Multi-Listener Auditory Displays

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Abstract

This thesis investigates how team working principles can be applied to Auditory Displays (AD). During this work it was established that there the level of collaboration and team work within the AD community was low and that this community would benefit from a enhanced collaborative approach. The increased use of collaborative techniques will benefit the AD community by increasing quality, knowledge transfer, synergy, and enhancing innovation.

The reader is introduced to a novel approach to collaborative AD entitled Multi-listener Auditory Displays (MLAD). This work focused upon two areas of MLAD distributed AD teams and virtual AD teams. A distributed AD team is a team of participants who work upon a common task at different times and locations. The distributed approach was found to work effectively when designing ADs that work upon large scale data sets such as that found in big data. A virtual AD team is a group of participants who work upon a common task simultaneously and in separate locations. A virtual AD team is assisted by computer technology such as video conferencing and email. The virtual auditory display team was found to work well by enabling a team to work more effectively together who were geographically spread.

Two pilot studies are included; SonicSETI is an example of a distributed AD team, where a remote group of listeners have background white noise playing, and use passive listening to detect anomalous candidate signals; and a geographically diverse virtual AD team that collaborates through electronic technology on an auditory display which sonifies a database of red wine measurements. A workshop was organised at a conference which focused upon ensemble auditory displays with a group of participants who were co-located.

Contents

Abstract **2**

List of Figures **8**

List of Tables **10**

Acknowledgements **11**

Author's Declaration **12**

1 Introduction **13**
1.1 Introduction 13
1.1.1 Distributed auditory display teams 13
1.1.2 Virtual auditory display teams 14
1.1.3 Auditory display ensemble 14
1.2 The hypothesis 14
1.2.1 Discussion of hypothesis 14
1.3 Thesis objectives 15
1.4 Permanent On-line record 15
1.5 Thesis structure 16

2 Collaboration and teamwork **18**
2.1 Introduction 18
2.2 Advantages and disadvantages of collaborative work 18
2.3 Definitions of group-based activities 20
2.3.1 Cooperation or collaboration 20
2.3.2 Team definition 21
2.3.3 Types of teams 22
2.3.4 Team lifespan 24

2.3.5 Team roles and tasks 25
2.4 The fourth paradigm of science 28
2.4.1 Citizen science and crowd-sourcing 29
2.4.2 Characteristics of crowd sourced projects 30
2.5 Computer-Supported Cooperative Work 31
2.6 Discussion and conclusions 32

3 Auditory displays 34
3.1 Introduction 34
3.2 Definitions 34
3.2.1 Interactive sonification 37
3.2.2 Why use sound to communicate? 37
3.3 Types of auditory display 38
3.3.1 Alerts and alarms 39
3.3.2 Auditory Icons 39
3.3.3 Earcons 40
3.3.4 Auditory graphs 40
3.3.5 Audification 40
3.3.6 Sonification 41
3.4 Conclusions 42

4 Collaborative auditory displays 44
4.1 Introduction 44
4.1.1 Interactive Sonification Workshops 44
4.2 Existing collaboratory AD research 45
4.2.1 Aftershock 46
4.2.2 AlloSphere and Allobrain 46
4.2.3 Augmented Reality based Interception Interface 48
4.2.4 Bat Detective 49
4.2.5 DynaWall 49
4.2.6 Interactional Sound and Music 50
4.2.7 Many-ears 51
4.2.8 MoodifierLive 52
4.2.9 Sonification of brain and body signals in collaborative tasks using a table top musical interface 53
4.2.10 Exploration of sonification design process through an interdisciplinary workshop 53
4.3 Other related research 54

4.3.1 Drum2Drum . . . 54
4.3.2 EMOListen . . . 54
4.3.3 MoodMixer . . . 55
4.3.4 Touch screen ensemble music . . . 55
4.3.5 Whale FM . . . 56
4.4 Discussion and conclusions . . . 57

5 Multi-listener auditory displays 60
5.1 Introduction . . . 60
5.2 Overview . . . 60
5.3 Auditory display teamwork . . . 61
5.3.1 Remote Collaboration . . . 62
5.3.2 Co-located Collaboration . . . 64
5.3.3 Conclusions . . . 65

6 SonicSETI 66
6.1 Introduction . . . 66
6.2 The Search for Extra-Terrestrial Intelligence . . . 66
6.2.1 SETIQuest Explorer . . . 68
6.2.2 SETIQuest . . . 69
6.3 SonicSETI . . . 70
6.3.1 Audification of SETI data . . . 71
6.3.2 Listening to white noise . . . 72
6.3.3 Experimental design . . . 73
6.4 Active Listening test . . . 74
6.4.1 Results . . . 75
6.4.2 Discussion of results of active listening test . . . 77
6.5 Passive Listening test . . . 78
6.5.1 Experimental procedure . . . 78
6.5.2 Results . . . 79
6.5.3 Discussion of results of passive listening test . . . 80
6.6 Discussion of SonicSETI . . . 81

7 Multi-listener workshop 83
7.1 Introduction . . . 83
7.1.1 Presentation . . . 84
7.1.2 Task one: Distributed auditory display . . . 84
7.1.3 Task two: Pair sonification . . . 85

7.1.4 Task three: Ensemble radio finder 87
7.2 Conclusions of workshop 89

8 Virtual auditory display team 90
8.1 Introduction 90
8.2 Red wine quality 91
8.3 Organisation 92
8.3.1 Week 1: Virtual meeting 1 92
8.3.2 Week 4: Virtual meeting 2 93
8.3.3 Week 8: Virtual meeting 3 93
8.4 Teamwork 93
8.4.1 Team Member A 94
8.4.2 Team Member B 94
8.4.3 Team Member C 94
8.4.4 Team discussion 95
8.5 Conclusions 95

9 Conclusions 101
9.1 Introduction 101
9.2 Multi-listener auditory displays 101
9.2.1 SonicSETI 101
9.2.2 Multi-listener workshop 103
9.2.3 Virtual auditory display team 103
9.2.4 Discussion of multi-listener auditory displays 104
9.3 Discussion of hypothesis and project objectives 105
9.3.1 Thesis objectives 105
9.3.2 Hypothesis 109
9.4 Conclusion 109

10 Further work 111
10.1 Introduction 111
10.2 SonicSETI 111
10.3 Virtual auditory display teams 112
10.4 Virtual reality auditory displays 112
10.4.1 Ensemble sonification 113

Appendix A Listening to the invisible: Sonification as a tool for astronomical discovery 114

Appendix B Phantom signals: Erroneous perception observed during the audification of radio astronomy data **122**

Appendix C Multi-listener sonification: A team approach to Interactive Auditory Display **132**

Appendix D Listening tests feedback forms **138**

Appendix E Multi-listener workshop presentation **146**

Appendix F Virtual auditory display team **174**

References **185**

List of Figures

2.1 Tuckman's theory of team evolution 24
2.2 Gersick's punctuated equilibrium model 25
2.3 The managerial grid 26
2.4 Galaxy Zoo interface 30
2.5 The CSCW matrix 32

3.1 The AD process 35
3.2 A listener within an interactive control loop 37
3.3 A graph demonstrating points on an X-Y plane 41

4.1 Plan of the Allosphere 47
4.2 Fiducial for image tracking as used with a Reactable 48
4.3 The Bat Detective user interface 49
4.4 Dynawall 50
4.5 MoodifierLive setup 52
4.6 Moodmixer set up 56

5.1 The MLAD matrix 62

6.1 A waterfall plot of a Long Wave (LW) radio broadcast 67
6.2 The SETIQuest Explorer console 70
6.3 Spectrum of audified SETIQuest data 72
6.4 Spectrograms of pulse signal 74
6.5 Spectrograms of squiggle signal 75
6.6 Histogram showing incidence of reports against time 81

7.1 Task one transmitter interface 85
7.2 Task one receiver interface 86
7.3 Task two pair radio interface 87
7.4 Task three ensemble radio interface 88

8.1 Screenshot of team member A's code 98
8.2 Screenshot of team member B's Max/MSP patch 99
8.3 Screenshot of team member C's Max/MSP patch 100

9.1 The MLAD matrix 106

List of Tables

4.1 Table illustrating size of author teams for each ISon 45
4.2 Group AD research mapped to CSCW matrix 58

5.1 Comparison of distributed and virtual team characteristics . . 65

6.1 Results of listening test one 76
6.2 Signal frequencies, amplitudes and start times 78
6.3 Times of signal detection reports for each participants 79
6.4 Table of correctly identified signals per candidate 80

8.1 Attributes and quality of red wine 91

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Author's Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, university. All sources are acknowledged as references.

Some content in this thesis has been published in three peer reviewed conference papers:

- P. Lunn and A. Hunt, "Listening to the invisible: Sonification as a tool for astronomical discovery," in Making visible the invisible: art, design and science in data visualisation, 10th-11th March 2011, Huddersfield, UK. Georgia Institute of Technology, 2011. [1]
- P. Lunn and A. Hunt, "Phantom signals: Erroneous perception observed during the audification of radio astronomy data," in Proceedings of the 19th International Conference on Auditory Display (ICAD2013). Lodz, Poland. 6-9 July 2013. Georgia Institute of Technology, 2013. [2]
- P. Lunn and A. Hunt, "Multi-listener sonification: A team approach to interactive auditory display," in Interactive Sonification Workshop, Erlangen, Germany, 10/12/13- 10/12/13. Georgia Institute of Technology, 2013, pp. 12–16. [3]

Chapter 1

Introduction

1.1 Introduction

Collaborative working has been a key driver of human evolution. One of the main reasons for our success as a species is our ability to work together on a common task. In an interview in the New York Times, social anthropologist Kim Hill stated that:

> Humans are not special because of their big brains, that's not the reason we can build rocket ships — no individual can. We have rockets because 10,000 individuals cooperate. [4]

The central theme of this work is an investigation into teamworking with Auditory Display (AD)s. Teamwork has been highly successful in industry, and this work incorporates these ideas and principles to multiple listeners within an AD research set up, with an objective of discovering whether the benefits of teamworking can be applied to this area.

This thesis proposes a series of team techniques, grouped together under the umbrella term of MLAD. There are three proposed areas within MLAD which are summarised below.

1.1.1 Distributed auditory display teams

A distributed AD team is a group of people who listen to an AD in isolation from each other. Members of the team mainly interact with a central facilitator who manages the AD. SonicSETI is the name of the study which implements distributed team characteristics. Here, members of a group of isolated listeners each listen to audified radio astronomy data to perceive candidate Search for Extra-Terrestrial Intelligence (SETI) signals mixed in. It was found that participants could detect candidate signals whilst both actively and passively listening to the white noise source.

1.1.2 Virtual auditory display teams

A virtual AD team is a group of people who are geographically remote, but who use virtual team methods to interact with an AD. This type of team communicates with the assistance of technology such as video conferencing and email. In this study a small remote team was organised to collaborate on the design of an AD to explore a Portuguese red wine data set.

1.1.3 Auditory display ensemble

The main focus of this study was the development of remote teamworking methods mentioned above, however some preliminary work was undertaken on co-located teams. An AD ensemble is a group of listeners who are simultaneously located within the same geographical space, i.e. the same room. A trial ensemble was attempted at an International Conference on Auditory Displays (ICAD) workshop with limited success.

1.2 The hypothesis

In this thesis the following hypothesis is investigated:

> An organised team of listeners can be an efficient and effective tool for auditory displays.

1.2.1 Discussion of hypothesis

The main theme of this research is the development of collaborative approaches to ADs. Originally this was focused upon the development of techniques for dealing with large data sets found in big data. The focus was to investigate techniques for utilising AD techniques on the exploration of radio astronomy data. During this phase, it was realised that one approach would be based upon team-working principles. The scope of the project was re-aligned towards collaboration as it became apparent that the team-working approach could be utilised in many other AD areas outside of the big data arena.

An *organised team of listeners* is a collection of individuals who work upon an AD task in a collaborative and structured way. For the purpose of this study a team needs to be defined as such from its inception, rather than evolving into a team after a period of time. A group of listeners (using the term *group* as defined in chapter 2) is too ambiguous to be considered for this study, as this could describe any loose collection of people.

When considering the scope of the hypothesis, the terms *efficient and effective* have been selected. Efficiency is a quality that describes a time-based attribute; an AD technique could be stated to be efficient if its application is faster than using other methods with similar accuracy. Effectiveness is a term that describes quality; an AD technique could be stated to be effective if its application offers an improvement in quality, e.g. using a technique will provide more accurate results than alternative techniques. An effective and efficient approach is one that can achieve a more accurate result in a shorter time.

1.3 Thesis objectives

The objectives of this study are to:

- design a framework for the implementation of organised AD teams.
- establish whether organised groups of listeners can be an efficient tool for ADs.
- establish whether organised groups of listeners can be an effective tool for ADs.

1.4 Permanent On-line record

A permanent on-line record of all data generated during this research is available at:

https://github.com/dalmatianrex/multi-listener-auditory-displays

1.5 Thesis structure

The following statements describe the structure of this thesis and briefly outline the contents of each chapter.

- Chapter 1 Introduction — an introduction to this study.
- Chapter 2 Collaboration and teamwork — an overview of teamwork theories, discussing the benefits and drawbacks of teamwork, team structure, team development and lifespan.
- Chapter 3 Auditory displays — a review of the AD subject area. This chapter defines the various techniques utilised in this field, such as parameter mapping and audification.
- Chapter 4 Collaborative auditory displays — is a literature review of previous research involving collaboration within the AD community. The review is also expanded into other arenas such as human-computer interaction (HCI), and computer-supported cooperative work (CSCW).
- Chapter 5 Multi-listener auditory displays — A summary of multi-listener AD techniques developed in this study. This chapter describes distributed ADs, virtual ADs, and AD ensembles.
- Chapter 6 SonicSETI — describes the SonicSETI project which is an example of a remote distributed AD. SonicSETI audifies radio astronomy data and presents it as white noise for background listening. A series of listening tests were performed to establish whether listeners can detect signals whilst actively and passively listening to white noise.
- Chapter 7 Multi-listener workshop — describes a workshop delivered during ICAD 2015. This workshop was used to pilot multi-listener auditory display ideas to the international AD community and test their effectiveness.
- Chapter 8 Virtual auditory display team — describes a pilot study on a the creation of a virtual AD team, where a group of auditory display researchers collaborate remotely upon the design of an AD to solve a problem.

- Chapter 9 Conclusions — is a summary of the work undertaken for this study, including further work.

- Appendix A — A conference paper submitted for ADS-VIS2011: Making visible the invisible: Art, Design and Science in Data Visualisation [1].

- Appendix B — A conference paper submitted for the International Conference on Auditory Display in 2013, and that discusses the "Phantom Signal" effect which was discovered in early listening tests [2].

- Appendix C — A conference paper presented at the 4th Interactive Sonification Workshop in Germany, and introduced the topic of team-based ADs to the Auditory Display community [3].

- Appendix D — feedback forms generated for listening tests undertaken for SonicSETI project.

- Appendix E — Presentation made to the multi-listener workshop at ICAD 2015

- Appendix F — Description of task, research consent, questionnaires and responses of virtual AD team.

Chapter 2

Collaboration and teamwork

2.1 Introduction

It is rare for humans to exist in isolation from each other. Much of our society is based upon individuals arranging themselves into groups for activities such as work, sports, and political organisations. This chapter discusses how collective working can benefit the AD community, exploring the idea that organised teams can be more effective than individuals. This section presents background theory on collaboration with a view to applying these principles within an AD context.

2.2 Advantages and disadvantages of collaborative work

There are various reasons why team-based collaborative work is viewed as an advantageous method of working [5].

- Effectiveness — A team can work more effectively than an individual because multiple team members can work on different parts of a task in parallel. This is more effective than one individual working on a task serially

- Knowledge transfer — Teamwork provides opportunities for team members to learn from each other. New team members are provided with an existing support network of colleagues. If an individual leaves the team, some knowledge is retained which could have been lost to the organization if the task was originally completed by a solo worker

- Synergy — Teamwork offers the opportunity for synergy, since the combined resources of a team is greater than the sum of its individual parts

- Improved quality — A collection of individuals will have a diverse set of experiences and skills which can be called upon to enhance the quality of the end product

- Innovation — Teamwork provides the opportunity for cross fertilisation of ideas with the team

- Organisational structure — An organisation that is team-based can be managed more effectively than one that is based upon many individuals by having a pyramidal structure of management.

Despite the merits of teamwork there are some disadvantages, from [6] and [7]

- Unequal Participation - There is always the opportunity for some individuals to sit back and let others do all the work, which can lead to reduced productivity and conflict within the team

- Potential for conflict - When any group of individuals are collected together there is the potential for personality clashes and disagreements

- Reduced creativity - When some individuals are placed in teams, this can hinder their creativity. They may feel hesitant to contribute valuable ideas with the team, some may have concerns about intellectual property . A unified team can be a great propagator of new ideas, but this is hindered if individuals are not interacting with other team members

- Loners - Teamwork is not for everyone, as some people loathe being forced to participate in group activities and will actively resist or become disruptive to the team.

It is clear that teamwork offers some attractive benefits beyond that of the *many light hands* approach. Teamwork provides a framework that works well with complex problems whose solution would not be possible by solo working. Many of the disadvantages listed above relate to an individual's perspective inside the team; some people just aren't suitable for this type of work. Overall it may be better to recruit team members based upon willingness to participate rather than skill base, although this is discussed later in the discussion section of this chapter.

2.3 Definitions of group-based activities

This section looks at some key definitions of terms used to describe the collaborative team process.

2.3.1 Cooperation or collaboration

Olga Kozar provides an excellent summary of the differences between team cooperation and collaboration:

> Cooperation can be achieved if all participants do their assigned parts separately and bring their results to the table; collaboration, in contrast, implies direct interaction among to produce a product and involves negotiations, discussions and accommodating other's perspectives. [8]

When individuals or organisations work together their approach can be described as either cooperation or collaboration, and it is important to distinguish between these two terms. Cooperation is an activity where an objective is met by tasks being allocated to each individual in the group. Each individual has responsibility for their own task. Collaboration is a process where a group works together upon a common goal, and each participant is engaged in achieving a different part of the goal. The nature of the proposed project may dictate whether a cooperative or a collaborative approach is undertaken. For a basic project, cooperative work may suffice, with one manager independently coordinating each sub-worker.

Interdependence

Interdependence is the joint reliance that two or more participants have with each other. In a dependent relationship only some of the participants are dependent upon each other, whereas in an interdependent relationship all parties are reliant upon the co-operation of each other for success in a task.

Griffith and Dunham state that there are three types of interdependent cooperation found within work-based teams [9]:

Pooled interdependence is a task divided amongst a group of workers, with very little communication or cooperation between each individual. An example of pooled interdependence is a sales force where each sales rep has their own area of the country. Here each worker contributes to the company's success but works in isolation from other workers.

Sequential interdependence is where tasks are organised in a chain. In a sequentially interdependent system, tasks are reliant upon the completion of previous tasks. An example of a sequentially interdependent system is a motor vehicle production line where the car passes through processes on its way through the factory. There is a prescribed order that the car needs to be assembled in, for example paint would need to be applied to the chassis prior to the engine being installed. The level of interdependence in a sequential system varies dependent upon the position in the chain, with later processes being heavily reliant upon earlier ones.

Reciprocal interdependence is a cyclical system of tasks. Similar to a sequential system, tasks are reliant upon the successful completion of other tasks, however in this type of system the task may be passed between stakeholders multiple times. An example of a reciprocally interdependent system is an operating theatre, where everyone has specific tasks such as nurse, surgeon or anaesthesiologist. During surgery members of the team need to communicate with each other. This type of system is complex, requiring a high level of collaboration and communication.

2.3.2 Team definition

A cluster of people can be described as either a group or a team. These are two terms that are often used interchangeably, however a real distinction needs to be made between each.

A collection of two or more individuals with a common characteristic or purpose is called a group. There is very little interaction between members of the group, as each member is independent. Membership of the group will advance the participant towards their own goals rather than the goals of the collective. When a group identifies a goal, it will be delegated to a team. Examples of groups include trade unions, societies, and people collected based upon ethnic background or religion.

A team is where two or more individuals work towards a common goal. Paris et al. provide a good definition of what a team is:

> A distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited life-span membership. [10]

In a team the participants share a common goal and have a specific role which is related to the pursuit of that goal. The roles allocated to team members are synergistic and each member has responsibility towards the success of the team in achieving its goals. When a team identifies a goal, it will then promote an action within the team. Examples of teams are football teams, management teams, and medical emergency teams.

ICAD is an example of a group, as it is comprised of a cluster of individuals who share a common interest in the research field of ADs. With the exception of ICAD board members, most people associated with this organisation do not have allocated roles, and their membership advances their personal goals rather than group goals. When ICAD wants to deliver a conference, a separate team is formed which has the goal of the successful organisation of the event. Each member of the conference organising team will be allocated a specific role such as marketing or website development. The team members need to interact with each other to successfully achieve their goals.

Within the context of this research we will focus upon the development of AD-based teams rather than groups.

2.3.3 Types of teams

In an organisation there are generally five types of team found [11].

- Department teams - This is a team containing a collection of individuals who are all working towards a long-term work-based goal
- Problem-solving teams - Problem solving teams tend to be short-term, and focus upon a specific issue

- Virtual teams - This is a team that is geographically diverse and interacts through digital media such as email or video conferencing
- Cross-functional teams - Another work-based team that is comprised of individuals taken from several departments
- Self-managed teams - Self-managed teams do not have a formalised leader but are given the power to make decisions collectively.

In this study we shall be looking at two types of teams that are most appropriate to AD research; problem-solving teams and virtual teams. AD researchers tend to be geographically isolated from each other. Although there are examples of AD research groups these tend to be in the minority. The yearly conference of ICAD [12] serves as a focal point for meeting other researchers in this field and this is an excellent opportunity to develop team based activities. A workshop was organised to develop some of the ideas in this thesis. It took place at ICAD 2015 where teams of AD researchers gained experience of working in small teams working on a problem solving task, and is discussed in further detail in chapter 8.

Virtual teams

"Unlike conventional teams, a virtual team works across space, time, and organisational boundaries with links strengthened by webs of communication technologies." (Lipnack and Stamps)[13]

The development of cheaper technology and increasing internet access speeds has led to new methods of collaborating together. Geographical location, different time-zones, and organisational structures are no longer barriers to collective research. A virtual team is a collection of people who work independently and separately upon a common task and they predominantly communicate via technology rather than face-to-face meetings.

There are many advantages of working in a virtual environment [14]: team members are not bound by location; virtual working reduces commuting and does not require physical meeting rooms. This can be particularity attractive to team members who are disabled or those with family commitments. As the team is not set in one location, the team can recruit members based upon experience and interests rather than proximity. A virtual team can be comprised of members from differing time zones. A virtual team can be more cost effective than a face-to-face team.

Of course, there are disadvantages to working in a virtual environment. The lack of physical contact can lead to social isolation. Team members may require training on new technology. Cultural differences can lead to conflicts, misunderstandings and lack of trust within the team. Truly global teams may experience issues with finding times where everyone is available for meetings. Virtual teams are heavily reliant on technology which can have a cost implication.

The use of virtual teams is of interest to the AD community as it will enable researchers to collaborate without limitation by location and accessibility.

2.3.4 Team lifespan

The first systematic investigation of team development was produced by Tuckman [15], who observed that all teams progress through several distinct stages which are illustrated in Figure 2.1.

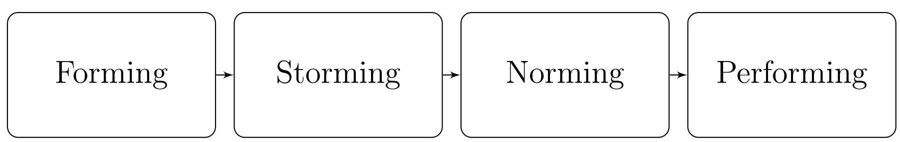

Figure 2.1: Tuckman's theory of team evolution

In the Forming stage the team members are introduced to each other and the initial project goals are discussed. Once the team begins working on the project, some interpersonal conflict should be expected. In the Storming stage, team members will compete for status within the team and have differing views on how to approach the project goal. Once the conflict of the Storming stage is resolved, the team begins to work more effectively together rather than competing with each other; this is the Norming stage. The project can then enter a more productive stage of its life cycle, which is called the Performing stage. In the Performing stage the team is working at a highly productive level. A final Adjourning stage was added by Tuckman in a later review [16]. At the end of the project the Adjourning stage is where the team separates and moves on. This stage would include evaluation of project success.

