ecological environments. Examples are the research on Affective Computing at MIT and research on KANSEI Information Processing in Japan. The broad concept of 'expressive gesture', including music, human movement and visual (e.g., computer animated) gesture, is the object of much contemporary research.

Key Issues

A deeper understanding of music performance

Despite some successes in computational performance modelling, current models are extremely limited and simplistic *vis–à–vis* the complex phenomenon of musical expression. It remains an intellectual and scientific challenge to probe the limits of formal modelling and rational characterisation. Clearly, it is strictly impossible to arrive at complete predictive models of such complex human phenomena. Nevertheless, work towards this goal can advance our understanding and appreciation of the complexity of artistic behaviours. Understanding music performance will require a combination of approaches and disciplines — musicology, AI and machine learning, psychology and cognitive science.

For cognitive neurosciences, discovering the mechanisms that govern the understanding of music performance is a first–class problem. Different brain areas are involved in the recognition of different performance features. Knowledge of these can be an important aid to formal modelling and rational characterisation of higher order processing, such as the perceptual differentiation between human–like and mechanical performances. Since music making and appreciation is found in all cultures, the results could be extended to the formalisation of more general cognitive principles.

Computational models for artistic music performance

The use of computational music performance models in artistic contexts (e.g., interactive performances) raises a number of issues that have so far only partially been faced. The concept of a creative activity being predictable and the notion of a direct 'quasi–causal' relation between the musical score and a performance are both problematic. The unpredictable intentionality of the artist and the expectations and reactions of listeners are neglected in current music performance models. Surprise and unpredictability are crucial aspects in an active experience such as a live performance. Models considering such aspects should take account of variables such as performance context, artistic intentions, personal experiences and listeners' expectations.

In artistic contexts, music performance models are often integrated in interactive systems. An important open issue in such a context is the definition of suitable strategies for mapping the information obtained from the analysis of users' behaviour (e.g., a performer's expressive gestures) onto real–time generation of expressive outputs (e.g., expressive sound and music output). The objective is therefore to develop high–level indirect strategies related to rational and cognitive processes. These strategies, which are usually characterised by a state evolving over time and by decisional processes, will make it possible to implement adaptive and dynamic behaviour.

Multi– and cross–modal processing of expression

Research is needed on the integrated analysis of information flow in different multimedia streams (e.g., audio, video) affecting different sensorial modalities (e.g., auditory, visual). When dealing with multi–modal rendering of expression in actions, the focus is on fusion not only at the perceptual level but also on the modelling and representation levels. The architecture of a multimodal processing system should take into account this problem and should be specifically designed for this purpose. An open problem is the identification of a set of cross–modal features that could be abstracted from modal features and used for defining higher–level feature spaces, so that multimodal mapping of data from one modality onto another becomes possible.

Music interaction models in multimedia applications

There will be an increasing number of products which embed possibilities for interaction and expression in the rendering, manipulation and creation of music. In current multimedia products, graphical and musical objects are mainly used to enrich textual and visual information. Most commonly, developers focus more on the visual rather then the musical component, the latter being used merely as a realistic complement or comment to text and graphics. Improvements in the human–machine interaction field have largely been matched by improvements in the visual component, while the paradigm of the use of music has not changed adequately. The integration of music interaction models in the multimedia context requires further investigation, so that we can understand how users can interact with music in relation to other media. Two particular research issues that need to be addressed are (1) models for the analysis and recognition of users' expressive gestures and (2) the communication of expressive content through one or more non–verbal communication channels mixed together.

4.2.3 Sound Interaction Design

Sound–based interactive systems can be considered from several points of view and several perspectives: content creators, producers, providers and consumers of various kinds, all in a variety of contexts. Sound is becoming more and more important in interaction design, in multimodal interactive systems, in novel multimedia technologies which allow broad, scalable and customised delivery and consumption of active content. In these scenarios, some relevant trends are emerging that are likely to have a deep impact on sound related scientific and technological research in the coming years. Thanks to research in Auditory Display, Interactive Sonification and Soundscape Design, sound is becoming an increasingly important part of Interaction Design and Human–Computer Interaction.

Auditory Display is a relatively new field that has already reached some kind of consolidated state. A strong community in this field has been operating for more than twenty years (see http://www.icad.org/). Auditory Display and Sonification are about giving audible representation to information, events and processes. Sound design for conveying information is, thus, a crucial issue in the field of Auditory Display. The main task of the sound designer is to find an effective mapping between the data and the auditory objects that are supposed to represent them in a way that is perceptually and cognitively meaningful. Auditory warnings are perhaps the only kind of auditory displays that have been thoroughly studied and for which solid guidelines and best design practices have been formulated. A milestone publication summarising the multifaceted contributions to this sub–discipline is the book edited by Stanton and Edworthy [5].

Interactive Sonification is a more recent field of research. Due to the rapid growth in relevance and diffusion of interactive systems in almost all scenario of life, it is an extremely promising one. At present, when compared to the much more exploited use of visual and haptic feedback, it is a relatively unexplored and unsystematic field. A promising approach is that of using sound modelling techniques in such a way that sound emerges as an organic product of interactions among modelling blocks and/or external agents. In this sense, the practice seen in cartoons by which complex information is reduced to its essential elements offers an appropriate model for the effective and economic representation of information: The motto could be rendered as "minimal yet veridical" [8]. A recently published work relevant to this field is [9], in which Model Based Sonification (MBS) is proposed. The main idea here is to reproduce a natural situation, in which a holistic approach to sound production and listening is used: the sound is an organic and physically coherent result of user interaction with a data –driven dynamic model. A similar approach can be found in [7], where interaction is enabled by physically based sonic feedback.

A third emerging area of research with strong implications for social life and whose importance is astonishingly underestimated is that of sound in the environment on different scales which range from architectonic spaces to urban contexts and even extend to a geographical dimension. Soundscape design as an auditory counterpart of landscape design is the discipline that studies sound in its environmental context, from both naturalistic and cultural viewpoints. It is going to become more and more important in the context of the acoustically saturated scenarios of our everyday life. Concepts such as "clear hearing" and hi–fi versus lo–fi soundscapes, introduced by Murray Schafer [6], are becoming crucial as ways of tackling the 'composition' of our acoustic environment in terms of appropriate sound design.

Key Issues

Evaluation methodologies for sound design

Before Sound Interaction Design, there is Sound Design. And it is worth asking whether this latter is a mature discipline in the sense that Design itself is.

Is there anybody designing sounds with the same attitude that Philippe Starck designs a lemon squeezer? What kind of instruments do we have at our disposal for the objective evaluation of the quality and the effectiveness of sound products in the context, for example, of industrial design? As a particular case, sound product design is rapidly acquiring a more and more relevant place in the loop of product implementation and evaluation. Various definitions of Sound Quality have been proposed and different evaluation parameters have been put forward for deriving quantitative predictions from sound signals. The most commonly used parameters (among others) are Loudness, Sharpness, Roughness and Fluctuation Strength. Loudness is often found to be the dominant measurable factor that adversely affects Sound Quality. However, more effective and refined measurement tools for defining and evaluating the aesthetic contents and the functionality of a sound have not yet been devised. The development of appropriate methodologies of this kind is an urgent task for the growth of Sound Design as a mature discipline.

Everyday listening and interactive systems

In the field of Human Computer interaction, Auditory Icons have been defined as 'natural' audio messages that convey information and feedback about events in an intuitive way. The concepts of Auditory Icons and "Everyday Listening", as opposed to "Musical Listening", were introduced by William Gaver [4]. The basic notion of auditory icons lies within the more general philosophy of an ecological approach to perception theories. The concept of auditory icons is to use natural and everyday sounds to represent actions and sounds within an interface. In this context, a relevant consideration emerges: a lot of research effort has been devoted to the study of musical perception, while our auditory system is first of all a tool for interacting with the outer world in everyday life. When we consciously listen to or more or less unconsciously hear 'something' in our daily experience, we do not really perceive and recognise sounds but rather events and sound sources. Both from a perceptual point of view (sound to sense) and from a modelling/generation point of view (sense to sound), a great effort is still required to achieve the ability to use sound in artificial environments in the same way that we use sound feedback to interact with our everyday environment.

Sonification as art, science, and practice

Sonification, in its very generic sense of information representation by means of sound, is still an open research field. Although a lot of work has been done, a systematic definition of sonification methodologies has not yet arisen. Clear strategies and examples of how to design sound in order to convey information in an optimal way have only partially emerged. Sonification remains an open issue which involves communication theory, sound design, cognitive psychology, psychoacoustics and possibly other disciplines. Cooperative action between these disciplines would allow a deeper analysis and understanding of the correlations existing within some given data sets and of the correlations among the representing sounds as a result of a sonification process.

At this point, a question naturally emerges: could the contribution of a composer, accustomed to organising sound in time and polyphonic density, be crucial for more 'pleasant' (and thus effective) auditory display design? Would it be possible to define the practice of sonification in terms that are informed by the practice of musical composition? Or, more generally, is an art–technology collaboration a positive, and perhaps vital, element in the successful design of auditory displays?

Another inescapable issue is the active use of auditory displays. Sonification is especially effective with all those kinds of information which have a strong temporal basis, and it is also natural to expect that the active involvement of the receiver may lead to better understanding, discoveries and aesthetic involvement. In interactive sonification, the user may play the role of the performer in music production. In this sense, the interpreter of a precisely prescribed music score, adding expressive nuances, or the jazz improviser jiggling here and there within a harmonic sieve could be two good metaphors for an interactive sonification process.

Sound and multimodality

Recently, Auditory Display research and Sonification research have also entered the field of multimodal and multi–sensory interaction, exploiting the fact that synchronisation with other sensory channels (e.g., visual, tactile) provides improved feedback. An effective research approach to the kinds of problem that this enterprise throws up s the study of sensorial substitutions. For example, a number of sensory illusions can be used to ‘fool’ the user via cross–modal interaction. This is possible because every day experience is intrinsically multimodal and properties such as stiffness, weight, texture, curvature and material are usually determined via cues coming from more than one channel.

Soundscape Design

A soundscape is not an accidental by– product of a society. On the contrary, it is a construction, a more or less conscious ‘composition’ of the acoustic environment in which we live. Hearing is an intimate sense similar to touch: the acoustic waves are a mechanical phenomenon and they ‘touch’ our hearing apparatus. Unlike eyes, the ears do not have lids. It is thus a delicate and extremely important task to take care of the sounds that form the soundscape of our daily life. However, the importance of the soundscape remains generally unrecognised and a process of education which would lead to more widespread awareness is extremely urgently needed.

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4.3 MUSIC

This section reviews research oriented to understanding, describing and generating music. This area includes several very difficult problems which are a long way from being solved and require extreme multidisciplinary approaches to tackle them. All the disciplines involved in SMC have something to say here. Humanities and engineering approaches are required and scientific and artistic methodologies are also needed.

4.3.1 Music Description and Understanding

Music is central to all human societies. Moreover, there is an increasing belief that interaction with musical environments and the use of music as a very expressive medium for communication helped the evolution of cognitive abilities specific to humans [7]. Despite the ubiquity of music in our lives, we still do not fully understand, and cannot completely describe, the musical communication chain that goes from the generation of physical energy (sound) to the formation of meaningful entities in our minds via the physiology of the auditory system.

An understanding of what music is and how it functions is of more than just academic interest. In our society, music is a commercial commodity and a social phenomenon. Understanding how music is perceived, experienced, categorised and enjoyed by people would be of great practical importance in many contexts. Equally useful would be computers that can 'understand' (perceive, categorise, rate, ...) music in ways similar to humans.

In the widest sense, then, the basic goal of SMC in this context is to develop veridical and effective computational models of the whole music understanding chain, from sound and structure perception to the kinds of high–level concepts that humans associate with music — in short, models that relate the physical substrate of music (the *sound*) to mental concepts invoked by music in people (the '*sense*'). In this pursuit, SMC draws on research results from many diverse fields which are related either to the sound itself (physics, acoustics), to human perception and cognition (psycho–acoustics, empirical psychology, cognitive science), or to the technical/algorithmic foundations of computational modelling (signal processing, pattern recognition, computer science, Artificial Intelligence). Neurophysiology and the brain sciences are also displaying increasing interest in music [7], as part of their attempts to identify the brain modules involved in the perception of musical stimuli and the coordination between them.

With respect to computational models, we currently have a relatively good understanding of the automatic identification of common aspects of musical structure (beat, rhythm, harmony, melody and segment structure) at the symbolic level (i.e., when the input to be analysed is musical scores or atomic notes) [4]. Research is now increasingly focusing on how musically relevant structures are identified directly from the audio signal. This research on musically relevant audio descriptors is driven mainly by the new application field of Music Information Retrieval (MIR) [5]. Currently available methods fall short as veridical models of music perception (even of isolated structural dimensions), but they are already proving useful in practical applications (e.g., music recommendation systems).

In contrast to these bottom–up and reductionist approaches to music perception modelling, we can also observe renewed interest in more 'holistic' views of music perception which stress the importance of considering music as a whole instead of the sum of simple structural features (see, e.g., [3], who argues that purely structural features, such as rhythm or harmony, may have their roots in music theory rather than in any psychological reality). Current research also tries to understand music perception and action not as abstract capacities, but as 'embodied' phenomena that happen in, and can only be explained with reference to, the human body [2]. Generally, many researchers feel that music understanding should address higher levels of musical description related, for example, to kinaesthetic/synaesthetic and emotive/affective aspects. A full understanding of music would also have to include the *subjective* and *cultural contexts* of music perception, which means going beyond an individual piece of music and describing it through its relation to other music and even extra–musical contexts (e.g., personal, social, political and economic). Clearly, computational models at that level of comprehensiveness are still far in the future.

Key Issues

'Narrow' SMC vs. multidisciplinarity research

As noted above, many different disciplines are accumulating knowledge about aspects of music perception and understanding, at different levels (physics, signal, structure, 'meaning'), from different angles (abstract, physiological, cognitive, social), and often with different terminologies and goals. For computational models to truly capture and reproduce human–level music understanding in all (or many) of its facets, SMC researchers will have to learn to acquaint themselves with this very diverse literature (more so than they currently do) and actively seek alliances with scholars from these other fields — in particular from the humanities, which often seem far distant from the technology–oriented field of SMC.

Reductionist vs. multi-dimensional models

Quantitative–analytical research like SMC tends to be essentially reductionist, cutting up a phenomenon into individual parts and dimensions, and studying these more or less in isolation. In SMC–type music perception modelling, this manifests itself in isolated computational models of, for example, rhythm parsing, melody identification and harmony extraction, with rather severe limitations. This approach neglects, and fails to take advantage of, the interactions between different musical dimensions (e.g., the relation between sound and timbre, rhythm, melody, harmony, harmonic rhythm and perceived segment structure). It is likely that a 'quantum leap' in computational music perception will only be possible if SMC research manages to transcend this approach and move towards multi–dimensional models which, while not 'holistic' in the sense of some musicologists and psychologists, at least begin to address the complex interplay of the many facets of music.

Bottom–up vs. top–down modelling

There is still a wide gap between what can currently be recognised and extracted from music audio signals and the kinds of high–level, semantically meaningful concepts that human listeners (with or without musical training or knowledge of theoretical music vocabulary) associate with music. Current attempts at narrowing this "semantic gap" via, for example, machine learning, are producing sobering results. One of the fundamental reasons for this lack of progress seems to be the more or less strict bottom–up approach currently being taken, in which features are extracted from audio signals and ever higher–level features or labels are then computed by analysing and aggregating these features. This may be sufficient for associating broad labels like genre to pieces of music (as, e.g., in [6]), but already fails when it comes to correctly interpreting the high–level structure of a piece, and definitely falls short as an adequate model of higher–level cognitive music processing. This inadequacy is increasingly being recognised by SMC researchers and the coming years are likely to see an increasing trend towards the integration of high–level expectation (e.g., [1]) and (musical) knowledge in music perception models. This, in turn, may constitute a fruitful opportunity for musicologists, psychologists and others to enter the SMC arena and contribute their valuable knowledge.

Understanding the music signal vs. understanding MUSIC

Related to the previous issue is the observation that music perception takes place in a rich context. 'Making sense of' music is much more than decoding and parsing an incoming stream of sound waves into higher–level objects such as onsets, notes, melodies and harmonies. Music is embedded in a rich web of cultural, historical, commercial and social contexts that influence how it is interpreted and categorised. That is, many qualities or categorisations attributed to a piece by listeners cannot solely be explained by the content of the audio signal itself. It is thus clear that high–quality automatic music description and understanding can only be achieved by also taking into account information sources that are external to the music. Current research in Music Information Retrieval is taking its first cautious steps in that direction by trying to use the Internet as a source of 'social' information about music ('community meta–data'). Much more thorough research into studying and modelling these contextual aspects is to be expected. Again, this will lead to intensified and larger scale cooperation between SMC proper and the human and social sciences.

4.3.2 Music Generation Modelling

Due to its symbolic nature — close to the natural computation mechanisms available on digital computers — music generation was among the earliest tasks assigned to a computer, possibly pre–dating any sound generation attempt (related instead to signal processing). The first well–known work generated by a computer, Lejaren Hiller's *Illiac Suite* for string quartet, was created by the author (with the help of Leonard Isaacson) in 1955–56 and premiered in 1957. At the time, digital sound generation was no more than embryonic (and for that matter, analog sound generation was very much in its infancy too). Since these pioneering experiences, the computer science research field of "Artificial Intelligence" has been particularly active in investigating the mechanisms of music creation.

Soon after its early beginnings, music generation modelling split into two major research directions, embracing compositional research on one side and musicological research on the other. While akin to each other, these two sub–domains pursue fundamentally different goals. In more recent times, the importance of a third direction, mathematical research on music creation modelling, has grown considerably, perhaps providing the necessary tools and techniques to fill in the gap between the above disciplines.

