

SONIFICATION FIRST: THE ROLE OF ICAD IN THE ADVANCEMENT OF SONIFICATION-RELATED RESEARCH

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ABSTRACT

Sonification as a means for exploring and analysing data is an established research domain in the field of Auditory Displays. Since 1992, the International Community for Auditory Displays (ICAD) fosters the development of this field through the organization of annual conferences, special journal issues, scientific publications, and research advancements. Sonification has been a focal point in these activities. This paper reflects on nearly 3 decades of sonification research, analysing the proceedings of the past 24 ICAD conferences in a semi-automated manner. The balance between artistic and scientific data exploration as well as changes in the focus of sonification-related work published are monitored and discussed. Word frequency analysis on the abstracts and titles of selected papers shines further light into the evolution of sonification as reflected in the ICAD conference proceedings.

1. INTRODUCTION

Hermann et al., in the Sonification Handbook, [1] consider sonification as the core component of Auditory Display, which renders data and interactions sonically. Walker and Nees further clarify: “Sonification seeks to translate relationships in data or information into sound(s) that exploit the auditory perceptual abilities of human beings such that the data relationships are comprehensible” [2]. The evolution of sonification has been linked to the sonification methods employed. Since the early years of the International Community for Auditory Displays (ICAD), sonification has been used in a wide variety of domains, including interfaces for visually impaired users, medicine, geo-science, finances, etc. With the growth of the Web and Big Data, the need for real-time monitoring of multiple data streams has evolved. Example applications include: financial data sonification systems [3, 4], Twitter data sonification [5], network data sonification [6], EEG data sonification [7], and sonification of astrophysics data [8]. A focused knowledge of the domain science is essential, to analyze data or interactions in any of these fields.

The sonification domains that the community focuses on at different points in time are evolving. This change of focus may be related to the external technological evolution, public

need/demand, as well as changes in the publication venues available. For example, today, sound design has emerged into our everyday objects, human-computer interfaces, and environmental spaces. Our daily interactions and experiences with sounds emitted by different objects and products varies. One could have an aspiration for an electric car because of its sophisticated and quiet engine sound, or one may dislike a coffee machine due to its loud sound. As a result, studies on product sound design have emerged in the last decades and have appeared in ICAD publications.

Apart from the necessary domain knowledge, an effective and useful sonification system requires a deep understanding of psychoacoustics, signal processing, computer science, and musicology, fact which renders sonification a highly interdisciplinary field. Neuhoff considers the interdisciplinarity of sonification as one of the main obstacles to its extensive use and wide acceptance and suggests getting more specific on the art-science continuum [9]. Vickers, on the other hand, puts sonification closer to the art on the continuum and looks at some of the issues surrounding the relationship between sonification and music and the potential to bring sonification and the sonic arts closer [10].

In nearly three decades of ICAD, the concern regarding the lack of sonification theory is identified as a major hurdle to the development of the field [11, 2]. According to Nees, some practical components of sonification have not been formally shaped as theoretical knowledge yet; a holistic theoretical sonification design, widely applied to practice is missing [12]. The predominant focus of the sonification field on academic research illustrates the huge gap between sonification research and practice. Most sonification projects seen in ICAD proceedings seem to be short-term (3-5 year) endeavors leading to tools built within a lab by scholars. Maintaining, updating, and evolving such tools requires long-term commitment from the labs and resources, which, unlike the industry, are not always available in academia. This problem has led to many sonification projects which have produced tools/systems that remain at a prototype stage with no maintenance and no possibility of being reproduced, until they are rendered obsolete.

In addition to the above, in [13] Degara and Hermann report a general reluctance of the ICAD community in employing robust subjective and objective evaluation methods for the published sonification methodologies and tools, and suggest a community-based framework for the formal evaluation of the published Sonification work. A year earlier, Alexandra Supper had published her observations on the debate of scientific rigor vs. objectivity in sonification [14]. The work, which was based on a study of published sonification manuscripts, attendance of ICAD conferences, as well as



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interviews with key ICAD figures, revealed that the ICAD community was divided amongst researchers who believed that the scientificity of Sonification was dependent on objectivity and that clear steps towards formal evaluations of the sonification were necessary in order to “increase the quality of the papers”, and those who believed that scientific objectivity was not necessarily linked to such evaluations but could be assured by the subjective decisions made by trained sonification experts. As it will be revealed in this work, a decade later, the community still seems reluctant taking further steps towards either direction, and remains divided between those who advocate for and practice rigorous evaluations of their published sonification works, and those who employ a less formal approach on that matter.