There are other alternatives to Tuckman's model. Wheelan produced a model which had stages named dependency and inclusion, counter-dependency and fight, trust and structure, and work and productivity [17]. Gersick felt that groups self-organise during the first meeting and then continue working until the mid-life of the project when a period of instability is resolved by the team defining a new structure [18]. The new structure causes the team to work more effectively up until the project conclusion. Gersick's punctuated equilibrium model is illustrated in Figure 2.2.

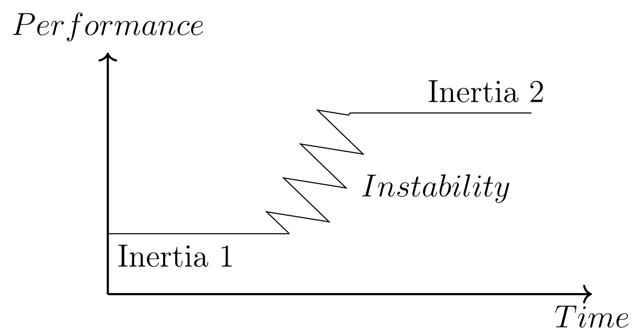

Figure 2.2: Gersick's punctuated equilibrium model

In practice most teams will develop with aspects of both Tuckman's and Gersick's models. Both predict that conflict within the team is a natural and necessary process of team development.

2.3.5 Team roles and tasks

McGrath identified two main critical functions of a team: task functions and maintenance functions [19]. Task functions directly relate to the teams' goals, whereas maintenance functions are those that develop the team. A third function of self-interest has been suggested by Lussier [20]. Any individual participating in any self-interest behaviour could be putting their own needs before that of the team, which will have a negative effect upon the team performance.

Leadership in teams

The majority of teams are led by a team leader, who is responsible for setting goals, and provides supervision and motivation [21]. Various leadership models have been developed that reflect interaction between the team and its leader. Early models like Katz et al. [22] discovered that leaders tend to be focused upon people or production, and that good leaders were concerned with both aspects whereas poor leaders where not concerned with either [23]. This two-dimensional model was later felt to be too simplistic. The managerial grid was developed by Blake and Mouton [24] and places an individual's leadership style into four quadrants as shown in Figure 2.3. Participants complete a questionnaire and are scored between one and nine on their concern for people or production. Dependent upon their scores for the two criteria this model can demonstrate the individual's leadership style.

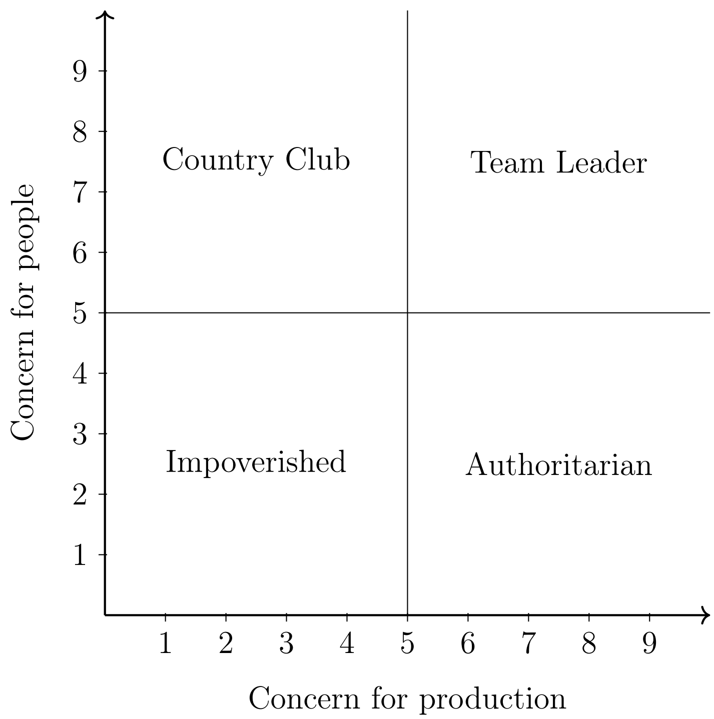

Figure 2.3: The managerial grid

- Impoverished - weak production and people - a leader who is detached from both the task and the team members
- Authoritarian - strong production and weak people - task orientated and autocratic
- Country Club - weak production and strong people - a leader that

avoids interpersonal conflict which has an adverse effect upon production quality

- Team Leader - strong production and people - a leader that leads by example and develops a team that enables each member to reach their highest potential

Within the managerial grid a good leader will be scored within the team leader range, although situations may dictate that the leader may need to temporarily adopt other characteristics. For example, if a hazardous situation occurs the leader may need to adopt an authoritarian approach temporarily.

Leaderless teams

> If you cut off a spider's leg, it's crippled; if you cut off its head, it dies. But if you cut off a starfish's leg it grows a new one, and the old leg can grow into an entirely new starfish. [25]

One consideration is that it is not necessary for a team to have a hierarchical leadership structure This idea was pioneered by Brafman and Beckstrom in their book The starfish and the spider: The unstoppable power of leaderless organisations [25]. This book describes team organisations as either spider-like or starfish-like. Spider teams have a linear management structure, whereas Starfish teams are decentralised and rely on its team members' inter-personal relationships for structure. The advantages of being a starfish is that the organisation is very flexible and can easily and quickly adapt to fluid situations. Starfish organisations like Wikipedia and Skype have been very successful.

Belbin team inventory

Meredith Belbin found that successful teams required a mix of people with different personality types to function effectively [26]. Belbin highlighted nine types of personality found in teams and named them:

- Co-ordinator - This personality type describes those who take on a team-leader role within the team

- Shaper - Tend to be extroverts who enjoy challenging the team to find the best solutions to problems. They tend to shake up the team, and provide energy when others are flagging
- Implementer - These are people who are able to turn plans into practical actions. They are organised and disciplined but can be inflexible
- Completer Finisher - Perfectionists who direct the project towards its completion. They are deadline focussed but maybe overly anxious concerning the project
- Team Worker - Those who have a nurturing attitude towards the team. They act as negotiators between team members to ensure that the team works together effectively
- Resource Investigator - These favour a role that is outward looking towards external stakeholders. Resource Investigators tend to be extroverted
- Plant - An introverted creative individual who will come up with new innovations and ideas. Plants tend to be poor communicators who prefer not to work as part of a team
- Monitor Evaluator - This type of individual is analytical and strategic, and is good at setting project objectives
- Specialist - Experts in an area that is vital to the project goals. Specialists can often become over occupied with technical aspects of the project

Ideally, attention should be paid to the personalities of members when forming a team to provide a balance of personality types, although in practice team composition may be dictated by those who are readily available at the time.

2.4 The fourth paradigm of science

The fourth paradigm of science is a term coined by Microsoft that describes the next stage of scientific discovery, namely the analysis of massive data sets [27]. The first three paradigms were experimental science, theoretical science, and computational science. In previous paradigms science was based around small data, however this data was often hidden in academic journals or stored in libraries or data warehouses, inaccessible to outsiders. Often data was lost when a scientist retired. With the development of faster computer processors modern science is now at the stage where more data is generated than can possibly be observed. The fourth paradigm describes a future where scientific data is stored online and available to all who wish to explore it. Rather than developing supercomputing algorithms to manipulate this data, there is an emphasis on collaboration. The democratisation of big data in the cloud presents numerous advantages, the main one being the reproducibility of experiments. Astronomy is one field of science that has embraced the fourth paradigm, with many projects involving the public interacting with their data [28]. This approach is termed crowd-sourcing [29].

2.4.1 Citizen science and crowd-sourcing

Both crowd-sourcing and citizen science are two techniques which have been used with some success to analyse big data [30]. A citizen scientist is a: "volunteer who collects and/or processes data as part of a scientific enquiry" [31].

A citizen science project could be limited in scope to just one citizen, whereas a crowd-sourced project would involve multiple participants. Crowd-sourcing involves a collaboration with a large number of volunteers, and the crowd could consist of both professionals and amateurs. A project could be both citizen science and crowd-sourced, depending on its nature.

Crowd-sourcing can involve collaboration with a large number of volunteers, in fact some projects can have millions of participants [32]. Many crowd-sourcing projects have been highly successful, engaging the public, promoting science, and facilitating research that would be impossible to implement purely with professionals alone. Citizen science is by no means a new approach. The Christmas Bird Count (where the public are invited to count bird species over the Christmas period) started in 1900 and has successfully attracted participants all over the western hemisphere [33].

There many examples of crowd-sourcing projects within the field of astronomy. Galaxy Zoo asked the public to classify galaxies based upon photographs (Figure 2.4) [34]. Space Warps was a project where the public viewed images to search for gravitational lenses [35]. Planet Hunter used crowd-sourcing to search for planets based upon NASA's Kepler Space Mis-

Figure 2.4: Galaxy Zoo interface

sion data [36]. Zooniverse is a web portal which collates many crowd-sourced projects [37].

2.4.2 Characteristics of crowd sourced projects

Although there is a wide range of crowd-sourced projects, many share common features. Most are facilitated and administered by a scientific professional who is an expert in the subject field [38]. This project leader organises the data and presents it in a format suitable for the crowd. The crowd receives the data and then generates a response which requires an analysis by the project leader. In many projects a participant has to go through a training phase before they are allowed to progress to real data. Some projects have a reward system which identifies successful participants. Another feature of crowd-sourced projects is the inclusion of known correct data which is used to keep the participants active because long periods without any positive results may lead to participants losing interest in the project.

2.5 Computer-Supported Cooperative Work

Computer-Supported Cooperative Work (CSCW) is a multidisciplinary academic field which focuses upon facilitating collaborative groups with technology. Wilson defines CSCW as:

> a generic term that combines the understanding of the way people work in groups with the enabling technologies of computer networking and associated hardware, software, services and techniques. [39]

Within the CSCW community, the term groupware describes software that is designed to support collaboration over a computer network. Examples of groupware are email, blogs, calendars, video conferencing tools, and digital white boards.

One of the key elements of this research field is the CSCW Matrix [40] which is illustrated in Figure 2.5. The matrix demonstrates collaboration in two dimensions. Collaboration can occur at the same time (synchronously) or at differing times (asynchronously), and collaboration can occur in the same place (co-located) or in a different geographical place (remote). This provides four distinct contexts for team-based collaboration:

- Face to face interaction - Interactions occurring at the same place and time, utilising the same venue, and technology such as digital white boards.
- Remote interaction - Interactions occurring at the same time in different venues. Utilises technology such as video conferencing, instant messaging, email, and telephone.
- Continuous task - Interactions occurring in the same venue at different times. Utilising team rooms, post it notes, memos, and wall displays.
- Communication and Coordination - Different times and different places. Utilising technology such as version control systems and blogs.

	Synchronous	Asynchronous
Co-located	Face to face interactions	Continuous task
Remote	Remote interactions	Communication and Coordination

Figure 2.5: The CSCW matrix

2.6 Discussion and conclusions

This chapter has presented a review of team-based methodologies which provide a basis for exploring this topic within an AD setting. We have looked at the advantages and disadvantages of group work and defined team structure, life span, and team roles.

Going forward there are several themes that may be of importance when considering AD-based team work.

- A team can be more efficient than solo working, providing enhanced quality and encouraging innovation

- There may be individuals who are not best suited for this type of work, although the great majority of people would benefit from being involved in a team

- A key phase of team development involves conflict and instability. This is a necessary dynamic of all groups and therefore some disagreements should be expected within any team

- The role of a team leader is important for teams of short durations and teams of individuals who haven't interacted before. The team leader is responsible for setting goals and activities

- Ideally a team should be developed from individuals with personalities sympathetic to its goals. In reality this may be problematic due to not having access to a large enough population of willing participants. The geographical spread of the AD community would require remote team solutions rather than co-located.

- CSCW provides a research led framework for encouraging collaboration in teams within the AD community.

Chapter 3

Auditory displays

3.1 Introduction

This chapter introduces the reader to the subject of ADs. There is an emphasis on describing ADs and various techniques including audification, model-based sonification and parameter mapping sonification. It includes a discussion on the advantages and disadvantages of using sound to present information.

3.2 Definitions

An AD is a human-computer interface where audio plays the main role in communicating information to the human user. The associated research field is relatively young, with the first major conference taking place in 1992 - the International Conference on Auditory Displays, with its proceedings published in a book [41]. In 2011 a new collection of writing on the subject, The Sonification Handbook, was published [42].

An AD uses sound to present information. There are many common examples of this from everyday life:

- A microwave oven emits a beep when its timed cycle is finished.
- In Westminster, every fifteen minutes, Big Ben chimes to inform Londoners of the time.
- When a document is placed in the recycle bin on a desktop computer a paper basket sound is played through the speakers.

All of these are examples of using sound to portray information. A more sophisticated example is that of a Geiger counter, a device used to measure ionising radiation. This device makes a clicking sound whenever it detects ionising particles [43] — the more particles detected, the greater the frequency of clicks.

Kramer [41] defines two broad categories of how ADs represent information: analogic and symbolic. An analogic display is where the sound directly corresponds to the information; any change in the structure of the information causes a matching change in the sound. The Geiger counter is an analogic display. The sound in a symbolic display, such as a microwave oven alarm, does not have a direct relationship to the information.

Although it is a distinct subset of ADs, the term sonification is often used to describe the process of transforming data into sound. In the pioneering 'Sonification Report' this is defined as: "The transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation" [44].

ADs use a series of techniques that take data as an input and generate sound as an output (see Figure 3.1). Generally, the input data is a numeric series such as a column of a spreadsheet, and can be multidimensional. An AD algorithm is a computer program that transforms data into sound. This algorithm can be implemented in a traditional programming language, such as C++/Java, or a graphical-based environment such as Max/MSP. The output is a synthesised sound, an audio file or a Musical Instrument Digital Interface (MIDI) file that is played through a synthesiser.

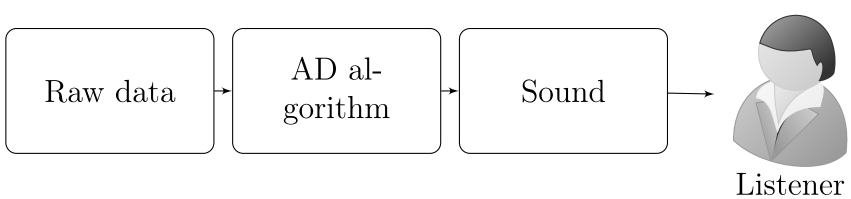

Figure 3.1: The AD process

Hermann [45] provides perhaps the most comprehensive definition of ADs to date. His definition is that a sonification technique may be considered to be an AD if it receives data as an input and then generates a sound signal output. In addition it must demonstrate the following characteristics:

- The sound reflects objective properties or relations in the input data

- The transformation is systematic
- The sonification is reproducible
- The system can be intentionally used with different data and also be used in repetition with the same data.

The term sonification has parallels with the term visualisation. Whereas visualisation is a process of representing data in a graphical format, sonification is a process where data is represented sonically. Listening to data can reveal patterns and structures that may not be apparent through visual methods. Hermann [46] identified several areas where ADs techniques could be utilised within a scientific context:

- Process monitoring
- Rapid summary of large data sets
- Searching for patterns in data
- Exploratory data analysis.

AD techniques have been applied in many scientific disciplines including astronomy, particle physics, chemistry, mechanical engineering, medicine, seismology and meteorology.

Many scientific investigations involve the analysis and exploration of large multidimensional data sets that have traditionally been explored by visualisation techniques alone [47]. However, there are limitations to visual perception, such as temporal resolution. Temporal resolution is the ability of the visual system to resolve time-based aspects of vision. This can be measured by a process called Critical Flicker Frequency (CFF) threshold. In this test, participants are presented with a flickering light and asked to indicate when the light appears to be constantly on rather than flickering. This threshold is in the region of 32 to 40 Hz, dependent upon the participant's age [48]. It is therefore difficult for an individual to resolve visual elements which change at a rate in excess of 40 Hz. However, the auditory system is able to resolve temporal data between 20 Hz and 20 kHz. ADs can provide an alternative to visualisation techniques or used in conjunction with them to enhance analysis by human users.

3.2.1 Interactive sonification

Interactive sonification is a subject that focuses on the importance of the listener influencing the sonification process in real time [49]. The user interacts with the data through its sound. They may have a controller that allows them to navigate the data, replaying a section, and adjusting playback speed and position. They may be able to adjust the sonification algorithm or the data-to-sound mapping process as it performs its transformation task. Interactive sonification studies the interface between the user and the data; a good interface should enhance the experience, whereas a poor interface could prove distracting. When interacting with the sonification process, the user becomes part of a feedback loop (as shown in Figure 3.2), the user becomes a proactive listener and thus is more engaged with the data and its interpretation.

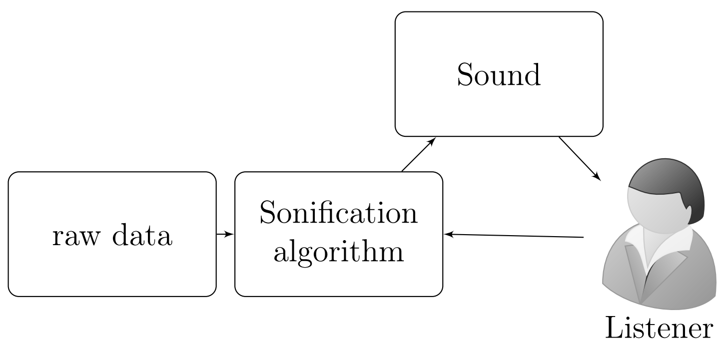

Figure 3.2: A listener within an interactive control loop

3.2.2 Why use sound to communicate?

There are several characteristics of auditory perception that ADs exploits [41]. The ear is excellent at perceiving time-based information, such as rhythm and pitch.

Humans can perceive several sounds simultaneously. Whilst listening to a classical music performance, one can distinguish the individual components of the orchestra concurrently. This ability means that we can listen to several sonified streams in parallel, which is advantageous when dealing with multidimensional information.

Backgrounding (ibid) is the ability of the human auditory system to relegate sounds to a lower priority. Although we are constantly surrounded by sound, we are not aware of most sounds until our attention is drawn to them. For example, we may not be aware of road traffic outside until a passing motorist sounds their horn.

Our hearing is multidimensional; we have the ability to localise sound. If a tiger snaps a twig behind us, we are alerted to this danger that we did not see because it was not in our field of vision. Unlike a visualisation system, we do not have to be orientated in the direction of the AD. The Geiger counter takes advantage of this trait. As it provides its information via audible clicks we do not have to constantly observe a meter, so we can safely walk around taking measurements, using our eyes more naturally to orient ourselves in the environment.

An AD can be eyes-free, enabling the user to listen to the data while occupied with another task. So the addition of sound can increase the amount of data presented without increasing visual overload. Our hearing is constant; we do not have the ability to stop hearing. This can be useful when monitoring data because if the data was visual we could miss an event if we looked away momentarily.

There are of course some disadvantages to the use of sound. Auditory perception is relative; when comparing two stimuli we can only state if one characteristic is same or if one is higher in magnitude than the other. We cannot give an absolute value. Many characteristics of hearing are co-dependent upon others, so a change in one will change how we perceive another. For example, our perception of loudness changes with pitch [50].

Some individuals may find the use of sound to be an irritation. Consideration should be given to environmental issues of sound; someone quietly working in the next office may not appreciate hearing your AD. The hearing capabilities of the listener may also be a consideration. Some people may have noise-induced hearing loss or even congenital amusia, otherwise known as tone deafness [51].

3.3 Types of auditory display

There are various classifications of ADs:

- Alerts and alarms
- Auditory icons

- Earcons
- Auditory graphs
- Audification
- Sonification.

ADs can be categorised as either discrete or continuous [52]. A discrete display represents information by a single audio event, e.g., a beep, alarm or short sound. A continuous display produces an evolving sound that progresses over time. These descriptors should be considered on a continuum, with no one technique being completely discrete or completely continuous. Whereas alerts, earcons and auditory icons provide information about discrete events, continuous displays use a process where raw data is analysed or explored through the medium of sound.

3.3.1 Alerts and alarms

The simplest use of sound in an interface is that of an alert or an alarm. An example of an audio alert is the telephone, which rings when someone calls. The modern motor vehicle utilises a number of alarm sounds, for example some will produce a tone if the driver attempts to drive with one of the doors open, and a different tone if the seatbelt is not worn.

3.3.2 Auditory Icons

Auditory icons are everyday sounds that are mapped to an event on a computer interface. The sound presented can be a realistic representation of the event, for example when transferring a document to a trash folder on a computer, the sound of a ball of paper entering a waste basket is played. Auditory icons share some characteristics of visual icons in that they are both representations of real-world experiences. The auditory icon is a caricature of the real-world sound. It is also possible to parametrise an audio icon. Gaver recognised that dimensional data could be directly mapped to the magnitude of a characteristic of an audio icon [53]. In the waste basket example, the sound could change in relation to how full the trash folder is, or the sound could be played at a different amplitude corresponding to the size of the document.

The main advantage of auditory icons is that they are familiar to the user. As they are natural sounds the user does not usually require any additional training to comprehend their meaning. The use of familiar sounds in a computer interface helps to make the interface more transparent to the user. There is also the advantage that icons are not based upon language so can be correctly interpreted irrespective of the listener's native language.

Buxton comments that "By making the model world of the computer more real, one makes the existence of an interface to that world less noticeable" [54]. The use of auditory icons is less appropriate when expressing abstract events such as changing a font on a text document [55].

3.3.3 Earcons

Blattner, Sumikawa, and Greenberg proposed the concept of earcons [56]. These differ from auditory icons in that they are an abstract synthesised tone that bears no direct relationship to a real-world event, so they are not a caricature of the event [57].

3.3.4 Auditory graphs

The concept of a graph is a familiar one (Figure 3.3), having an X and Y axis and a series of data points plotted between. Auditory graphs are a sonic representation of data. Each data point on the graph is mapped to a pitch on a synthesiser. The pitch of the synth depends upon where the point falls upon the Y axis. Starting at the XY origin each point is played from left to right so that the output is a series of notes that corresponds to the input sequence, with time representing the distance from the origin.

Multidimensional graphs can be represented by converting each dimension into a different instrument, for example piano, guitar and violin. This form of sonification can be beneficial for presenting graphical data to both visually impaired and sighted users [58].

3.3.5 Audification

In the Sonification Handbook Dombois and Eckel define audification as:

"a technique of making sense of data by interpreting any kind of one-dimensional signal (or of a two-dimensional signal-like data set) as amplitude

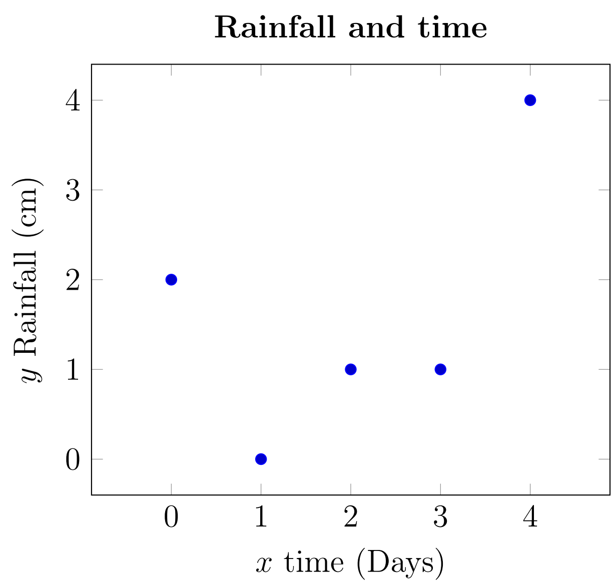

Figure 3.3: A graph demonstrating points on an X-Y plane

over time and playing it back on a loudspeaker for the purpose of listening." [59]

Audification is where a data set is directly converted to amplitude values of an audio waveform. Techniques are based around converting the data to digital audio samples, which can then be saved in an audio file. This practice is beneficial for working with large data sets. Although audification is the most direct and simplest AD technique it can be enhanced by signal conditioning such as re-sampling or filtering.

In an engineering context, audification was used by Pauletto and Hunt [60] in collaboration with Westland Helicopters to analyse flight data. There are numerous flight sensors on a helicopter, which the Westland engineers would print out in graphs and place on the floor so that they could examine all the data visually at once. Audifying the data was found to accelerate the diagnostic process.

3.3.6 Sonification

Sonification techniques are the most commonly used within AD research, and include parameter mapping and model-based sonification.

Parameter mapping

Parameter mapping is a sonification technique where input data is used to control a characteristic (parameter) of a synthesised sound. There are numerous characteristics of sound that can be utilised for mapping to a parameter such as pitch, loudness, localisation, rhythm, and timbre, which could be independently mapped to data in a multi-dimensional set. This is the most common form of sonification found in research. One method of parameter mapping is called sinification, where the data is mapped to the frequency of a sine wave oscillator [61]. Midification describes a process where the data is converted to MIDI note values that can then be played on a MIDI synthesiser [62].