Music generation modelling has enjoyed a wide variety of results of very different kinds in the compositional domain. These results obviously include art music but they certainly do not confine themselves to that realm. Research has included algorithmic improvisation, installations and even algorithmic *Muzak* creation. Focusing on algorithms in music composition is an obvious choice when contemplating the generation of music by computers. Algorithmic composition applications can be divided into three broad modelling categories: modelling traditional compositional structures, modelling new compositional procedures, and selecting algorithms from extra–musical disciplines [8]. Some of this last type have been used very proficiently by composers to create specific works. These algorithms are generally related to self–similarity (a characteristic that is closely related to that of "thematic development", which seems to belong to many types of music) and they range from genetic algorithms to fractal systems, from cellular automata to swarming models and coevolution. In this same category, a persistent trend towards using biological data to generate compositional structures has developed since the 60's. Using brain activity (through EEG measurements), hormonal activity, human body dynamics and the like, there has been a constant attempt to equate biological data with musical structures [12]. Another use of computers for music generation has been that of "computer–assisted composition". In this case, computers do not generate complete scores. Rather, they provide mediation tools to help composers manage and control some aspects of musical creation. Such aspects may range, according to the composers' wishes, from extremely relevant decision–making processes to minuscule details. While computer assistance may be a more practical and less 'generative' use of computers in musical composition, it is currently enjoying a much wider uptake among composers.

The pioneering era of music generation modelling has also had a strong impact on musicological research. Ever since Hiller's investigations and works, the idea that computers could model and possibly re–create musical works in a given style has become widely diffused through contemporary musicology. Early ideas were based on generative grammars applied to music. Other systems, largely based on AI techniques, have included knowledge based systems, neural networks and hybrid approaches [9].

Early mathematical models for music generation modelling included stochastic processes (with a special accent on Markov chains). These were followed by chaotic non–linear systems and by systems based on the mathematical theory of communication. All these models have been used for both creative and musicological purposes. In the last 20 years, mathematical modelling of music generation and analysis has developed considerably, going some way to providing the missing link between compositional and musicological research. Several models following different mathematical approaches have been developed. They involve "enumeration combinatorics, group and module theory, algebraic geometry and topology, vector fields and numerical solutions of differential equations, Grothendieck topologies, topos theory, and statistics. The results lead to good simulations of classical results of music and performance theory. There is a number of classification theorems of determined categories of musical structures" [10].

A relevant result of mathematical modelling has been to provide a field of potential theories where the specific peculiarities of existing ones can be investigated against non–existing variants. This result creates the possibility of the elaboration of an 'anthropic principle' in the historical evolution of music similar to that created in cosmology (that is: understanding whether and why existing music theories are the best possible choices or at least good ones [10]).

Key Issues

The wide spectrum of tools, functions and endeavours concerning music generation modelling carries with it an obvious load of unsolved problems and open issues. What follows below is an attempt to summarise and collate the issues into some grouping related to those described in the previous section.

Computational models

The main issue of computational models in both the 'creative' and the 'problem solving' sides of music generation modelling seems to relate to the failure to produce 'meaningful' musical results. "... computers do not have feelings, moods or intentions, they do not try to describe something with their music as humans do.

Most of human music is referential or descriptive. The reference can be something abstract like an emotion, or something more objective such as a picture or a landscape." [9]. Since 'meaning' in music can be expressed as "planned deviation from the norm", future developments in this field will need to find a way to formalise such deviations in order to get closer to the cognitive processes that lie behind musical composition (and possibly also improvisation). In addition, "multiple, flexible, dynamic, even expandable representations [are needed] because this will more closely simulate human behaviour" [9].

Computer–assisted composition tools

Currently, composers who want to use computers to compose music are confronted, by and large, with two possible solutions. The first is to rely on prepackaged existing software which presents itself as a 'computer–assisted composition' tool. The second is to write small or not–so–small applications that will satisfy the specific demands of a given compositional task. Solutions that may integrate these approaches have yet to be found. On the one hand, composers will have to become more proficient than at present in integrating their own programming snippets into generalised frameworks. On the other, a long overdue investigation of the 'transparency' (or lack thereof) of computer–assisted composition tools [11] is in order. Possibly, the current trend that considers good technology as technology that creates the illusion of non–mediation could provide appropriate solutions to this problem. In this case, however, the task will be to discover the multi–modal primitives of action and perception that should be taken into consideration when creating proper mediation technologies in computer–assisted composition.

Notation and multiple interfaces

The composing environment has radically changed in the last 20 years. Notation devices and compositional tools unavoidably involve the use of computer technology. However, little investigation has been conducted into the taxonomy of composing environments today. A related question is whether composing is still a one–man endeavour, or whether it is moving towards some more elaborate teamwork paradigm (as in films or architecture)? Where do mobility, information, participation and networking technologies come in? These questions require in–depth multidisciplinary research whose full scope is yet to be designed.

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CHAPTER 5

Challenges and Strategies

In this chapter, after having reviewed the identity of SMC, its context and the key issues which are the focus of current research, we can look ahead, identify key challenges and propose the strategies with which to face them. This is the main contribution of this Roadmap — a proposal for a pathway to the future in the SMC field.

We have consciously taken a broad view of research in SMC. We have recognised several contextual issues which have a big impact in our area. For several reasons, these have to be taken into account when delineating the key strategies that would help push SMC forward. First, as SMC is an multidisciplinary subject nourished by various research disciplines, there are strong mutual influences. Second, because most SMC research is of the applied kind, an understanding of the industrial and social contexts helps define many of the targets to be aimed at. Finally, as SMC is a field without clear or well-established educational curricula, the future of the academic framework will influence its research community.

Our pathway proposal identifies five challenges. Two of these cover research goals, one addresses educational aspects, another focuses on knowledge transfer and the last one is centred on social concerns. Then, to meet each challenge, we have proposed a number of strategies.

5.1 CHALLENGE 1: TO DESIGN BETTER SOUND OBJECTS AND ENVIRONMENTS

> *Improvements in the sounds produced by the objects present in our environment will enhance the affective and emotional character of these objects and consequently our quality of life.*

We modern humans are constantly surrounded by sound — both natural and artificial. Due to long habituation, we are often relatively unaware of the richness of the soundscape surrounding us and of its potential effects, not only in terms of its information content and distraction and manipulation potential but also its health–related aspects. The artefacts and devices which surround and equip us often come with artificially designed sounds that are poorly suited to their function and aesthetics (think of mobile phones, for instance). Due to the widespread availability of broadcast and reproduced sound, we live in ‘schizophonic’ environments, where sound is separated from its source. In addition, public and personal environments tend to be cluttered with unwanted sound and music. This trend is impairing the exploitation and appreciation of sound and music.

There are several areas where sound modelling is not yet exploited and we are stuck with pre–recorded sound (e.g. in computer interfaces). This lack impairs the flexibility and effectiveness of communication and negatively affects the emotional and affective character of objects in use.

On the music side, the notion of musical instrument is being challenged by information technology and the widespread availability of networked sensors and actuators. Sound synthesis is definitely remains an unsolved problem but at the same time the concepts of music instrument and of sound device are taking quite a number of new directions.

In short, the growing abundance of artificial sounds in our environment, coupled with the rapid advances in information and sensor technology, present SMC with unprecedented research challenges, but also opportunities to contribute to improving our audible world.

Strategies to address challenge 1:

Strategy 1: Seek directions in which to extend the notion of musical instrument.

Objects may be turned into musical instruments as soon as someone starts exploiting their expressive capabilities and employing some kind of virtuosity. This had happened with many everyday objects in the past, and, in a world of sensorised and networked objects and spaces, is likely to occur in the future. Furthermore, new forms of music performance based on distributed and collaborative instrumentation require a research effort to make sure that the complex environments of the future offer flexible support to creative uses (or unexpected abuses) of technological infrastructures.

Strategy 2: Improve technologies for pervasively producing, transforming and delivering sounds.

All SMC research involves, in one form or another, the manipulation of sound signals. Research is needed to improve synthesis algorithms, both those based on Signal/Spectral Models and those based on Physical Modelling. At a more structural level, Computer–Assisted Composition should be included and seamlessly integrated with these algorithms. For natural human/sound interactions at an individual level, all advances in Personal Sound Reproduction should be encouraged. They might range from 3D audio over headphones to Computer/Brain Interfaces, from prophylactic uses as in cochlear implants to general–use biofeedback techniques.

Strategy 3: Intensify research in sound modelling that goes beyond imitation towards capturing the communicative potential of sound.

Sound is a powerful means through which to convey rapid and continuous information about objects, events, processes, functions and relations. Research should isolate the physical, acoustic and perceptual features that contribute to the salience of such items, so that sounds can be molded according to specific communication needs. The result of such advances will be that information display, interaction design and artistic expression may benefit from suitable sound models accessible via meaningful parameter spaces which thus go well beyond collections of pre–recorded samples.

Strategy 4: Promote research in fields involved in the shaping of natural, artificial and cultural acoustic ecosystems.

The SMC community should enlarge its scope to give itself the potential to affect fields concerned with designing spaces for a better quality of life on various scales: product design, architecture, urban planning, landscape design and conservation. Sound is increasingly perceived as an important component at all levels, not only as a source of pollution, but as a facilitator of interaction and a component of the aesthetic experience of a place or its genius loci.

Strategy 5: Promote research on the effect of environmental constraints on artificially diffused sound and music.

We need research projects which help us to better understand the impact of sound and music on everyday activities. More attention should be devoted to context–based studies, so that sound and music emission can be tuned to the needs of individuals and groups of people in specific environments. The constraints involved can be behavioural, psychological, social and/or technological, and it is imperative that they be considered when evaluating the sound quality of objects, services and environments.

Strategy 6: Promote studies aimed at reducing sound and music pollution in public and private ecosystems. Our sense of hearing is a precious resource whose capabilities should be exploited but whose effectiveness can be impaired by oppressive and hostile acoustic environments. Any studies, technologies or campaigns that promote a sparing and intelligent use of sound in public and private contexts should be encouraged, as should psychologists, sociologists and policy makers to get involved.

5.2 CHALLENGE 2: TO UNDERSTAND, MODEL, AND IMPROVE HUMAN INTERACTION WITH SOUND AND MUSIC

> *Truly useful and rewarding machine-mediated sonic environments and services will require a better understanding of human interaction with sound and music in all its breadth, including perceptual, cognitive, emotional, bodily and social aspects.*

Human interaction with sound and music is currently rather limited in scope and applications. But new insights into human action and perception may radically improve and profoundly transform the nature of this interaction. This transformation will be based on a better understanding, up to the point where computational models can be developed, of how auditory perception functions in an interactive context. As a result, devices can then be developed that assist and enhance human listening by providing improved analytical capabilities, and training the user's auditory expertise while doing so. Such devices will be in high demand in industry (e.g., for noise reduction) as well as for the ageing population.

However, if SMC is to deliver its full promise — new, rich, captivating, rewarding machine–mediated sonic experiences and services — research will have to transcend the boundaries of a narrow interpretation of 'perception'. The real challenge is to understand the human relation to, and interaction with, sound and music in all its breadth — not just as a perceptual and cognitive phenomenon, but also as a personal, bodily, emotional, social experience. Meeting this challenge will require more multidisciplinary work, and a diversification and partial re–orientation of research efforts. It may perhaps be beneficial to focus on specific application scenarios to guide this research, in order to provide concrete motivation and contexts. For instance, work on auditory prostheses necessitates more research on auditory perception. The design of novel musical instruments and interactive sound environments is a challenging research question in which new concepts of embodied interaction need to be explored. The development of intelligent devices that understand music and musical queries in terms of human–level concepts — a central goal of Music Information Retrieval – requires broad research into the semantics of sound and music, including the linguistic and social contexts. And work on sonification and novel multimedia applications will require researchers to investigate more deeply the functions of sound as a carrier of both information and emotion.

Strategies to address challenge 2:

Strategy 1: Promote computational modelling approaches in human auditory perception and cognition research.

At the centre of many challenges faced by SMC is the human listener. Ultimately, the goal is to produce tools that can interact meaningfully with the user via sound. To do so, these will have to incorporate knowledge about human sound perception. Auditory perception and cognition is a broad and multidisciplinary field of research, so SMC should focus on aspects that are directly relevant to the present challenge. Computational Auditory Scene Analysis is one such aspect. It should be studied and improved with the aim of identifying and tracking the different sound sources present in a given soundscape or piece of music. Auditory Attention is another. This is a fundamental cognitive capability of human listeners that requires more study to assist in the design of effective interactive systems. Aspects of Memory and Learning are related to attention but are necessary for SMC to bridge the gaps between time–scales (listening to a single note, to a whole piece of music, using an SMC system for years and improving one's expertise). Finally, Musical Structural Analysis by human experts should inform the musicological aspects of SMC.

Strategy 2: Provide extensive augmented perception paradigms.

In order to focus its research and demonstrate the utility of its methods, SMC should target specific applications that benefit human users. In the context of auditory perception research, an application on which to focus is the development of devices that enhance aspects of normal auditory perception and cognition. For instance, such devices could focus the attention of the user on some aspect of the auditory scene, to help her get a clearer understanding of it. In the educational field, learning applications should be encouraged. The use of such augmentary devices has a strong social aspect as possible crucial elements in the Auditory Prostheses of the future, prostheses that should allow music listening in addition to speech comprehension.

Strategy 3: Intensify research on expressivity and communication in sound and music.

Sound is a source of information about the environment, but also a communication medium. An essential aspect of sound and music that must be understood, beyond the physical, perceptual and cognitive phenomena themselves, is *expressivity* in sound and music communication and its relation to emotion. A prime field in which this can be studied is music performance, where expressivity is often just as important as the 'actual' music–structure itself. In particular, performance research should transcend its current (narrow) focus on mostly classical music. This favours abstract music–score–centred models that neglect the human in the loop. Instead, it should put more systematic effort into studying the processes of expression transmission in musical environments, with a focus on all three components of the communication channel: the expressive sound (music) itself, the performer and the listener (with the whole body — see next item).

Strategy 4: Develop an embodied, integrated approach to perception and action.

There is a growing consensus in cognitive science that perception, be it natural or artificial, cannot be fully understood without reference to action. This awareness is especially important for SMC, where action is intrinsically linked to sound interaction and music making. Research in perception–action topics should thus be encouraged. Ergonomics is the most applied level of research where perception and action meet. At a more fundamental level, sensory–motor theories and embodiment of cognitive abilities are defining and formalising the important aspects of the perception and action loop. These strategies will have a clear impact on the much needed change in human/computer interfaces for SMC, which may include whole–body interaction for expressive purposes.

Strategy 5: Intensify multimodal and multidisciplinary research on computational methods for bridging the semantic gap in music.

The Semantic Gap in computational music — the discrepancy between what can be recognised in music signals by current state–of–the–art methods and what human listeners associate with music — is the main obstacle on the way towards truly intelligent and useful musical companions. Current research efforts aim at the automatic recognition and modelling of higher–level musical patterns (e.g., rhythmic or harmonic structure), but they still essentially adhere to the traditional bottom–up pattern analysis scenario. This is comparatively easy to master. But really bridging the semantic gap will require a radical re–orientation towards the integration of top–down modelling of (incomplete) musical knowledge and expectations, and also towards a widening of the notion of musical understanding by embracing and exploiting other media and modalities, including the Web. This research will have to be notably multidisciplinary, involving, among others, specialists in musicology, music perception, Artificial Intelligence and Machine Learning.

Strategy 6: Intensify interaction with the arts.

It is our conviction, supported by the experience of numerous cases of cooperation, that some artists have an extremely refined understanding — albeit (perhaps) not in 'scientific' terms — of issues of perception and perceptibility and, more importantly, of the *effect* of sound, including its emotional and social ramifications. In order to understand the human experience of sound and music in its full breadth, SMC needs to exploit this resource. Artists may bring up new questions and ways of looking at human and social contexts related to sound. Joint art/research projects, even those which, at first sight, focus on 'artistic' and not overtly 'scientific' questions, should be promoted and adequately funded. In fact, the strict distinction between the 'artistic' and the 'scientific' must continually be challenged. The SMC community should also make efforts to strengthen this viewpoint in funding agencies and among decision makers.

5.3 CHALLENGE 3: TO TRAIN MULTIDISCIPLINARY RESEARCHERS IN A MULTICULTURAL SOCIETY

SMC is a highly multidisciplinary domain. But the boundaries of the academic disciplines involved are actually quite sharp. The increasing need for specialists in this domain will require a decisive growth in the size and quality of existing relevant educational programmes and the creation of appropriate new ones.

While SMC is a highly multidisciplinary domain, it turns out that the boundaries of the academic disciplines involved are actually quite sharp. This becomes particularly clear when we compare education in the arts and sciences, where different methodologies and strategies are used, and where there is a lack coordination facilitating multidisciplinarity. In view of future developments, this situation is problematic. In a number of industrial and artistic domains, there will be a need for specialists that can deal both with systems development and also with content development. To meet this need, the SMC Higher Education structure must grow both in size and quality, so that the necessary manpower can be supplied.

Strategies to address challenge 3:

Strategy 1: Design appropriate multidisciplinary curricula for SMC.

Higher Education in SMC must take into account the wide variety of student backgrounds as well as the different final goals of their education. Master's and PhD students may arrive at SMC both from natural science studies and from the humanities.

Collectively, they may target their studies at a wide canvas of objectives, ranging from fundamental and applied research to creative endeavours such as composition and sound design. Education in SMC should ensure comprehensive and high–quality training. Therefore, appropriate curricula which allows specialisation must be designed to provide a wide spectrum of knowledge. These curricula must be developed and coordinated at the European (and possibly extra–European) level and they should promote student mobility which takes into account the individual characteristics of each academic and research centre (cf. also strategy 4).

Strategy 2: Promote broader integration of Arts and Sciences.

In the past, composers and content creators were a driving force behind SMC innovation. Their interaction with scientists constituted a positive ecosystem for technological innovation. In return, science provided many methodologies and tools which were greatly inspiring for several art forms. However, the drive for innovation coming from art has progressively diminished due to the increasing specialisation of the domains involved. The arts can again play a creative role when curricula in SMC are better integrated. Composition and Sound Design is a typical example where this integration is possible. Specific pro–active initiatives must be implemented to allow composers and content creators to complement their training in Europe and abroad. The complementarity of art and science can be utilised through the careful design of specific courses at the Master's level and the possibility of long–term collaboration between centres in Europe at the PhD level.

Strategy 3: Promote cross-cultural integration.