Since 1992, the conferences of the International Community for Auditory Display, have fostered several topics pertinent to the field of Auditory Display. While the term Sonification was originally used to refer to the mapping of data into sound, as demonstrated above, it has gradually grown into a complex interdisciplinary field. This paper reflects on nearly 3 decades of sonification research in ICAD, analyzing the proceedings of its past 24 conferences. It is the first step towards an in-depth exploration of the field of sonification which will focus on the evolution of the sonification-related work undertaken by the ICAD community.

2. RESEARCH GOALS

A study on the evolution of sonification is subject to a complex and multifaceted investigation. Sonification methods and domains of application could be some of the factors shaping this evolution. Additionally, the interdisciplinarity of the field allows for the use of both scientific and artistic methodologies forming the domains and guiding the field towards new and novel directions. This paper is the first step towards an in-depth and systematic study of the evolution of sonification through the prism of the conferences of the International Community for Auditory Display. The ultimate goals are to make researchers aware of the need to understand and investigate the direction of sonification research systematically and to bring the lack of standardized and sustainable processes in sonification to the fore. Cohesive and systematic guidelines are necessary to create comparative evaluations of sonification projects, so as to avoid repetitive work in such an abundant research field.

For this work, all sonification-related manuscripts, published in the past 24 ICAD conferences were identified and their metadata were collected, standardized, and manually tagged to facilitate an in-depth analysis. A preliminary exploration of the collected metadata and tags is attempted first, in order to investigate their representativeness of the full dataset. The metadata and tag analysis is further supplemented by a word frequency analysis in an attempt to investigate whether the use of frequent terminology can be reduced to types and domains of sonification explored, as well as methods and means employed for its realization. Possible means for expanding the data pool beyond the conference proceedings to other sources of information regarding sonification in ICAD conferences, such as conference programs, concert program notes, write-ups of sonification and concert music pieces, the sonification contest etc., are also discussed.

3. DATA COLLECTION AND STANDARDIZATION

3.1. Paper Metadata Corpus

The analysis is based on a collection comprising of data associated with the proceedings of past ICAD conferences, as they appear in the Georgia Tech Library ¹. The library hosts 1141 pdf files of unique ICAD scientific publications along with the necessary metadata for archiving purposes. This metadata information was collected, categorized per conference year, and standardized for consistency. The title and abstract entries of this collection were filtered by the key words “sonification”, “audification” and their derivatives in an attempt to identify publications within the scope of sonification. No further selection criteria were applied. This process resulted in 456 entries, which composed the core data of the analysis.

Each data entry in this collection includes the title, abstract, and year of publication in ICAD, a list of corresponding authors and their affiliations, as well as information regarding the conference location, dates, and host institution. Based only on information available in the abstract and title of each entry, all sonification-related works were manually labelled (*artistic*, *scientific* etc.) and categorized according to their type. Finally, an additional tag was added to all entries that mentioned the use of some method of evaluation of the discussed work based on human assessors (from this point onwards referred to as subjective evaluation) .

3.2. Text Analysis Corpus

All titles and abstracts in the corpus were processed by a text analysis algorithm, stripped of high-frequency / stop words and suffixes, and reduced to word stems, in an attempt to minimize redundancy. Following this process, the resulting word list was manually inspected for the occasional removal of words, which, albeit frequent, were not necessarily directly related to sonification and ICAD. Amongst the manually removed words were 3 entries whose connection to sonification research was too obvious and their frequency of appearance was so high (2 to 5 times higher than that of the 4th word entry in the word list), that they dominated subsequent word analysis, rendering other word connections insignificant. These words were “sonification”, which by default existed at least once in every title / abstract, as it was the original search word for the collection of publications under analysis, followed by the words “data” and “sound”. The outcome of this semi-automated process was a dictionary of 230 words, ranked according to their frequency of occurrence across all selected 456 ICAD abstracts and titles.