An early example of parameter mapping was demonstrated by Bly [63] who showed that sound could be used to distinguish between three species of Iris flowers. She mapped characteristics such as sepal length and width to pitch, volume and timbre. When this was played back, each variety of Iris had its own characteristic timbre. Bly found that most listeners had the ability to accurately identify each species through sound alone.

Model-based sonification

In this technique a sonification model is a set of instructions which responds with sound by stimulation with data. Once stimulated the model will respond to the data dynamically until it comes to rest [64] With this technique data is used to map points in a multidimensional space. Each point of data has physical laws imposed upon it, which dictate how the data points relate to each other and the modelled space. The user then excites the data points by stimulating the system and the reaction of the points is sonified. In model-based sonification the data forms an instrument that is played by applying a stimulus.

3.4 Conclusions

There are several advantages to presenting information in a sonic format: the ear has a better temporal resolution than the eye, it can process multiple sounds simultaneously, and we can monitor sound whilst undertaking other tasks. These advantages are exploited by ADs. An AD is a computer interface that incorporates the use of sound, typically enhancing the experience for users. There are several techniques incorporated into ADs such as parameter mapping, audification and model-based sonification. AD techniques can be utilised for the rapid exploration of data sets, and pattern searching, characteristics that are relevant to this thesis. The next chapter looks at the prevalence of team-based AD activities within the existing auditory design community.

Chapter 4

Collaborative auditory displays

4.1 Introduction

This chapter investigates collaboratory ADs within existing auditory display research, to establish the extent of any previous work and to identify good practices or gaps in knowledge that may be suitable for further study. As identified in chapter 2, collaboration is a process where a group works together upon a common goal, and each participant is engaged in achieving a different part of the goal. Multiple participants in a research project are not necessarily collaborating, and this review has tried to identify existing work that explicitly expresses a collaboratory aspect of the work which involves AD techniques.

4.1.1 Interactive Sonification Workshops

The Interactive Sonification Workshop (ISon) is a series of five conferences that have been organised by Hermann, Hunt, and various collaborators [65]. Studying the number of authors of each paper can provide a rough metric of the depth of collaboration within this field, although there are some issues with this approach as the level contribution of an author is not apparent from them having their name on such a document. The number of papers submitted by pairs could be down to submissions of PhD students and their supervisors, where the extent of collaboration is undefined due to the practice of automatically adding the supervisor as an author.

Table 4.1 shows how many papers have been submitted for each year based upon the number of authors of each paper. The total number of papers

Number Authors	2004	2007	2010	2013	2016	Total	Total %
1	3	5	5	1	0	14	19%
2	6	2	4	4	5	21	28%
3	2	1	6	7	4	20	27%
4	1	4	3	1	3	12	16%
5	1	0	2	1	1	5	7%
6	0	0	0	0	0	0	0%
7	0	0	0	0	1	1	1%
8	0	0	0	0	1	1	1%
Total Papers	13	12	20	14	15	74	

Table 4.1: Table illustrating size of author teams for each ISon

submitted by solitary researchers is 19%, whereas 28% were submitted by pairs. There were just a few papers (9%) submitted by large groups of 5 or more researchers. It is clear that the majority of papers were submitted by smaller groups of researchers (three or less) which would indicate that some degree of collaboration is evident in a minor way.

4.2 Existing collaboratory AD research

To clarify the scope of this review, we have focused upon research that has the following criteria:

- Evidence of an AD context
- Evidence of collaboration of participants upon the AD task.

The search was not limited to purely AD research, for example from the ICAD community, but also expanded into the CSCW and Human Computer Interaction (HCI) arenas. CSCW is a field of research which focuses upon techniques that support multiple people working on common tasks [66]. HCI is a scientific field of study that focuses upon the design of technology for interaction between humans and computers. The following is presented in alphabetical order.

4.2.1 Aftershock

Aftershock was a collaboration between Natasha Barrett, a composer, and Karen Mair a professor of geosciences [67]. This creative work is based upon the AD of data received from crushing rock samples in a high-pressure rock deformation apparatus. When the rock samples are crushed they emit high frequency acoustic emissions and twenty four ultra-sonic transducers record this at a sampling rate of 4 MHz. The crushing event lasts only 0.15 seconds and produces a large amount of three-dimensional data. This data was conditioned by scaling in time, pitch and 3D space to produce an audification of the original data set. This audification was then incorporated into an installation called Crush.

This work describes a collaboration between a composer and a scientist, where the scientist guides the composer in understanding the nature of the data and how to obtain samples. It is not apparent how much input the scientific partner had over the creative components of this project, as it appears that any creative decisions were left to the composer. It would appear that this work is co-operative rather than collaborative, as both partners were not fully interdependent throughout the project.

4.2.2 AlloSphere and Allobrain

The AlloSphere is a surround view and surround sound immersive environment based at the University of California Santa Barbara [68]. It is constructed of two 10 m diameter hemispheres interconnected with two cylindrical central sections which contains a central bridge which can accommodate up to thirty people inside. A cluster of computers is used to render video feeds for twenty-six stereophonic video projectors, and sound is provided by a fifty-five speaker ambisonic system. The systems provide a 360°audio and visual environment for groups of people (as shown in Figure 4.1). Users can interact with the visual and audio systems by the use of a website which can be accessed on smart phones, tablets and any computer system that is internet enabled.

The Allobrain is an installation designed for the AlloSphere that creates a virtual world based upon brain blood density measured by functional Magnetic Resonance Imaging (fMRI) [69]. The data space is traversed by autonomous agents, which constantly emit a sound which is a parameter mapping of the measured blood density at that position. The position of

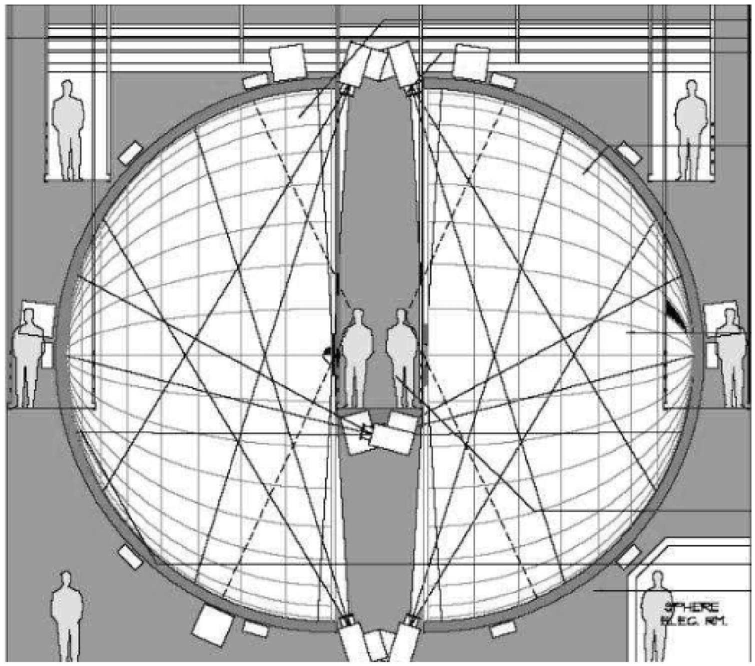

Figure 4.1: Plan of the Allosphere

the agent is continuously portrayed to the user by localisation of the sonified sound within a 3D soundscape. The user can navigate the data space using a gestural controller glove.

Cloud Bridge[1] is an interactive tool for the Allosphere where users synchronously explore data as an ensemble [70]. This system uses data derived from the Seattle public library as a basis for an ensemble performance/composition. Members of the ensemble interact with a Graphical User Interface (GUI) on iOS devices, which searches for keywords in the library's database. This returns data including check in and out time, number of times item has been borrowed, and the item's Dewey decimal classification. The data returned from the database is processed by the Max/MSP application which parameter maps the data into sound characteristics of a FM synthesizer.

The AlloSphere appears to be an exciting multi-media system that has been designed incorporating a 3D sound system that can accommodate teams of users within it. This system seems ideal for the development of a team-based AD space, where the users can interact with the data and each other

[1] A demonstration video of Cloud Bridge is available at https://vimeo.com/59465842

simultaneously. This would be ideal for both scientific and creative team AD tasks, however the high cost of this infrastructure would be a barrier to accessing such a system.

4.2.3 Augmented Reality based Interception Interface

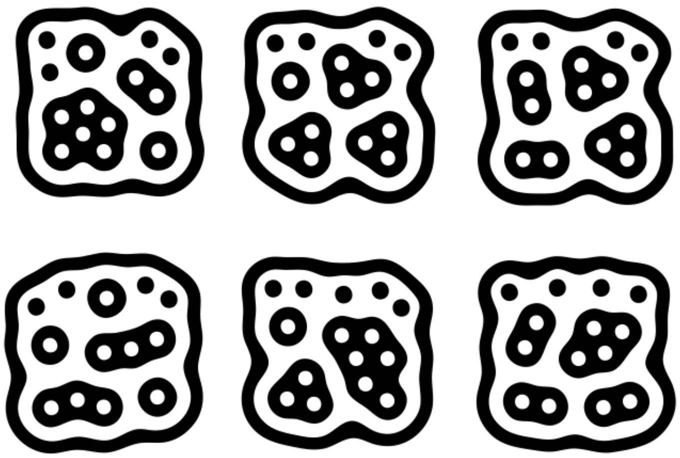

Figure 4.2: Fiducial for image tracking as used with a Reactable

The Augmented Reality based Interception Interface (ARbInI) is an Augmented Reality (AR) based system designed by Neumann and Hermann [71]. This system is based upon two users who collaborate upon a task within a AR setting. Each user wears headphones and the environment is set up with several cameras, a Kinect [72], and a Reactable [73] on which several fiducial cubes are manipulated. Fiducials are patterns used in image processing which have been designed to be easy for a computer system to detect its position and rotation easily, examples are illustrated in Figure 4.2. This system utilises AD techniques to add sound to activities such as moving one of the cubes. The use of AD in this setting allows users to be notified if an event happens outside of their (otherwise limited) field of view.

ARbInI is of interest to this work because it describes an AR system that may have benefit to a virtual AD team. The use of AR could enhance any interactions that may take place within a geographically isolated team.

4.2.4 Bat Detective

There have been a small number of audio-based crowd-sourced projects. Bat Detective [74] is a project which aims to identify and classify recordings of bats. An ultrasonic microphone was used to record overnight in the countryside, and the recorded ultrasound is then pitch-shifted down into the human hearing range. Unfortunately, each hour of recording then takes over six hours of playback to identify bat calls and to classify the calls based upon species. The microphone also picks up additional sounds such as motor noise, insects, and birds. The listener needs to filter out all these additional sounds to identify individual bats. The data is presented as a sonogram and as an audio snippet, so that the volunteer can decide if the data does contain a bat call based upon visual and auditory information. Bat Detective's interface is shown in Figure 4.3.

Figure 4.3: The Bat Detective user interface

4.2.5 DynaWall

DynaWall® is a large interactive electronic whiteboard measuring 4.5 m by 1.5 m which is touch sensitive [75], an example is illustrated in Figure 4.4. This system has been supplemented with audio capability to provide sound feedback to enhance human-computer interaction and human-human interaction. Examples of audio enhancements include using low frequency audio to provide haptic feedback to the users, and playing a sound when objects are moved around the screen. The use of audio cues enables groups of users to be notified if an event occurs outside of their vision. The authors describe their approach to AD as being a combination of auditory icons and parameter mapping.

This is yet another technological solution to group working with sound. However, at the stage described in this paper the AD appears to be an add-on, and an interesting approach to this technology would be to establish whether it could be used primarily for AD within a team setting.

Figure 4.4: Dynawall

4.2.6 Interactional Sound and Music

Interactional Sound and Music (ISM) is an emerging field of research described by Bryan-Kinns et al., as “multi-person technological mediated interactions primarily using audio” [76]. The authors recognise that collaborative aspects of interactive systems are under-explored and they offer several examples of how collaboration can be incorporated more fully into performance and AD based projects. This work is based around some principles of CSCW and identifies both remote and co-located aspects of collaboration.

Daisyphone[2] is an example of a remote music group compositional system [77]. This system is based upon music loops where participants collaborate upon improvisations by changing aspects of the loop such as pitch or adding their own loop. The system can be remotely accessed through a web interface and the results can be saved for later listening or performance.

Sensory Threads is an example of a co-located system where a group of people is placed within an installation that incorporates a soundscape which evolves according to data generated by the participants [78]. Each group member wears a device that measures aspects of their environment, such as heart rate, or light level, and this data is parameter mapped to pitch, tempo, and a filter. In both Daisyphone and Sensory Threads the authors found that adding visual cues greatly enhanced mutual engagement with the systems.

This appears to be the only AD based research that approaches the issue of collaboration in both remote and co-located situations and demonstrates that there is some previous work upon collaborative AD to expand upon. However, the work described in these papers is predominantly compositional or focuses upon the AD of a group's activity rather than investigating how interaction can enhance the AD process in a group setting which is the focus of this thesis.

4.2.7 Many-ears

Many-ears was a website developed by Schertenleib and Barrass [79] which was inspired by International Business Machines Corporation (IBM)'s collaborative data visualisation service called Many Eyes [80]. Many-ears was intended to collect together data and AD tools upon an open web framework with social media technology such as messaging, comments and email. The public was invited to share data and opinions on AD's via personal profile pages. On-line AD tools were implemented by utilising algorithms from XSonify [81].

Unfortunately, the Many-ears.com site is no longer active. There appears to be no further work on this site other than what is described in the above paper (which explains the site's objectives but does not provide an analysis of how successful the site was). In principle this appears to be an excellent idea, as a resource for social AD could be the stimulus for future collaborations

[2] A video describing Daisyphone can be viewed at http://isam.eecs.qmul.ac.uk/projects/daisyphone/daisyphone.html

and could raise the profile of AD among the general public. However, the fact that this site is no longer active could indicate that this approach is not successful or was difficult to manage.

4.2.8 MoodifierLive

This research describes the development of an interactive and collaborative mobile phone app called MoodifierLive [82]. This device is based upon the Kungliga Tekniska Högskolan (KTH) rule system of musical performance [83]. The app uses data from the phone's accelerometer to map the user's gestures to parameters of a musical performance (Figure 4.5). The authors found that mapping gestures to tempo, sound level, phrasing and articulation was most effective. To collaborate with this system several phones are linked to a server which plays a pre-selected MIDI file. During playback the performers can influence the performance by moving their phones, so that in essence the system sonifies the user's gestures. The authors found that the users responded positively to this system for manipulating elements of a musical performance.

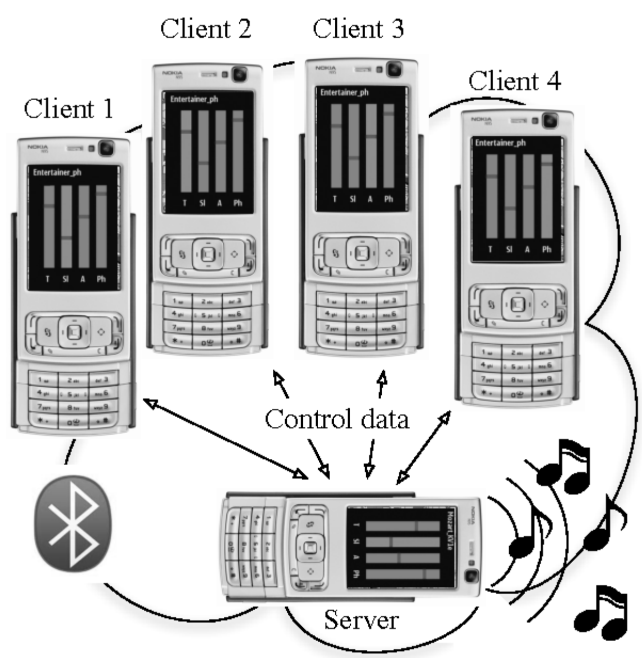

Figure 4.5: MoodifierLive setup

This work demonstrates another collaborative system where users can interact with sound in the same environment. It is unclear from the above paper how well the system enabled its users to collaborate with each other as it was only quantified by measuring the user's personal experience.

4.2.9 Sonification of brain and body signals in collaborative tasks using a table top musical interface

This research describes the development of an interactive system that utilises the AD of real-time physiological data to enable musical collaboration [84] and [85]. This system incorporates a Reactable, which is a table top tangible user interface [86], and Enobio, an hybrid Brain-Computer Interface (BCI) that is capable of outputting the user's Electroencephalogram (EEG) [87]. The system is operated by two people, one who wears the Enobio which records their EEG, and the other who moves fiducials on the Reactable. The EEG signal is mapped to a series of band-pass filters which control the frequency content of a white noise signal, therefore a peak in the EEG will be mapped to a peak in the white noise spectrum. The second collaborator can then interact with the sonified signal by moving fiducials on the Reactable, controlling various parameters of sound such as filters and delay. The two operators collaborate via the system to generate music.

The system developed in this example is collaborative as both users are fully engaged in the task and are reciprocally interdependent for the success of the project. The authors found that when the study was running with pre-recorded EEG signals with a solo user operating the Reactable, the user reported that the experience was less responsive than when collaboratively operated.

4.2.10 Exploration of sonification design process through an interdisciplinary workshop

Goudarzi [88] describes the organisation and implementation of a two-day multidisciplinary workshop where auditory display practitioners worked together with climate scientists and audio programmers to develop climate data AD's. In particular the group practised 'participatory design' which is an approach to design that actively involves all stakeholders [89]. The group found the collaborative approach to ADs refreshing and innovative, and they found that the workshops were especially helpful to the climate scientists (who were initially sceptical concerning the effectiveness of auditory displays).

These workshops demonstrate that a group approach to auditory displays can have a positive effect upon its participants, given appropriate time, resources and the correct personnel. The idea of involving all stakeholders in participatory design is particularly appropriate to this study.

4.3 Other related research

This section contains examples of other related research that has elements of group-work and is stated to involve an AD but does not strictly contain a AD algorithm.

4.3.1 Drum2Drum

Drum2Drum is a tangible device that was designed to encourage bilateral interaction by means of non-verbal sound [90]. It is constructed of two bongos which have been fitted with a piezoelectric sensor to detect when the drum has been hit, and a solenoid which is used to strike the drum head to create a sound. Both are controlled by an integral Arduino board. The two bongos are placed in separate rooms and when one bongo is struck, this sends a message to the other bongo to reproduce the sounds. Therefore, two users can interact with sound through the bongos in different environments.

Users found the system enabled them to participate in an enjoyable experience. The above paper is mainly descriptive of a prototype and does not go into too much analysis of how it could improve interaction. There appears to be no further evidence that the system was developed further after 2013.

4.3.2 EMOListen

EMOListen [91] is a multi-user platform that enables a group of listeners to interact and sonify bio-signal data. This system is based around a Nokia N900 Maemo computer, which can connect via a cloud server to multiple users. Input is provided to the device by a Varioport bio-signal capturing device, a Neurosky Mindset sensor and a Nokia Polar sensor. EMOListen is capable of receiving respiration, heart rate, Electromyogram, Galvanic Skin

Response, and EEG data. A graphical user interface was developed to map the bio-signals to effect plug-ins such as echo, reverb, and filters.

This is an interesting attempt at multiple-listeners interacting with each other via sound, however this device does not seem to purely sonify data, only applying effects to an audio stream based upon bio-signals generated by the group. This paper does not describe in any detail any evaluation of how the system performed.

4.3.3 MoodMixer

Moodmixer is an installation where participants collaborate to mix electronic music via EEG [92]. Two participants were positioned in a room which has a four-channel surround sound system and a video projector (Figure 4.6. Each participant wears a headset which streams EEG data to a computer system running Max/MSP. The Max patch decodes the raw EEG data and uses the participants ' brain states to control the mix level of four tracks of an electronic music composition. In addition to the audio system, a projector is used to display a visual representation of each user's brain state. The participants use meditation to induce a calm state to control the level of the tracks.

It could be argued that this is a BCI system as it doesn't strictly convert data to sound. This work does highlight the possibilities for having a AD system which is based upon two user's collaboration via EEG through non-traditional interfaces other than keyboard or mouse control which could enhance the collaborative aspects. This work could be the basis for an ensemble type collaboration, where multiple users interact in a co-located environment.

4.3.4 Touch screen ensemble music

Favilla and Pedell designed an interactive interface used to encourage patients with dementia to collaborate musically in a group setting with other patients [93]. This system was based around several iPads which communicated with a centralised server through the Open Sound Control (OSC) protocol. Each patient can control a parameter of the sound by moving their finger on the iPad screen, which generates sound which in turn can be heard by all of the participants. Two trials were conducted, one where participants collaborated to create an abstract electronic performance, and another where

Figure 4.6: Moodmixer set up

each individual controlled a parameter of a performance of J.S. Bach's Goldberg Variations. The authors found that this system worked well in bringing these patients together to collaborate on a performance without any musical experience.

This project is of interest to this thesis because it describes a real-time collaborative system where operators can interact with each other and the sound. This could be a basis of an ensemble-based method of a group of individuals interacting within the same environment.

4.3.5 Whale FM

Whale FM is an audio-based citizen science project where volunteers were presented with a sonogram and audio. The purpose of this work was to classify killer whales based upon recordings of their song [94]. This project has since been retired, since it was found that listeners were able to classify whale song but were not as accurate as computer-based methods [95].

There are a number of similar sound-based crowd-sourcing projects involving nature classification. Papadopoulos et.al. [96] demonstrated that volunteers could differentiate different birds based upon recordings . Anderson describes a citizen science initiative to measure sound levels in aquariums

[97], and Zilli [98] describes a smartphone app that can be used to identify an endangered insect called the New Forest Cicada .

4.4 Discussion and conclusions

The most regular source for examples reviewed here are from ICAD, however the majority of research has been submitted through other venues such asThe International Conference on New Interfaces for Musical Expression (NIME), and other sources which focus upon interactive HCI or CSCW. This would indicate that although there is some evidence of collaborative AD based research within the ICAD community it has not been a major theme, and most work on this subject appears to be sources from other research communities. As demonstrated in Table 4.1, the majority of AD based research does not focus on a collaboratory approach. Although teamwork would not be appropriate for all, this community could benefit from working together in a more structured manner.

Encouraging more collaboration in ADs could offer this community the following advantages:

- Multiple users independently listening to the same data will provide a more rigorous verification of any results obtained — automatic peer review
- Team synergy — the team is greater than the sum of its parts
- Improved quality through increased peer review
- Increased opportunities for knowledge transfer
- Promotes innovation
- Increased opportunities for personal development/mentorship
- Promotes the research area to other disciplines and the public.

Table 4.2 maps the research discussed in this chapter to the CSCW matrix, which illustrates how the nature of this work fits into an established framework. It is apparent that the majority of collaboratory work undertaken was predominantly synchronous and co-located, i.e., occurring within

Project Name	Sync	Async	Remote	Co-located	AD Scheme
AfterShock		*		*	Audification
AlloBrain	*			*	Parameter Map
ARbInI	*			*	Auditory Icons
Bat Detective		*	*		Audification
Brain and body	*			*	Parameter Map
Cloud Bridge	*			*	Parameter Map
Daisyphone		*	*		Parameter Map
DynaWall	*			*	Auditory Icons
Many-ears		*	*		Multiple
MoodifierLive	*			*	Parameter Map
Sensory Threads	*			*	Parameter Map
Workshop	*			*	Multiple

Table 4.2: Group AD research mapped to CSCW matrix

the same environment at the same time. As the AD community is relatively small and spread over the globe, remote collaboration would seem to be an attractive proposition as it would encourage researchers to work together when previously isolated. This may also be of benefit to those who have limited travel opportunities such as parents and disabled people.

The most striking feature of this review is the scarcity of collaboratory AD's, especially when compared to the large amount of research presented in this field over the last thirty years. Although it could be argued that some collaboratory work may exist but hasn't been explicitly expressed in writing, there does not appear to be a focus upon working together within this community with structured methods. Perhaps the most formally structured example of collaboratory AD's is the interdisciplinary workshop described by Goudarzi [88] where a multidisciplinary group was organised, which was considered a success. However that event was a single occurrence which would be prohibitively expensive to organise on a larger scale. The geographical spread of the AD community would require a different approach to collective working, such as virtual teams or other remote methods. The use of teamwork could also provide an important method of engaging the wider public with this community, which could raise the profile of this research field.