The recent surge in non–European industries and global markets requires a reconsideration of how education faces up to globalisation, multiculturalism and cross–cultural integration. In particular, the growing population of students in Europe that come from different non–European cultures and backgrounds requires appropriate education and pedagogical approaches that reflect a concern for multiculturalism. The challenge is to develop new types of educational collaboration with selected non–European universities and research institutions, using a supportive framework that should fund scholarships, staff positions and research mobility.

Strategy 4: Promote better coordination in Higher Education.

SMC research has a successful track record connected to an excellence spread over several centres which have gained world leadership through complementarity and coordination, duly supported by EC funding mechanisms. In order to maintain the leadership in this domain, this excellence should be exported to the Higher Education domain. This can be achieved through the integration of Masters' curricula, PhD programmes and postgraduate activities at the European level. In this context, student/teacher mobility must be encouraged through appropriate funding actions. Stable and enduring support for common activities such as the Sound and Music Computing Summer School and target–oriented Sound and Music Computing ateliers and workshops must be granted in order to provide continuity in Higher Education.

Strategy 5: Enhance education resources for Higher Education.

Currently, the SMC field is short on dedicated educational resources. This leads to a fragmentary, partial and discontinuous availability of pedagogical materials and specific teaching conditions. A substantial effort must be made to provide the following assets:

- SMC–dedicated high–quality textbooks and tutorials that tackle the multi-disciplinarity of the field (both at foundation and specialist levels);
- A set of interactive multimedia electronic learning objects that can be exchanged and used in SMC–related curricula. These objects should use a standard language for information exchange (e.g. SCORM) and be based on distributed repositories which freely share and exchange such objects.

Strategy 6: Promote the dissemination of available Higher Education in SMC.

There is a crucial need for increased access to SMC information in order to attract students and related industrial partners. An enhancement of the SMC portal (http://www.soundandmusiccomputing.org) is in order. It should provide more up–to–date and expanded information on SMC and related fields. This information must concern curricula, courses, news of events, scholarships, available funding, open positions and so on. Student and post–graduate research can be displayed and promoted through newer communication means such as blogs and dedicated spaces in multimedia–aware settings.

5.4 CHALLENGE 4: TO IMPROVE KNOWLEDGE TRANSFER

A large part of SMC research is devoted to applications that can be directly exploited in the arts, in industry and in society at large. Proper knowledge transfer can lead to successes whose size and impact are bound to be very large.

SMC is a research field with a strong focus on applied research and most of its results can be used directly by artists, industry and society at large. This knowledge transfer should be further improved by the strategies recommended below.

Strategies to address challenge 4:

Strategy 1: Promote dissemination of SMC research and objectives among the general public.

The visibility and identity of SMC research should be enhanced. Greater efforts should be made to disseminate it and its objectives in venues outside the standard academic ones. We should promote the presence of SMC at conferences and industrial fairs, in special issues of scientific journals and on mainstream media channels. We should promote tutorial installations in science museums and at festivals to educate the general public and especially to arouse the interest of children in the SMC field. We should also promote the presence of SMC in cultural activities such as concerts, exhibitions and installations in public spaces.

Strategy 2: Promote projects containing artistic components.

A significant proportion of SMC research results can be used in artistic applications. More interestingly, creation and innovation in SMC research are particularly driven by the context of artistic applications. The inclusion of artistic aspects in scientific and technical research projects is clearly beneficial from a research point of view. For example, solving specific artistic needs can lead to technological breakthroughs. SMC research should also be involved in cultural projects that go beyond the logic of economic rationality; that is, projects that contribute to sustainable development and societies.

Strategy 3: Promote the awareness of the various models of IP protection of research results.

Research results can be protected in many different ways, but most research is only published in conferences and journals. Researchers should be aware of the various possibilities for disseminating their work and protecting their IP, know-ing the advantages of each. Support should be given to the filing of patents, the overcoming of legal obstacles and to the promotion of alternative means of legal protection, such as creative commons or free software licenses.

Strategy 4: Promote venues for meeting industry experts.

Representatives of academia and industry should meet more often for open discussions and the exchange of information. It is important that companies explain their needs to researchers, so that academia can become aware of new applications and research opportunities. Conversely, it is equally essential that researchers inform companies about advances in academic research, advances which may not be widely known in industry. For this latter to be fruitful, it is important to hold demonstrations directly showing the exploitation potential of a research project.

Strategy 5: Promote direct industrial exploitation of research results.

Very few of the research results of the SMC community are taken up by European industry. A large part of the industry that actually takes advantage of these results is in Asia and the USA. The returns for European industries are, most of the time, very small or non–existent. Researchers and students must be made aware of the possibilities for profit in their research results through direct industrial exploitation, for example by creating start–ups

Strategy 6: Promote academic quality standards.

There is a wide variety of journals and conferences in which SMC research is being published. We should promote publication in those journals and conferences that conduct a proper peer review process in the evaluation and selection of papers. However, in some research areas within the SMC field, there are no clear academic criteria for the evaluation of publications and research results. Therefore, there also needs to be a more general push to promote quality academic standards in all the research activities of SMC.

5.5 CHALLENGE 5: TO ADDRESS SOCIAL CONCERNS

SMC must be able to empower users – to put the relevant choices and decisions back into the hands of the individual, while offering her/him access to the whole universe of available sound and music.

It is both an opportunity and a duty for a multidisciplinary field such as SMC to define its role as one which goes beyond that of a mere provider of solutions to technological or commercial challenges. SMC has the potential to contribute to maintaining and furthering the richness of human culture. Global technological trends have a tendency to make the world uniform — to establish and favour a kind of 'mainstream', at the expense of alternative, specialised sub–cultures. Music is no exception. Culturally aware SMC research should actively aim towards maintaining, highlighting and making accessible the diversity of (musical) cultures, both in a geographical and in a more general sense.

Likewise, given the social importance of music(s) and music–defined codes and identities in our society, SMC must remain aware of questions of democratic access to music, and of technological solutions that favour inclusion over exclusive elitism. SMC can also have an effect on inter–personal relations. Music listening via headphones can be an isolating experience; but intelligent music devices and environments can also be designed so as to stimulate novel kinds of human interaction.

The ultimate social and cultural goal of SMC must be to empower the user – to put the relevant choices and decisions back into the hands of the individual, while offering her/him access to the whole universe of available sound and music.

Strategies to address challenge 5:

Strategy 1: Identify social needs relevant to SMC development; develop methods for the evaluation and assessment of SMC technologies in social contexts.

Currently, development of an SMC tool is often based on a good or interesting idea, without too much consideration of its possible social relevance. By taking into account the needs of society, it will be possible to develop SMC tools dedicated to these needs. A good example is access to a digital music library, where a thorough analysis of user groups, their backgrounds, their qualifications and their possible interest in using such a library is necessary information for the development of tools that provide access. Similarly, once SMC tools have been developed, it is of interest to evaluate their use in the social contexts for which they have been designed.

Strategy 2: Expand existing SMC methodologies (currently targeted at individuals) to understand music in its social dimension.

The current methodologies for understanding music are typically based on experimental methods that address the cognitive system of a single listener. In practice, however, music is often a social activity in which musical engagement is influenced by the behaviour of other participants. Existing empirical and experimental methodologies should be expanded towards understanding aspects of social music cognition. These involve the study of the social context in which musicians and listeners influence each other during musical activities.

Strategy 3: Promote development of technologies and tools for broader collaboration, information and communication engagement; emphasise user-centred and group experience-centred research and development.

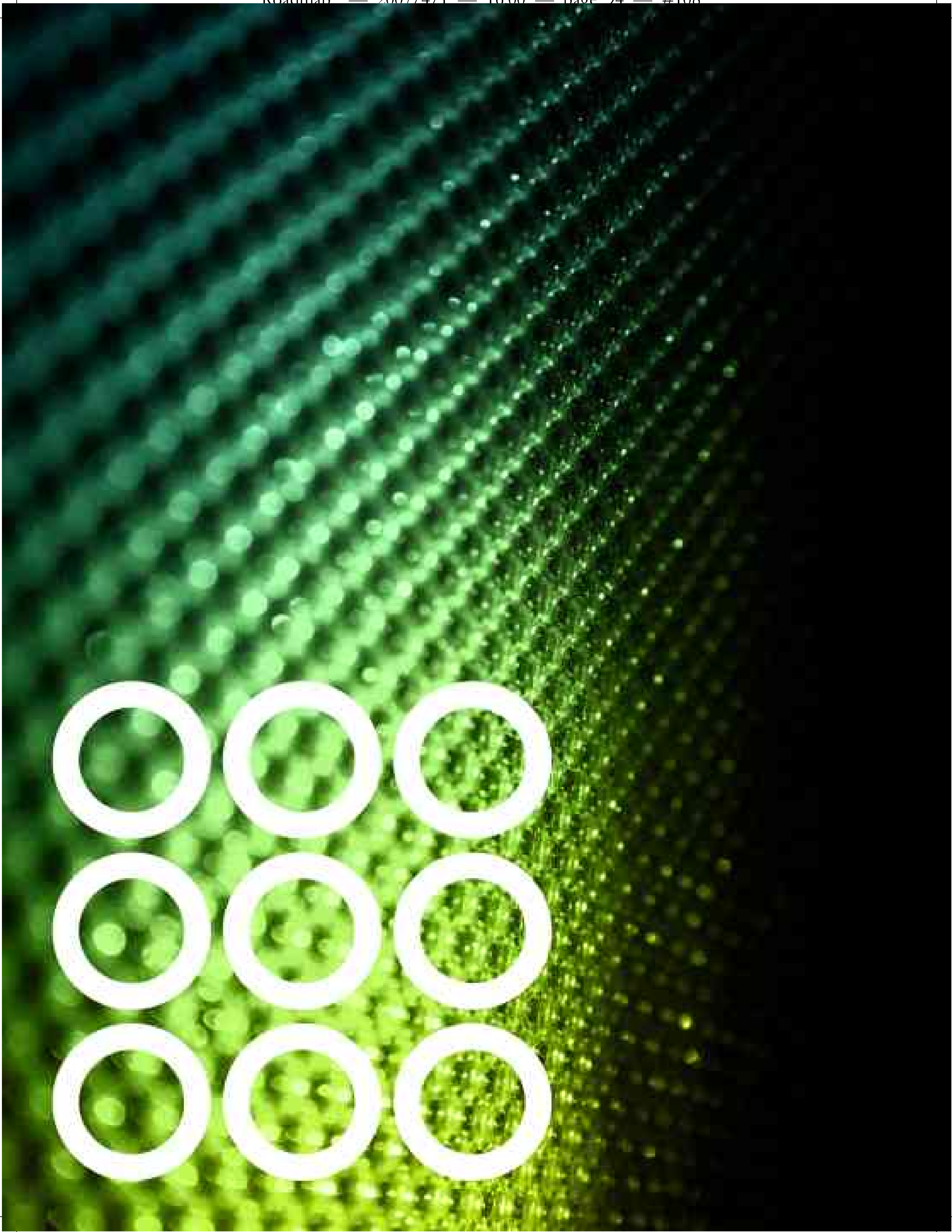
Tools for collaboration, information and communication exchange are now developed in the context of e–science and e–learning. However, for music, there are at present no tools that combine audio files with verbal descriptions and other types of content–based information (such as scores, extracted audio features or maps) in any flexible way. Such tools should take into account the profile and experience of particular users involved with music.

Strategy 4: Exploit cross-fertilisation between human sciences, natural sciences, technology, and the arts.

Apart from cognitive theories of music such as tonality and rhythm categorisation, the human sciences (e.g. musicology, anthropology and sociology) have had little impact on the development of SMC technologies. And yet there is a large amount of knowledge about the social functioning of music that is currently unexploited in SMC research. Cross–fertilisation between the human and natural sciences, as it is currently being developed in embodied music cognition, may offer new concepts and perspectives for understanding the social functioning of music. Examples are concepts such as synchronisation, corporeal attuning in response to music, empathy and the sharing of actions. These concepts may provide a useful framework for the development of artistic applications that take into account social interaction as a basic feature of artistic expression.

Strategy 5: Expand the horizon of SMC research through a multicultural approach.

Current SMC research is dominated by a narrow focus on traditional Western tonal music. SMC should make a conscious effort to transcend this focus, which tends to exclude SMC researchers from other cultures, making it difficult for them to publish results on their 'native' music. The goal must be to establish a common awareness in the SMC community of the importance of multicultural research. The musical and cultural expertise of foreign students from non–European countries, who are increasingly coming to study at European universities, should be actively used as a valuable resource in this endeavour.



CHAPTER 6

Conclusions

Sound and Music Computing is a highly multidisciplinary domain that is at the core of ICT–innovation in the cultural and creative industries of modern Europe. SMC has inherited the impressive artistic, scientific and technological history of Electroacoustic and Computer Music and expanded it into innovative realms such as artificial cognition, neurosciences and interactive design. This Roadmap is the result of a coordinated effort by some of the foremost SMC researchers in Europe to identify and share with the community the medium and long term research issues that might contribute to industrial and social developments. This contribution is likely to have a particular impact in the cultural and creative industries. Given the planetary relevance of these European industries, both in economic and state–of–the–art terms, the innovative pathway proposed in the Roadmap is of special relevance.

This SMC Roadmap is targeted not only at scientific policy makers and stakeholders. It will also appeal to a wide public ranging from the research specialist to the curious layman, from the R&D engineer to the contemporary musician.

Many of the challenges presented in Chapter 5 indicate that SMC requires support for basic fundamental research. This level of research must be catered for by academic researchers working in conjunction with visionary creators. Public funding (whether national or European) is an absolute necessity at this level. However, the rapidly changing paradigms of the Information Society have completely transformed the opportunities for applied research in SMC. The progressive switch from "product industries", such as musical instrument and audio device manufacturers, to "service industries", such as sound and music information providers and content aggregators, offers new, unexplored avenues for SMC knowledge transfer in addition to the classical ones. The target industries for SMC have extended beyond specific music areas: the role and impact of sound and music is of growing importance in, for example, the multimedia industry, home entertainment and therapy and rehabilitation. In particular, the rising importance of the content industry as the fundamental asset for many other large industrial endeavours (such as the network and mobile industries) is certain to create opportunities that SMC must be ready to pick up. Furthermore, the musical instrument industry, the classic reference industry for SMC, is currently expanding into that of manufacturers of any appliance that supports audio interaction (i.e.practically any device that carries an audio transducer of some sort).

This roadmap has been designed to maximise the impact of SMC research in several areas:

Fundamental Knowledge.
We still lack essential knowledge at very fundamental levels in topics related to SMC. Examples are perception and cognition, multi–modal interaction and music creation processes. This roadmap has provided a pathway for addressing these fundamental scientific issues.

Quality of Life.
The amount of sound and music is growing at a brisk pace, the audio channel being currently exploited in a wide range of applications which carry an unprecedented number of signals and messages. This roadmap has devoted much attention to research fields addressing audio channel pollution and cluttering because these fields will undoubtedly need robust expansion in the near future.

Cultural and Creative Industries.
Content industries are, in Europe, larger than the Chemicals, Rubber and Plastic industries put together. Furthermore, they are still rapidly evolving within the context of the Information Society. SMC's impact on these industries is bound to grow along with research discoveries and technological developments.

Information and Communication Technologies.
The SMC research outlined in this Roadmap will contribute to new solutions in content–based access to sound and music, thereby adding a new technological layer to current audio recordings and the mobile broadband industry.

Social Health.
As it develops, SMC research, by providing technology that fosters access to music, is bound to have an increasingly deep and wide impact on cultural identification and social bonding. Social and cultural issues have been a key concern of the Roadmap.

In this Roadmap we have looked forward and have tried to identify future trends, while remaining very conscious that is impossible to predict reliably the future of SMC research. However it is clear that the future of SMC is bound to be connected to cross–fertilisation among new and previously loosely related disciplines, such as neurosciences, nanotechnologies, sound design and many more. SMC researchers need to be pro-active in this cross–fertilisation, promoting extensive joint research activities with neighbouring fields.

The relevance of many of the contributions of this Roadmap is short lived. Given the exponential advances and changes that are taking place in most of the fields and topics covered, this document should be updated regularly if it is to reflect the current context and state of the art. It is the intention of the promoters of this document to maintain the site http://www.soundandmusiccomputing.org as a discussion forum for the Roadmap and as the place to house future versions of it. This Roadmap has been the result of many contributions. Basically it belongs to the whole international SMC research community. As a means of promoting a shared view of our field, we encourage this community to take advantage of it.

APPENDIX A

Notes for SMC Curricula

There is a wide variety of educational programmes that include SMC related topics, but there is no consensus on what should be taught to actually train future SMC researchers and related professionals. As part of this Roadmap, this appendix presents an overview of the current situation and proposes some initial ideas on what to include in a SMC curricula. Below are the results of a questionnaire survey of most of the European educational institutions involved in SMC education. We first list the academic topics that were used as the basis for the questionnaire, then the institutions targeted. Finally we analyse the results.

For our purposes, a topic is defined as the raw material out of which courses and curricula may be composed. A content area is defined as a course or as a course module which can be mapped onto courses or used to tailor a curriculum for various sorts of students.[1] We have loosely grouped the content areas into three main clusters: broad-focus, in-focus, and narrow-focus.

Broad-focus content areas

The content areas listed in this cluster refer to disciplines that are of general interest for SMC.

- **Systematic Musicology**
  Including: music semiotics, score analysis, computational models for music analysis.
- **Auditory and Music Perception-Action**
  Including: psychoacoustics, music perception, computational approaches and models.
- **Auditory and music cognition**
  Including: sound-based cognition, music cognition, artificial intelligence.
- **Music Acoustics**
  Including: acoustics of musical instruments, room acoustics.
- **Audio Signal Processing**
  Including: systems, sampling and quantisation, spectral and time-spectral representations, digital filters.

[1] A similar approach has been taken by the ACM-SIGCHI Curriculum Development Group, for the design of a set of recommendations for education in Human-Computer Interaction. See the report available at http://www.sigchi.org/cdg/.

- **Hardware and Software**
  Including: sensors and actuators, real-time systems, output devices, software platforms, software engineering.