3.3. Limitations

Some basic assumptions needed to be made in order to proceed with data analysis. These posed certain limitations to the presented work. First, the core source of information for both the selection of relevant articles and the subsequent analysis was the titles and abstracts of the published manuscripts, instead of the full-texts. The central assumption behind this decision, was that titles and abstracts of scientific manuscripts constitute self-contained written work, which captures the fundamental information of each full-text. The direct consequence of this assumption was that any

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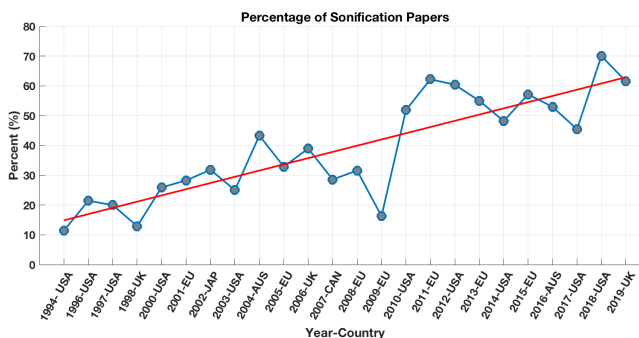


Figure 1: Percentage of publications related to sonification per conference year

publications in the ICAD proceedings which were related to sonification research without explicitly using that terminology in their titles or abstracts were inevitably excluded from this work.

Building off of this first assumption, abstracts were expected to include information regarding the sonification type and the execution of any form of evaluation in each data entry. In practice, oftentimes this information was either hard to infer, or absent. It should therefore be made clear that all subsequent analysis was solely based on the information present in the titles and abstracts of each paper and not on the corresponding full-texts.

Similarly, titles and abstracts were treated as representative text excerpts which were expected to contain the essential terminology describing the core work presented in each manuscript. While this is true to a certain extent, one would assume that terminology related to technical details, which are key to the description of a sonification design and process, would be generally absent from these short-length abstracts. It is therefore possible that the dictionary of sonification-related key words, which will be discussed in the following section, would be enriched, should the text analysis was expanded to include the full published manuscripts.

Auditory display related artistic works in the form of live concerts, installations, and sonification contests are an integral part of ICAD. Nevertheless, they were not always associated with a written document. And even when they were, these were not systematically archived, as part of the ICAD proceedings. As a result, in the data corpus under analysis most of the artistic sonification entries concern publications of artwork discussed in a scientific scope, through a research paper, and hence they are not fully representative of the percentage of artistic work fostered in ICAD.

Finally, the metadata associated with each ICAD publication in the Georgia Tech Library exhibited inconsistencies in the way metadata information was entered between conference years. Considerable effort was made to manually cleanup these variations, but errors potentially still exist. Nevertheless, because the conducted analysis primarily highlights trends in the data, these inconsistencies are not expected to have significantly affected the results.

4. DATA ANALYSIS

4.1. General Overview

Sonification is an integral part of ICAD. Especially in the last few years, a simple inspection of the conference proceedings reveals that a lot of the work presented in the conferences is somehow

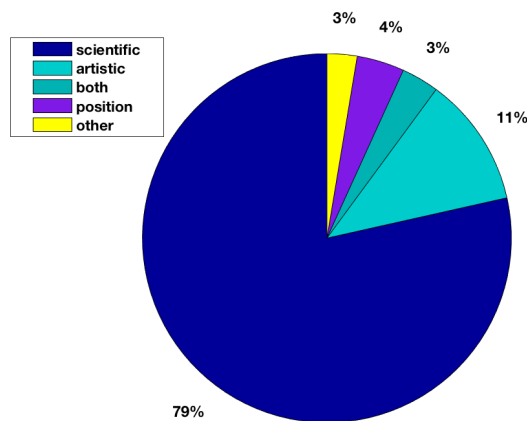


Figure 2: Distribution of sonification papers according to their focus

related to this domain. It is, therefore, worth looking at the representation of sonification-related research published in ICAD since 1994, the first year that the conference proceedings were made available online. Figure 1 shows the percentage of ICAD publications related to sonification per conference year. That is, the percentage of papers which included any of the aforementioned keywords in their titles and / or abstracts. As can be seen there, this percentage was relatively low during the first 4 conference years (1994-1998), ranging between 11% and 21%, while during the last 5 conference years (2015-2019) it has increased to 45.5% - 70%, reaching a global maximum in 2018. The positive slope of the 1st degree fitted polynomial, depicted in red, confirms the general increase trend in the data. Closer inspection of the graph reveals a breaking point in year 2010. Since then, sonification-related work accounts for more than 50% of the published papers, with the exception of conference years 2014 (48.2%) and 2017 (45.4%), in which the percentage lies below 50%, while still being higher than that of the majority of past conferences. It is also worth noting that this increase-trend appears to be irrelevant to the Conference location, indicated on the graph next to each conference year.