Given the importance prescribed to team-working principles within industry and the benefits of this approach described in chapter 2, the AD community may be missing an opportunity to enhance, promote and improve upon the work developed in this area. This thesis will investigate how teamworking methods can be promoted and further implemented within the AD field.

Chapter 5

Multi-listener auditory displays

5.1 Introduction

Previously this thesis has covered some background theories of group working, provided an overview of the AD research field and reviewed the current literature on collaboration within AD. The purpose of this chapter is to synthesise the previous learning and to propose novel approaches to AD within a collaboratory environment. This collection of collaborative techniques will be called MLAD.

5.2 Overview

> The current enthusiasm for team working in organizations reflects a deeper, perhaps unconscious, recognition that this way of working offers the promise of greater progress than can be achieved through individual endeavour. [99]

This thesis began by exploring background information and theories of collaboration and group work (chapter 2), where it was found that there are several advantages to working together on a project, such as increased effectiveness, improved quality and synergy. A lot of work on encouraging collaboration with people assisted by computers is provided by the CSCW research field. The CSCW matrix (illustrated in Figure 2.5) shows us that collaboration has several dimensions - asynchronous/synchronous and remote/co-located.

Next, an overview of AD was provided (chapter 3). This young research field has a yearly conference organised by ICAD where researchers from all over the globe come together to share information and to network. The process of turning data into sound is called sonification, and this is just one technique explored by this area, with other techniques such as audification, parameter mapping, model-based sonification, auditory icons and earcons.

In the literature review (chapter 4), research was identified that highlighted examples of AD research where participants interacted with both the sonification process and other individuals. The results in this field are scarce but do illustrate some evidence of collaborative sonification occurring successfully, albeit in a minor way.

5.3 Auditory display teamwork

The low incidence of pre-existing fully collaborative groups within the AD community is of concern, as it appears that this community may not be making full use of collaborative techniques which could offer many potential benefits. The development of virtual teams within AD could offer advantages including the removal of geographical barriers to collaboration and enabling research opportunities for those who cannot travel for family or disability reasons. Developing remote AD strategies could open this research area to a new audience of external subject specialists and might also engage members of the public.

It is proposed to develop techniques for MLAD. These approaches will incorporate aspects of traditional group work, CSCW, and existing AD algorithms such as audification and parameter mapping. It is proposed that the nature of these techniques will incorporate elements of the CSCW matrix (illustrated in Figure 2.5), with each section divided into remote/co-located and synchronous/asynchronous. This is illustrated in Figure 5.1 below.

Classifying these groups by location and time allows us to approach each area with a clearly identified methodology. As identified in chapter 4, the majority of historical research incorporating collaboration occurs in a co-located environment (as illustrated in Table 4.2) therefore the majority of focus in this thesis will be upon methods which incorporate remote working methods to bridge this gap in knowledge within this area. To provide a complete overview of group work, co-located methods will also be considered under the collective term AD Ensemble. Ensembles will incorporate both

	Asynchronous	Synchronous
Remote	Distributed AD Team	Virtual AD Team
Co-located	Asynchronous AD Ensemble	Synchronous AD Ensemble

Figure 5.1: The MLAD matrix

asynchronous and synchronous methods.

5.3.1 Remote Collaboration

Remote collaboration occurs where team members are not in the same environment as each other, and computer technology is used to facilitate interaction within the team. The technology utilised ranges from email to video conferencing, and enables collaboration unlimited by geographical location, travel costs, and in some circumstances can have a time-saving benefit as it cuts down commuting time.

Remote collaboration can take place both synchronously and asynchronously. Synchronous remote collaboration occurs where team members work upon a task in separate locations at the same time. An example of this would be a team of academics who hold a video conference to interact upon a task. Asynchronous remote collaboration occurs where team members work upon a task in separate locations and at different times. An example of this would be a team of academics who communicate via email. The boundaries between asynchronous/synchronous may be fluid in certain situations, for example a team may communicate via email and video conferences.

For this thesis we have developed two distinct types of remote AD teams, Distributed AD teams and Virtual AD teams. A case study has been developed for both which is described in subsequent chapters.

Distributed AD Teams

A distributed AD team is a group of people who work upon a common task in separate locations and at separate times. The team is distributed geographically, and interaction will only occur with a centralised facilitator who administers the group. This approach to AD shares many characteristics of a grid computing system, where a task is implemented on several separate computers. Parallels can also be drawn with a project such as Eric Whitacre's Virtual Choir [100], where thousands of singers separately record their own voices, which are then combined to form a choir. Like Whitacre's Virtual Choir, it is anticipated that distributed AD teams will require a central administrator or facilitator to co-ordinate the collective's activities.

A distributed approach to AD will be advantageous where there is a large amount of data that requires analysis. For example, a data-mining task may result in a twenty-hour long sonification. A solo listener would have difficulty in listening to this in one sitting. They would naturally experience fatigue and distractions which would reduce the efficiency of their work. If, however, this was listened to by a community of forty listeners, each only interacting with thirty minutes of data, the influence of listener fatigue would be reduced. Confirmation of any results could be achieved by multiple people listening to the same data. The use of a distributed collective, when dealing with large amounts of data, could lead to more accurate results.

The case study developed to investigate distributed AD teams is a project called SonicSETI, where a team of remote listeners are utilised to detect signals in radio astronomy data. This is discussed in detail in chapter 6.

Virtual AD Teams

A virtual AD team is a group of people who work upon a common task in separate locations simultaneously. Interaction within the virtual team is assisted by computer technology such as video conferencing. A virtual AD team may have a facilitator; however, all team members will fully interact with each other. There will be a high level of interdependence within a well-organised virtual team.

There are several possible benefits of having a virtual AD team. The AD community is relativity small and geographically diverse. Opportunities for face-to-face collaborative work are diminished by the high cost of travel and limitations on time. Interacting in virtual teams can provide many benefits that would be attractive to this community such as increasing opportunities for collaborative research and disseminating experience to a wider audience.

The case study developed to investigate virtual AD teams is a project where a team of remote researchers from three different countries come together virtually to work upon an AD problem. This is discussed in detail in chapter 8.

5.3.2 Co-located Collaboration

Although the focus of this thesis is on remote AD collaboration, some preliminary work was undertaken in exploring co-located techniques and is included here as it opens further possibilities for further work in this field.

Co-located collaboration occurs when a team interacts within the same environment. A car production line is an example of this, where workers collaborate on tasks in the same production line. This approach to AD teams has been called Ensemble AD's.

AD ensembles are where a group of listeners synchronously interact with a common data set in a shared environment. The advantages of this approach are that the group can interact with both the data and each other. A shared environment means that the group is collectively influenced by the same stimuli. This adds another level of interaction as the members of the ensemble will interact with both the sonification and each other.

The user listens to the sound and through an interface can adapt the sonification algorithm. The addition of a second listener enables the team to interact with each other and the sonification (data and algorithm). It should be noted that there may be a limit to the maximum number of members of the ensemble, since an excessive number of listeners may only distract each other.

5.3.3 Conclusions

The main difference between a distributed and a virtual team is the level of interaction and interdependence between team members. In a distributed setup most of the team will only interact with the facilitator, and there is a low level of interdependence. There is a high level of both interaction and interdependence in a virtual team. A comparison of both team types is provided in Table 5.1.

AD team type	**Task complexity**	**Scale**	**Interaction**	**Inter-dependence**
Distributed	Low	Large	Low	Low
Virtual	High	Small	High	High

Table 5.1: Comparison of distributed and virtual team characteristics

The distributed AD team may be most appropriate for tasks that are large scale, challenging in terms of scope, and not easily achievable by a single practitioner. This type of team could be described by a *many hands make light work* philosophy.

The virtual AD team is best suited for complex tasks that would benefit from a synergistic team of listeners. The high level of interaction within the team enables the team to perform at a much higher level, which is required for tasks that are too complex to achieve by a solo practitioner.

The following chapters of this thesis will explore different aspects of MLAD through case studies of experimental group work designed by this author. Starting with SonicSeti, which is a distributed AD, then exploring a virtual AD. Ensemble based work is examined by the organisation of a work shop at a ICAD conference. After each case study is considered the overall field of MLAD is considered in this reports conclusions section.

Chapter 6

SonicSETI

6.1 Introduction

This chapter discusses the sonicSETI project, a citizen science-based AD tool. This project builds upon the techniques developed in this thesis of distributed multi-listener AD's. An application will be developed that will provide white noise as a background masking tool, this tool will use data generated by SETIQuest, which is an open data initiative developed by the SETI Institute. This tools interface will include the facility to report back if any candidate signals are perceived within the white noise. These reports will be collated centrally to ascertain if multiple hits are received on the same data.

6.2 The Search for Extra-Terrestrial Intelligence

The SETI is a scientific endeavour concerned with the detection of intelligent life originating outside of our planet. One of the first academic documents on the SETI is a paper written by [101]. They proposed that a technologically advanced civilization, like our own, might be broadcasting information utilising radio waves. These waves would propagate at the speed of light throughout the universe and may be detectable here on Earth. Since the advent of radio we have been emitting electromagnetic radiation and this could be detectable. However, radio waves are subject to the inverse-square law their power diminishes proportionally to the square of distance. Broadband signals are likely to be lost over great distances, it is theorised that intelligent extra-terrestrial civilisations may use high power narrow band beacons to communicate over large distances [102], this is why SETI-based searches are looking for evidence of narrowband signals.

SETI involves monitoring radio waves received on Earth, and then establishing if any signal has characteristics of intelligence, as opposed to a signal of natural origin [102]. An Earth-based example of an intelligent signal would be a radio broadcast, where an audio signal which has been modulated by a carrier signal, an example of this is illustrated in Figure 6.1.

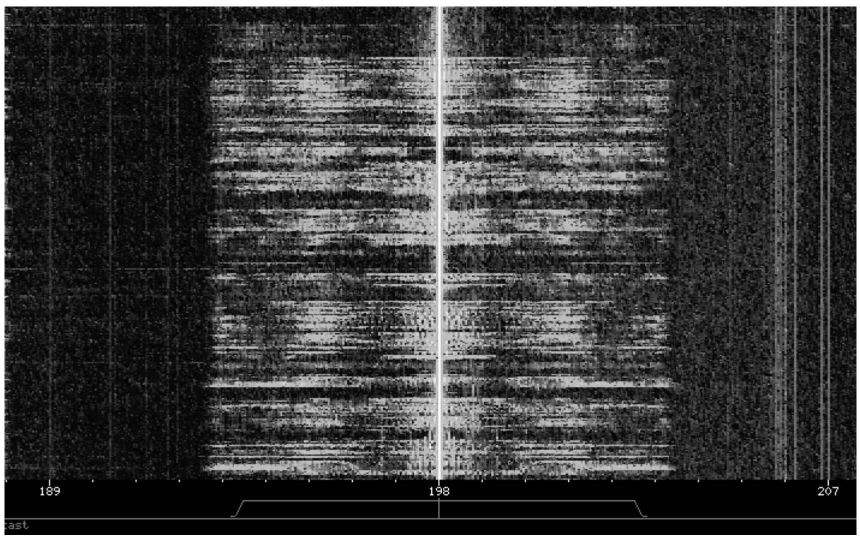

Figure 6.1: A waterfall plot of a LW radio broadcast

This figure demonstrates a waterfall spectrum plot which is a common method of visually representing radio frequency data over time, and was generated by taking a screen shot of a BBC Radio Four broadcast on a web-based Software Defined Radio (SDR) [103]. A waterfall plot is generated by taking successive Fast Fourier Transform (FFT)'s' of a radio signal, and then converting them into one horizontal line of an image, each pixel representing the energy stored within one FFT bin. If the energy stored within the bin is greater than a pre-set threshold level then the pixel is set to white, otherwise it is set to black. Each horizontal row of the image represents a FFT of the data, and the vertical axis represents time.

Figure 6.1 indicates the presence of a carrier signal at 198 kHz which has the appearance of a vertical white line. The modulated audio information is stored in the side bands of this signal which can be seen radiating out from the carrier. The background of this image shows a static distribution which is characterised by random points. This is due to the radio observations being mainly comprised of Brownian white noise [104].

The two main issues with this approach to SETI is the size of data and the ambiguous definition of what an intelligent alien signal could look like. Radio observations generate a large amount of data and it is impractical for the scientific community to actively observe this data for any candidate signals due to the large amount of time that it would take. This has been called the data deluge [105]. Secondly, any candidate extra-terrestrial civilisation may be at such an advanced stage of technology in comparison to our own that it is simply impossible to predict the nature of any signals emitting from it. In essence this approach to SETI requires us to detect candidate signals within a static background and the rule out those from known sources such as radar, satellite communication or natural phenomenon's such as pulsars. One solution to these issues is to involve the public in citizen science projects like SetiQuest [106] or SETILive [107]. In these projects the public is asked to identify signals visually and then any candidates are vetted by the scientific community.

6.2.1 SETIQuest Explorer

SETIQuest Explorer is a citizen science project which asked volunteers to look at a series of waterfall plot images. If the volunteer noticed the presence of any signal within the image they could click a button to notify SETIquest [108]. The volunteer was asked to classify the signal into several subgroups. Whilst it is impossible to predict the nature of any signal of intelligent origin, SETIQuest have made an educated guess that they may fall into the following groups -

- Local Locked - this type of signal of terrestrial origin, which is indicated by the fixed centre frequency which could come from a radio broadcast or a geostationary communications satellite
- Diagonal - diagonal signals show a source which is increasing or decreasing in frequency, this is often caused by the Doppler effect and is generally considered to be caused by motion of the source of the signal and the earth. Doppler shifted signals are considered to be of non terrestrial origin

- Squiggle - The squiggle signal describes a signal of randomly varying frequency
- Pulse - pulse type signals are non-continuous signals
- Broadband - broadband signals are characterised by a wide
- Modulation - signal exhibiting modulated characteristics
- Radar - radar pulses
- unknown - a signal with characteristics not listed above.

Images showing expected spectra of these signals can be seen in Figure 6.2. Some of these signals will be of an terrestrial origin. For example, Local Locked would be a signal received by a satellite in Earth's orbit, and radar signals may be man-made. A signal received from an intelligent source may be subject to a Doppler shift, which is caused by the source and the Earth both being in motion. This type of signal would appear as a diagonal line.

SETIQuest Explorer was decommissioned in 2012, because it was found that volunteers struggled to view images containing mainly static for any length of time [109]. SETIQuest then concentrated its effort on a new project called SETILive [107], which was based upon a live feed of radio astronomy data. SETILive was discontinued in 2014 due to limited funds. Both SETIQuest Explorer and SETILive were successful projects, in that they captured the public's imagination and they were able to cross-check computer simulated searching with human results.

6.2.2 SETIQuest

SETIQuest is a citizen scientific project set up by the SETI Institute [110] which as a objective of making SETI based data and algorithms that act upon that data available for the public to access and use.

The SETIquest data archive contains four TB of data recorded from radio telescope observations [106]. This data is presented in eight-bit quadrature samples. Quadrature data techniques are often utilised in radio transmission, as these techniques greatly simplify radio modulation and demodulation. A quadrature signal comprises of two elements, the first element I, contains information a that is required to be transmitted. The second element Q, is

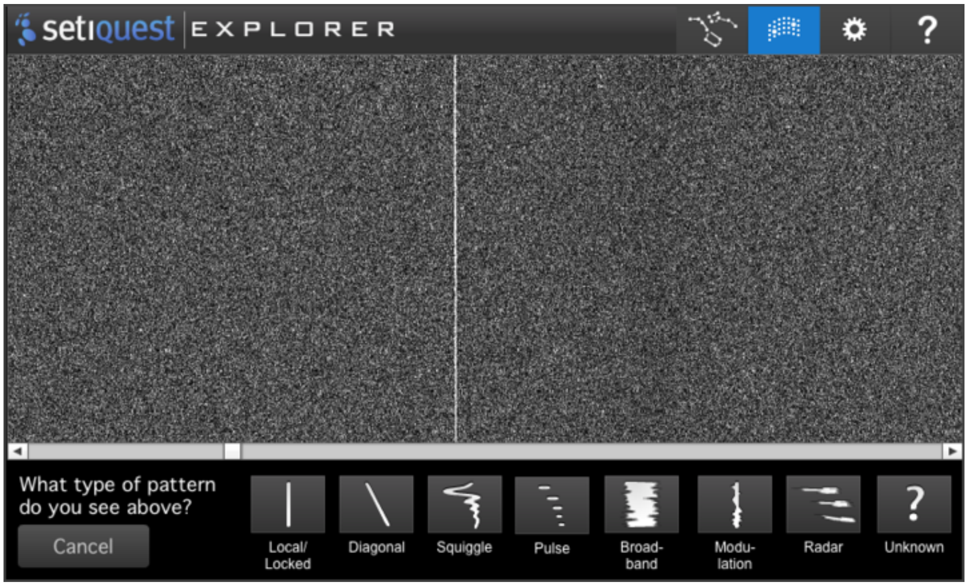

Figure 6.2: The SETIQuest Explorer console

a version of I that has been phase shifted by 90°[111]. The word quadrature comes from 90°being a quarter of a circle.

SETIQuest data is drawn from a variety of different targets such as the Moon, pulsars, quasars, and exoplanets. Each observation can generate around eight to ten GB of data, and this data is accessible on their website and is separated into multiple two GB files to assist in downloading. Visual inspection of this data is aided by the generation of waterfall plots.

6.3 SonicSETI

To visually search for signals representative of an alien intelligence requires the generation of a high volume of waterfall plots, and a great deal of time to observe them. Visual methods have been shown to be inefficient in the exploration of large scale data, could this be an application where ADs can provide greater efficiency? There have been several areas identified where AD techniques could be utilised within a scientific context [46]:

- Rapid summary of large data sets
- Searching for patterns in data

- Exploratory data analysis.

This would indicate that AD techniques may be a useful tool for the exploration of SETI based data.

6.3.1 Audification of SETI data

The first AD technique prototyped was audification. Data for this experiments was taken from setiQuest radio observations of the Moon [112], this was used as a source due to its similarities with the noise distribution of other SETI based observations. The data was audified by creating a Python program that extracts the sample data and converts it to a mono audio wav file, which was thirty seconds in duration at 44.1kHz, sixteen-bit resolution. The Python code used for this is shown in Listing 6.1. The white noise characteristic of this programs output were confirmed by visually inspecting a spectrogram of the data (Figure 6.3).

```
import wavfile
import measurement

def createWhiteNoiseWavFile(lengthInSeconds, noiseLevel,
    sampleRate):
  file = open("moon.dat", 'rb')
  lengthInSamples = lengthInSeconds * sampleRate
  data = [0] * lengthInSamples
  scaler = 32767.0/128.0

  # Read each complex sample and multiply real x scaler
  for i in range(0, lengthInSamples):
      value = file.read(2)
      double_value = struct.unpack("<b", value[0])
      data[i] = double_value[0]* scaler

  # Calculate level
  peak = measurement.getPeakLevel(data)
    rms = measurement.rms(data)
    peak_dBFS = measurement.dBFS(rms, 16)
  level = noiseLevel - peak_dBFS

```

```python
    # Apply gain to data and save as wav file
    gain = measurement.dBtoLinear(level)
      data = wavfile.applyGain(data, gain)
    wavfile.createWav("audified_seti.wav", sampleRate, data)

createWhiteNoiseWavFile(1200, -30, 44100)
```

Listing 6.1: Audification of radio astronomy data in Python

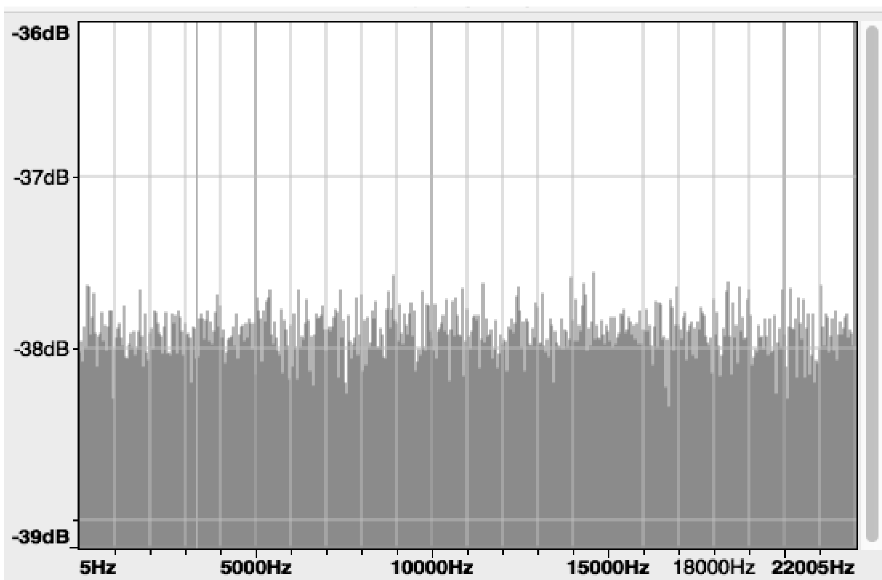

Figure 6.3: Spectrum of audified SETIQuest data

6.3.2 Listening to white noise

It was recognised that white noise is often used in office environments to block out environmental distractions such as traffic noise, building works, or colleagues' conversations. There are various examples of web-based white noise generators designed specifically for this purpose, for example [113].

The initial hypothesis of this research was to discover whether participants could detect signals within white noise played in the background in an office environment. As the audified SETI data resembles white noise, this could be utilised as a masking source. With this premise, a number of listening tests were designed to establish if participants could detect the presence of signals in white noise of varying time-scales, and with varying levels of distraction.

6.3.3 Experimental design

To test if SonicSETI would work in principle, a couple of listening experiments were designed to establish firstly if listeners were able to detect these signals when actively listening to white noise. The second experiment will establish if listeners can detect signals for a longer time whilst undertaking a distraction activity. The following hypotheses were developed;

- Listeners are able to detect the presence of SETI-type signals presented during thirty seconds of white noise.
- Listeners can detect the presence of signals mixed in with white noise whilst engaging in a distraction activity for fourteen minutes.

The first hypothesis tests users' signal detection ability using active listening, the second tests their ability whilst passive listening.

The test signals were selected based upon criteria described by SETI, when giving examples of potential alien signals (see figure 6.2). A C++ program was developed to synthesise tones, and the pulse and squiggle waveforms were generated by *The Voice*, a Java application that converts images to sound [114]. The following signals were generated:

- Sine wave at 200 Hz
- Sine wave at 1 kHz
- Sine wave at 10 kHz
- Chirp from 200 to 10 kHz
- Pulse
- Squiggle – tone that deviates randomly in frequency.

Spectrograms illustrating the sonic characteristics of the pulse and squiggle signals are shown in Figures 6.4 and 6.5.

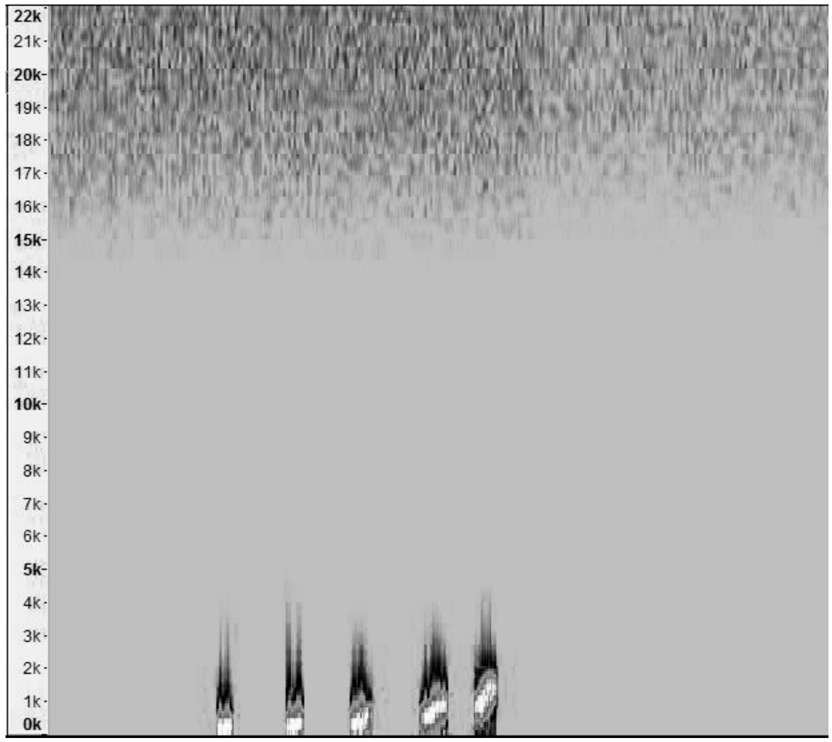

Figure 6.4: Spectrograms of pulse signal

6.4 Active Listening test

The purpose of the first experiment was to establish whether listeners were able to detect the presence of candidate SETI signals whilst actively listening to thirty seconds of white noise. A listening test was designed to play back several samples of SETI-type signals which were mixed in with white noise. Due to the short time-frame that these signals were presented it was anticipated that these tests would provide feedback on listeners' active listening skills, as opposed to passive or background listening. This initial test was intended to ensure that listeners can actually detect such signals while pro-actively listening to them, prior to testing their passive listening abilities.