In-focus content areas

The content areas listed in this cluster represent core disciplines that might characterise a curriculum of studies in SMC

- **Sound Modelling**
  Including: models for sound synthesis, physically-based modelling, digital audio effects, spatial sound and virtual acoustics.
- **Sound Analysis and Coding**
  Including: auditory-based audio signal processing, perceptual coding, content-based audio processing and audio descriptors, content description/transmission languages, content-based transformation.
- **Music Information Processing**
  Including: feature extraction/classification, automatic transcription, music information retrieval, computer assisted composition.
- **Music Performance**
  Including: performance analysis, emotion and expression in music performance, computational models and control of music performance.

Narrow-focus content areas

The content areas listed in this cluster represent more specialised and research-oriented disciplines that might be taught at an advanced stage of a curriculum. It is likely that some of these disciplines will be more widely represented among in-focus content areas in future curricula.

- **Multimodal Interfaces**
  Including: multimodal perception and action, gesture and multisensory analysis and synthesis, representations of multisensory data, control mappings and interaction strategies, evaluation of interaction models.
- **Sound Design and Auditory Display**
  Including: auditory warnings, sound in interaction design, sonification, sound design.
- **Applications Areas**
  Including: digital and virtual musical instruments, interactive performing arts, interactive installations, education, entertainment, multimedia and new media, therapy and rehabilitation.

Table A.1.: Information collected for courses and curricula in SMC.

title	
teacher	*(or teachers for curricula)*
institution	
level	*(undergraduate, Master's, or PhD)*
credits	*(ECTS, only for single courses)*
contents	
objectives	
hours	*(only for single courses)*
bibliographical references	*(only for single courses)*
areas	*(one or more from the list of content areas discussed above)*
school	*(one or more among engineering; humanities, music and arts; brain and cognitive sciences; mathematical, physical and computer sciences)*
evaluation	*(only for single courses)*
language	
prerequisites	

A.1 A SURVEY OF SMC EDUCATION

A survey of existing courses and curricula in SMC around the EU was conducted, with the aim of analysing current trends in SMC education. The survey collected relevant data for both single courses and entire curricula centred on SMC topics. The structure of the collected data is shown in Table A.1.

A total of 170 courses and 40 curricula across 15 European countries were surveyed. The complete list of surveyed institutions is given in Table A.2. Note that the institutions are not evenly distributed across countries. Nonetheless, some preliminary conclusions can be drawn.

Table A.2.: Institutions taken into account for the survey of SMC education (for brevity, individual departments within an institution are not listed).

Country	Name	URL
Austria	• University of Music and Dramatic Arts Graz	www.uni-graz.at
	• University of Music and Performing Arts Vienna	www.mdw.ac.at
Belgium	• Liege University	www.ulg.ac.be
	• Université Libre de Bruxelles	www.ulb.ac.be

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Table A.2 – continued from previous page

Country	Name	URL
	• Ghent University	www.ugent.be
	• Université Catholique de Louvain	www.ucl.ac.be
Denmark	• Aalborg University	www.aau.dk
	• Aarhus University	www.au.dk
Finland	• University of Helsinki	www.helsinki.fi/university/
	• Helsinki University of Technology	www.tkk.fi
	• Sibelius Academy, Helsinki	www.siba.fi
	• University of Jyväskylä	www.jyu.fi
	• Tampere University of Technology	www.tut.fi
	• University of Tampere	www.uta.fi
France	• Université René Decartes Paris 5	www.univ-paris5.fr
	• Université Pierre et Marie Curie Paris 6	www.upmc.fr
	• Institut de Recherche et Coordination Acoustique/Musique (IRCAM)	www.ircam.fr
	• Université Paris 8	www.univ-paris8.fr
	• Université du Maine Le Mans	www.univ-lemans.fr
	• Université de Provence, Aix-Marseille	www.up.univ-mrs.fr
	• Université de Marne-la-Vallée	www.univ-mlv.fr
	• Université Bordeaux 1	www.u-bordeaux1.fr
	• Université Lyon 2	www.univ-lyon2.fr
Germany	• Ruhr-Universität Bochum	www.ruhr-uni-bochum.de
	• Technical University Berlin	www.tu-berlin.de
	• Rostock Academy of Music and Drama	www.hmt-rostock.de
	• Liszt School of Music in Weimar	www.hfm-weimar.de
	• Detmold Academy of Music	www.hfm-detmold.de
	• Martin-Luther University Halle-Wittenberg	www.uni-halle.de
	• University of Hamburg	www.uni-hamburg.de
	• Helmut-Schmidt-University Hamburg	www.hsu-hh.de
	• Hannover Academy of Music and Drama	www.hmt-hannover.de
	• Ilmenau Technical University	www.ilm-kreis.de
	• University of Köln	www.uni-koeln.de

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Table A.2 – continued from previous page

Country	Name	URL
	• Hamburg Academy of Music and Drama	www.hmt-hamburg.de
	• Karlsruhe University of Music	www.hit-karlsruhe.de
	• Johannes Gutenberg University Mainz	www.uni-mainz.de
	• Berlin University of the Arts	www.udk-berlin.de
Greece	• University of Athens	www.uoa.gr
	• Aristotle University of Thessaloniki	www.auth.gr
Ireland	• Trinity College Dublin	www.tcd.ie
	• University of Limerick	www.ul.ie
	• National University of Ireland, Maynooth	www.nuim.ie
	• Dundalk Institute of Technology	www.dkit.ie
Italy	• University of Padova	www.unipd.it
	• University of Genova	www.unige.it
	• University of Verona	www.univr.it
	• IUAV University of Venice	www.iuav.it
	• University of Bologna	www.unibo.it
	• University of Salerno	www.unisa.it
	• University of Torino	www.unito.it
	• University of Milano	www.unimi.it
	• Milano Technical University	www.polimi.it
	• University of Roma "Tor Vergata"	www.uniroma2.it
	• University of Pisa	www.unipi.it
Netherlands (the)	• University of Amsterdam	www.uva.nl
	• Radbout University Nijmegen	www.ru.nl
Norway	• Norwegian University of Science and Technology, Trondheim	www.ntnu.no
Portugal	• Instituto Politécnico do Porto	www.ipp.pt
	• Instituto Politécnico de Castelo Branco	www.ipcb.pt
	• Escola Superior de Música de Lisboa	www.esm.ipl.pt
	• Universidade Catolica Portuguesa (Braga, Porto, Beiras, Lisboa)	www.ucp.pt
Spain	• University of Seville	www.us.es
	• Universitat Pompeu Fabra Barcelona	www.upf.es

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Table A.2 – continued from previous page

Country	Name	URL
	• University of Alicante	www.ua.es
	• Escola Superior de Musica de Catalunya	www.esmuc.net
Sweden	• Royal Institute of Technology, Stockholm	www.kth.se
	• University of Linköping	www.liu.se
	• University of Lund	www.ulund.se
	• Kristianstad University	www.hkr.se
UK	• Queen Mary University London	www.qmul.ac.uk
	• Queen's University, Belfast	www.qub.ac.uk
	• University of Salford	www.salford.ac.uk
	• University of York	www.york.ac.uk
	• City University, London	www.city.ac.uk
	• De Montfort University, Leicester	www.mti.dmu.ac.uk
	• University of Surrey	www.surrey.ac.uk
	• University of Glasgow	www.gla.ac.uk
	• University of Leeds	www.leeds.ac.uk

A.2 RESULTS OF THE SURVEY

In this section we summarize the main results obtained from analysis of the survey data.

A.2.1 Distribution of content areas

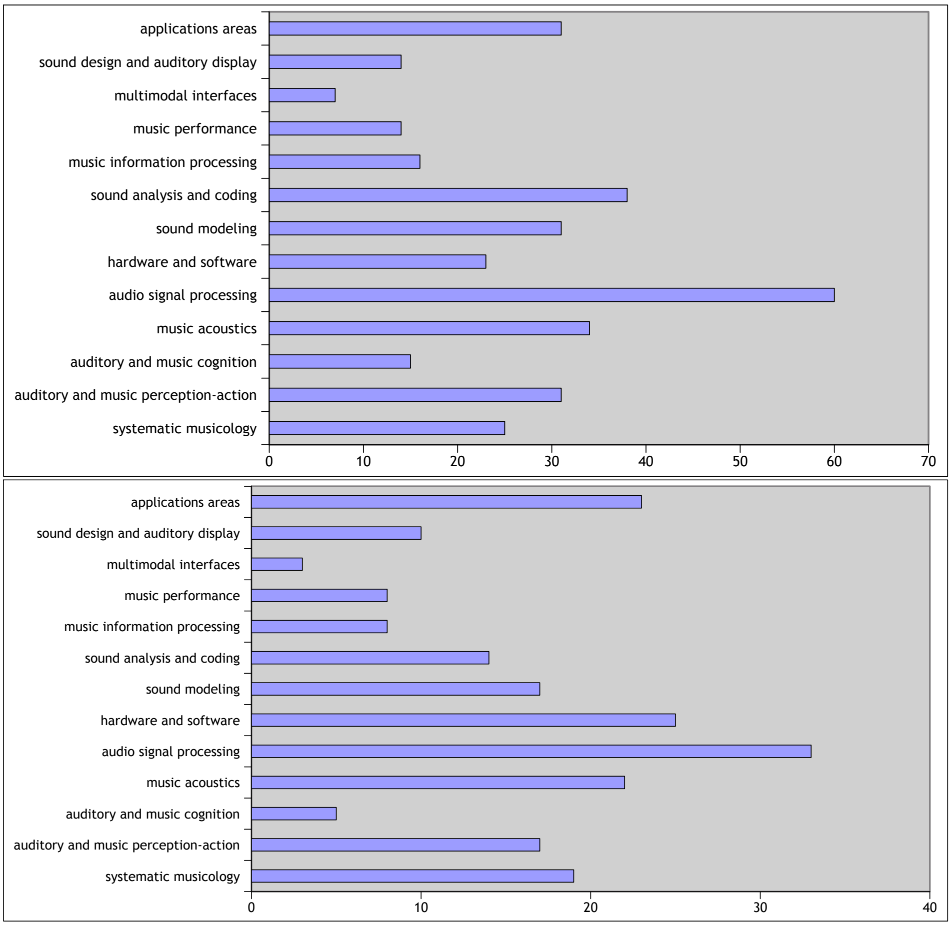

Figure A.1.: Distribution of surveyed courses (top) and curricula (bottom) across content areas.

A first-level analysis of the data reveals a generally 'conservative' picture. Figure A.1 shows the distribution of the surveyed courses and curricula across the content areas. It can be noticed that broad-focus content areas are more often addressed than more recent and research-oriented ones: Audio signal process-

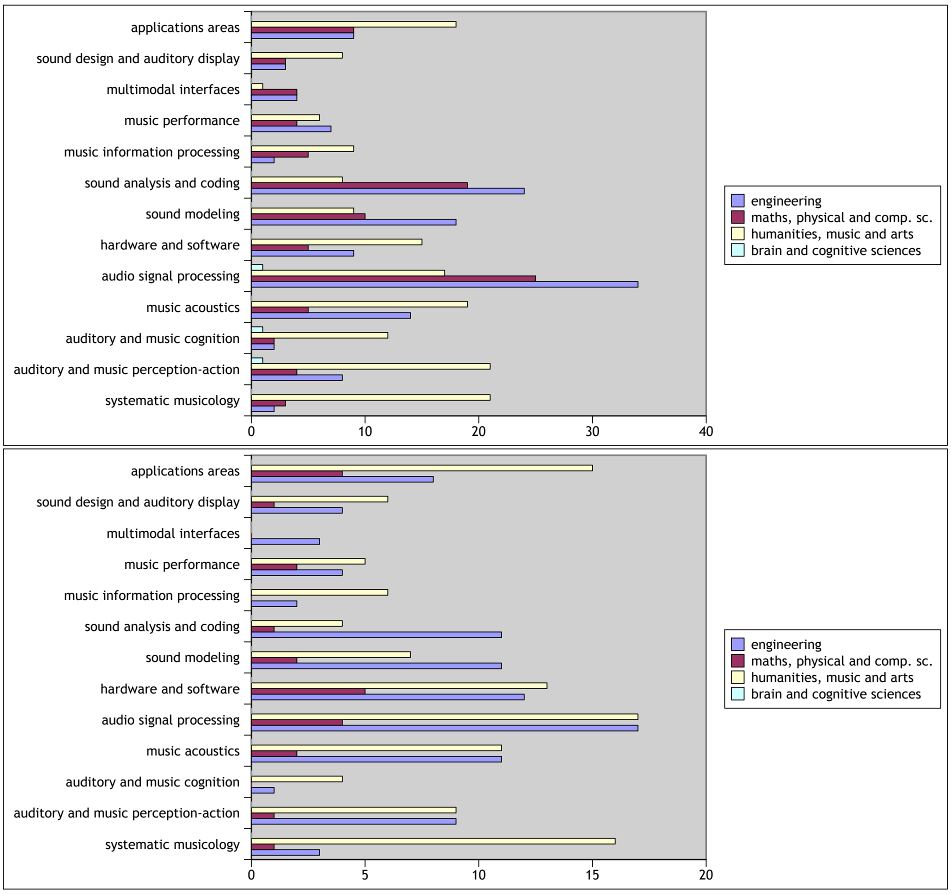

Figure A.2.: Distribution of content areas across schools for courses (top) and curricula (bottom).

ing, Sound analysis and coding and Music Acoustics are addressed in nearly 35%, 25% and 20% of the surveyed courses respectively. Conversely, Multimodal interfaces and Sound design/Auditory display feature in only about 4% and 9% respectively of the surveyed courses.

Figure A.2 provides a picture of what is taught in different schools: specifically it shows the distribution of the content areas across schools. It can be noticed that there is little attention to multidisciplinarity. As an example, 80% of the courses that address the content area of Systematic Musicology are run in Humanities and Arts schools, with only 12% being run in Engineering schools and 8% run in Mathematical-Physical-Computer Sciences schools. Similarly, 76% of the courses that address the content area of Audio Signal Processing are run in Engineering or Mathematical-Physical- Computer Sciences schools, with only 23% being run in Humanities and Arts schools and 1% run in Brain and Cognitive Sciences schools.

The classification of the courses by school also shows that a very small proportion of courses are run within Brain and Cognitive Sciences schools: only 2% of the total of the surveyed courses, at any level.

A.2.2 Content co-occurrence analysis

Regarding the number of content areas per course, it can be noticed that this is generally low, suggesting that the surveyed courses are typically focused on a limited number of topics and do not offer a broad spectrum. A more detailed analysis on this point was conducted by deriving a "co-occurrence matrix" for the content areas: this means that for every pair of content areas, we computed the number of times that the two areas are addressed within the same course or the same curriculum.

The results show that most content areas are correlated strongly with only one or two neighboring areas, while there are a notable lack of links between disciplines. For example, among the courses that address the content area of Systematic Musicology, only 10% also address the content area of Music Information Processing. These figures suggest that there is a strong need for diseemination of knowledge.

An exception to this trend is the content area of Hardware-Software. This area has a 'wider' coverage, in the sense that it equally relates to almost all other content areas (with the exceptions of Systematic musicology and Auditory/Music perception/cognition).

The multidisciplinary nature of SMC should be emphasized in curriculum design, in order to provide a wider spectrum of knowledge to students

Appendix A. Notes for SMC Curricula

	systematic musicology	auditory and music perception-action	auditory and music cognition	music acoustics	audio signal processing	hardware and software	sound modeling	sound analysis and coding	music information processing	music performance	multimodal interfaces	sound design and auditory display	applications areas
systematic musicology	25	6	5	2	3	1	1	1	5	3	0	2	1
auditory and music perception-	6	31	10	9	6	0	4	3	2	1	0	3	2
auditory and music cognition	5	10	15	1	2	0	0	1	3	1	0	0	1
music acoustics	2	9	1	34	6	0	6	3	0	0	0	0	2
audio signal processing	3	6	2	6	60	11	21	24	5	6	4	6	9
hardware and software	1	0	0	0	11	23	8	5	4	5	3	4	9
sound modeling	1	4	0	6	21	8	31	16	6	6	2	3	7
sound analysis and coding	1	3	1	3	24	5	16	38	7	4	3	0	7
music information processing	5	2	3	0	5	4	6	7	16	5	1	1	4
music performance	3	1	1	0	6	5	6	4	5	14	4	3	8
multimodal interfaces	0	0	0	0	4	3	2	3	1	4	7	1	4
sound design and auditory	2	3	0	0	6	4	3	0	1	3	1	14	8
applications areas	1	2	1	2	9	9	7	7	4	8	4	8	31

Figure A.3.: Matrices of content area co-occurrence for the surveyed courses.

	systematic musicology	auditory and music perception-	auditory and music cognition	music acoustics	audio signal processing	hardware and software	sound modeling	sound analysis and coding	music information processing	music performance	multimodal interfaces	sound design and auditory	applications areas
systematic musicology	19	8	4	7	11	8	6	2	5	2	0	2	5
auditory and music perception-	8	17	5	12	11	8	5	5	3	3	2	4	6
auditory and music cognition	4	5	5	3	4	2	1	1	2	0	0	2	2
music acoustics	7	12	3	22	16	10	7	6	3	2	3	3	6
audio signal processing	11	11	4	16	33	21	15	11	3	5	1	8	13
hardware and software	8	8	2	10	21	27	12	9	5	6	1	8	11
sound modeling	6	5	1	7	15	12	17	4	2	3	0	4	8
sound analysis and coding	2	5	1	6	11	9	4	14	1	1	2	3	3
music information processing	5	3	2	3	3	5	2	1	8	1	0	3	5
music performance	2	3	0	2	5	6	3	1	1	8	1	2	4
multimodal interfaces	0	2	0	3	1	1	0	2	0	1	3	0	1
sound design and auditory	2	4	2	3	8	8	4	3	3	2	0	10	10
applications areas	5	6	2	6	13	11	8	3	5	4	1	10	23

Figure A.4.: Matrices of content area co-occurrence for the surveyed curricula.

A.3 TOWARDS UNIFIED CURRICULA IN SMC

The analysis above can serve as a first step towards a structured design of courses and curricula in SMC. For such a task, many issues need to be addressed and we will briefly discuss those that we consider to be the most relevant.