Upon review of the selected abstracts, each paper was manually tagged according to the focus of the discussed work under one of 4 possible categories: *Scientific*, *Artistic*, *Position*, and *Other*. As *Scientific* were characterized all manuscripts which, according to their abstract, explored sonification to resolve a research task; as *Artistic* were characterized all manuscripts which concerned any form of artwork; as *Position* were characterized all manuscripts which discussed the documented opinion of the author(s) on a matter related to sonification; all remaining papers, which did not fit into any of above three categories were tagged as *Other*.

The tagging process was first completed by each author separately. The resulting categorizations were then compared and all inconsistencies were resolved through further data inspection and discussion. During the analysis, there was a small number of papers which discussed both some research-related task and an artistic implementation. These were originally flagged under a separate 5th category, labelled *Both*. The distribution of papers per category can be found in Figure 2. As can be seen there, Scientific work accounts for 79% of the papers, Artistic for 11%, Both for 3%, Position for 4%, and Other for 3%.

Table 1: Distribution of sonification papers grouped according to their focus in 5-year increments

(%)	'94-'98	'00-'04	'05-'09	'10-'14	'15-'19
Scientific	100	88.2	90.4	71.5	67.1
Artistic	0	11.8	7.5	19	19.7
Position	0	0	0	8	6.6
Other	0	0	2.1	1.5	6.6

The scientific / research work accounts for the vast majority of the sonification work published in ICAD. On the contrary, artistic work accounts for a small percentage of the publications. This finding was to a certain extent expected. As discussed in Section 3.3, while Auditory Display artistic work is central to the ICAD conferences, it has not been systematically archived as part of its proceedings. Consequently, there is an unknown number of artwork, performed and discussed during the ICAD conferences, which cannot be reflected in this analysis. A strong majority of the entries analyzed in this work concerns publications of artwork discussed through a research paper. Therefore, for all subsequent analysis, the Artistic and the Both tags will be merged into a single Artistic category accounting for 14% of the papers under analysis.

Table 1 outlines the evolution in the focus of sonification-related work in 5-year increments. As can be seen there, in the early conference years the proceedings included only scientific work. On the contrary, in the last decade the percentage of artistic work in ICAD has grown (≥ 19), indicating both an increase in the amount of artistic work published in the conference, and a more systematic approach in archiving this work. It is also worth pointing that position papers start appearing in the last decade (since 2010). This finding is also expected, as position-work needs a few years of (self)-reflection on a topic to offer anything meaningful.

Building on from the above, Figure 3 shows the distribution of the data according to type of sonification. Six (6) types of sonification work were defined: 1) *Sonification method* : papers which discussed the development of or relied on and described a sonifica-

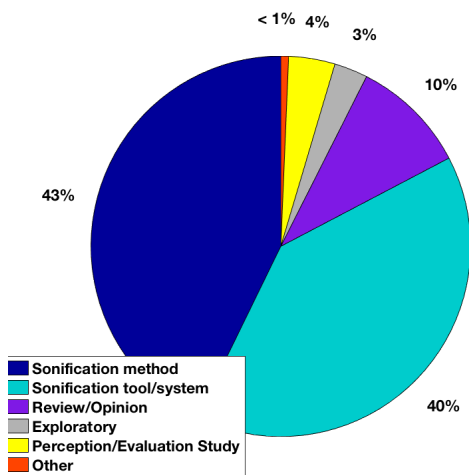


Figure 3: Distribution of papers per type of Sonification

Table 2: Distribution of sonification papers grouped according to their focus in 5-year increments

(%)	'94-'98	'00-'04	'05-'09	'10-'14	'15-'19
Sonification method	61.1	43.5	48.9	36.5	41.8
Sonification tool/system	38.9	27.1	21.3	50.4	51.6
Review/Opinion	0	15.3	16	8	5
Exploratory	0	5.9	5.3	1.5	0.8
Perception/Evaluation Study	0	5.9	8.5	2.9	0.8
Other	0	2.3	0	0.7	0

tion methodology. 2) *Sonification tool / system* : papers which discussed the development of a self-contained tool or system for sonification. 3) *Review / Opinion* : papers which reviewed one or multiple sonification methodologies / tools, 4) *Exploratory* : papers which explored the design of sonification methodologies / tools for a specific task, 5) *Perception / Evaluation study* : papers which discussed perceptual studies that somehow involved the use of sonification, and 6) *Other* : papers which did not fit in any of the categories above. The process for tagging papers under these categories was identical to the one described above concerning the categorization of papers according to sonification focus. The graph shows the collective analysis across all 24 ICAD conferences. As can be seen there, papers discussing sonification methodologies and tools / systems account for 83% of all sonification-related papers in ICAD (43% and 40% respectively). Another 13% of ICAD publications concerns papers either reviewing previously introduced methodologies and tools (10%), or exploring the design of sonification methodologies / tools for a specific task (3%). The remaining categories account for less than 5% of all publications.