The hypothesis of this experiment is:

Listeners are able to detect the presence of SETI-type signals presented during thirty seconds of white noise.

The test took place in the radio production studio at the University of

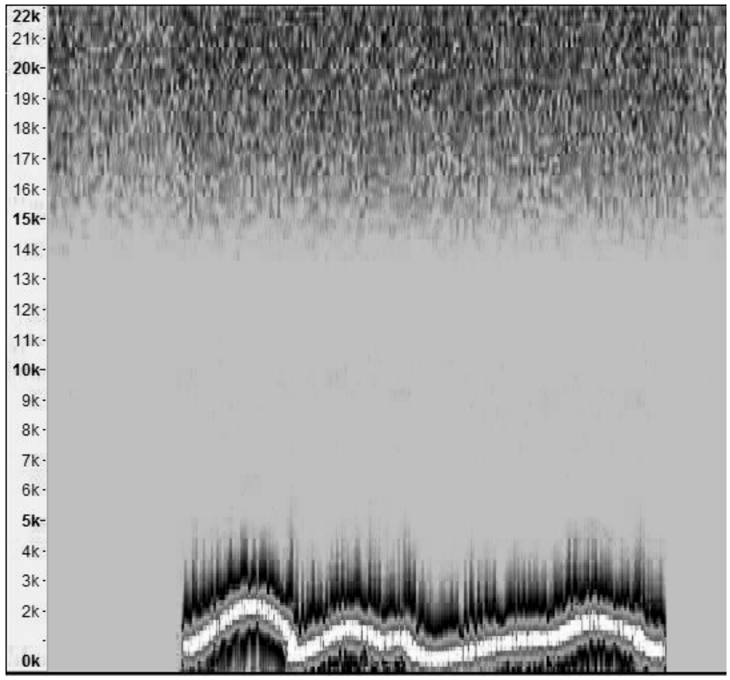

Figure 6.5: Spectrograms of squiggle signal

Huddersfield, which is acoustically neutral and isolated from external noise sources. The sequence of test files was randomized and played to the participants through a pair of Beyerdynamic DT100 headphones. After each file was played the participant was asked to score between one and ten their confidence that they perceived a signal, with ten indicating a high confidence that a signal was perceived and one indicating the strongest perception of no signal. In addition, they were asked to record whether they could identify the type of signal present; tone, pulse, chirp, squiggle, or no signal present. Prior to the test commencing, each participant was played examples of each signal type without white noise for reference. Nine participants performed this test, one female and eight males aged between 20 and 47.

6.4.1 Results

The combined results of this first listening test are shown in table 6.1. The table shows, signal type, level in dBFS, the number of participants who correctly detected the signal and the average confidence of a signal.

Num	Signal type	Level (dBFS)	Num correct detections	Average confidence
1	200Hz Tone	-46	9	10.00
2	Pulse	-40	9	9.33
3	Squiggle	-46	9	8.78
4	10kHz Tone	-46	8	8.89
5	None		7	1.67
6	Squiggle	-52	4	3.33
7	10kHz Tone	-52	8	7.89
8	Chirp	-40	9	10.00
9	1kHz Tone	-52	9	9.67
10	Pulse	-52	6	6.33
11	Chirp	-52	9	9.44
12	200Hz Tone	-40	9	9.89
13	1kHz Tone	-46	9	9.89
14	10kHz Tone	-40	9	9.89
15	Squiggle	-40	9	9.44
16	None		5	3.56
17	Pulse	-46	9	9.11
18	200Hz Tone	-52	9	9.56
19	1kHz Tone	-40	8	9.67
20	Chirp	-46	9	9.67

Table 6.1: Results of listening test one

6.4.2 Discussion of results of active listening test

These results show that those surveyed can detect the presence of signals mixed with white noise whilst actively listening. Confidence of detection is greatest with sinusoidal signal types, and increases with the amplitude of the signal. The correlation of increased detection with amplitude is to be expected as louder sounds can be distinguished easier than quiet sounds. The majority of signals presented in this experiment had a confidence score greater than 8.0 and a detection rate in excess of 89%. The poorest performing signal was the squiggle. The participants struggled to identify the absence of a signal. This would indicate that although participants are able to distinguish SETI-based candidate signals when presented within white noise whilst actively listening, there will be a reasonably high incidence of falsely reported signals.

These results show that this experiment's hypothesis stands; that **Listeners are able to detect the presence of SETI-type signals presented during thirty seconds of white noise.**

However, these results have identified issues with false detection, where individuals are reporting signals which were not actually present. The incidence of false reports appears to be randomly distributed throughout this group of listeners, rather than being down to a subset of 'bad' listeners. Therefore, any future attempts to detect signals within white noise should be presented to a group of listeners. The group would act as an automatic peer review system for reporting signals, whereby if several listeners indicate the presence of a signal at a certain time then this can confirm the presence of a signal. Any false reports would be randomly distributed and thus ignored.

Several of the test participants reported that they found the task quite difficult as they were unsure if they were actually hearing signals and that only after they had heard a "real" signal it reassured them that the signals they had earlier perceived were illusory. This reporting of "phantom signals", i.e. signals that were not present in the original files, was the most reported comment from this test. It was decided to further investigate this phenomenon by repeating the test, but this time with nine out of ten audio files containing white noise only, with no additional signals, and only one file that contains a signal as a control. Now test participants would be played just white noise, to establish the level of reporting of illusory signals. This experiment was conducted and it was found that the characteristic of phantom signals is heavily influenced by pre-playing example sounds. If a listener is

Signal start time(seconds)	Frequency	Amplitude (dBFS)
56	200Hz	-30
137	200Hz	-50
251	1kHz	-40
446	1kHz	-30
788	200Hz	-54

Table 6.2: Signal frequencies, amplitudes and start times

expecting a sound, they will perceive a sound with the same characteristics. The full phantom signal experiment was the subject of a conference paper presented at ICAD 2013 [2], and is included in appendix B.

Overall, this experiment has been effective at establishing a baseline ability of listeners to identify signals in noise, and has identified the important issue of phantom signals, which needs to be considered in further testing.

6.5 Passive Listening test

The results of the previous experiment indicated that test participants were able to detect signals mixed in with white noise whilst listening actively for short periods. The objective of this test is to establish if signals can be detected passively in the background whilst an individual is working. For this experiment participants were asked to read whilst having noise played (with occasional embedded signals). This experiment looked to establish whether individuals will respond to a signal if they are distracted.

The hypothesis of this experiment is:

Listeners can detect the presence of signals mixed in with white noise whilst engaging in a distraction activity for fourteen minutes.

6.5.1 Experimental procedure

An audio file, fourteen minutes in duration, was created containing noise at -30 dBFS, generated from a SETI radio observation of the Moon [115]. Mixed into the noise are five sine waves that are ten seconds in duration. These tones occur at various times throughout the test, and details of their frequency, amplitude and start times are shown in table 6.2.

	Time of report (seconds)								
ID	1	2	3	4	5	6	7	8	9
1	59	147	253	448	790				
2	57	60	140	172	252	447	792		
3	59	145	252	449	790				
4	59	140	250	447	789				
5	57	140	227	253	450	800			
6	57	141	254	450	793				
7	54	60	140	254	449	611	729	784	791
8	57	140	253	449	792	838			
9	58	140	253	310	448	789			

Table 6.3: Times of signal detection reports for each participants

These listening tests took place in an acoustically isolated room, where each listener was fitted with a pair of DT 100 Beyerdynamic headphones and asked to read a section of the novel The War of the Worlds [116] whilst listening to the audio file containing noise and signals. Listeners were asked to concentrate on the reading activity. If they perceived a signal, they reported this to the examiner by pressing a button, whereupon the examiner would log the time. The button was not connected to any device but acted as an indicator that the listener had heard something. After the audio file was played, each listener was asked to complete a short questionnaire on the reading material (see appendix C), which was intended to establish if each listener was taking an active part in the reading task. At the conclusion of the test each participant was given a short test upon the content of the first chapter of War of the Worlds, to ensure that they were actively reading during this experiment. All participants scored highly on this test, which demonstrates that all had been reading the text.

There were nine participants, aged between 29 and 61, eight males and one female.

6.5.2 Results

A table has been collated of the times that each participant registered a signal and pressed the button (Table 6.3). The leftmost column (ID) is the participants' number and the time in seconds that each listener reported a

ID	Sig 1	Sig 2	Sig 3	Sig 4	Sig 5	Correct	False
1	1	1	1	1	1	5	0
2	2	1	1	1	1	5	2
3	1	1	1	1	1	5	0
4	1	1	0	1	1	4	1
5	1	1	1	1	0	4	2
6	1	1	1	1	1	5	0
7	1	1	1	1	1	5	4
8	1	1	1	1	1	5	1
9	1	1	1	1	1	5	1

Table 6.4: Table of correctly identified signals per candidate

signal is listed in the rows to the right (for example participant four indicated five signals at 59, 140, 250, 447 and at 789 seconds. Several participants reported more than 5 signals, with participant seven reporting nine signals.

Table 6.4 indicates the number of correct reports per candidate. A report is identified as being correct if the candidate presses the button during the time that the signal was present. The column labelled 'correct' indicates the number of correctly identified signals, and the False column is the number of false positives – button presses when the signal was not present. The data appears to show some anomalous data: Participant two appears to identify signal one twice; Participant four's identification of signal three is before the signal started (which could either be a false positive or an error when the time was written down); Participant five identified signal 5 after the signal ended.

6.5.3 Discussion of results of passive listening test

These results demonstrate that the hypothesis of this experiment stands; **Listeners can detect the presence of signals mixed in with white noise whilst engaging in a distraction activity for fourteen minutes.**

There is a high incidence of correct detection of the signals mixed in with white noise; the majority of listeners correctly detected all five. Out of the fifty-nine signal reports, eleven of these were false (18%). This would indicate that listeners are able to detect the presence of signal mixed into white noise whist distracted by a reading activity. Evaluating these collated results as a group, it is clear to see that the real signals can be identified. When a listener falsely reports a signal, they do so in a random manner. A bar chart which plots the number of reports against the time of report is shown in Figure 6.6.

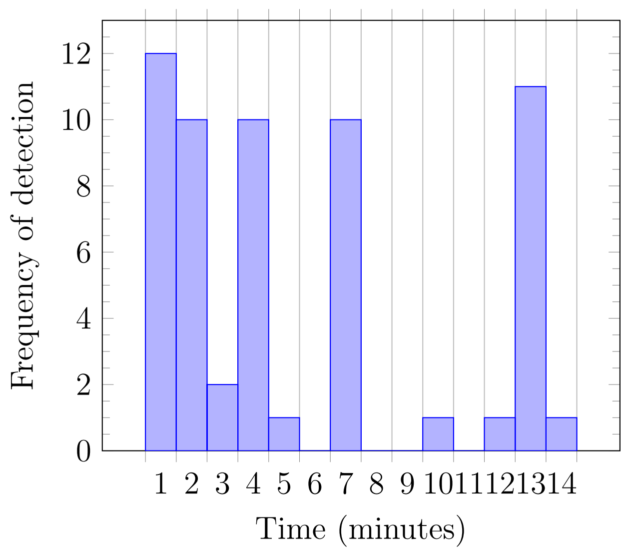

Figure 6.6: Histogram showing incidence of reports against time

Figure 6.6 shows that this ***team*** of listeners was able to correctly identify the presence of the five test signals presented; this is demonstrated by the five peaks on the histogram which correspond to the times of signals. The single points on the histogram are erroneous reports. By inspection of the graph it is easy to distinguish between clustering of hits when a signal occurs and the low incidence of errors.

6.6 Discussion of SonicSETI

These results demonstrate that within a short and medium time scale of fourteen minutes, participants were able to read and detect signals mixed in with white noise. They were able to subconsciously monitor background noise and became aware of sonic changes within it. This could indicate that this background noise approach to data exploration has potential, however it is still to be established if similar results would occur over longer time-scales such as one hour or even a eight hour day. This medium time scale experiment was useful for confirming that listeners can perform background monitoring. The next step would be setting up a study based upon longer durations (e.g. one hour) and should take place within the volunteers' workplace which includes all of the usual environmental noise. Such a study would naturally be the next step in this research, and a discussion of this will be contained in the further work section of this report.

As a proof of concept, SonicSETI would appear to have grounds for further research on longer time-scales. This does demonstrate that team work can be an effective distributed AD tool.

Chapter 7

Multi-listener workshop

7.1 Introduction

An experiential workshop was organised at the ICAD conference in Graz, Austria which took place in July 2015. The session was facilitated by this author and was two hours in duration. Eight attendees responded that they wished to attend prior to the event and two more turned up on the day. The attendees were aged between 21 and 50 years old, and came from a variety of destinations including USA, Australia, Germany, Austria and the United Kingdom. All attendees that pre-booked were advised to bring a laptop, with Max/MSP installed, and a set of headphones. Max/MSP provides a run-time version that can be downloaded at no cost and is capable of running all activities. All attendees had had some experience with ADs. The workshop had the following agenda:

1. Welcome and coffee
2. Multi-listener AD presentation
3. Task one: Distributed auditory display
4. Coffee break
5. Task two: Pair sonification
6. Task three: Ensemble radio finder
7. Feedback and conclusions

7.1.1 Presentation

After coffee the attendees sat around in a semi-circle and each member of the group introduced themselves and gave an overview of their AD experience.

A twenty minute presentation was made to the group. The purpose of this presentation was to introduce the attendees to some multi-listener techniques developed as part of this thesis. The presentation was also used to remind attendees to install a free version of Max/MSP to run the tasks. An overview of each task was introduced to the group.

7.1.2 Task one: Distributed auditory display

The first task was a demonstration of how a distributed AD could be utilised in a team-based situation. The design of this task was a simulation of the SETI-based white noise with signals mixed in. For this task each attendee was asked to work independently. Two separate Max/MSP patches were designed for this task. The first patch was installed on each attendee's computer, and played some white noise and had a button that they were asked to press if they heard a signal (see Figure 7.1). Each button press caused a message to be transmitted via User Datagram Protocol (UDP). The send message contains the time that the button was pressed. There was no limit to the number of times a message can be sent.

The second patch was run on the session facilitator's computer, and this collated any timestamped messages received via the network, and plotted a histogram of the results, with the test audio shown below for reference (Figure 7.2).

Results

The results of this test are illustrated in Figure 7.2. This exercise enabled several attendees to interact both independently and as a group. It served as a good warm-up exercise and enabled the facilitator to go around the room and make sure that everybody was set up with a computer. Unfortunately, several attendees did not bring their own computer which meant that they couldn't participate in this first task on their own. Several attendees tried to do this first task in pairs due to lack of computers, although the subject of this workshop was team working, we didn't want participants working together until the second exercise.

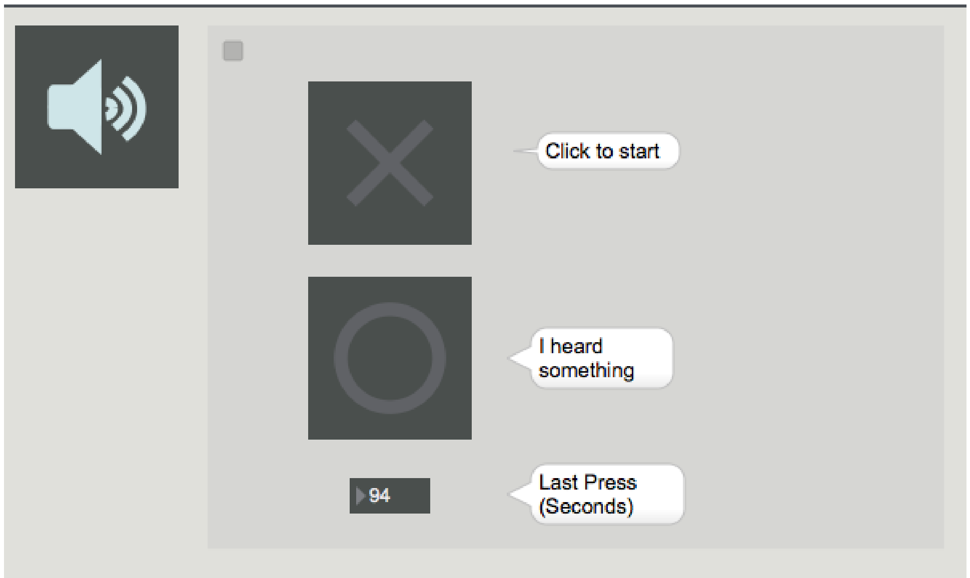

Figure 7.1: Task one transmitter interface

The output from all received messages (Figure 7.2) was shown to everybody after the task was completed. This figure shows at the bottom a graphical representation of the audio file used for this task, and on the top is a histogram of all responses. Both plots share the same time-line, so we can see when people clicked the button in response to hearing a signal. We can clearly see that most responses fall within the period when the signal occurred. There are a few spurious events which indicate erroneous data. This plot confirms the findings of the original experiments, in that several listeners can be used to find signals mixed in with white noise whilst actively listening.

7.1.3 Task two: Pair sonification

For the second task workshop attendees were asked to work in pairs. The purpose of this task was to demonstrate how two people can approach AD's (in a similar manner to the agile software technique of pair programming). This exercise was based around the tuning of a radio, where one attendee oversaw changing the controls under guidance from the other member.

The raw data for this task is a recording of speech that has been quadra-

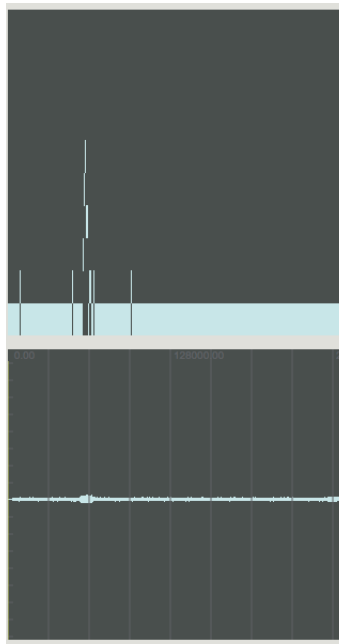

Figure 7.2: Task one receiver interface

ture amplitude modulated. To hear the speech clearly it is required to be demodulated, however the modulating frequency and filter width are not provided to the listener. To hear the speech with intelligibility the pair are required to try to find the best match of frequency and filter width – this can only be achieved by trial and error, it is hoped that each pair will work together to try to find the optimum settings. This task's GUI has three parameters - volume, filter width and frequency offset, and is illustrated in Figure 7.3.

Results

Five sets of pairs were able to tune this data so that it became intelligible. Several participants mentioned that they enjoyed the social aspects of working within teams. Some commented that the other member of the pair was able to dominate the task, and they didn't feel comfortable challenging them as they had only just met. The dominant member would take over both roles in this exercise. This would indicate that some pairs would need a little more time getting to know each other before embarking on such a task, time to

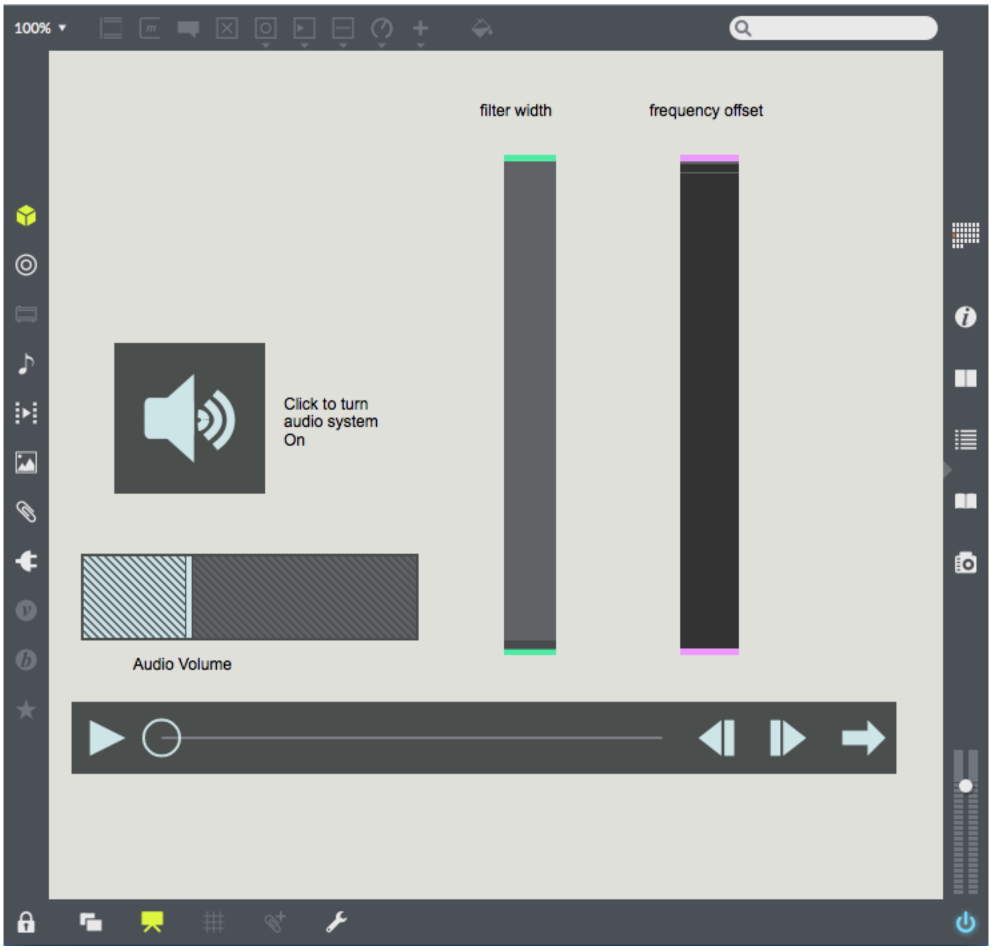

Figure 7.3: Task two pair radio interface

build understanding and trust between the pair. This could also be caused by the dominant individual being used to solo working and having difficulty adapting to a team setting.

7.1.4 Task three: Ensemble radio finder

The final task was designed to encourage the participants to work together in an ensemble upon a common problem with a deadline. The interface designed (see Figure 7.4) was similar to that developed for task two. This time the quadrature modulated radio signal consisted of a male voice saying the names of fruit. The radio transmission was thirty minutes in duration and the fruit names occurred at random times within the recording. Each team was given only fifteen minutes to find the best demodulated settings and to list as many fruit names as possible. Only having fifteen minutes to preview a thirty minute recording was intended to force each group to come up with a solution that required allocation of work within the team.

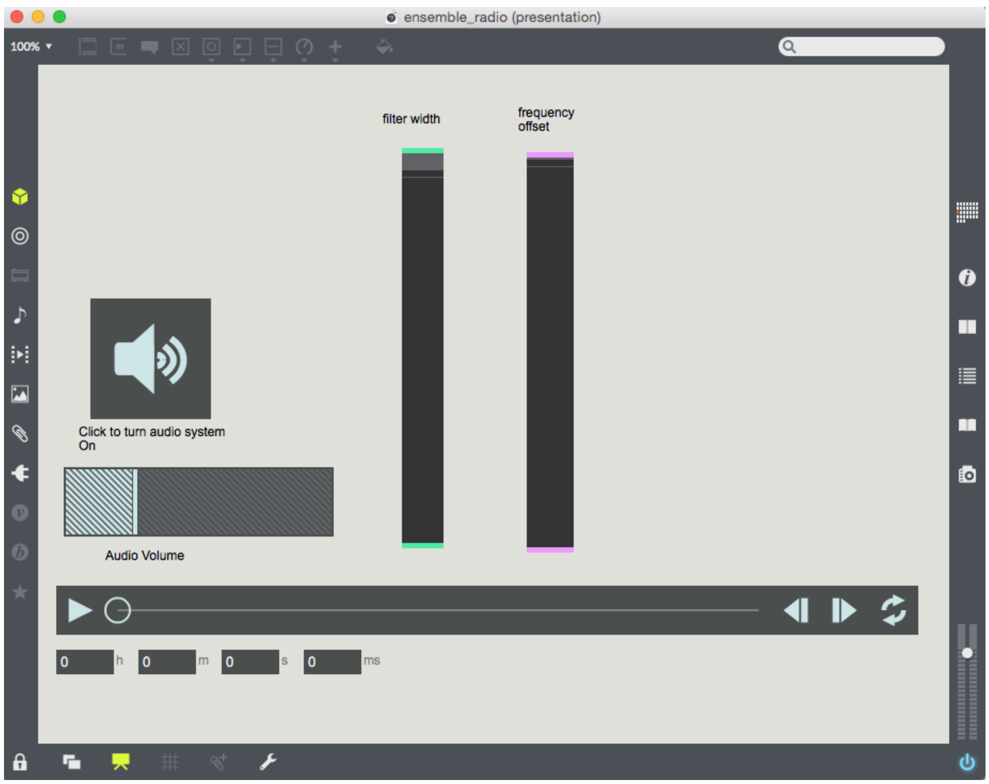

Figure 7.4: Task three ensemble radio interface

Results

This activity was more open ended than the previous two tasks, with the intention of keeping the brief broad to see if the groups would incorporate aspects of team working into their approach. There were three ensembles who undertook this activity. One team split the task amongst themselves and found 90% of the fruit names. The second team all listened to the same audio concurrently and were only able to find 50% of the fruit names. The third group cheated by opening the data up in another application to view a visualisation of it, which enabled them to visually find the times that the words were spoken and then tune the radio to listen. Consequently, they reported 95% of the fruit names. Apart from the team who "cheated" the best approach for this task was taken by the team who delegated the work amongst each other and received a score of 90% accuracy.