Part of the complexity of curriculum design in SMC arises from the relationship of SMC to many different disciplines, which suggests that a SMC curriculum could be comfortably housed within a number of different departments, e.g. Computer Science, Music, Psychology, Information Systems, or Electrical Engineering. Furthermore, the boundaries of the SMC discipline are fairly dynamic. In summary, designing SMC curricula requires that one specifies how SMC relates to various established disciplines. The field of SMC appears by nature to be multidisciplinary. It should therefore not allow itself to be absorbed into a single discipline, since its study requires multiple points of view as a way of avoiding an overly narrow focus.

A second point of debate concerns the 'scale' of the course and curriculum design.

- At a first level, one can think of designing introductory courses on SMC, to be embedded in already existing and well defined curricula. Different syllabuses may be designed for different audiences.
- At a second level, one can think of designing a set of courses that define a SMC orientation within a more general programme.
- Finally, one can design full curricula in SMC. A point of discussion here is whether, given the multidisciplinary nature of SMC topics, the need for a thorough grounding in various foundation areas and the risk of overly narrow specialization, a complete undergraduate degree programme in SMC is advisable.

Design of undergraduate curricula should be targeted at providing real possibilities for a qualified job in the cultural/creative and ICT industries; design of doctorate degrees should be targeted at preparing for research-oriented posts in public institutions or private companies.

The design should take market aspects into account. Example issues are: how many interested and available students there might be for courses and curricula in SMC, both now and in the future; how many jobs for these students might exist upon graduation; how many programmes might be interested in incorporating such courses. These estimates would have to be based on an assessment of the need for SMC education and projections for its growth over the next decade or so. Closely related is the issue of potential career paths for graduates. Addressing this issue would involve the generation of job descriptions and a skills inventory.

Other points to be considered include the economic and political feasibility. Courses should be built as much as possible from existing courses in existing departments. The facilities required should be carefully planned, and a comprehensive environment for providing knowledge and skill-building in a SMC curriculum should be provided. While some programmes may begin at a modest level of exposure to the technology, the progression of the student toward higher levels of proficiency is dependent on the environment provided.

Efforts should be made to implement joint/shared curricula, especially at the Master's and doctorate levels. Existing tools should be exploited for this purpose (e.g. initiatives within the People specific programme of FP7).

Course design should be based on a mapping of SMC "content areas" (discussed above) onto course structures designed for various types of student. Such a mapping can be performed at different levels, i.e. for the design of a single introductory course as well as for the design of an entire curriculum. The choice and balance of the content areas will depend on the background know-how of the particular student group for which the course is being designed. In other words, each course recommendation will be a representative of a family of possible courses which might be fashioned from the inventory provided by our list of content areas.

APPENDIX B

Resources Available for SMC Research

Relevant information for the elaboration of this Roadmap was to get quantitative data about the size and resources of the SMC community. We immediately realized that it was impossible to get data from the whole community but nonetheless we prepared and distributed a questionnaire to 83 European institutions. Less than a third responded. Thus the results cannot be taken as reflecting the whole SMC community. But it is valuable data and we believe that is already useful as a starting point. We hope to be able to obtain more answers in the near future and will update the electronic version of the document accordingly.

Appendix B. Resources Available for SMC Research

B.1 DATA COLLECTION PROCESS

B.1.1 Aims

Given that this was the first attempt to obtain an overview of the size and resources of the field in Europe, we basically wanted to answer the following questions.

- Which institutions do SMC research?
- What are the most important journals and conferences for SMC?
- How many people work in the field?
- How well and from what sources is their research funded?
- How much output is produced in terms of journal and conference papers, other publications, PhD and Master's degrees, patents and startup companies?

Besides answering these questions, we wanted to quantify the growth of the field, for example by looking at the number of publications per year, and to identify the most important journals and conferences for sound and music computing among the respondents to the questionnaire by analysing how their publications are distributed over the individual journals and conferences.

B.1.2 Questionnaire

To answer these questions the following questionnaire was composed

Human Resources

Please provide the current number of members of your institution conducting research on Sound and Music Computing with the following positions

- Full professors (tenure)
  Total number:
- Readers (tenure or tenure-track)
  Total number:
- Senior Lecturers (tenure or tenure-track)
  Total number:
- Assistant professors or Lecturer (fixed-term contract)
  Total number:

- Post-doctoral researchers
  Total number:
- Research staff on fixed-term contracts (with or without PhD)
  Total number:
- Funded PhD students
  Total number:
- NON-Funded PhD students
  Total number:
- Funded Master students
  Total number:
- NON-funded Master students
  Total number:
- Support staff (administration, technical support, etc.)
  Total number:

Dissemination

In the following, when we ask for a 'list' of your publications, we mean a list including the complete reference (authors, title, journal or conference, publisher, pages)

1) Please provide a list of SMC related papers published by members of your institution in international peer-reviewed JOURNALS since 1996 (including papers accepted for publication)
2) Please provide a list of SMC related papers published by members of your institution in international peer-reviewed CONFERENCES since 1996 (including papers accepted for publication)
3) Please provide a list of books related to SMC research published by members of your institution since 1996.
4) Please provide a list of book chapters related to SMC research published by members of your institution since 1996.
5) Please provide a list of PhD theses related to SMC research read in your institution since 1996.
6) Please provide a list of MSc theses related to SMC research read in your institution since 1996.
7) Please provide a list of international conferences related to SMC research that were organised by your institution since 1996.
8) Please provide the current number of members of your institution staff active as editor of any international journals related to SMC research.
9) Please provide a list of appearances of your institution in the general media since 1996 (press papers, television or radio show).

Appendix B. Resources Available for SMC Research

Funding

Please provide the global budget of your research group since 2001 broken down by funding agencies (such as EU, national research councils, industry, university, etc.) If you can not provide the budget in Euros, provide at least the % contribution to your budget by each funding agency.

Technology Transfer

1) Provide a list of patents related to SMC technology published by members of your institution since 1996.
2) Provide a list of patents related to SMC technology filed (i.e. submitted but still not approved) by members of your institution since 1996.
3) Provide the number and size of start-up companies created by members (or ex-members) of your staff from SMC technologies developed in your institution.

Research Centres

Do you think that the following list of European research centres active in SMC is complete?

See Table B.1 for the list of European SMC research centres; the list in the questionnaire contained a subset of 83 institutions from Table B.1.

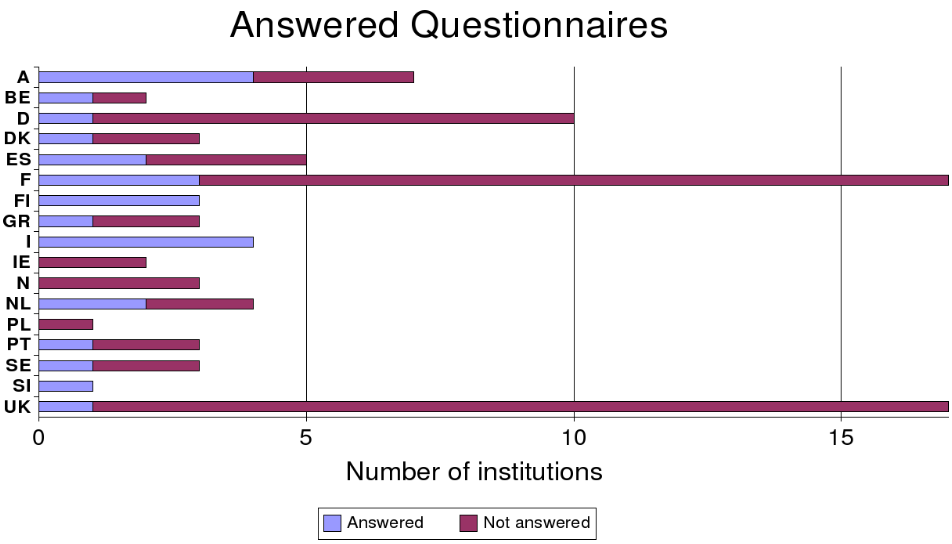

Figure B.1.: Returned questionnaires by country

B.1.3 Responses

Out of the 83 questionnaires that were sent out to the centres listed in Table B.1, 26 were returned. An additional 5 centres were added to the list based on the responses. Figure B.1 shows the distribution of responses over countries.

B.2 SMC RESEARCH CENTRES

Table B.1.: Centres identified as relevant to SMC

Country	Name	URL
Austria	• Acoustics Research Institute, Austrian Academy of Sciences, Vienna	http://www.kfs.oeaw.ac.at
	• Austrian Research Institute for AI, Vienna	http://www.ofai.at/research/impml/index.html
	• Cognitive Psychology Unit, Department of Psychology, University of Klagenfurt Klagenfurt	http://www.uni-klu.ac.at/psy/cognition/
	• Department of Computational Perception, Johannes Kepler University, Linz	http://www.cp.jku.at
	• Department of Musicology, University of Graz	http://www-gewi.uni-graz.at/muwi/
	• Department of Software Technology and Interactive Systems, Vienna University of Technology	http://www.ifs.tuwien.ac.at/mir/
	• Institut für Wiener Klangstil, Vienna	http://iwk.mdw.ac.at
	• Institute of Electronic Music and Acoustics, Graz	http://iem.at
Belgium	• Institute for Psychoacoustics and Electronic Music, University of Ghent	http://www.ipem.ugent.be
Germany	• Communication Systems Group, Technical University Berlin	http://www.nue.tu-berlin.de/index_e.html
	• Department of Signal Processing and Communications, University of the Federal Armed Forces Hamburg	http://www.hsu-hh.de/ant/index_bB6jJons4tNeMtUV.html
	• Fraunhofer IIS, Erlangen	http://www.iis.fraunhofer.de/amm/index.html
	• Fraunhofer Institute for Digital Media Technology, Ilmenau	http://www.idmt.fraunhofer.de/index_eng.html
	• Institute for Media Technology, Technical University Ilmenau	http://www.tu-ilmenau.de/mt/

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Table B.1 – continued from previous page

Country	Name	URL
	• Institute of Communication Acoustics, Ruhr-University Bochum	http://www.ruhr-uni-bochum.de/ika/index_en.htm
	• Institute of Communications Research, Technical University Berlin	http://www.kgw.tu-berlin.de
	• Institute of Music Physiology and Musicians' Medicine, Hanover University of Music and Drama	http://www.immm.hmt-hannover.de/index_en.html
	• Neurocognition of Music Group, Max Planck Institute for Human Cognitive and Brain Science	http://www.cbs.mpg.de/MPI_Base/NEU
	• ZKM, Karlsruhe	http://www.zkm.de/
Denmark	• Danish Institute of Electroacoustics Music, Aarhus	http://www.diem.dk
	• Intelligent Sound, Technical University of Denmark, Copenhagen	http://www.intelligentsound.org/home.php
	• Medialogy, Institute of Media Technology and Engineering, Aalborg University Copenhagen	http://new.media.aau.dk
Spain	• GAPS, Signal, Systems and Radiocommunications Department, Universidad Politécnica de Madrid	http://www.gaps.ssr.upm.es/index.htm
	• Institut d'Investigacio en Intelligencia Artificial (IIIA), Spanish Scientific Research Council (CSIC)	http://www.iiia.csic.es
	• Laboratory of Neurobiology of Hearing, Institute for Neuroscience of Castilla y León, Salamanca	http://www-incyl.usal.es/index.html
	• Music Technology Group, Universitat Pompeu Fabra, Barcelona	http://www.mtg.upf.edu
	• Pattern Recognition and Artificial Intelligence Group, University of Alicante	http://grfia.dlsi.ua.es
France	• ACROE, Grenoble	http://www-acroe.imag.fr
	• Department of Cognitive Studies, Ecole Normale Supérieure, Paris	http://lpp.psycho.univ-paris5.fr/Fiche-d-equipe-Audition.html

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Table B.1 – continued from previous page

Country	Name	URL
	• Equipe "Cognition Auditive et Psychoacoustique", Neurosciences et Systèmes Sensoriels, CNRS UMR5020, Université Claude Bernard Lyon 1	http://olfac.univ-lyon1.fr
	• Equipe "Langage, musique et motricité", Institut de Neurosciences Cognitives de la Méditerranée	http://www.incm.cnrs-mrs.fr/equipel2m.php
	• Equipe Modélisation, Synthèse et Contrôle des Signaux Sonores et Musicaux (S2M)	http://www.sensons.cnrs-mrs.fr/
	• GMEM, Marseille	http://perso.wanadoo.fr/gmem/html/gmem.htm
	• GRAME, Lyon	http://www.grame.fr
	• GRM, INA, Paris	http://www.ina.fr/grm/index.fr.html
	• IRCAM, Paris	http://www.ircam.fr
	• LEAD, Dijon	http://www.u-bourgogne.fr/LEAD/
	• LaBRI, Bordeaux	http://www.labri.fr/equipes/ImageSon/image_son.php
	• Laboratoire d'Acoustique Musicale, Université Paris 6, Paris	http://www.lam.jussieu.fr
	• Laboratoire de Mecanique et Acoustique, CNRS, Marseille	http://www.lma.cnrs-mrs.fr/
	• Sony CSL, Paris	http://www.csl.sony.fr
Finland	• Audio Research Group, Digital Media Institute, Tampere University of Technology	http://www.cs.tut.fi/sgn/arg/
	• Laboratory of Acoustics and Audio Signal Processing, Helsinki University of Technology	http://www.acoustics.hut.fi
	• Music Department, University of Jyväskylä	http://www.jyu.fi/musica/english/
Greece	• Centre for Music Acoustics and Technology, Department of Music Studies, University of Athens	http://www.music.uoa.gr

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Table B.1 – continued from previous page

Country	Name	URL
	• Department of Music Studies, Aristotle University of Thessaloniki	http://web.auth.gr/mus/en_index.html
	• Institute for Language and Speech Processing	http://www.ilsp.gr/info_eng.html
	• Department of Informatics, University of Athens	GeorgakiAnastasia,georgaki@music.uoa.gr,http://www.music.uoa.gr
Italy	• Dep. of Communication, Computer and System Sciences, University of Genoa Genoa	http://musart.dist.unige.it
	• Department of Computer Science, University of Verona	http://www.di.univr.it/dol/main?lang=en
	• Department of Information Engineering, University of Padova	http://www.dei.unipd.it
	• LIM - Laboratorio di Informatica Musicale, università degli Studi di Milano	http://www.lim.dico.unimi.it
Ireland	• Centre for Computational Musicology and Computer Music, University of Limerick	http://www.ul.ie/~ccmcm/
	• Sonic Arts Research Centre, Queen’s University Belfast	http://www.qub.ac.uk/sarc/
Norway	• Acoustics Group, Department of Electronics and Telecommunications, Norwegian University of Science and Technology, Trondheim	http://www.iet.ntnu.no/groups/akustikk/indexe.html
	• Department of Musicology, University of Oslo	http://www.hf.uio.no/imv/english/
	• Norwegian network for Technology, Acoustics and Music, Oslo	http://www.notam02.no
Netherlands	• Music Cognition Group, University of Amsterdam	http://cf.hum.uva.nl/mmm/
	• Music, Mind, Machine Group, Nijmegen Institute for Cognition and Information, Radboud University, Nijmegen	http://www.nici.kun.nl/index.shtml
	• STEIM, Amsterdam	http://www.steim.org/steim/
	• Universiteit Utrecht	www.cs.uu.nl

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Table B.1 – continued from previous page

Country	Name	URL
Poland	• Multimedia Systems Department, Gdansk University of Technology	http://sound.eti.pg.gda.pl/index.html
Portugal	• CITAR, Portuguese Catholic University, Porto	http://artes.ucp.pt/citar/
	• Center for Informatics and Systems, University of Coimbra	http://www.cisuc.uc.pt/index.php
	• Telecommunications and Multimedia Unit, INESC-Porto	http://telecom.inescporto.pt
Sweden	• Department of Psychology, Uppsala University	http://www.psyk.uu.se/eng/
	• Digital Media Division, Department of Science and Technology (ITN), Linköping Institute of Technology (LiTH)	http://dm.itn.liu.se/research/sound-technology-research?l=en
	• S3-SIP Sound and Image Processing Laboratory, School of Electrical Engineering, KTH Kungliga Tekniska Högskolan, Stockholm	www.ee.kth.se/sip
	• Swedish Institute for Computer Science SICS	www.sics.se
	• TMH Department of Speech Music and Hearing , CSC School of Computer Science and Communication, KTH Royal Institute of Technology, Stockholm	http://www.speech.kth.se
Slovenia	• Faculty of Computer and Information Science, University of Ljubljana	http://www.fri.uni-lj.si/en/
United Kingdom	• Acoustics Research Centre, Salford University	http://www.acoustics.salford.ac.uk
	• Audio Lab, University of York	http://www.elec.york.ac.uk/intsys/projects/audio.html
	• Center for Digital Music, Queen Mary, University of London	http://www.elec.qmul.ac.uk/digitalmusic/index.html
	• Center for Music and Science, University of Cambridge	http://www.mus.cam.ac.uk/external/research/CMS.html
	• Centre for Music Technology, University of Glasgow	http://cmt.gla.ac.uk

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Table B.1 – continued from previous page

Country	Name	URL
	• Electronic Studio, Department of Music, Leeds University	http://www.leeds.ac.uk/music/studio/
	• Faculty of Music, University of Edinburgh	http://www.music.ed.ac.uk/Research/
	• Intelligent Sound and Music Systems, Goldmiths College, London	http://www.doc.gold.ac.uk/isms/
	• Interdisciplinary Center for Computer Music Research, University of Plymouth	http://cmr.soc.plymouth.ac.uk
	• Interdisciplinary Centre for Scientific Research in Music, University of Leeds	http://www.leeds.ac.uk/icsrim/
	• Multimedia Knowledge Management Group, Imperial College	http://km.doc.ic.ac.uk
	• Music Informatics research group, City University, London	http://www.soi.city.ac.uk/organisation/doc/research/mi/
	• Music Information Systems and Technology Research, University of Sheffield	http://www.dcs.shef.ac.uk/~guy/mistres/
	• Music Technology Group, University of York	http://www.york.ac.uk/inst/mustech/
	• Music Technology, London Metropolitain University	http://jcamd.londonmet.ac.uk/mit/research.html
	• Music, Technology and Innovation Research Centre, De Montfort University, Leicester	http://www.mti.dmu.ac.uk
	• Signal Processing Group, Cambridge University Engineering Department	http://www-sigproc.eng.cam.ac.uk