Table 2 shows the breakout of the above distribution in 5-year increments. From this analysis, it appears that, with the exception of the first 4 ICAD years, when the conference was still trying to define its scientific identity, the last decade is a period of reclassification. More specifically, the percentage of published papers related to the design and discussion of sonification tools / systems has become the most popular publication type, accounting for more than 50% of the sonification papers. At the same time, the percentages of review and exploratory papers have progressively declined, while other types of works, marginally related to sonification have been reduced to a minimum.

One last discussion point concerns the assessment of sonification-related works. This point has been extensively discussed from various perspectives [15, 16, 14, 13, 12]. Our findings are in line, with past statistics, reflecting a) the difficulty in the implementation of evaluation routines in the abundance of sonification domains; b) a large number of sonification methodologies, tools, and systems, published without any discussion of formal evaluation. Out of the 456 papers under study only 32.7% (149 publications) mention some form of subjective assessment in their abstracts. Table 3 shows the evolution of this percentage in 5-year increments. As can be seen there, in the last 5 conference years (2015-2019) there has been a notable increase in the number of papers either implementing or discussing the evaluation of sonification work, fact which could be an indication of a slight change of

material and structures presented in sonification may be perceived as arbitrary in their relation to the data sets (or the mapping may even contradict specific dynamics of the data). In the dictionary of most frequent sonification-related terms in ICAD the word “mapping” appears among the top-10 ranked terms, across all ICAD conferences. The word “parameter” is a less frequent term (Figure 5, blue shades), but appears consistently across all conference years among the top ranked terms, affirming its inseparable connection to sonification.

- *Perception and Listening*: words related to subjective evaluations and studies are more visible since 2000. Especially words such as “perception” and “listen” are both consistently appearing in word clouds as third and forth-tier terms (green and blue shades) across all conferences (Figure 5). The community’s take on the subjective and objective evaluation of sonification work has been extensively discussed earlier in this paper. Only an average of 32.7% of sonification-related publications mention any form of subjective assessment of their work, in the repository under study. This percentage has reached a global maximum (42.6%) during the last 5 conferences (Table 3), fact which is also reflected in the word cloud of that period, where both terms appear to have a higher frequency of occurrence than before.

5. DISCUSSION OF RESULTS

This paper attempted an exploratory, preliminary approach to the field of sonification. The overview of the evolution of the field as presented through the proceedings of the International Conference on Auditory Display was based on a subset of 456 published papers, selected from the proceedings because they contained keywords related to sonification in their abstracts and titles. The subsequent analysis was also based on each article’s title and abstract, instead of the full-texts. This approach has introduced certain limitations in the data, which have been extensively discussed in Section 3.3. Despite those limitations, this preliminary analysis has revealed some interesting points regarding Sonification research and its place within the Auditory Display field.

The term sonification has evolved during nearly 3 decades of ICAD Conferences. While it was originally used to refer to the mapping of data information into sound, according to Vickers and Hogg, it has gradually evolved into a general umbrella incorporating most of the work in the area of Auditory Display [29]. This is apparent in the gradual but steady increase in the percentage of ICAD papers concerning sonification. Especially in the last decade (since 2010), sonification-related papers with very few exceptions account for more than 50% of the work published in the conferences, signifying that sonification has, indeed, become the signature scientific domain of ICAD.

In addition, there appears to be no correlation between the country where the conferences have taken place and the percentage of sonification-related work published. The presence of such a relationship is possible, but a more in-depth analysis is necessary to reveal it. More specifically, to test for such connections one would have to analyze the conference proceedings to their entirety, identify all major research domains, and try to correlate them with the hosting institutions. Such an analysis is beyond the scope of this work, but it is in the future work plans of the authors.

The distribution of papers per category of work, revealed that the vast majority of sonification-related manuscripts was research oriented (79%). Work related to any form of artistic expression

came second (14%). This finding was somewhat expected. As discussed earlier, any form of artwork presented in ICAD conferences was not systematically documented in the proceedings and archived in the Georgia Tech Library ICAD repository. This remark is further enhanced by the observation that in the last decade the percentage of published artistic work has raised to $\geq 19\%$ as a result of more organized archiving procedures. It should be acknowledged that this argument reveals another limitation of the work presented in this paper. The presented analysis is based only on information archived in the Georgia Tech Library. A more in-depth analysis of the work presented in the ICAD conferences, should look beyond publications, to all conference related events and activities, such as concerts, installations, workshops/tutorials, and sonification contests, just to name a few.