7.2 Conclusions of workshop

This workshop was useful in understanding how teams of people might be able to work together on AD tasks. Several of the attendees stated that they enjoyed the social aspect of team work and would be looking to incorporate these themes in their future work. One of the main findings of this session was to note how each group's task could have been monopolised by a dominant individual taken over control of the task. The brief time that the groups were together was not enough time to establish trust and many of the groups appeared to only progress to the storming stage of their formation, where individual members are establishing boundaries and hierarchies within the team. From this workshop it is apparent that a lot more time is required to develop effective groups than is available within a workshop setting. A more effective approach to team working in ADs would provide more time for a team to work through the developmental process described by Tuckman [15]. The AD research community is geographically spread around the world where individual researchers may not have the opportunity for regular face to face interaction with each other, this would indicate that a virtual team may be a more effective approach to collective research.

Chapter 8

Virtual auditory display team

8.1 Introduction

Many lessons were learned in the organisation and implementation of the multi-listener workshop (chapter 7). The two-hour duration did not allow the teams to develop past the forming stage which reduced the effectiveness of these groups, and severely limited the amount of communication and work that each group could undertake. Several groups were dominated by individuals, and without effective internal leadership this led to some individuals not fully participating in activities.

As the AD community is geographically widespread, a more effective approach to team collaboration could be provided by incorporating elements of virtual working into an AD team. This might offer several benefits including, allowing the team more time to develop and form working relationships, and enabling interaction with team members who cannot travel. A virtual AD team is a group of people in different geographical locations who collaborate on a common task. The virtual team can interact through digital communication systems such as email and video conferencing.

To gain insight into whether virtual teams can be an effective solution to collaborative ADs, a pilot study was designed where a team of remote AD researchers was organised to collaborate upon a sonification task within a virtual team. The team was given a task, and then worked both collectively and remotely upon a solution. The team met up virtually at regular times to communicate.

8.2 Red wine quality

The task for this pilot study was based upon a red wine quality data set, which was created by Cortez et.al [117], and downloaded from [118]. The data in this set is a chemical analysis of 1600 red wines. In addition, each wine has been subjectively analysed and evaluated by a panel of wine tasters for quality. Quality is a number between 0 and 10 (0 is poorest, 10 is best). The goal of this task is to use AD techniques to model wine quality based on chemical tests.

The data is in CSV format, which is an open source spreadsheet file format. Information concerning each column of data is summarised in Table 8.1.

Attribute	**Maximum**	**Minimum**
ID	1	1599
fixed acidity	15.9	4.6
volatile acidity	1.58	0.12
citric acid	1	0
residual sugar	15.5	0.9
chlorides	0.611	0.012
free sulphur dioxide	72	1
total sulphur dioxide	289	6
density	1.00369	0.99007
pH	4.01	2.74
sulphates	2	0.33
alcohol	14.9	8.4
quality	8	3

Table 8.1: Attributes and quality of red wine

A call for participants was posted on ICAD's message board and a small team of three members was formed. The team members all reside in different countries, Canada, Austria, and the UK. All team members had some experience of ADs prior to this study, and all had participated in at least one AD project leading to an academic paper before.

8.3 Organisation

The organisation of this virtual team was based around a series of video conferences, implemented through the Skype application [119]. All team members were provided with a copy of the data and a description listing maximum and minimum values prior to the first meeting. It was the author's intention to not prescribe any roles or working methodology on the team other than requiring attendance at several video conferences and to ask participants to fill out a questionnaire at the end of the study. The decision to have no prescribed team methodology was taken, to see if the team was self-organising. During the workshops (chapter 7) it was observed that there were several issues with team leadership, some teams were dominated by an individual, and some teams failed to understand the task and required additional support from the facilitator. This author decided that to avoid similar issues in this experiment, it would be necessary to participate and lead the team. This would hopefully have the advantage of enabling the team to focus on the task at an earlier stage. The authors approach to leadership was enabling rather than dictatorial, ensuring that the group worked on the task but every member gets the opportunity to fully participate if they choose to do so.

8.3.1 Week 1: Virtual meeting 1

The first meeting was organised as a welcome session, and to have a brief discussion on the task and data. One participant raised concerns about intellectual property rights during this study, and so it was agreed to implement the Lambert Agreement which is an Intellectual Property Rights (IPR) agreement written by the UK government for organisations who wish to collaborate on research [120]. Under this agreement each participant agreed to post the following disclaimer on any work shared within the virtual team:

> This document and the information in it are provided in confidence, for the sole purpose of [insert details], and may not be disclosed to any third party or used for any other purpose without the express written permission of [insert details].

The team felt that the best approach would be for everyone to work separately on the task and then come together at the end to compare and discuss each other's work.

There was some discussion on the best time to have video conferences as there is a significant time difference between Europe and Canada, and one member had a part-time job that they needed to give priority to. This meant that the best times for the meetings was to alternate between 13:00 BST or 23:30 BST (6:00 PDT or 16:30 PDT), as either was out of office hours for at least one participant.

The meeting ended with a discussion of what software was to be used, and it was decided to use a combination of Max/MSP, Python, and Supercollider [121].

8.3.2 Week 4: Virtual meeting 2

The second meeting was called for team members to update everyone on their progress so far, and to allow everyone to give feedback on the work others had done. There was some discussion on how to disseminate work between team members, and the team decided that the best approach would be to submit either via video or upload to an area of cloud storage on Google Drive [122].

8.3.3 Week 8: Virtual meeting 3

The third virtual meeting called for sharing of work and discussions of this. All team members submitted their work to the cloud storage in anticipation of this meeting. During the meeting each summarised their findings, and then received feedback from the group on their work. This prompted discussion of the data and the effectiveness of the auditory displays. It was felt by all team members that more work was required to refine the results, and that the team would continue to meet and work together after this report.

It was also decided that this process would make a good submission to the next ICAD conference, and they would work together on this.

8.4 Teamwork

Here follows a brief description of each individual's contribution to this task[1]:

[1] A series of screen casts have been created of all team members contributions and is available to download at https://github.com/dalmatianrex/multi-listener-auditory-displays

8.4.1 Team Member A

This team member produced a series of ADs of the data set utilising a parameter mapping algorithm. This AD was developed using an application called Sonic Pi [123], which is a textual coding language based upon Supercollider. A screenshot of this development is shown in Figure 8.1. The approach here was to create a histogram of each parameter in the data set and then sonify it into a chord, thus creating a single gestalt for each parameter. This team member found that normal distributions sounded *balanced* and skewed distributions sounded *murky*, and that the subjective quality parameter lacked enough resolution to provide any useful relationships with the objective measurements.

8.4.2 Team Member B

This team member took a statistical approach to examining the data prior to applying any sonification algorithm. They firstly calculated the mean, standard deviation, and coefficient variation of each individual data set to try to identify if any parameter had large fluctuations. This member that found only a few potential parameters would be of interest: fixed acidity, chlorides, density, pH, sulphates, and alcohol. These parameters were then sonified utilising a Max/MSP patch which mapped parameters to an FM or AM synthesis algorithm. A screen-shot of this patch is illustrated in Figure 8.2. This member found that they couldn't detect any interdependencies using an AD so far and suggested that this may be due to the nature of the quality parameter that appears to be averaged and therefore lacks resolution.

8.4.3 Team Member C

This team member approached the problem by mapping parameters to characteristics of a physical modelling synthesis algorithm in Max/MSP. This is illustrated in Figure 8.3. A vibraphone model was excited using all the objective measurements of an individual wine so that the sonified sound could be directly heard to establish if any there are any sonic similarities of wines of related quality. This member found that there was no sonic similarity in this approach.

8.4.4 Team discussion

The team came to the conclusion that they had not found any strong evidence so far that there is any relationship between a wine's subjective quality and its measured chemistry. However this is still a work in progress as the team wishes to continue in this study and will refine the AD's developed collaboratively.

There are several different results of investigations of this data set by other researchers using data mining methods. Some authors found similar results to this team [124] and [125], although some have identified a relationship between measured alcohol and quality [126]. At this stage it is difficult to conclude whether ADs have merit for the exploration of this type of data set, as there appears to be no conclusive relationship within this data set. However, this case study was designed to highlight how a team can virtually collaborate upon a problem rather than finding a single definitive solution.

8.5 Conclusions

During this case study the team interacted using cloud documents, email, Skype messaging and video conferencing. The most effective communication method appeared to be video conferencing where all team members were able to discuss the ADs with everybody contributing ideas and feedback. Skype was particularly useful as it provided a *show my desktop* function which allowed individuals to demonstrate their AD approach to the others, which offered greater opportunity for feedback and reflection.

Team members completed a short questionnaire at the end of the third meeting, about their experiences during this exercise. Although the team was small, some general findings can be reported:

- members felt that joining a virtual team didn't negatively affect their creativity
- members felt that this was a worthwhile exercise
- members strongly felt that they would incorporate teamwork in future research
- members strongly felt that working in teams can be an effective approach to ADs

- members strongly felt that working in teams can be an efficient approach to ADs

Team members verbally responded very positively to the experience of collaborating with academics from different backgrounds and found that this was an excellent learning experience. A copy of the questionnaire responses, consent form and overview sent to participants is available in appendix F.

This study indicates that the creation of a virtual AD team can greatly enhance the participation of team members. This team were geographically spread around the country and could not have effectively worked together on this project without virtual team methods. Additionally, it is concluded that these techniques could facilitate enhanced participation from those who have restricted access to travel, due to financial reasons, family commitments, or those researchers who have a mobility based disability.

During this process there were several issues raised concerning virtual team working within ADs:

- Time Zones - It was challenging to find times when all team members could be available for meetings. A virtual team which has an intercontinental spread may experience this issue. This was resolved in this team by alternating times between mornings and evenings. It may not be possible to collaborate over long distances during standard office hours for all participants.

- Team size - this author had difficult in attracting participants to this study. Although three members is technically a team, and this team worked well together, a larger number of volunteers may have yielded different results. This may be due to researchers' reluctance to work in teams, preferring solitary working methods. It is possible that if the profile of MLAD's is raised then more researchers would be open to this approach.

- Video conferencing involves listening to people speaking in several environments simultaneously. During one meeting, a team member was in a noisy café and the high amount of environmental back ground noise was very distracting to everyone else in the video conference. If one team member is in a noisy environment, this can adversely affect the clarity of speech and any AD's. Individual team members must take care to ensure that they are communicating in a environment conducive for AD research.

- Trust - building trust amongst the team is vital for the success of the team. Trust issues were raised at the inception of this team; however, this issue was not raised again as the team developed and gained trust with each other.

- Technology - this team collaborated via Skype discussion and shared screens of their developed AD's. To further enhance interaction within a virtual team one option could be to utilise virtual reality technology, creating a virtual reality space where remote users can interact with each other and aspects of an AD simultaneously.

Overall, the virtual AD team was a valuable exercise and stands as a good indicator of how this structured approach to AD's can be implemented. It demonstrates that a virtual team can provide some of the benefits of team working to the AD community, such as synergy and enhanced opportunities for knowledge transfer. Most importantly it can promote collaboration and build relationships without distance being a barrier, which can engage those members of this community who are restricted due to cost, family commitments or disability/accessibility reasons.

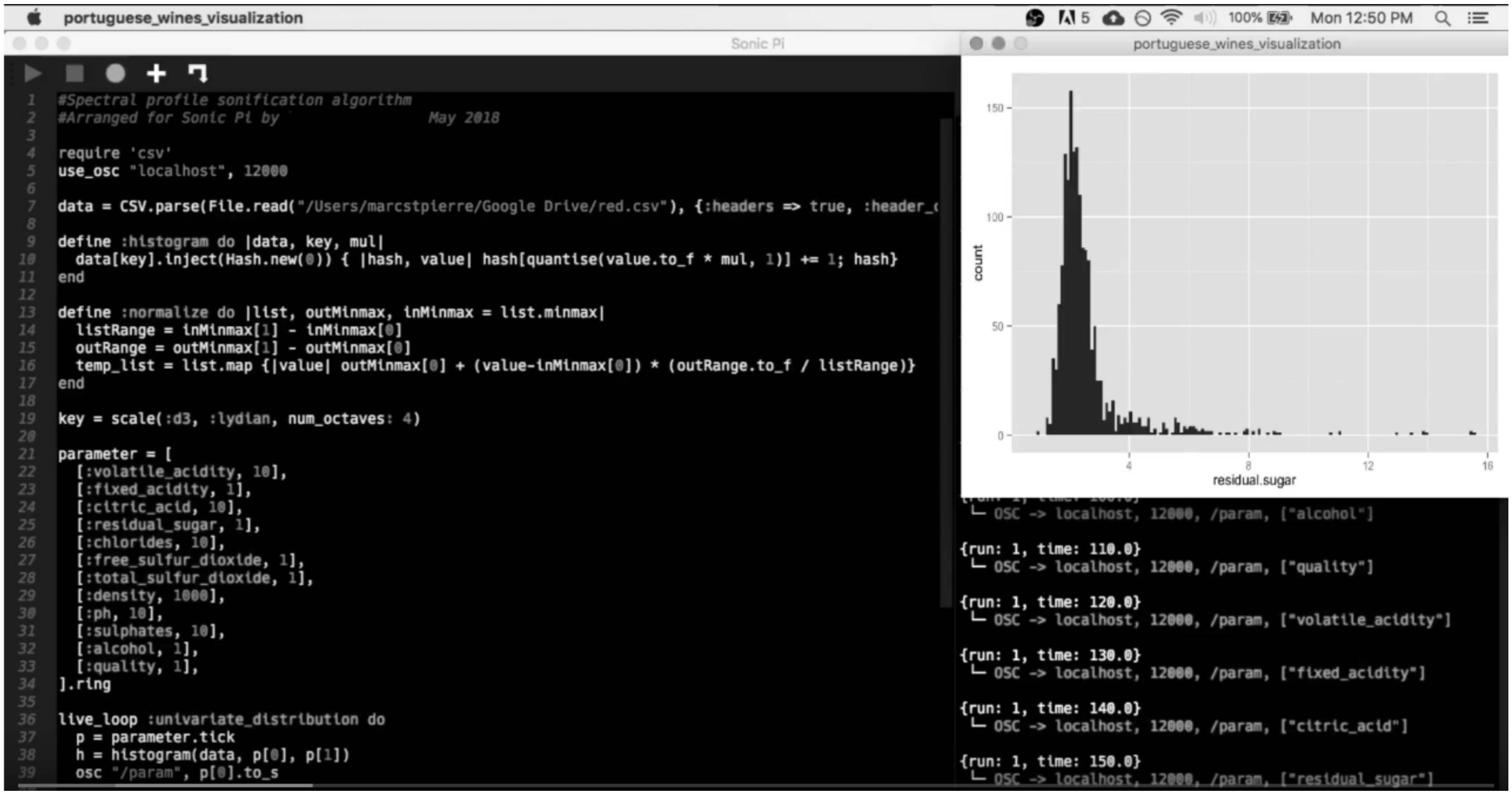

Figure 8.1: Screenshot of team member A's code

Figure 8.2: Screenshot of team member B's Max/MSP patch

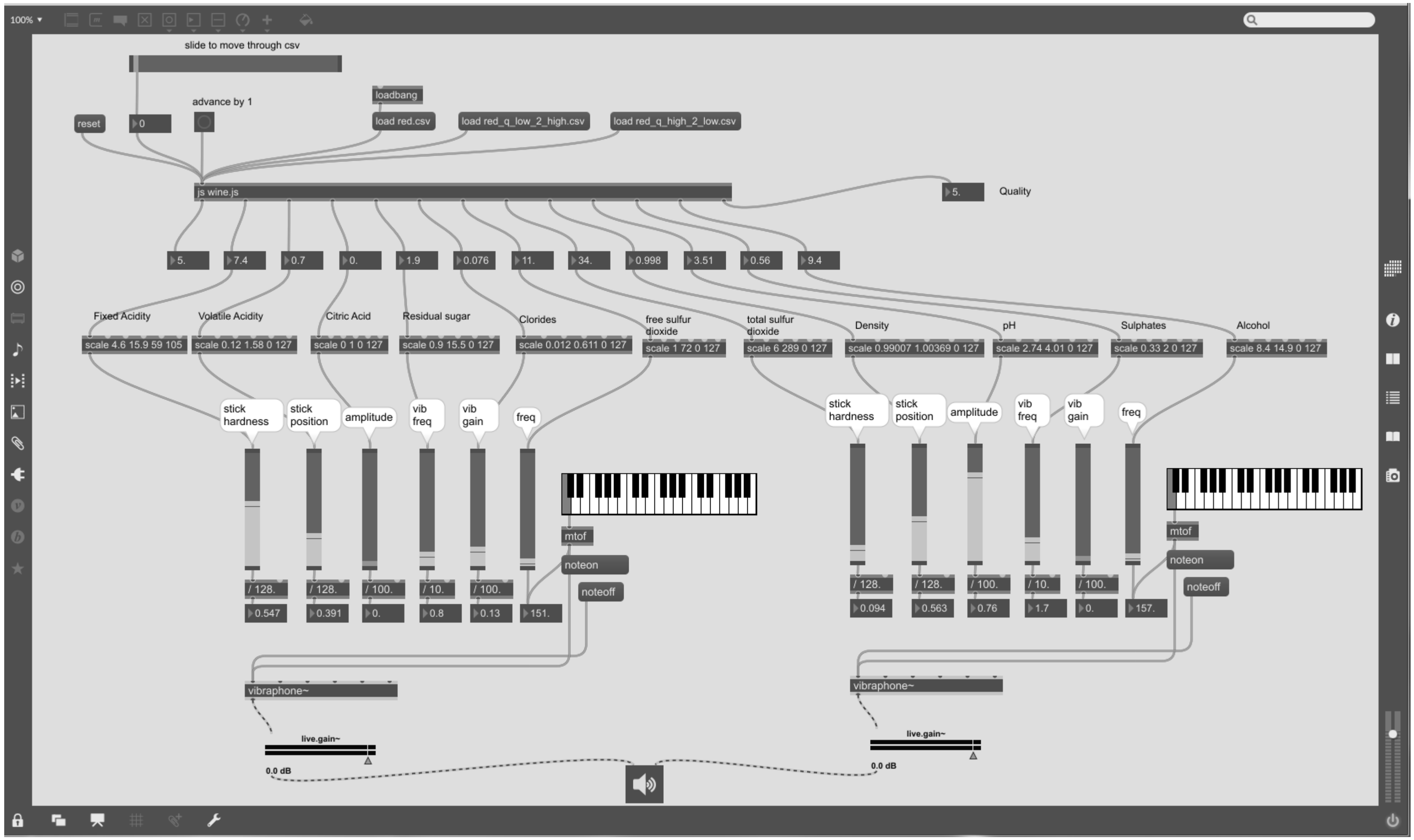

Figure 8.3: Screenshot of team member C's Max/MSP patch

Chapter 9

Conclusions

9.1 Introduction

This chapter provides a review of the work undertaken for this thesis. The findings from SonicSETI, the virtual AD team and the ICAD workshop are analysed.

9.2 Multi-listener auditory displays

In this thesis, the subject of MLAD is proposed and several case studies are presented to provide examples of how this can be applied to AD research. Here is a review of each case study in turn followed by a discussion of the overall conclusions of this study.

9.2.1 SonicSETI

The first case study was an example of a distributed AD, called SonicSETI. Here a team of people are utilised to listen to audifications of radio astronomy data to detect potential candidate signals. The described audification of radio astronomy data results in a white noise-like signal that can be played in the background over speakers as a sound masking device; this is often employed in offices as a means of improving productivity by reducing the impact of distracting environmental noise such as traffic, building work or office chatter. It would be highly inefficient to ask individuals to actively listen to white noise for long periods, therefore this thesis explored the concept of passive listening to detect anomalous signals in background white noise in an office environment.

Two listening tests were undertaken to establish if this proposed approach would be successful. The first aimed to establish whether listeners could detect SETI-type signals presented in short periods of white noise, and the second test established whether listeners could detect signals over longer periods of time whilst passive listening and distracted by a simulated work task.

Active Listening test

The first listening test was conducted with 18 audio files, 16 with signals and two pure white noise controls. Each test file was 30 seconds in duration. Participants were asked to actively listen to each file and indicate which type of signal they thought they had heard and give a score between 1 and 10 as to how confident they were that they had heard something. Each subject was played example signals at the beginning of the test, and they were only allowed to hear each test file once. Test participants were correctly able to detect all signals with an average confidence over 7.2, with the exception of the two white noise control files which were only correctly identified as having no signal by 67% of the participants , with an average confidence of only 2.6.

Passive Listening test

The second listening test involved participants being tested for longer time periods that the first. Each session has fourteen minutes of white noise, with some signals randomly mixed in. This experiment also required subjects to read whilst the white noise was played; this is a distraction activity designed to test listeners' passive background listening skills. It would be very difficult for a listener to actively listen to white noise for any length of time, so this experiment aimed to establish whether we could utilise passive listening for relatively long periods of time.

A test file containing white noise at -30 dBFS was created that was fourteen minutes in duration. Faded in and out at various times were sine waves at 200 Hz and 1000 Hz, and which also varied in amplitude from -30 dBFS to -54 dBFS. Each candidate was asked to read some text whilst the noise played in the background. If they perceived a signal they would press a button and the test assistant would log what time the button presses took place. Most of the listeners correctly detected all the signals that were mixed into the noise. There were also several incorrect responses which appeared to happen randomly; 18% of the reports were erroneous as they occurred when no signal was present.

Discussion

The findings of these tests are important in terms of this work as they indicate that listeners can use passive background listening to detect signals in white noise within in a modest time span and whilst distracted. This would indicate that a distributed AD system, based upon white noise, would be feasible subject to further testing. This researcher did not feel that designing another experiment with even longer timescales would be beneficial at this time, as the next stage would be to test passive listening over one-hour durations. It was felt that this length of test would be very time consuming and would have difficulty attracting participants to give up so much of their time. Longer test times could be resourced better if a prototype system was developed to allow participants to have white noise within their own office environment. This will be considered in the further work section.

9.2.2 Multi-listener workshop

A workshop was organised to explore ideas around MLADs developed for this thesis. This workshop was an opportunity to share these ideas with the auditory display research community and for this author to observe group interactions whilst participating in the exercises. A two-hour workshop was designed to introduce attendees to AD ensembles and distributed AD teams. A series of tasks was developed to replicate situations that may benefit from AD teams. The workshop confirmed the distributed approach was good for signal detection but demonstrated that the effectiveness of an ensemble AD can be detrimentally influenced by the personalities involved.

9.2.3 Virtual auditory display team

The third case study was the implementation of a virtual AD team, comprising three academics who resided in three separate countries. The group was tasked with designing an AD to explore a data set consisting of scientific measurements of red wine, and to establish whether any relationships could be found between the subjective measurement of quality and its objectively measured values. The team worked both independently and remotely, collaborating using email, cloud document storage, Skype messaging, and video conferencing.

In the brief time that this study took place, it became apparent that this approach was beneficial for several reasons; Team members felt that this was an excellent learning experience, it enabled a diverse set of individuals to collaborate with AD's, and the opportunities for discourse promoted a greater understanding of the task. Team synergy started to develop, and it is hoped that with further time this group of three academics can extend this experiment into other AD based solutions.