B.3 SMC CONFERENCES, JOURNALS AND SOCIETIES

B.3.1 Conferences

Table B.2.: Conferences identified as relevant to SMC

- AAAI Workshop on Artificial Intelligence and Music
- ACM Conference on Digital Libraries
- ACM Conference on Human Factors in Computing Systems (CHI)
- ACM Conference on Object-Oriented Programming, Systems, Languages and Applications
- ACM International Conference on Computer Graphics and Interactive Techniques (SIGGRAPH)
- ACM International Conference on Multimedia
- ACM Special Interest Group on Information Retrieval (SIGIR) Conference
- AES Conventions
- AES International Conferences
- AISB (Artificial Intelligence and the Simulation of Behaviour) Convention
- Advances in Inductive Rule Learning Workshop
- Annual Symposium Care of the Professional Voice
- Australasian Computer Music Conference
- Baltic-Nordic Acoustics Meeting
- Brazilian Symposium on Computer Music
- British Forum for Ethnomusicology Annual Conference
- Central European International Multimedia and Virtual Reality Conference
- Colloquium on Musical Informatics
- Conference on Artificial Intelligence in Music and Art
- Conference on Interdisciplinary Musicology
- Conference on Multimedia Technology and Applications
- Conference on Pattern Languages of Programs
- Conference on Real-Time and Embedded Computing
- Conference on Storage and Retrieval for Media Databases
- Conference on artistic, cultural and scientific aspects of experimental media spaces
- Congrès Français d'Acoustique
- Diderot Forum
- Digital Audio Effects (DAFX)
- Enactive International Conference
- European Conference on Artificial Intelligence

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Table B.2 – continued from previous page

- European Conference on Information Retrieval
- European Conference on Machine Learning
- European Conference on Research and Advanced Technology for Digital Libraries
- European Conference on Science, Art and Technology
- European Conference on Speech Communication and Technology
- European DSP Education and Research Symposium
- European Signal Processing Conference
- European Workshop on Evolutionary Music and Art
- European Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS)
- European Workshop on the Integration of Knowledge, Semantic and Digital Media Technologies
- Eurospeech Conference
- Florida Artificial Intelligence Symposium
- Forum Acusticum
- HCI International Conference
- IEEE Conference On Multimedia Computing and Systems
- IEEE Conference On Systems, Man and Cybernetics
- IEEE International Conference on Digital Information Management
- IEEE International Conference on Multimodal Interfaces
- IEEE International Conference on Music Applications of XML
- IEEE International Symposium on Virtual Environments
- IEEE International Telecommunications Symposium
- IEEE International Workshop on Projector-Camera Systems
- IEEE International Workshop on Robot and Human Interactive Communication
- IEEE Mediterranean Electrotechnical Conference (MELECON)
- IEEE Multimedia Conference
- IEEE Multimedia Systems
- IEEE Pacific-Rim Conference on Multimedia
- IEEE Symposium on Signal Processing and Information Technology
- IEEE Virtual Reality Conference
- IEEE Visualization Conference
- IEEE Workshop on Applications of Signal Processing to Audio and Acoustics
- IEEE Workshop on Machine Learning for Signal Processing
- IEEE Workshop on the Applications of Signal Processing to Audio and Acoustics
- IMAC Conference on Localization and Globalization in Technology Design, Use and Transfer as a Subject of Engineering

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Table B.2 – continued from previous page

- IRCAM MUSICNETWORK Workshop
- ISCA Speech Synthesis Workshop
- ISCA/DEGA Tutorial and Research Workshop on Perceptual Quality of Systems
- Iberian Conf. on Pattern Recognition and Image Analysis
- Iberoamerican Conference on Pattern Recognition
- Interaction Symposium on Mobile HCI
- International Association of Sound and Audiovisual Archives
- International Broadcasting Conference
- International CAiiA Research Conference
- International Computer Music Conference (ICMC)
- International Conference Music and Gesture
- International Conference on Artificial Reality and Teleexistance
- International Conference on Spatial Sound Reproduction
- International Conference on "Computer as a tool" (Eurocon)
- International Conference on Acoustics, Speech and Signal Processing
- International Conference on Adaptive and Natural Computing Algorithms
- International Conference on Artificial Intelligence and Applications
- International Conference on Audio-Visual Speech Processing
- International Conference on Auditory Display
- International Conference on Cognitive Musicology
- International Conference on Computer Music Modeling and Retrieval
- International Conference on Computer Technology Applications for Music Archives
- International Conference on Discovery Science
- International Conference on E-business and Telecommunication Networks
- International Conference on Enactive Interfaces
- International Conference on Fuzzy Systems Knowledge Discovery
- International Conference on Generative Systems in the Electronic Arts
- International Conference on Information Visualization
- International Conference on Intelligent Production Machines and Systems
- International Conference on Intelligent User Interfaces
- International Conference on Knowledge Discovery and Data Mining
- International Conference on Machine Learning
- International Conference on Multimedia and Expo
- International Conference on Music Perception & Cognition (ICMPC)
- International Conference on Music and Artificial Intelligence
- International Conference on New Interfaces for Musical Expression

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Table B.2 – continued from previous page

- International Conference on Semantics and Digital Media Technology
- International Conference on Signal Processing
- International Conference on Signal Processing Applications and Technology
- International Conference on Signal and Image Processing
- International Conference on Virtual Systems and Multimedia
- International Conference on Web Delivering of Music
- International Conference on Web Intelligence
- International Congress on Acoustics
- International Congress on Acoustics (ICA)
- International Congress on Science and Technology for the Safeguard of Cultural Heritage in the Mediterranean Basin
- International Congress on Sound and Vibration
- International Convention MIPRO
- International Convention on Sound Design
- International Cultural Heritage Informatics Meeting
- International FLAIRS Conference
- International Gesture Workshop
- International IGIP (International Society for Engineering Education) Symposium
- International Joint Conference on Artificial Intelligence
- International Linux Audio Conference
- International PD Convention
- International Semantic Web Conference
- International Stockholm Acoustic Conference
- International Symposium on 3D Data Processing Visualization and Transmission
- International Symposium on Computer Music Modeling and Retrieval
- International Symposium on Control, Communications and Signal Processing
- International Symposium on Electronic Art
- International Symposium on Lattice Field Theory
- International Symposium on Measurement, Analysis and Modeling of Human Functions
- International Symposium on Music Information Retrieval (ISMIR)
- International Symposium on Musical Acoustics
- International Symposium on Systematic and Comparative Musicology
- International Symposium on Virtual and Augmented Architecture
- International Workshop on Artificial Neural Networks in Pattern Recognition
- International Workshop on Auditory Displays for Mobile Context-Aware Systems

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Table B.2 – continued from previous page

- International Workshop on Constructive Methods for Parallel Programming
- International Workshop on Content-Based Multimedia Indexing
- International Workshop on Gesture and Sign Language based Human-Computer Interaction
- International Workshop on Gesture in Human-Computer Interaction and Simulation
- International Workshop on Human Supervision and Control in Engineering and Music
- International Workshop on Interactive Sonification
- International Workshop on Kansei
- International Workshop on Models and Analysis of Vocal Emissions for Biomedical Applications
- International Workshop on Multidimensional Systems
- International Workshop on Multimedia Information Systems
- International Workshop on Multimedia Signal Processing
- International Workshop on Pattern Recognition in the Information Society
- International Workshop on Virtual Reality Rehabilitation
- Joint Conference on Declarative Programming
- Journees d'Informatique Musicale
- Meetings of the Acoustical Society of America
- Multimedia Applications in Education Conference
- Multimedia and Hypermedia Systems Conference
- Nordic Music Technology Conference
- Nordic Signal Processing Symposium
- Others
- Pacific Rim International Conference on Artificial Intelligence
- Resonances
- Rhythm Perception and Production Workshop
- Sound and Music Computing Conference
- Stockholm Music Acoustics Conference
- Symposium on Adaptive Models of Knowledge, Language and Cognition
- Symposium on Gesture Interfaces for Multimedia Systems
- Symposium on Musical Creativity
- Symposium on Principles of Distributed Computing
- Tonmeistertagung (VDT)
- Triennial Conference of the European Society for the Cognitive Sciences of Music
- Workshop on Current Research Directions in Computer Music
- Workshop on Friend of a Friend, Social Networking and the Semantic Web

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Table B.2 – continued from previous page

- Workshop on Pattern Recognition in Information Systems
- Workshop on Scripting for the Semantic Web
- Workshop on Tangible Interaction in Collaborative Environments
- Workshop on Haptic and Audio Interaction Design
- World Multi-Conference on Systemics, Cybernetics and Informatics

B.3.2 Journals

Table B.3.: Journals identified as relevant to SMC

- ACM Computers in Entertainment
- ACM Transactions on Applied Perception
- ACM Transactions on Multimedia Computing, Communications, and Applications
- AI Communications
- AI Magazine
- Acoustics Research Letters Online
- Acta Acustica
- Annals of the NY Academy of Sciences
- Applied Signal Processing
- Artificial Intelligence
- BMC Neuroscience
- Behavior Res. Methods
- Behavioral and Brain Sciences
- Brain
- Brain Research
- Chaos: An Interdisciplinary Journal of Nonlinear Science
- Cognition
- Cognition, Technology and Work
- Computer
- Computer Animation and Virtual Worlds
- Computer Music Journal
- Computers and the Humanities
- Contemporary Music Review
- Ecological Psychology
- EURASIP Journal on Advances in Signal Processing
- EURASIP Journal on Audio, Speech, and Music Processing
- Electronic Journal of Art and Technology
- General Psychology
- Hearing Research

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Table B.3 – continued from previous page

- IEEE Computer
- IEEE Computer Graphics and Applications
- IEEE Multimedia Magazine
- IEEE Signal Processing Letters
- IEEE Signal Processing Magazine
- IEEE Transactions on Audio, Speech and Language Processing
- IEEE Transactions on Instrumentation and Measurement
- IEEE Transactions on Multimedia
- IEEE Transactions on Signal Processing
- IEEE Transactions on Systems Man and Cybernetics
- INFORMS Journal on Computing
- Intelligent Data Analysis
- Interdisciplinary Science Reviews
- International Journal of Artificial Intelligence Tools
- International Journal of Arts Medicine
- International Journal of Audiology
- International Journal of Human-Computer Studies
- International Journal of Music Education
- Journal of Cultural Heritage
- Journal of Experimental Psychology
- Journal of Intelligent Information Systems
- Journal of Music and Meaning
- Journal of New Music research
- Journal of Visualization and Computer Animation
- Journal of Voice
- Journal of the Acoustical Society of America
- Journal of the American Society for Information Science and Technology
- Journal of the Audio Engineering Society
- Knowledge Based Systems
- Lecture Notes in Computer Science (Springer)
- Leonardo Music Journal
- Logopedics Phoniatrics Vocology
- Machine Learning
- Medical Engineering and Physics
- Mov. Disord.
- Multimedia Tools and Applications
- Music Perception
- Musicae Scientiae
- Nature
- Neurocase

Continued on next page

Table B.3 – continued from previous page

• Neuroimage
• Neuropsychologia
• Neuroscience Letters
• Nordic Journal of Music Therapy
• Organised Sound
• Pattern Recognition Letters
• Perception
• Personal and Ubiquitous Computing
• Psychology of Music
• Reports on Progress in Physics
• Research in Computing Science
• ST Journal on Research
• Signal Processing
• South-African Computer Journal
• Speech Communication
• The Journal of VLSI Signal Processing
• Virtual Reality
• Zeitschrift für Neuropsychologie

B.3.3 Academic Societies

Table B.4.: Academic Societies identified as relevant to SMC

• International Computer Music Association
• International Musicological Society
• Acoustical Society of America
• European Acoustics Association
• Institute of Electrical and Electronics Engineers
• Association for Computing Machinery
• Audio Engineering Society
• European Society for the Cognitive Sciences of Music
• Society for Music Perception and Cognition

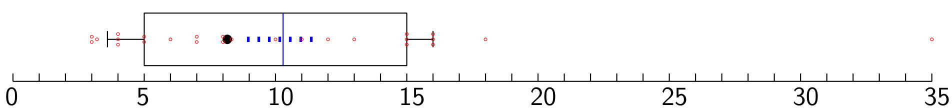

Figure B.2.: Academic and Research Personnel

B.4 ANALYSIS OF RESULTS

B.4.1 Size of the Field (Budgets, Personnel)

Figures B.2, B.3, and B.4 show the number of employees working as academic personnel or research staff for every institution that answered the corresponding questions. Each institution is shown as a small dot. The whiskers represent the 25 % and 75 % percentiles, while the box contains the middle 50 % of data points. The median is shown as a fat dot, while the vertical line shows the mean. The standard deviation is shown as a dotted line around the mean. The total numbers shown in Figure B.2 are further split up in Figures B.3 and B.4.

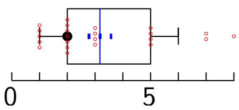

Figure B.3.: Academic Personnel

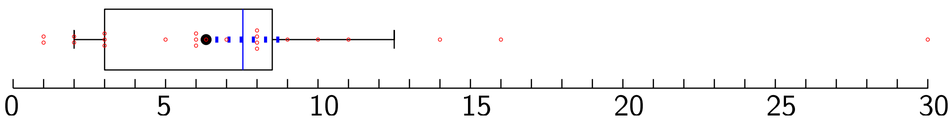

Figure B.4.: Research staff

Figures B.3 and B.4 show that a typical European SMC institution employs about 3 to 4 people as academic staff (professors) and about 7 to 9 as research staff (postdocs, funded PhD students, research staff and support staff).

Only 10 institutions reported budget sizes in absolute numbers. Figure B.5 shows their budgets.

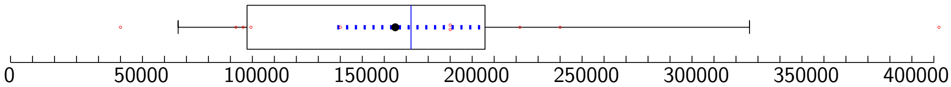

Figure B.5.: Funding per year in EUR, excluding salaries.

For 16 institutions, the percentage of total funding dervied from the EU is known. See Figure B.6.

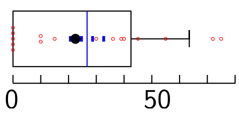

Figure B.6.: EU funding as a percentage of total funding

B.4.2 Publications

Quantitative Trends

23 respondents reported a total of 1812 journal and conference papers for the years 1996–2006. These were not checked for overlaps, so there might be some publications that were co-authored and reported by more than one institution. Three respondents did not make publication lists available and are therefore not included here. Since the questionnaire was sent out and partially answered in 2006, there might well be more publications in 2006 than the number shown here.

Figure B.7 shows how the yearly number of peer-reviewed journal and conference publications has grown in the last decade. This growth might be caused by an increase in the number of institutions active in SMC research, by a tendency of those institutions to grow or by an increase in productivity. As can be seen from Figure B.8, both the number of institutions and the number of papers per institution has grown grow over the years. We do not know how many people worked at each institution over time, but it also seems likely that more and more people are doing SMC research at individual institutions.

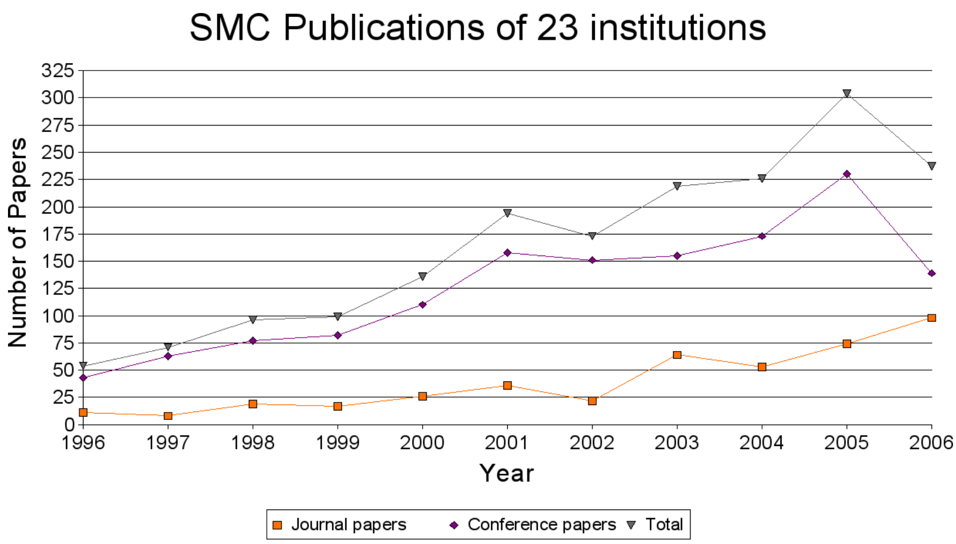

Figure B.7.: SMC publications over the last 10 years

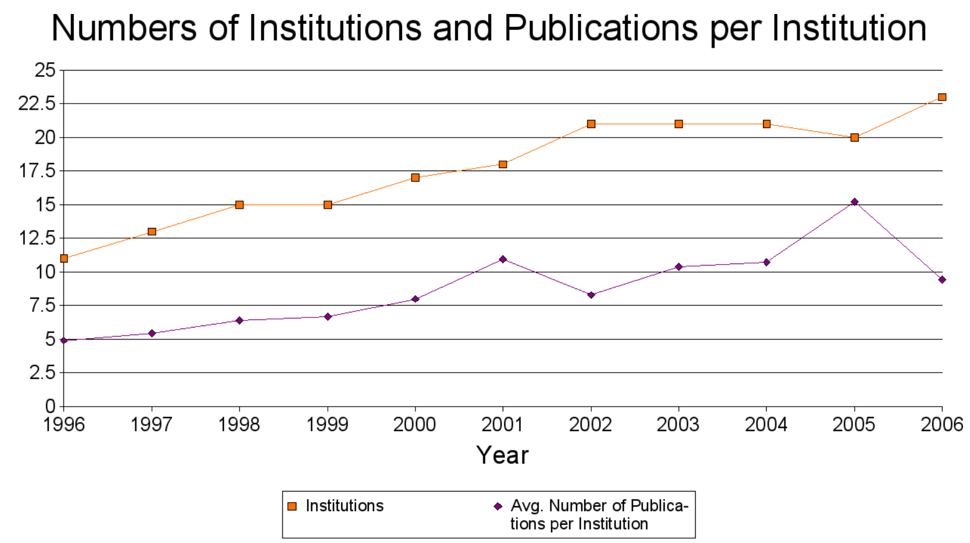

Figure B.8.: Both the number of institutions with at least one publication and the average number of publications per institution show a growth trend.