Over the last decade, the ICAD scientific community appears to be more focused towards the development of sonification tools and methodologies and more open to the idea of evaluation of the designed work. Upon closer inspection of the proceedings it becomes clear that the sonification domains that the community focuses on are evolving with time, as a result of technological advancements, public need / demand, publication venues available, etc. In the early years of ICAD, one may see several sonifications related to auditory icons, earcons, and auditory graphs. Over the last few years, it is quite possible that publications related to such work are directed to other venues and conferences such as: the Audio Mostly, the Sound and Music Computing, the International Conference on Computational Creativity, and CHI, resulting in fewer product sound design related submissions in ICAD. Similarly, the Interactive Sonification Workshop (ISON) has brought more attention to interactive sonifications and has claimed interactivity in auditory interfaces as a focal point. Therefore, many sonification-related work concerning movement data, navigation, or interactivity, in general, which were traditionally presented at ICAD, may have evolved into projects and publications in ISON. While these observations stem from a systematic inspection of the evolution of sonification-related ICAD papers published since 1994, their interpretation remains highly subjective. A definitive such statement would require systematic inspection of publications in several of the aforementioned conferences and venues.

In an attempt to look deeper into the evolution of sonification domains within ICAD, a preliminary text analysis was conducted, focusing on word frequency in the selected data corpus. Several text analysis tools make use of word clouds. For example, they are frequently used for the analysis of large collection of news articles, patent analysis, opinion mining, or investigative analysis [30, 31, 32]. In most of these domains, word clouds are used in a static way to visually summarize text documents. Word clouds generated for a body of text can help as a starting point for a deeper analysis [33, 34, 35]. For example, they serve to determine whether a given text is relevant to a specific information need. The only problem is that they provide an entirely statistical summary of isolated words without taking linguistic knowledge of the words and their relations into account.

In this paper, word frequency analysis was implemented as a method for studying changes in the focus of sonification in papers published in ICAD conferences. This exploration revealed trends in the data that are complementary to the results of the statistical analysis of the metadata presented in Section 4.1. One such example is the prominent presence of the terms “listen/listener” and “perception” in the word-clouds of the 1994 to 1998 and 2015 to 2019 conference years (Figure 5), which according to Table 3

are periods during which subjective evaluations of proposed sonification works were more common. Words such as “user” and “interaction” suggest an anthropocentric approach in data sonification, while words such as “research”, “process”, “describe” and “explore” outline some central tasks associated to sonification. A point worth raising concerns the prominence of the term “music” throughout all conference years, fact which supports the well established observation that sonification lies in between the arts and science [10, 9]. The term is also very frequent in the 1994 to 1998 conference years, during which, according to Table 1, there were no artistic publications in the ICAD proceedings. This fact further enhances the observation that the discussions as to whether sonification needed to be musical, concerned researchers since the early years of ICAD.

6. CONCLUSIONS AND FUTURE WORK

The systematic exploration of ICAD proceeding titles and abstracts revealed that sonification has gradually grown to become the most popular research topic of ICAD conferences (Figure 1). There’s a trend towards more systematic and design-related mapping focused sonification. A direct link to the domain sciences that apply sonification is not apparent. In spite of the fact that artistic sonifications are a small percentage of the proceedings, the artistic sonification has grown over time (Table 1). It should also be noted that music is an important topic across all ICAD conferences (Figure 4).

If sonification is to be considered scientifically legitimate for representing data, the community should consider shifting towards empirical sonification, suggested by Neuhoff, further exploring ecological mappings [9]. Furthermore, the community should avoid the identity crisis of hanging in the middle of art and science. We would like to further explore methodologies that bring open mapping strategies and systematic approaches of sonification to the fore. In order to expand this analysis, an investigation beyond abstracts and titles of the ICAD proceedings is necessary. The next phase of this research will take the analysis a step further, focusing on the full-texts of the selected ICAD papers and of ICAD special issue journal articles related to sonification. This could lead to a stronger statistical analysis and a deeper discernment of the evolution of the sonification field. The ultimate goal is to create a systematic overview of the field by analyzing the evolution of topics and the progress of sonification algorithms and methodologies over time. This should lead to a comprehensive body of work that relies on the knowledge gathered in nearly three decades of sonification research.

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