9.2.4 Discussion of multi-listener auditory displays

Originally the focus of this study was to investigate whether ADs could be utilised for the exploration of large data sets. Big data is an ever-increasing issue now and remains an excellent subject to approach with ADs. During early work on large SETI data sets, it became apparent that one approach to applying ADs to this domain would be to utilise a team of listeners. Dividing a large task and distributing the work amongst a team of people is an established method of increasing efficiency, and so these principles were applied to ADs, demonstrated by the SonicSETI case study found in chapter 6.

This author then began to realise that teamworking principles could be of benefit in other AD applications and developed a series of concepts around teamworking in AD called MLAD. Taking inspiration from CSCW, MLADs have 2 dimensions: environment (remote/co-located) and time (asynchronous/synchronous). The predominant focus of this report has been an investigation of remote AD teams. This was for several reasons: there was more evidence of previous co-located collaborative work, and as a disabled person who experiences accessibility problems this author was attracted to developing methods that could make AD's more accessible.

SonicSETI is an example of a distributed AD. A group of listeners interacted with an audification of radio astronomy data, each group member pressing a button when they perceived a signal within background noise. It is intended to develop SonicSETI into a citizen science project, which could prove to be an excellent method of engaging the public in ADs, thus raising the profile of this subject area.

The pilot virtual AD team study conducted as part of this thesis demonstrates that a team of academics can benefit from virtual team methods. The clear majority of AD research is undertaken by individuals and small unstructured groups. Virtual teams can offer this community a method of enhancing communication, personal development, removing barriers to access and increasing quality.

This author suggests that MLADs can offer the following specific benefits to the AD community:

- In certain situations, especially with large or complex data, a team can work more effectively than an individual can
- Some large-scale data sets can only be efficiently processed by distributing the workload
- Improved accessibility to researchers who have travel restrictions
- Opportunities for team members to learn from each other and share experience and solutions
- Some complex problems may be more effectively solved by a group
- Innovation can be promoted by cross-fertilisation of ideas
- Automatic peer review
- Humans are inherently social, and isolation can be a problem in research

MLADs are not a panacea for every issue. Many researchers may avoid collaborative work in favour of solo working, and the personalities within a team of people can adversely affect performance, however this author feels that there are far more advantages to working in teams than disadvantages.

9.3 Discussion of hypothesis and project objectives

9.3.1 Thesis objectives

Here the objectives of this research are reviewed to establish if each has been achieved.

Design a framework for the implementation of organised AD teams

The framework developed as part of the thesis is called MLAD. Any AD team problem can be placed into a context on the MLAD matrix, which has been repeated below in Figure 9.1.

	Asynchronous	Synchronous
Remote	Distributed AD Team	Virtual AD Team
Co-located	Asynchronous AD Ensemble	Synchronous AD Ensemble

Figure 9.1: The MLAD matrix

MLADs has 2 dimensions: environment and time, and these dimensions define the structure of any AD team that is derived from it. An ad hoc group of individuals may be more effective than a solo practitioner, however the real benefits of collaborative teamworking can only come from a structured and facilitated approach. An effective team requires effective leadership.

In this thesis this objective has been met. A framework has been implemented and two main case studies have been put forward to support it. This framework is not complete, as the focus was upon remote teams, and it is intended to extend this framework to ensembles, which are discussed in the further work section.

Establish whether organised groups of listeners can be an efficient tool for ADs

Efficiency has been defined by Goh as "Performing or functioning in the best possible manner with the least waste of time and effort." [127]

The question of efficiency is related to time. If we were to compare two processes which had similar results, but one took half of the time of the other, we would state that one process was more efficient than the other. The SonicSETI case study showed how ADs can be applied to the exploration of large-scale data sets. If an individual was to listen to a five-hour audification of radio astronomy data, this task would be achieved in five hours (disregarding listener fatigue). A distributed AD with twenty listeners would be able to process the same task in fifteen minutes. Distributing the task substantially reduces the total time taken to explore the data, however it does not reduce the actual amount of listening as there is still a total of five hours of listening required. This distributed approach is mainly efficient for the lead investigator who now does not have such an arduous task to perform and can now concentrate upon other related tasks. This is the basis of citizen science, where the public are motivated to participated in distributed time-consuming tasks, which frees up the scientific community to focus upon more complex tasks. A citizen science project is efficient from the perspective of the lead investigator, not from total hours spent on the task by the many. This approach has the advantage of scalability in that if we were to substantially increase the length of listening required, we soon exceed the physical capabilities of an individual listener, whereas we can always recruit more distributed listeners.

The SonicSETI case study demonstrates that distributed teams can be an efficient tool for ADs.

Establish whether organised groups of listeners can be an effective tool for ADs

Effectiveness has been defined by Goh as: "Adequate to accomplish a purpose; producing the intended or expected result." [127]

Whereas efficiency is defined in terms of time, effectiveness is a measure of how well a process can produce a successful conclusion or output. Its success is defined in terms of accuracy, quality or another desired attribute. To establish if multi-listener teams are an effective tool for ADs, we need to establish if their application can improve the accuracy or quality of an AD.

This thesis shows that MLAD is an effective tool for ADs because of the following:

- automatic peer review - having multiple listeners provides fast peer review of results. In the case of virtual AD teams this review is part of the process of interaction within the group, so it is likely that any results would have been reviewed by the group several times in the lifetime of the project.

- the group ear - there are many factors which may negatively influence an individual interacting with sound. They may not be working in a conducive environment for listening, the individual may be fatigued, distracted or may have a hearing deficiency. Working in groups will provide a group ear which cancels out these factors. Several listeners are more effective than one.

- synergy - synergy is where a team produces a greater combined effort than the sum of its individual contributions. A team will be be more effective than individual, which may be particularly important in circumstances where the complexity of the task is higher than one individual is capable of implementing. A synergistic team is more effective than a collection of individuals.

- knowledge transfer - teamwork provides increased opportunities for team members to learn from each other. A team provides a support network of colleagues, which is an excellent learning experience for those new to the discipline and provides opportunities for feedback, cross pollination of ideas, and constructive criticism for those more experienced. A more knowledgeable researcher is more effective.

- improving accessibility - traditional approaches to research can often involve international travel which can be problematic to those with family commitments or disabled researchers with mobility issues or funding restriction. Virtual AD teams can provide a research framework without borders, making it truly internationalised.

The items listed above demonstrate that multi-listener teams can be an effective tool for ADs.

9.3.2 Hypothesis

In this thesis the following hypothesis was investigated:

> An organised team of listeners can be an efficient and effective tool for auditory displays.

We have shown through discussion of the thesis objectives above that an organised team of listeners can be more efficient and effective than an individual. Distributed ADs demonstrated that a team of listeners would be able to analyse more audio data than a single listener, and virtual AD teams can provide opportunities for synergy, knowledge transfer, and peer review.

There have been some problems raised during this study, most noticeably in the workshop where teams did not have time to form synergistic relationships, and strong individuals dominated those new to the subject of ADs. The application of distributed teams may have scope for a project like SETI where lots of people are interested in the subject but may struggle to attract participants for less exciting pursuits such as accountancy. A group is heavily dependent upon the attitude of its members, and a disgruntled or unmotivated group member can be very damaging to the effectiveness of the task.

On balance, MLADs can offer several enhancements to the AD process and supports the hypothesis of this experiment.

9.4 Conclusion

This thesis offers the following original contributions to knowledge in the international AD community:

- developed a framework for approaching teamwork within AD called MLAD
- developed a novel approach to teams with AD called virtual AD teams
- developed a novel approach to the AD of SETI data via the development of SonicSETI

This thesis presents new and novel research on teamwork within ADs. MLAD describes how teams of listeners can work together on AD projects.

For this research three forms of MLAD were developed; distributed AD's, virtual AD teams and ensemble sonification.

In summary, there are many aspects of life where people work in groups, and the auditory display community can utilise this in future work. Teamwork provides many benefits to this community that can enhance and promote this subject. It is felt by this author that MLAD techniques will enhance the effectiveness of AD research by encouraging more active collaboration in the community, and encouraging researchers who have restricted access to travel (either through financial, disability or family reasons) to participate. Team work can offer this community many positive attributes such as enhancing quality, providing team synergy, and offering the opportunity for automatic peer review. This work hopes to prompt the AD community to appraise how it approaches ADs suggests that team-based activities could be a potential benefit in the future.

Chapter 10

Further work

10.1 Introduction

Based upon the research described in this thesis it is proposed that the following further work is required.

10.2 SonicSETI

It is proposed that the work highlighted in chapter 6 be extended to a publicly accessible citizen science project. This project will use the internet to stream audifications of radio astronomy data generated by the SETI Institute. The public will be asked to have this white noise on in the background - very much like the masking white noise used to hide environmental noise. If a member of the public perceives a signal within the noise they will be asked to press a button on the application's interface, which will then send a message to a server with information on which data and at what time the candidate signal was perceived. These results will be collated to discover if several listeners report at the same time. The system will be initiated by a small pilot study, which will extend the research listed here by investigating if listeners can detect signal mixed in with white noise over longer periods of time such as one hour. It is hoped that the subject matter of this citizen science project will engage the public getting them involved in sonification.

<u>Long duration study</u>

This study will be conducted to establish if the conclusions from this thesis stand when applied to longer time periods - from one to eight hours.

Participants will be asked to have the application running on their computer which will play the white noise source in the back ground. Each participant will be asked to do about their usual day in the office. Occasionally amongst the white noise test signals will be played and any responses recorded to establish if they were detected. The application will upload reports to a centralised database, which will be analysed by the study supervisor.

Public release

Subject to a successful completion of the long duration study, a limited public release will be conducted where a small number of participants from the public will be invited to take part. As with the long duration study, participants will be asked to have the application playing in the background whilst proceeding with a normal days work. Results will be centrally logged and analysed. The purpose of this limited release is to establish any requirements of technology prior to a full public release, i.e. if the computing resources are adequate for streaming.

10.3 Virtual auditory display teams

The case study in chapter 8 describes the set up and development of a virtual AD team comprised of several academics based in different countries. This work was positively received by all participants and all have indicated a desire to continue with this experiment past the remit of the original study. It is intended to continue work and then present a more advanced summary of virtual AD teams by collaborating on a paper to be submitted for consideration at a future ICAD or ISon conference. There is also scope for consolidating the knowledge contained within this thesis into a journal article.

10.4 Virtual reality auditory displays

Based upon the experiences gained with the Virtual AD team, there is scope for the development of a virtual reality software solution that aims to encourage more interaction both with team members and the AD. This could be similar to the Reactable work highlighted in chapter 4, but rather than a team working around a physical Reactable, a virtual AD team could work around a virtual table in a remote virtual space.

10.4.1 Ensemble sonification

This thesis has focused upon remote team methods, however there is scope for additional work in co-located teams, particularly in evaluating their effectiveness. The results from the multi-listener workshop demonstrates that there is potential for these techniques, but the lack of time for group development and poor sonic environment meant that this was not an optimal experience. The next stage for these techniques would be to set up a collaborative group of individuals who will work together as a sonification community. The focus of this experimental community would be to develop multi-listener sonification techniques. More time is required to build upon the ensemble techniques identified in this thesis. If a community of sonifiers works together over a period of time they will build relationships and mutual understanding, and it would be interesting to see what new practices arise from this.

Appendix A

Listening to the invisible: Sonification as a tool for astronomical discovery

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Listening to the invisible
Sonification as a tool for astronomical discovery

Abstract
Sound has been used for scientific investigation for many years; the stethoscope and the Geiger counter are just two examples. Sonification is a method of transforming data into sound. The listener can then explore the data sonically, which can reveal hidden structures and relationships not apparent through visualisation. This paper discusses the advantages of sonification and introduces the reader to techniques such as audification, parameter mapping and model-based sonification. It provides case studies of astronomy-based sonification and concludes with a brief discussion of current work on the sonification of radio astronomy data as part of the Search for Extra-Terrestrial Intelligence (SETI).

Keywords
astronomy, audification, interdisciplinary, parameter mapping, science, sonification

Introduction
Just for one moment, close your eyes and listen.

What cues about your environment can you establish just by listening? Are you sat in large reverberant hall or a small-enclosed room? Can you hear a clock ticking? In what direction is the clock? We are often unaware of the richness of information sound can portray to us. For example, if we pour water into a vessel it will resonate with increasing pitch, providing an acoustic indication of its fullness. When driving a car we often use the sound of the engine to anticipate changing gear.

Sonification describes a process where raw data is analysed or explored through the medium of sound. In Greg Kramer's 'Sonification report' this is defined as 'The transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation' (Kramer et al., 1999).

Sonification is a series of techniques that take data as an input and generate sound as an output. Generally the input data is a numeric series such as a column of a spreadsheet, and it can be multidimensional. The sonification algorithm is a computer program that transforms data into sound. This algorithm can be implemented in a traditional programming language, such as C++/Java, or a graphical based environment such as MAX/MSP. The output is a synthesised sound, an audio file or a MIDI file that is later played through a synthesiser.

The phrase 'sonification' has parallels with the term 'visualisation'. Whereas visualisation is a process of representing data in a graphical format, sonification is a process where data is represented sonically. Listening to data can reveal patterns and structures that may not be apparent through visual methods. Hermann (2010) identifies several areas where sonification techniques could be utilized within a scientific context. Process monitoring, rapid summary of large datasets, searching for patterns in data, and exploratory data analysis. Sonification techniques have been applied in many scientific disciplines, including astronomy, particle physics, chemistry, mechanical engineering, medicine, seismology and meteorology.

Many scientific investigations involve the analysis and exploration of large multidimensional datasets that have traditionally been perceived by visualisation techniques. There are limitations to visual perception, such as temporal resolution and difficulties in representing multiple dimensions of data. Sonification can provide an alternative to visualisation techniques or used in conjunction to enhance analysis.

Multidisciplinary aspects of sonification

Sonification combines skills found in many areas such as music technology, computer science, sound design, composition and performance, data mining, acoustics and physics. An excellent example of multidisciplinary sonification is the *sonEnvir* project (Campo et al., 2006), which investigated implementing sonification techniques in a range of scientific disciplines including neurology, theoretical physics, signal processing and sociology. The project produced a series of tools based around the Supercollider programming language (Cycling74, n.d.).

Why use sound?

There are several characteristics of auditory perception that sonification exploits (Kramer, 1994: 7). The ear is excellent at perceiving time based information, such as rhythm and pitch. The highest pitch we can theoretically perceive is 20Khz (in practice it is often much lower) – that is we can detect acoustic vibrations that oscillate over 20,000 times a second. If such a frequency rate was to be presented visually – much of the information would be blurred or lost completely. The ear is better at detecting rapid or transient changes than the eye.

We are capable of perceiving several sounds simultaneously. Whilst listening to a classical music performance, you will be able to distinguish the individual components of the orchestra concurrently. This ability means that we can listen to several sonified streams in parallel, which is advantageous when dealing with multidimensional information.

Backgrounding is the ability of our auditory system to relegate sounds to a lower priority. Although we are constantly surrounded by sound, we are not aware of most sounds until our attention is drawn to them. For example, you may not be aware of road traffic outside until a passing motorist sounds their horn.

Our hearing is multidimensional; we have the ability to localise sound. If a tiger snaps a twig behind us, we are alerted to this danger that we didn't see because it was not in our field of vision. Unlike a visualisation system, we do not have to be orientated in the direction of the sonification. An example of this is the Geiger counter. As it provides its information in clicks we do not have to constantly observer the meter, so we can safely walk around taking measurements.

A sonification can be 'eyes free' – enabling the user to listen to the data while occupied with another task. So the addition of sound can increase the amount of data presented without increasing visual overload. Our hearing is constant; we do not have the ability to stop listening. This can be useful when monitoring data because if the data was visual we could miss an event if we blinked or looked away momentarily.

There are of course some disadvantages of using sound. Auditory perception is relative. When comparing two stimuli we can only state if they are the same or if one is larger than the other; we cannot give an absolute value. Many characteristics of hearing are co-independent upon others, so a change in one will change how we perceive another – for example our perception of loudness changes with pitch.

Some individuals may find the use of sound to be an irritation. Consideration should be given to environmental issues of sound; someone quietly working in the next office may not appreciate hearing your sonification. The hearing capabilities of the listener may also be a consideration. Some may have noise-induced hearing loss or even amusia (tone deafness).

Sonification techniques
There are several algorithmic techniques used to transform data to sound, in this section we discuss these processes and provide examples within a science.

Auditory graphs
Most readers will be familiar with the concept of a graph, having an x and y axis and a series of data points plotted between. Auditory graphs are a sonic representation of graphical data. Each data point on the graph is mapped to a note on a synthesizer. The pitch of the note depends upon where the point falls upon the Y axis. Starting at the XY origin each point is played from left to right – so that the output is a series of notes that corresponds to the input sequence. Multidimensional graphs can be represented by converting each dimension into a different instrument, for example piano, guitar and violin. This form of sonification can be beneficial for presenting graphical data to both visually impaired and sighted users.

Audification
Audification is where data is directly converted to sound. Techniques are based around converting the data to digital audio samples, which can then be saved in an audio file. This practice is beneficial for working with large datasets. One second of CD quality audio requires 44,100 data points. If the playback length is too short the listener may not be able to distinguish any sonic features or recognize patterns.

Audification has been applied to seismology with relative success. Speeth (1961) found that it was difficult to differentiate atomic bomb explosions from earthquakes just by visual observation of seismograph data. By audification, listeners were able to distinguish between the two types of events.

In an engineering context, audification was used by Pauletto and Hunt (2004) in collaboration with Westland Helicopters to analyse flight data. There are numerous flight sensors on a helicopter, which the Westland engineers would print out in graph form and place on the floor so that they could examine all the data visually at once. Sonifying the data was found to accelerate the diagnostic process.

Audification was utilised by Pereverzev et al. in their research on weakly coupled super fluids. Presenting data visually demonstrated no useful information, but when the data was directly audified Pereverzev was able to hear frequency components that led to a discovery.

> If the electrical output of the displacement transducer is amplified and connected to audio headphones, the listener makes a most remarkable observation. As the pressure across the array relaxes to zero there is a clearly distinguishable tone smoothly drifting from high to low frequency during the transient, which lasts for several seconds. This simple observation marks the discovery of coherent quantum oscillations between weakly coupled superfluids. (Pereverzev et al., 1979)

Parameter mapping
Parameter mapping is a sonification technique where input data is used to control a characteristic of a synthesised sound such as pitch, loudness, timbre, rhythm and melody. This is perhaps the most common form of sonification. In 'sinification' the data is mapped to the frequency of a sine wave oscillator. Midification describes a process where the data is converted to MIDI note values that can then be 'played' on a MIDI synthesizer. As there are numerous acoustic characteristics of sound, parameter mapping can be used for sonifying multidimensional datasets.

An early example of parameter mapping was demonstrated by Sara Bly (1982) who showed that sound could be used to distinguish between three species of Iris flowers. She mapped characteristics such as sepal length and width to pitch, volume and timbre. When this was played back each variety of iris had its own characteristic 'sound'. Bly found that most listeners had the ability to accurately identify each species through sound alone.

An audio-visual browser was developed by Grond et al. (2010) to explore the structure of RNA. The software developed provides a visualisation of RNA structure that the user can interact with, that is, focus upon a particular section or expand out. The software maps RNA shape information to parameters of sound such as loudness, phase and timbre. This is a good example of how sonification can enhance visualisation techniques.

Model-based sonification

Developed by Thomas Hermann (2002), this moderately new technique data is used to form points in a multidimensional space. Each point of data has physical laws imposed upon it, which dictate how the data points relate to each other and the modelled space. The user then excites the data points by stimulating the system and the reaction of the points is sonified. In model-based sonification the data forms an instrument that is played by applying a stimulus. The prepared piano is a good analogy for model-based sonification. This instrument has physical objects inserted between its strings and dampers with the purpose of altering timbre. For example, a composer may attach ping pong balls, paper clips or spoons. In this analogy the objects are data, and the piano is the data space. The presence of objects on the strings changes the sound of the piano when the instrument is played, very much how the data points interact with the model space when excited by an input.

Interactive sonification

Interactive sonification is an area that focuses on the importance of interaction between the listener and the sonification (Hermann and Hunt, 2005). Rather than passive listening, the user interacts with the data. They may have a controller that allows them to navigate the sound, replaying a section, and adjusting playback speed and position.

Sonification toolkits

Several authors have developed open source sonification toolkits. A toolkit is a set of off-the-peg software that provides sonification functionality. The toolkit can be an entire application or a library of functions that can be incorporated into other tools. These applications make sonification more accessible to those new to the area, providing a quick and easy introduction to sonification techniques.

The *sonification sandbox* (Walker and Cothran, 2003) is a standalone Java application developed to facilitate the creation of auditory graphs. The user can upload vector data in a comma separated values (CSV) format and control many parameters to the graph output such as voice, note length, etc.

MAX/MSP is a visual programming language for sound, which is popular with music composers. Instead of text the user manipulates graphical elements to build a program. *aeSon Toolkit* is a framework that adds sonification functionality to MAX/MSP's impressive set of audio objects. This toolkit includes objects to extract data from files, to transform the data and to map to synthesisers.

Some toolkits have been developed to extend the functionality of existing programming environments. The use of these tools enables users to rapidly incorporate sonification into their existing research. *SKDtools* (Miele, 2003) is a library that extends the MATLAB (MathWorks, n.d.) numerical computing environment, and *Sonipy* (Sonipy, n.d.) is a set of modules that add sonification modules to the Python computer programming language.

Case study of sonification within astronomy

Exploring the vacuum of deep space with sound may seem to be counter-intuitive, but there are some interesting examples of sonification within an astronomical context.

The Jet Propulsion Laboratory (JPL) has a multimedia presentation called *Spooky Sounds* intended to introduce concepts of sonification of space-based data (Jet Propulsion Laboratory, n.d.). This resource includes a variety of sonifications including Jupiter's radio emissions, Ganymede's magnetosphere, Cassini spacecraft flybys of Enceladus and Saturn, and Voyager 1 recordings of Jupiter's bow shock. This site is an interesting introduction to space-based sonification.

Sonification techniques were used to detect the impact of micrometeoroids upon the Voyager 2 spaceship while investigating Saturn's rings (Scarf et al., 1982). There was a problem with the spacecraft that its controllers were trying to pinpoint using visual methods – but this only resulted in visual noise. By sonifying the data, a 'machine gun' sound was perceived. This machine gun sound was caused by micro-meteoroid impacts on the spacecraft.

Selene (Selenological and Engineering Explorer) was a lunar orbiter spacecraft launched by JAXA (Japan Aerospace Exploration Agency) in 2007. Sobue et al. (2010) developed a Geographical Information System based upon laser altimeter data obtained from the mission. The altimeter provides a topographical contour of the surface of the moon. The system developed was a web-based Java application called *Moonbell* (Higashiizumi et al., 2009). This application sonifies the altitude along the route by converting the measured reading into musical notes. The interface is highly configurable, allowing the user to adjust many parameters, such as speed, note range, instrument and volume.

Cosmic Microwave Background Radiation (CMBR) is a nearly uniform space-based radiation that is received in all directions with the majority of its power spectrum contained within the microwave bandwidth. CMBR is a background 'noise' signal that is found all over the universe. It is now considered that this is the faint after-glow of radiation generated by the big bang. The Planck Visualization Project is a NASA education and public outreach initiative to increase public understanding of the CMBR. This project plans to create multimedia displays using CMBR data sourced from the Planck space observatory. Sonification of this data is also being implemented (Van der Veen, n.d.). This team has also sonified the power spectrum of the CMBR (Van der Veen, 2009, 2010).

xSonify is a Java-based sonification toolkit developed to assist in the development of astronomy-based data (Candey et al., 2006). It is designed to implement sonification functionality of NASA's Space Physics Data Facility (SPDF). The SPDF is an online collection of data collated during space-based missions from 1963 onwards. Data is organised by spacecraft and then individual instruments. This resource includes 'heliospheric, magnetospheric, ionospheric and upper-atmospheric data from all NASA and some non-NASA space physics missions' (NASA, 2009).

Finally, audification functionality has been incorporated in relatively new software used to detect the presence of exoplanets (planets orbiting a star other than our own sun) (Systemic, 2011). This approach is experimental but further investigation may be beneficial.

Summary and further work

There are several examples where sonification techniques have proven advantageous in scientific research. The work of Pereverzev, Scarf and Speeth demonstrates that transforming data into sound can provide insights not revealed by visualisation alone. There is a history of sonification within astronomy, from the detection of micro meteors at Saturn, to contemporary research on cosmic microwave background radiation and exoplanet detection. Nevertheless, are there spheres of astronomical research that would warrant investigation using sonification techniques?