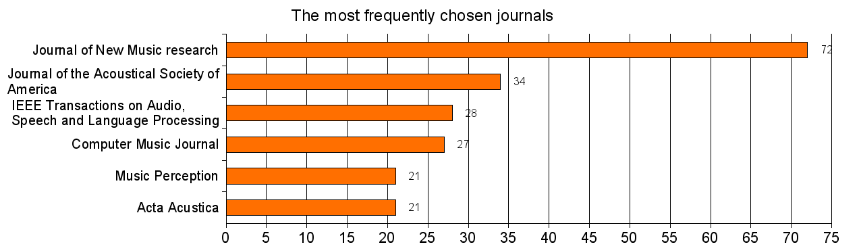

Figure B.9.: These six journals were chosen for publishing the largest groups of papers among all 433 journal papers that were reported.

Distribution over Journals

The largest group of papers among the 433 reported journal papers were 72 papers published in the Journal of New Music Research. For the top six journals, see Figure B.9. Their impact factors (1995) are listed in table B.5.

Figure B.10 gives a rough idea of how the share of different journals fluctuates over time. Only the second half of the decade from 1996 to 2006 is covered here because the numbers are very small for the first half.

For example, the Journal of New Music Research, shown at the bottom, does not manage to retain its share from 2001 to 2006. The Journal of the Acousti-

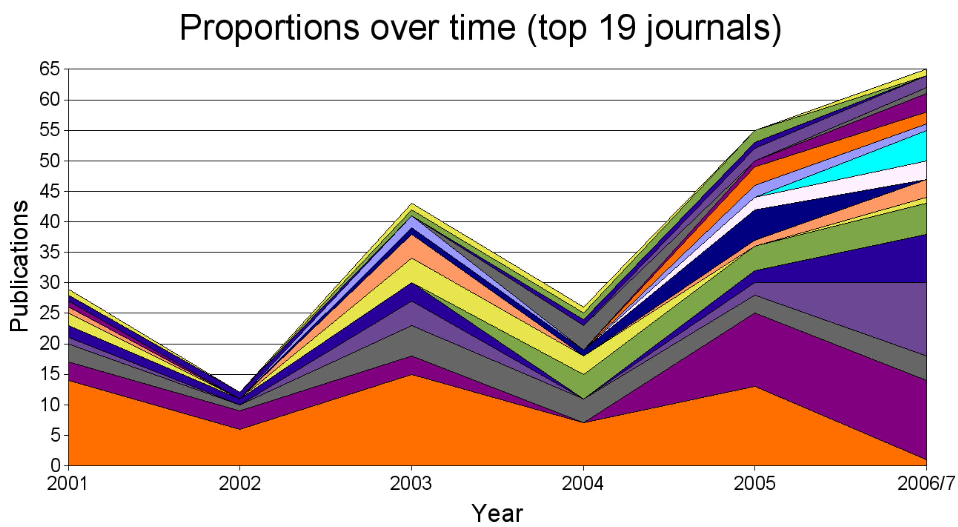

Figure B.10.: The number of publications in the 19 most popular journals from 2001 to 2006/7. The journals are ordered, from bottom to top in decreasing order, by the total number of SMC publications covered by this survey: Journal of New Music Research (56), Journal of the Acoustical Society of America (34), Computer Music Journal (20), IEEE Trans. on Audio, Speech and Language Processing (19), Music Perception (16), Acta Acustica (13), Applied Signal Processing (10), Annals of the NY Academy of Sciences (9), IEEE Multimedia Magazine (7), Musicae Scientiae, IEEE Signal Processing Magazine, Logopedics Phoniatrics Vocology, Psychology of Music, LNCS (5 each), Journal of Voice, Organised Sound, Contemporary Music Review, Hearing Research (4 each).

Journal of New Music Research	0.650	JCR Science
Journal of the Acoustical Society of America	1.677	JCR Science
IEEE Transactions onf Audio, Speech, and Language Processing	1.008	JCR Science
Computer Music Journal	0.486	JCR Science
Music Perception	0.917	JCR Social Science
Acta Acustica	0.467	JCR Science

Table B.5.: Impact Factors (2005) of the top six SMC journals

cal Society of America (second from the bottom), on the other hand, increases its share.

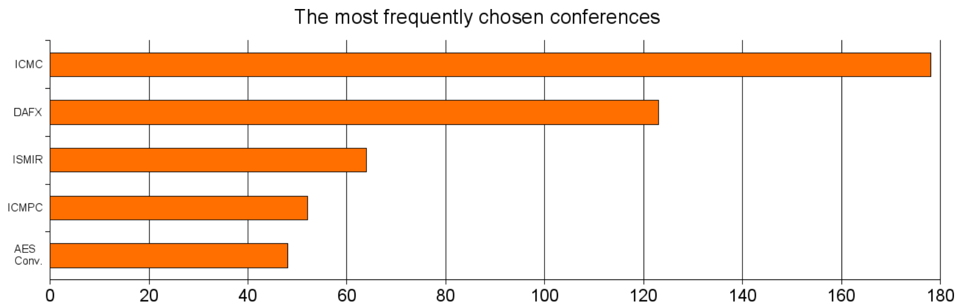

Figure B.11.: These five conferences were the venues for the largest groups of papers among all 1381 reported conference papers. The abbreviations mean: ICMC – International Computer Music Conference, DAFX – Digital Audio Effects, ISMIR – International Conference on Music Information Retrieval, ICMPC – International Conference on Music Perception and Cognition, AES Conv. – Audio Engineering Society Conventions.

Distribution over Conferences

The International Computer Music Conference (ICMC) attracted the largest group of conference papers, 178 out of a total 1381 reported. For the top five conferences, see Figure B.11

Figure B.12 shows the shares of the top 11 conferences from 2001 to 2006. The most important conferences are shown at the bottom, with the smaller ones stacked above them, ordered by the total number of publications between 2001 and 2006. Please note that this covers only the second half of the decade reflected in Figure B.11 (because the numbers are rather small in the first half). It can be seen that the proportion of papers published at the ICMC, though not necessarily their absolute number, shrinks from 2001 to 2006. This seems to be a consequence of a higher degree of specialisation. For example, the International Conference on Music Information Retrieval (ISMIR) was inaugurated only in 2000 and is attracting a steadily growing number of publications. The International Conference on Music Perception and Cognition (ICMPC) managed to attract an especially high proportion of the reported papers in 2006, which might indicate a growing importance of human-centered research in music perception and cognition.

Degrees

Not only budget size but also output in terms of PhD theses (Figure B.13) and Master's dissertations (see Figure B.14) displays great diversity among European

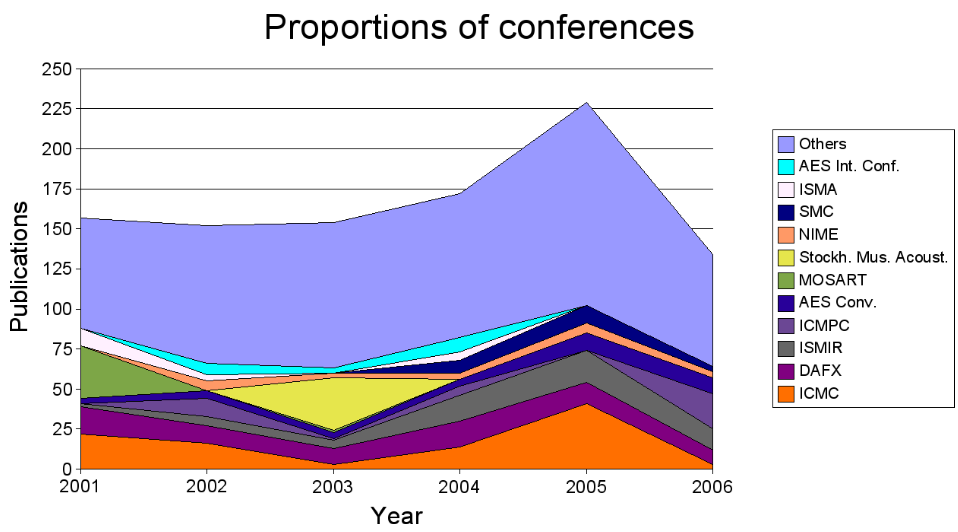

Figure B.12.: The number of publications at the 11 most popular conferences from 2001 to 2006, plus all others grouped together.

SMC institutions.

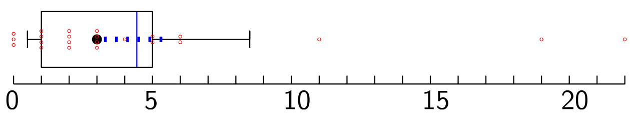

Figure B.13.: PhD theses per institution since 1996

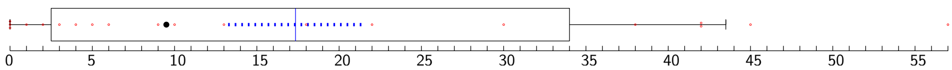

Figure B.14.: Master's theses per institution since 1996

From Figure B.15, it can be seen that the number of SMC-related Master and PhD theses has grown in the last decade. Sound and Music computing is thus also increasingly important in education.

B.4.3 Startups and Patents

All 26 institutions together have published 22 patents (minimum/maximum per institution: 0 and 8) and filed another 36 (minimum/maximum: 0 and 31).

15 startups have grown out of the SMC research of the 26 respondents (minimum: 0, maximum: 6).

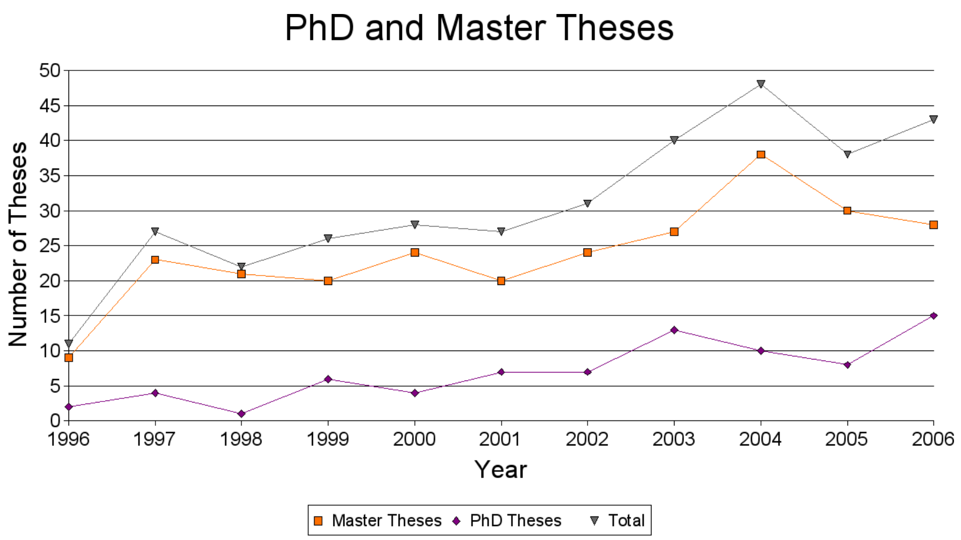

Figure B.15.: 16 institutions reported their PhD and Master's theses separately for each year. Their total combined data are shown in this chart.

B.5 CONCLUSIONS

Since only 26 out of 83 institutions returned a completed questionnaire, and some of the larger institutions are missing (IRCAM in France, for example, and some institutions in the UK), the following observations and conclusions have to be taken with a grain of salt. However, one can recognize some trends even from this small sample.

The SMC field is growing rapidly. Both the number of research centres that publish in this field and the average number of publications per centre (which is probably closely linked to the number of researchers per centre) seem to have doubled in the last ten years. The research output is not only of academic interest but also leads to patents and startups. All this is achieved with relatively modest funding. To sustain the growth of the field, the funding needs to grow accordingly.

APPENDIX C

SMC European Projects

AGNULA	A GNU/Linux Audio distribution			
	Start	Stop	Funding	Cost
	01/04/2002	31/03/2004	1.7M€	1.7M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	34879	AM
Line	2001-4.3.3 Free software development: towards critical mass			
Partners	*Centro Tempo Reale* ; IRCAM; Universitat Pompeu Fabra; Kungliga Tekniska Högskolan; Free Software Foundation Europe; Red Hat France			
Keywords	Free software; Gnu/linux; Operating system; Sound and music softwares.			
Website	http://wwww.agnula.info			

ALMA	Algorithms for the Modelling of Acoustic Interactions			
	Start	Stop	Funding	Cost
	01/11/2001	31/10/2004	1.11M€	1.43M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	33059	CSC
Line	IST-2001-6.1.1 Open domain			
Partners	*Politecnico di Milano*; University of Erlangen-Nuremberg; Generalmusic			
Keywords	Block-based physical modeling; Bi-directional interaction; Authoring software.			
Website	http://www-dsp.elet.polimi.it/alma/			

CARROUSO	Creating, Assessing and Rendering in Real Time of High Quality Audio-Visual Environments in MPEG-4 Context			
	Start	Stop	Funding	Cost
	01/01/2001	30/06/2003	2.7M€	5.6M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	20993	CSC
Line	1.1.2.-3.5.1 Multi-sensory forms of content			
Partners	*Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung E.V.*; Technische Universiteit Delft; Institut Fuer Rundfunktechnik GMBH; France Telecom; IRCAM; Friedrich-Alexander Universitaet Erlangen - Nuernberg; Ecole Polytechnique Federale de Lausanne; Studer Professional Audio AG; Aristotle University of Thessaloniki; Thales Broadcast and Multimedia SA			
Keywords	Mpeg-4; Wave field synthesis.			
Website	http://www.emt.iis.fraunhofer.de/projects/carrouso/			

CUIDADO	Content-based Unified Interfaces and Descriptors for Audio/music Databases available Online			
	Start	Stop	Funding	Cost
	01/01/2001	31/12/2003	2.5M€	3.52M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	20194	CSC
Line	1.1.2.-3.5.2 Media representation and access: new models and standards			
Partners	IRCAM; Artspages; Ben Gurion University; Universitat Pompeu Fabra; Oracle Spain; Creamware GMBH; Sony-CSL			
Keywords	Audio content description; Content transformation; Music information retrieval; Mpeg-7.			
Website	http://recherche.ircam.fr/produits/technologies/multimedia/cuidado-e.html			

IMUTUS	Interactive Music Tuition System			
	Start	Stop	Funding	Cost
	01/05/2002	28/02/2005	1.19M€	2.18M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	32270	CSC
Line	IST-2001-3.2.2 e-Learning futures			
Partners	*Institute for Language and Speech Processing*; Exodus S.A.; Systema Technologies S.A.; Università di Firenze; Music School of Fiesole; Grame; Kungliga Tekniska Högskolan			
Keywords	Audio recognition; Optical music recognition; Music tuition; Digital content; Signal processing.			
Website	http://www.exodus.gr/imutus/			

	KTH Music Acoustics group: EU Training Site			
	Start	Stop	Funding	Cost
	01/10/2000	30/09/2004	0.15M€	0.15M€
	Prog. Type	Program	Reference	Contract
	FP5	HP	00119	BUR
Line	1.4.1.-1.2. Marie Curie Fellowships			
Partners	Kungliga Tekniska Högskolan			
Keywords	Training.			
Website				

LISTEN	Augmenting everyday environments through interactive soundscapes			
	Start	Stop	Funding	Cost
	01/01/2001	31/12/2003	3.01M€	4.41M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	20646	CSC
Line	1.1.2.-3.5.1 Multi-sensory forms of content			
Partners	*Fraunhofer Gesellschaft Zur Foerderung Der Angewandten Forschung E.V.*; AKG Acoustics GMBH; IRCAM; Bundesstadt Bonn; Technische Universitaet Wien			
Keywords	Everyday environments; Multi-sensory content; Dynamic soundscape.			
Website	http://listen.gmd.de/			

MEGA	Multisensory Expressive Gesture Applications			
	Start	Stop	Funding	Cost
	01/11/2000	31/10/2003	1.14M€	1.84M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	20410	CSC
Line	1.1.2.-4.6.1 Adaptable multi-sensory interfaces			
Partners	*University of Genova*; University of Padova; Ghent University; Royal Institute of Technology; Uppsala University; Telenor; Generalmusic; Consorzio Pisa Ricerche; Eidomedia			
Keywords	Expressive gesture; Multimodal interactive systems; Performing arts applications; Museum and cultural applications.			
Website	http://www.megaproject.org			

MOSART	Music Orchestration Systems in Algorithmic Research and Technology			
	Start	Stop	Funding	Cost
	01/01/2000	31/12/2003	1.31M€	
	Prog. Type	Program	Reference	Contract
	FP5	IHP	00115	RTN
Line	N/A			
Partners	*University of Copenhagen*; University of Science and Technology; Kungliga Tekniska Högskolan; University of Aarhus; Danish Technical University; University of Sheffield; University of Nijmegen; Austrian Research Institute for Artificial Intelligence; University of Padova; University of Genova; CNUCE/C.N.R.; LMA-Centre Nationale de la Recherche Scientifique; Universitat Pompeu Fabra			
Keywords	Training; Mobility of young researchers; Workshop organisation.			
Website				

MusicNetwork	The interactive MUSIC NETWORK			
	Start	Stop	Funding	Cost
	01/08/2002	31/07/2005	17.3M€	17.3M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	37168	THN
Line	2002-8.1.2 Networks of Excellence and working groups in IST			
Partners	Universita degli Studi di Firenze; Giunti Interactive Labs S.R.L.; IRCAM; Institute for Language and Speech Processing; University of Leeds; Musik Informations Centrum Austria; Listesso; Exitech S.R.L.; Rigel Engineering S.R.L.; Arca Progetti SRL; Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung E.V.; Stichting FNB			
Keywords	Interactive multimedia; Music industry.			
Website	http://www.interactivemusicnetwork.org/			

OPENDRAMA	The Digital Heritage of Opera in the Open Network Environment			
	Start	Stop	Funding	Cost
	01/11/2001	31/10/2003	2.0M€	3.51M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	28197	CSC
Line	2000-3.1.1 Authoring interactive Web content			
Partners	Space S.p.A; Teatro del Maggio Musicale Fiorentino; Opera North; Ministero per i Benni e le Attività Culturali; Dynamic S.r.L; Politecnico di Milano; University of Glasgow; Universitat Pompeu Fabra; Europe Online Networks S.A.; System Simulation Ltd.			
Keywords	Multimedia content description; Opera; Mpeg-7.			
Website				

RAA	Advanced Design Approach for Personalised Training. Interactive Tools			
	Start	Stop	Funding	Cost
	01/02/2000	31/10/2002	3.28M€	
	Prog. Type	Program	Reference	Contract
	FP5	IST	12585	CSC
Line	1.1.2.-4.3.2 Engineering of intelligent services			
Partners	Joanneum Research Forschungsgesellschaft MBH; HS-Art Digital Service GMBH; Universitat Pompeu Fabra; Nederlans Omroeproduktie Bedrifj NV; Ràdio Flaixbac; Taurus Media Technik GMBH; Filmkunst und Musikverlags-und Produktionsgesellschaft MBH			
Keywords	Fingerprinting; Audio analysis; Recognition.			
Website	http://raa.joanneum.ac.at/			

RIIM	Real-time Interactive Multiple Media Content Generation Using High Performance Computing and Multi-Parametric Interfaces			
	Start	Stop	Funding	Cost
	01/01/2001	31/12/2001	0.1M€	0.13M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	21022	BUR
Line	1.1.2.-3.2.1 Authoring and design systems			
Partners	*University of York*; IRCAM; Staatliches Institut fuer Musikforschung, Preussischer Kulturbesitz			
Keywords	Human computer interaction; Performance.			
Website	http://www.york.ac.uk/res/rimm			

SOb	the Sounding Object			
	Start	Stop	Funding	Cost
	01/01/2001	31/12/2002	0.734M€	0.734M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	25287	CSC
Line	IST-2000-6.2.1 P1: The disappearing computer			
Partners	*Università di Verona*; Università di Udine; University of Limerick; Kungliga Tekniska Högskolan			
Keywords	Sound design; Interaction design; Everyday sound perception.			
Website	http://www.soundobject.org			

WEDELMUSIC	Web Delivering of Music Scores			
	Start	Stop	Funding	Cost
	01/01/2000	30/06/2002	1.73M€	3.12M€
	Prog. Type	Program	Reference	Contract
	FP5	IST	10165	CSC
Line	1.1.2.-3.2.2 Content management and personalisation			
Partners	*Università di Firenze*; Institute for Language and Speech Processing; Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung E.V.; Artec Group G.E.I.E; Sugarmusic S.P.A.; IRCAM; Fondazione Scuola di Musica di Fiesole; Stichting FNB; BMG Ricordi SPA			
Keywords	Web delivery; Digital right management; Interactive music.			
Website	http://www.wedelmusic.org/			

AXMEDIS	Automating Production of Cross Media Content for Multi-channel Distribution			
	Start	Stop	Funding	Cost
	01/09/2004	31/08/2008	8.4M€	12.8M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	511299	IP
Line	IST-2002-2.3.2.7 Cross-media content for leisure and entertainment			
Partners	*Università di Firenze*; Strategica S.R.L.; Fondazione Accademia Nazionale di Santa Cecilia; Hewlett Packard Italiana SRL; Universitat Pompeu Fabra; Exitech S.R.L.; Xim Limited; Associazione Dei Fonografici Itliana; Eutelsat S.A.; The University of Reading; Fraunhofer Gesellschaft Zur Foerderung der Angewandten Forschung E.V.; Giunti Interactive Labs S.R.L.; Ecole Polytechnique Fédérale De Lausanne; Tiscali Services S.R.L.; University of Leeds; Advance Concepts for Interactive Technology GMBH			
Keywords	Content production; Content distribution; Mpeg.			
Website	http://www.axmedis.org			

BrainTuning	Tuning the Brain for Music			
	Start	Stop	Funding	Cost
	01/08/2006	31/07/2009	2.5M€	
	Prog. Type	Program	Reference	Contract
	FP6	NEST	028570	STREP
Line	NEST-2004-Path-IMP Measuring the Impossible			
Partners	*University of Helsinki*; University of Jyväskylä; Kungliga Tekniska Högskolan; Vita-Salute San Raffaele University; University of Leipzig; University of Montreal			
Keywords	Neuroscience; Cognition; Emotions; Aesthetics; Therapy.			
Website	http://www.braintuning.fi			

CLOSED	Closing the Loop Of Sound Evaluation and Design			
	Start	Stop	Funding	Cost
	01/07/2006	30/06/2009	1.42M€	1.79M€
	Prog. Type	Program	Reference	Contract
	FP6	NEST	029085	STREP
Line	NEST-2004-Path-IMP Measuring the Impossible			
Partners	*IRCAM*; Università di Verona; Hochschule fur Gestaltung und Kunst Zurich; Technischen Universität Berlin			
Keywords	Sound design; Interaction design; Product sound quality.			
Website	http://closed.ircam.fr/			

EASAIER	Enabling Access to Sound Archives through Integration, Enrichment and Retrieval			
	Start	Stop	Funding	Cost
	01/05/2006	31/10/2008	2.1M€	2.92M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	033902	STREP
Line	IST-2005-2.5.10 Access to and preservation of cultural and scientific resources			
Partners	*Queen Mary, University of London*; The Royal Scottish Academy of Music and Drama; Nice Systems LTD.; Leopold-Franzens-Universitaet Innsbruck; Alkalmazott Logikai Laboratorium Kutato Fejleszto Szovetkezet; Dublin Institute of Technology; Silogic S.A.			
Keywords	Digital sound archives; Retrival system.			
Website	http://www.elec.qmul.ac.uk/easaier/			

EmCAP	Emergent Cognition through Active Perception			
	Start	Stop	Funding	Cost
	01/10/2005	30/09/2008	1.95M€	2.5M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	13123	STREP
Line	IST-2002-2.3.4.1 FET - Open			
Partners	University of Plymouth; Universitat Pompeu Fabra; Magyar Tudományos Akadémia Pszichológiai Kutatóintézet; Universiteit van Amsterdam			
Keywords	Music cognition; Neuroscience; Interactive systems.			
Website	http://emcap.iua.upf.es/			

Enactive	Enactive Interfaces			
	Start	Stop	Funding	Cost
	01/01/2004	31/12/2007	5.0M€	6.97M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	002114	NoE
Line	IST-2002-2.3.1.6 Multimodal interfaces			
Partners	*Scuola Superiore Sant'Anna - PERCRO*; Institute National Polytechnique de Grenoble; University of Exeter; Centro de Estudios e Investigaciones Tecnicas de Guipuzcoa; University of Lund; Université de technologie de Compiègne; Uppsala University; DLR Institute of Robotics and Mechatronics; Limburgs Universitair Centrum; McGill University; University of Minnesota; Fundacion Labein; Max Planck Institute for biological cybernetics; University of Geneva; Ecole Polytechnique Federale de Lausanne; Università degli Studi di Padova; Sony-CSL; Ecole des Hautes Etudes en Sciences Sociales; University of Genoa; Association pour la Création et la Recherche sur les Outils d'Expression; Université Pierre Mendès; Centre National de Recherche Scientique; University of Montpellier I; Queen's University of Belfast			
Keywords	Multisensory interaction; Embodiment.			
Website	http://www.enactivenetwork.org/			

Appendix C. SMC European Projects

HUMAINE	Human-Machine Interaction Network on Emotion			
	Start	Stop	Funding	Cost
	01/01/2004	31/12/2007	4.95M€	
	Prog. Type	Program	Reference	Contract
	FP6	IST	507422	NoE
Line	IST-2002-2.3.1.6 Multimodal interfaces			
Partners	*The Queen's University of Belfast*; Deutsches Forschungszentrum für Künstliche Intelligenz GmbH; Institute of Communication and Computer Systems; Université de Genève; The University of Hertfordshire; Istituto Trentino Di Cultura; Université de Paris VIII; Österreichische Studiengesellschaft für Kybernetik; Kungliga Tekniska Högskolan; Universität Augsburg; Università Degli Studi di Bari; Ecole Polytechnique Féderale de Lausanne; Friedrich-Alexander Universität Erlangen; Università Degli Studi di Genova; University of Haifa; Imperial College of Science; Instituto de Engenharia de Sistemas e Computadores; King's College London; Centre National De La Recherche Scientifique; The Chancellor, Masters and Scholars of the University of Oxford; The University of Salford; Tel Aviv University; Trinity College; La Cantoche Production SA; France Telecom; T-Systems Nova GmbH; Instituto Superior Técnico			
Keywords	Emotion; Emotion-oriented systems; Affective interfaces; Multimodal interactive systems.			
Website	http://www.emotion-research.net			

i-Maestro	Interactive Multimedia Environment for Technology Enhanced Music Education and Creative Collaborative Composition and Performance			
	Start	Stop	Funding	Cost
	01/10/2005	30/09/2008	2.35M€	3.63M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	026883	STREP
Line	IST-2004-2.4.10 Technology-enhanced Learning			
Partners	*University of Leeds*; Sibelius Software Limited; Fundacion Isaac Albeniz; Fondazione Accademia Nazionale di Santa Cecilia; Exitech S.R.L.; Stichting FNB; IRCAM; The University of Reading; City University			
Keywords	Music education; Gestural interface; Collaborative environment.			
Website	http://www.i-maestro.org/			

PHAROS	Platform for searching of audiovisual resources across online spaces			
	Start	Stop	Funding	Cost
	01/01/2007	31/12/2009	8.5M€	14.25M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	045035	IP
Line	IST-2005-2.6.3 Advanced search technologies for digital audio-visual content			
Partners	Engineering Ingegneria Informatica SpA; France Telecom; Fast Search and Transfer; University of Hannover; Fraunhofer Institute for Digital Media; Ecole Polytechnique Fédérale de Lausanne; Knowledge Media Institute of The Open University; Universitat Pompeu Fabra; Technical Research Centre of Finland; Circom Regional; Metaware SpA; Web Models; SAIL LABS Technology,			
Keywords	Audiovisual search; Search platform; Distributed architecture.			
Website	http://www.pharos-audiovisual-search.eu/			

S2S^2	Sound to Sense, Sense to Sound			
	Start	Stop	Funding	Cost
	01/06/2004	31/05/2007	1.3M€	1.53M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	03773	CA
Line	IST-2002-2.3.4.1 FET - Open			
Partners	*Firenze Tecnologia*; Kungliga Tekniska Högskolan; Università di Padova; Università di Verona; Università di Genova; Helsinki University of Technology; Ecole Normale Supérieure; Ghent University; Université de Bourgogne; Universitat Pompeu Fabra; Austrian Research Institute for Artificial Intelligence			
Keywords	Sound and sense; Sound and music computing; Roadmap.			
Website	http://www.s2s2.org			

SALERO	Semantic AudiovisuaL Entertainment Reusable Objects			
	Start	Stop	Funding	Cost
	01/01/2007	31/12/2009	9.0M€	14.11M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	027122	IP
Line	IST-2004-2.4.7 Semantic-based Knowledge and Content Systems			
Partners	Joanneum Research; Activa Multimedia; Blitz Games Ltd; Pepper's Ghost Product Ltd; Universitat Pompeu Fabra; Universitat Ramon Llull; Dublin Institute of Technology; Taideteollinen Korkeakoulu; The University of Glasgow; Leopold-Franzens Universität Innsbruck; Grass Valley Germany GmbH; DTS Europe Ltd			
Keywords	Intelligent content; Media production; .			
Website	http://www.salero.info/			

SEMANTIC Hi-Fi	Browsing, listening, interacting, performing, sharing on future HIFI systems			
	Start	Stop	Funding	Cost
	01/12/2003	30/11/2006	2.78M€	52.6M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	507913	STREP
Line	IST-2002-2.3.1.8 Networked audiovisual systems and home platforms			
Partners	Fraunhofer Institut für Digitale Medientechnologie; IRCAM; Native Instruments; Universitat Pompeu Fabra; Sony Network and Software Technology Center Europe; Sony Computer Science Laboratory; Ben Gurion University			
Keywords	Hifi systems; Search; Interaction; Rendering; Personalisation and edition of music material.			
Website	http://shf.ircam.fr			

SIMAC	Semantic Interaction with Music Audio Contents			
	Start	Stop	Funding	Cost
	01/01/2004	31/03/2006	1.9M€	2.97M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	507142	STREP
Line	IST-2002-2.3.1.7 Semantic-based knowledge systems			
Partners	*Universitat Pompeu Fabra*; Matrix Data; Queen Mary University; Austrian Research Institute for Artificial Intelligence; Philips Research			
Keywords	Audio semantic description; Music recommendation; Music browsing; Annotation.			
Website	http://www.semanticaudio.org			

TAI-CHI	Tangible Acoustic Interfaces for Computer-Human Interaction			
	Start	Stop	Funding	Cost
	01/01/2004	31/12/2006	2.35M€	3.31M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	507882	STREP
Line	IST-2002-2.3.1.6 Multimodal interfaces			
Partners	*University of Wales Cardiff*; Association vaudoise pour promotion des innovations et des technologies; Universita Degli Studi Di Genova; Institut pour le Developpement de la Science, l’Education et la Technologie; Clausthal University of Technology; The University of Birmingham; Politecnico di Milano			
Keywords	Tangible acoustic interfaces; In-solid acoustic propagation; Multimodal interactive systems; Expressive gesture.			
Website	http://www.taichi.cf.ac.uk/			

U-CREATE	Creative Authoring Tools for Edutainment Applications			
	Start	Stop	Funding	Cost
	15/06/2005	15/12/2006	1.13M€	1.65M€
	Prog. Type	Program	Reference	Contract
	FP6	SME	17683	COOP
Line	SME-1 Co-operative Research			
Partners	*Alterface SA*; Imagination Gmbh; Ion2s Gmbh; University of Genova; Vienna University of Technology; Zentrum für Graphische Datenverarbeitung; HadroNet Számítástechnikai és Szolgáltató Kft			
Keywords	Authoring tools; Multimodal interactive systems; Edutainment application.			
Website				

VEMUS	Virtual European Music School			
	Start	Stop	Funding	Cost
	01/10/2005	30/09/2008	1.81M€	2.45M€
	Prog. Type	Program	Reference	Contract
	FP6	IST	27952	STREP
Line	IST-2004-2.4.13 Strengthening the Integration of the ICT research effort in an Enlarged Europe			
Partners	*Institute for Language and Speech Processing*; GRAME; Kungliga Tekniska Högskolan; Ellinigermaniki Agogi; UAB BALTECK; Philippos Nakas S.A.; Ou Miksike; Asociatia TEHNE			
Keywords	Self-practicing; Distance learning; Music classroom.			
Website	http://www.vemus.org/			

HARMOS	European multilingual digital data collection for multimedia content in music heritage			
	Start	Stop	Funding	Cost
Harmos	01/04/2004	31/03/2006	1.4M€	2.79M€
	Prog. Type	Program	Reference	Contract
	eContent		11189	DEM
Line	AL1 Action Line 1: Improving access to and expanding the use of public sector information			
Partners	Fundación Isaac Albéniz; Universitat Pompeu Fabra; Orbi Team; Association of European Conservatories; Lithuanian Academy of Music; Koninklijk Conservatorium Brussels; Staatliche Musickhochschule Stuttgart; Royal College of Music; Escola Superior de Música de Catalunya; Escola Superior de Música e Artes do Espectáculo del Instituto Politécnico do Porto			
Keywords	Segmentation; Tagging; Musical heritage.			
Website	http://www.harmosproject.com			

Appendix C. SMC European Projects

VARIAZIONI	Collaborative Authoring of Localized Cultural Heritage Contents over the Next Generation of Mashup Web Services			
	Start	Stop	Funding	Cost
	01/09/2007	28/02/2009	1.881M€	
	Prog. Type	Program	Reference	Contract
	eContentplus		038264	CEP
Line	Cultural and scientific/scholarly content			
Partners	Fundación Isaac Albéniz; Germinus XXI; Universitá degli Studi di Firenze; Rigel Engineering S.R.L.; Universitat Pompeu Fabra; Lithuanian Academy of Music and Theatre; Koninklijk Conservatorium Brussels; Escola Superior de Música e das Artes do Espectáculo do Porto; Sibelius Academy; Association Europeenne des Conservatoires, Academies de Musique et Musikhochschulen; Exitech S.R.L.			
Keywords	Content enrichment; Musica heritage; Audio content processing; Automatic retrieval; Indexing.			
Website	http://www.variazioniproject.org/			

MODEM	Music Open Distance Exchange Model			
	Start	Stop	Funding	Cost
	01/11/2006	31/10/2008	0.5105M€	
	Prog. Type	Program	Reference	Contract
	Leonardo da Vinci		154059	PP
Line	N/A			
Partners	I.T.C.G. Attilio Deffenu; Universitat Pompeu Fabra; Steinberg; ISTI; Midiware; SCIENTER; Sintagma; Brighton Art Ltd			
Keywords	E-learning; Virtual community; Web learning sphere.			
Website				

DAFx	Digital Audio Effects			
	Start	Stop	Funding	Cost
	08/09/1997	07/09/2001	1.2M€	1.2M€
	Prog. Type	Program	Reference	Contract
	COST		G6	N/A
Line	N/A			
Partners	Belgium; Czech Republic; France; Germany; Ireland; Italy; Norway; Spain; Switzerland; United Kingdom			
Keywords	Digital audio effects; Conference organisation.			
Website	http://echo.gaps.ssr.upm.es/COSTG6/			

ConGAS	Gesture Controlled Audio Systems			
	Start	Stop	Funding	Cost
	14/03/2003	13/03/2007	5.5M€	5.5M€
	Prog. Type	Program	Reference	Contract
	COST	ICT	287	N/A
Line	N/A			
Partners	Belgium; Denmark; Finland; France; Germany; Iceland; Ireland; Italy; Netherlands; Norway; Portugal; Spain; Sweden; Switzerland; United Kingdom			
Keywords	Sound and music control; Musical gesture analysis.			
Website	http://www.cost287.org/			

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