Wall (2010) describes the deluge of information that is facing modern astronomers, who are increasingly trying to find a needle in a haystack of data. This data overload has motivated the formation of several citizen science projects such as Galaxy Zoo (2010) and Stardust@Home (n.d.). These projects distribute images to the public so that they can classify them. There is essentially more astronomical data available than there are astronomers to process it. Sonification is a tool that could be utilised for the exploration of large amounts of data.

This paper's authors are currently researching into sonifying radio waves used in the Search for Extra-Terrestrial Intelligence (SETI). SETI is a project initiated in 1961 to search for evidence of intelligent life by the detection of electromagnetic radiation emitted by extra-terrestrial technology (SETI Institute, 2010). If there is intelligent alien life, it *may* use radio waves for communication, much like earth-based television transmission. Radio waves will propagate through the universe, and might be detected as they reach earth. SETI's approach is to selectively position the Allen Telescope Array at a co-ordinate and then take measurements. This process produces a large amount of data that is freely available to researchers through the SetiQuest project (SetiQuest, 2011). We will be investigating how sonification techniques can be implemented in conjunction with a high performance computer cluster to assist in rapid data exploration.

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Appendix B

Phantom signals: Erroneous perception observed during the audification of radio astronomy data

Phantom signals: Erroneous perception observed during the audification of radio astronomy data

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This paper describes the work in progress of an investigation into utilizing audification techniques upon radio astronomy data, generated by the Search for Extraterrestrial Intelligence (SETI). The proposed system involves subjects listening to the data presented as background noise. The initial tests established that subjects are able to detect the presence of simulated signals when presented with white noise; however it was observed that there were significant reports of signals that were not present in the test files. Subjects regularly reported perceiving these "phantom signals". Further experimentation confirmed that phantoms were reported when listeners were presented with pure white noise and were asked to identify signals with this data. Exposing subjects to examples of potential signals prior to the test has a heavy influence on the prevalence and sonic characteristics of the illusory signals reported.

O INTRODUCTION

This team is investigating methods of utilizing sonification for data mining of large scale data sets, with a particular focus upon the exploration of radio astronomy data produced by the Search for Extraterrestial Intelligence or SETI [1]. Modern SETI techniques involve undertaking radio astronomy observations of a candidate star, storing this data as a file and then exploring the data for anomalies. A SETI definition of intelligence is the presence of a technology capable of being detected over interstellar distances. Our own technological society has been broadcasting radio waves throughout the universe since the development of radio. As radio waves propagate throughout the universe, early SETI researchers such as Drake [2] and Morrison & Cocconi [3] proposed that they could be used for interstellar communications. Another advantage is that our atmosphere is opaque to the radio spectrum – thus allowing earth bound observations.

The data used as a basis for this work was obtained via setiQuest [4]. Each observation produces approximately 8GB of data, which is saved in 8 bit format. Radio astronomy observations mainly consist of random fluctuations which have a Brownian noise characteristic. The search involves scanning through the noise-based data to detect signals that could be of extraterrestrial origin. Although it is impossible to anticipate the spectral composition of a signal transmitted from an alien civilization, it has been speculated that these signals would be narrowband and could be sinusoidal or pulse type signals [5]. Due to the Doppler Effect, caused by relative motion of celestial objects from the earth, signals could be shifted in frequency producing a chirp like effect.

Exploring large amounts of data through visualization can be time intensive, and so this team is investigating whether sonification methods are more effective than visualization alone.

It is proposed that this data could be audified and then explored by a listener, who could identify any sonic events that are different to the white noise background. However it would not be feasible for a listener to actively listen to a large amount of data, as a direct audification of one observation would take 54 hours to listen to. An alternative would be to present this data to the listener as background noise, so that they can listen to it passively. It is relatively common, when working in a noisy environment to use either white or pink noise at a low level to mask distracting noises e.g., construction noise or conversation. This team is investigating if this background white noise can be used for passive data exploration. If there are signals within this data, will a distracted listener perceive the signal?

It is anticipated that a series of experiments is required to establish the validity of this approach. The hypothesis of the first experiment is to establish if listeners are able to detect additional pseudo signals whilst actively listening to short periods of white noise. The next experiment would ascertain if listeners were able to detect signals presented with white noise, whilst passively listening with a distraction activity.

This paper outlines the experimental procedure and results of the first experiment into active listening to white noise.

0.1 Generation of sound sources

The white noise source for these experiments was taken from setiQuest radio observations of the Moon, the data was audified by creating a C++ program that extracts the sample data and converts it to an audio wav file, which was 30 seconds in duration @ 44.1Khz, 16 bit resolution. The white noise characteristics were confirmed by visually inspecting a spectrogram of the data – see Figure 1.

The pseudo signals were selected based upon criteria describe by SETI, when giving examples of potential alien signals. A C++ program was developed to synthesise tones, and the pulse and squiggle waveforms were generated by The vOICe, a Java application that converts images to sound [6]. The following signals were generated:

1) Sine wave at 200 Hz
2) Sine wave at 1 KHz
3) Sine wave at 10 KHz
4) Chirp from 200 to 10 KHz
5) Pulses
6) Squiggle – tone that deviates randomly in frequency.

Spectrograms illustrating the sonic characteristics of the white noise source, pulse and squiggle signals are shown in Figures 1 to 3.

A C++ application was created that mixed together the white noise at -30dB and the pseudo signals at -40dB, -46dB, and -52dB. The application randomized when the pseudo signal would start. As a control, two files were created that contained white noise only. This created a set of 18 files which were segued randomly using Steinberg's Cubase. Two files containing purely white noise, with no signal, were included as a control.

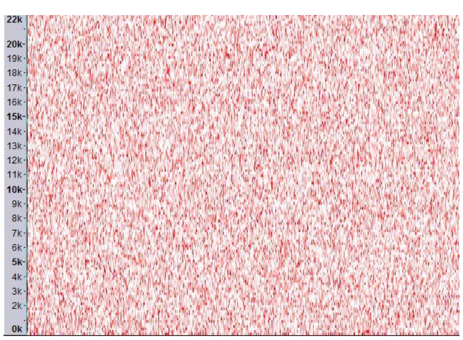

Fig.1 White noise source file spectrogram

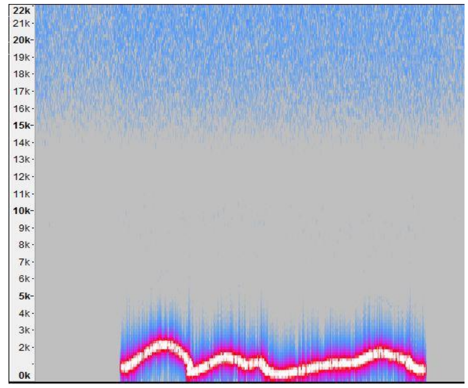

Fig.2 Squiggle signal spectrogram

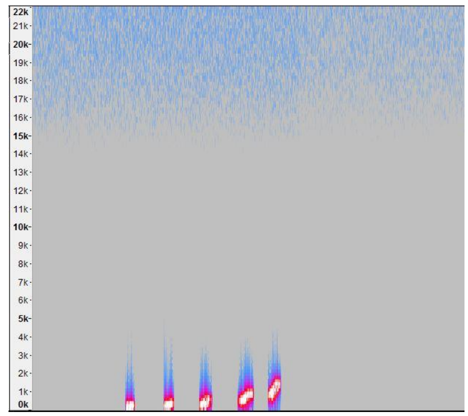

Fig.3 Pulsed signal spectrogram

1 EXPERIMENT 1 – DETECTION OF SIGNALS PRESENTED WITHIN WHITE NOISE

This test was designed to establish whether subjects are able to perceive signals presented within a background of white noise, actively listening over 30 seconds.

1.1 Experimental procedure

The tests took place in the radio production studio at the University of Huddersfield, which is an acoustically neutral room with modest sound isolation properties. The sequence of test files was randomized and played via the Audacity application on an Apple Mac Book Pro to the subject through a pair of Beyerdynamic DT100 headphones. After each file was played the subject was asked to score between 1 and 10 their confidence that they perceived a signal, with 10 indicating a high confidence that a signal was perceived. In addition they were asked to record whether they could identify the type of signal present; tone, pulse, chirp, squiggle, or no signal present. Prior to the test commencing each subject was played examples of each signal type without white noise for reference.

1.2 Test subjects

9 subjects performed this test, 1 female and 8 males aged between 20 and 47. All were Music Technology undergraduate students or lecturers at the University of Huddersfield, and all originated from the UK.

1.3 Experiment 1 results

Tables 1 and 2 provide a summary of the subjects' responses. For Table 1, the confidence scores from each subject are averaged for each signal type. The final column provides a summary of how accurate all subjects were at detecting the correct signal. Table 2 collated confidence and detection rates based upon the amplitude of the signal.

Table 1. Averaged confidence scores of detection of various signals

Signal Type	Average Confidence Score	Correctly Detected %
200Hz Tone	9.814	100
1KHz Tone	9.740	96
Chirp	9.703	100
10Khz Tone	8.888	93
Pulse	8.259	89
Squiggle	7.185	81
No signal	2.611	67

These results show that those surveyed can detect the presence of signals mixed with white noise. Confidence of detection is greatest with sinusoidal signal types, and increases with the amplitude of the signal.

1.4 Experiment 1 discussion

The two files containing only white noise had a relatively low level of accurate detection – 33% of subjects *incorrectly* identified a signal when none was present. Anecdotally several of the test subjects reported that they found the task quite difficult as they were unsure if they were actually hearing signals and that only after they had heard a "real" signal it reassured them that the signals they had earlier perceived were illusory. This reporting of "phantom signals", i.e., signals that were not present in the original files, was the most reported comment from this test. It was decided to further investigate this phenomenon by repeating the test, this time with the majority of audio files containing white noise only, with no additional signals. Now test subjects would be played just white noise, to establish the level of reporting of illusory signals. The team also wished to examine the influence of listening to example signals prior to the start of the test, as it appeared that subjects reported phantom signals with characteristics resembling the reference files.

Table 2. Averaged confidence scores of detection of various signals collated on signal amplitude

Signal Amplitude	Average Confidence Score	Correctly Detected %
-40 dB	9.666	98
-46 dB	9.488	98
-52 dB	7.977	83

2 EXPERIMENT 2 – DETECTION OF SIGNALS WITH PREVIEW

The object of this experiment was to establish whether listeners would report illusory signals with characteristics similar to reference audio files played prior to the test.

2.1 Experimental procedure

A series of 10 wav files, each 30 seconds in duration, was created, all containing white noise at -30dB. A control file, featuring both white noise and a 200 Hz tone at -40dB, was created. This control audio file (file number 6), with an actual signal mixed in, was used to establish if phantom signals are experienced after a real stimulus. This experiment was delivered under the same conditions as Experiment 1. Each subject was asked to actively listen to a series of excerpts of white noise and score their confidence that they perceived a tone from 1 to 10 (low to high). A score of 10 would indicate that the subject was highly confident that they perceived a signal, a score of 1 would indicate that they were confident that there was no signal, and the file contains pure white noise. They were also asked to record whether the signal was a tone, chirp, pulse, squiggle or no signal; examples of each signal were played to each subject prior to the experiment.

2.2 Test subjects

13 subjects performed this test, 12 males and 1 female, aged between 20 and 23. All were Music Technology undergraduate students at the University of Huddersfield. One subject originated from Greece, the remainder from the UK.

2.3 Test results

For each of the 10 files an average was calculated based upon the subjects' scoring of how confident they were that they had or had not perceived a signal – this data is collated into Table 3. The data was also collated by the incidences of incorrect reporting by signal type. This is displayed in Table 4, and ranked in order of the most reported signal types.

Table 3. Averaged confidence scores, and correct detection levels of Experiment 2

File Number	Average Confidence Score	Correctly Detected %
1	2.231	69
2	3.385	38
3	4.385	31
4	3.538	38
5	4.538	31
6	8.462	100
7	2.923	62
8	2.846	38
9	4.538	23
10	3.769	31

Table 4. Incidence of incorrect reporting of signal types

Signal Descriptor	% Incorrectly Reported
Squiggle	18.46
Pulse	16.92
Tone	7.69
Chirp	6.15
Other	4.62

130 separate tests were conducted (13 test subjects, each listening to 10 files). Only 60 returned with the correct response (no signal in files 1, 2, 3, 4, 5, 7, 8, 9 and 10 and a tone in file 6). 53.8% of tests returned with an erroneous response from the subjects. The best performing subjects in this test correctly identified 8 out of 10 files; the worst performance only correctly identified 2 files. ***All*** subjects correctly identified the control file with a tone. On average this subject group correctly classified 46% of the test files. A breakdown of the correct classification rates per file is detailed in Figure 4, with subject confidence in Figure 5.

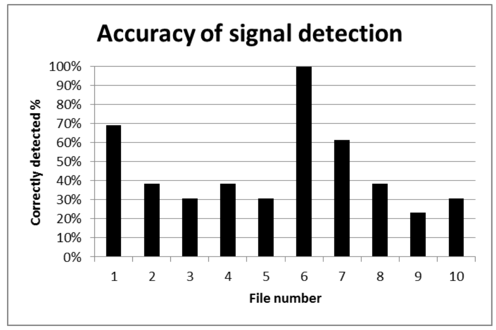

Fig.4 Accuracy of signal detection

Fig.5 Averaged listener confidence

2.4 Discussion of Experiment 2's results

100% of subjects correctly identified the test file with the tone added. Not one subject successfully identified every recording correctly – in other words all subjects reported phantom signals.

Files 1, 6, and 7 have greatest level of correct classification. It appears that subjects tend to accurately classify the first file played to them and then this accuracy tails off. File 7 has an increased accuracy, which could be due to its proximity to the only recording with a definite signal mixed in. Accuracy then tails off again when they are played subsequent examples of white noise.

Table 4 provides a summary of the prevalence of which phantom signals were reported. Most subjects reported phantom signals with similar characteristics to those played prior to the listening test, with only 4.6% of reports being of phantom signals with novel characteristics.

An interesting effect happens with the reporting of phantom tones, which is illustrated in Figure 6. The reporting of tones (as opposed to other signal types) diminishes after file 6, which contains a real tone. This would indicate that when a tone is heard within the context of white noise the listener then becomes less likely to false report tones in subsequent files. However, the presence of a real tone does not appear to influence the level of reporting of other phantom signal types.

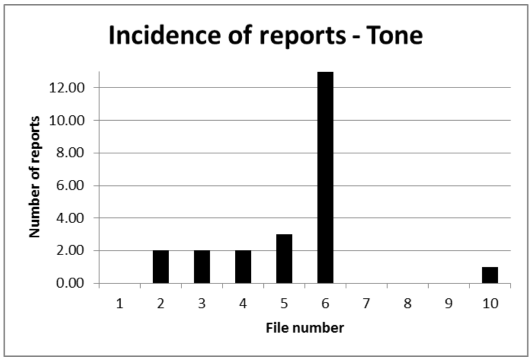

Fig.6 Number of reports of phantom tone

3 EXPERIMENT 3 – DETECTION OF SIGNALS WITHOUT PREVIEW

The objective of this experiment was to establish the prevalence of illusory signal reporting on white noise listening with no preview of potential signals.

3.1 Experimental procedure

This test was conducted in similar conditions to Experiment 2, utilizing the same set of test files. No discussion of potential signal types was entered into with the subjects, and no examples were previewed. Each subject was told that there may be a signal mixed in with the white noise.

3.2 Test subjects

10 subjects performed this test, 7 males and 3 females, aged between 20 and 31. Most were Music Technology undergraduate students at Birmingham City University, one was an administrator. All subjects originated from the UK. None of these subjects had participated in the previous 2 studies.

3.3 Test Results

The results of this experiment have been collated into Tables 6 and 7. Table 6 has a column for averaged confidence, and a column for how many subjects correctly detected whether the audio file had a signal mixed in with the white noise or not. Table 7 is a collation of the characteristics described by the listeners, when falsely reporting signals. Responses have been categorized into 5 broad descriptors. Terms like water or wind are Natural sounds. Mechanical sounds describe motorway, railway or machine type sounds. Any speech type reports are included into Voice, and Tones describes any sinusoidal or test tone reports. The Filter category is included because several listeners reported hearing filter sweep type events. The second column in Table 7 describes the incidence of false reports of signals in each category.

Table 6. Averaged confidence scores and detection levels of Experiment 3

File Number	Average Confidence Score	Correctly Detected %
1	3.9	30
2	4.3	50
3	5.1	20
4	5.0	20
5	4.2	30
6	9.9	100
7	5.3	40
8	5.4	40
9	7.5	10
10	5.8	20

Table 7. Incidence of incorrect reporting of signal types

Signal Descriptor	% Incorrectly Reported
Natural	15.38
Mechanical	25.00
Tones	36.54
Voice	13.46
Filter	9.62

3.4 Discussion of Experiment 3's results

Similar to the results of Experiment 2, 100% of listeners correctly identified file 6, a 200Hz tone mixed with white noise. Besides file 6, the second file played to listeners had the highest level of correct detection – 50%. However, in contrast to the results from Experiment 2, listeners reported higher levels of phantom signals after listening to the one file which did have a signal present.

Several different descriptors were used to describe the phantom signals perceived by listeners, from natural sounds (such as the sea and wind noises), mechanical sounds (such as railway or motorway type sounds), and sounds with speech-type characteristics (such as talking or voices). Sinusoidal signals were the most commonly reported in this experiment. This may be due to listeners anticipating that a listening test may feature signals of this type. 8 out of 10 participants reported experiencing the same signal in multiple files.

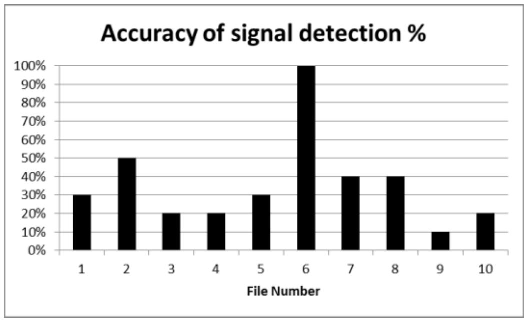

Fig.7 Accuracy of signal detection for experiment 3

4 PHANTOM SIGNALS

Taking into consideration the results of these experiments, it is clear that participants are reporting the presence of illusory or phantom signals when asked to actively listen to short bursts of white noise. When tests are pre-empted with example signals, as in Experiment 2, the majority of phantoms reported are identified as having similar characteristics to the examples. Although each listener was given the option to identify the signal as “other” i.e., not sharing characteristics of tone, pulse, or squiggle, the majority chose to categorize the phantom within the scope presented by the researcher. It would appear that the listener’s perception is influenced by the examples played before the test. It is possible to steer a listener to report a particular type of phantom signal, just by playing an example earlier.

The incidence of phantom signal reporting increases when no examples are played to the test subject. It seems that by providing no context to the listener this enhances their perception of phantoms. The phantom signal effect disappears completely with knowledge; if a subject is informed of the true purpose of these experiments they are no longer reported. A musician sat the test with prior knowledge and achieved a 100% detection rate; this was used to externally confirm that the test files are purely random in nature, with no artifacts that could be perceived as a signal. Listeners were allowed only one listen to the test files, so they could not go back and confirm if the phantom signal was present. If an interactive sonification [1] approach was adopted where the listener could replay the audio, this may improve the accuracy of signal detection.

There are several possible explanations for the phantom signal effect. Most readers will be aware of the human need to find order when presented with chaotic stimuli, seeing shapes of animals in the clouds or seeing faces in woodchip wallpaper. This effect is called pareidolia [2], and phantom signals are a form of auditory pareidolia. The role of the researcher who engages the listener in these tests may be significant. Most subjects were students and the researcher was a senior lecturer. The participants may want to perform well in these tests, to save face in front of an authority figure. This is similar to the authority figure effect first observed by Milgram [3]. These phantom signals are similar to the auditory illusions discovered by Diana Deutsch [4]. A similar effect has been observed when white noise has been added to gaps in speech [11] and [12], where the addition of noise in gaps provides spectral restoration. Termed the picket fence effect, this describes how, if a tone or speech is interspersed with gaps containing just noise, there is an illusion of continuality of the tone during the noise bursts. The phantom signals reported by listeners in this test, differ from the picket fence effect as they occur with no tonal stimulus present.

5 CONCLUSIONS AND FURTHER WORK

The results of Experiment 1 demonstrate that test subjects are able to distinguish the presence of pseudo signals when actively listening to white noise, although under the experimental conditions described most listeners reported the existence of illusory tones that were not added to the white noise by this team.

Experiments 2 and 3 confirm that when presented with pure white noise and asked to detect signals, listeners will report phantom signals. The pre-test phase, where listeners are played examples of possible signals appears to heavily influence perception during the test – subjects are more likely to report phantom signals with similar characteristics. These results highlight an interesting phenomenon when actively listening to white noise. Further testing is required to establish if the effect persists when listeners are exposed to white noise passively.

This will have implications when audifying white noise type data. It is recommended that interactive sonification techniques are utilized to reduce the impact of phantom signal detection. Consideration should also be given to the influence on the participant of pre-listening prior to a listening test, as these results indicate that this can have an effect upon perception during the test.

This team intends to continue this study by investigating listener’s abilities to detect signals mixed into white noise passively. These tests will be longer in duration, and each subject will be involved in a distraction task to prevent them from actively listening to the subject material.

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Andy Hunt is a senior lecturer in Music Technology at the University of York, UK. His research focuses on the human-computer interaction techniques for music and creative engineering; bringing together new musical instruments and complex interaction techniques for auditory display. He is also supervising a number of Masters and PhD students in the area of sonification, aiming at improving auditory display interaction, and especially on mobile, multi-touch devices. Together with Thomas Hermann he initiated the Interactive Sonification workshop series and is guest editor for the IEEE Multimedia special issue on Interactive Sonification. Together with Roberto Bresin and Thomas Hermann, he co-organized the ISon 2011 workshop and is guest editor of a Springer JMUI special issue (in production).

Appendix C

Multi-listener sonification: A team approach to Interactive Auditory Display

Multi-listener sonification: A team approach to Interactive Auditory Display

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ABSTRACT

When interactive sonification occurs in the real world – i.e., in a busy office environment, the listener is exposed to a wide range of sensory information. If the listener is distracted by their environment this reduces the effectiveness of the sonification, since a distracted listener will not interact with the data. The effect of localized distractions can be reduced when multiple listeners interact with the same data. This position paper discusses the merits of a team approach to sonification: sonifying in ensembles and in a distributed collective. In order to demonstrate this, a short pilot study of a group based sonification of listeners detecting signals in white noise whilst distracted is included.

1. INTRODUCTION

"The current enthusiasm for team working in organizations reflects a deeper, perhaps unconscious, recognition that this way of working offers the promise of greater progress than can be achieved through individual endeavor"

(West and Markiewicz, 2008) [1]

There are disadvantages to a single user listening to a sonification;

- The individual may not have perfect hearing
- They may have missed important information due to fatigue or distraction
- Everyone's individual perception of sound may be unique, so what one listener perceives as a signal may not be obvious to another, and
- The environment that the sonification may not be conducive for listening.

Utilizing multiple listeners can resolve some of these issues.

Multi-listener sonification involves two or more listeners interacting with a common data set. A team approach to sonification can provide several advantages. When dealing with a large data set, subdivision of the work amongst several listeners will reduce the overall time taken to listen to the data – a "many hands make light work" distributed approach. Multiple users independently listening to the same data will provide a more rigorous verification of any results obtained. Having users interact with a common data set in different environments will reduce the impact of localized environmental factors – such as distractions or intrusions.

2. MULTI-LISTENER SONIFICATION

Multi-listener sonification could be broadly subdivided into two approaches: ensemble sonification and distributed sonification. Ensemble sonification is when a sonification team works together in the same environment and at the same time, whereas in distributed sonification the listeners work on a common data set in isolation from each other.

2.1. Ensemble Sonification

There are several examples of sonifications that have utilized a multi-user approach. Cloud Bridge [2] is a multi-user interactive tool where several users simultaneously explore data as an ensemble. A tool was described by Tunnermann et al [3] where a multi-touch interface could be operated by an ensemble to interact with data via model-based sonification. EMOListen [4] is a multi-user platform that enables a group of listeners to interact with bio-signal data.

The above could all be classified as examples of ensemble sonification, where a group of listeners synchronously interact with a common data set in a shared environment. The advantages of this approach are that the group can interact with both the data and each other. However, a shared environment means that the group is collectively influenced by the same stimuli. This adds another level of interaction as the members of the ensemble will interact with both the sonification and each other. Figure 1 illustrates an individual listener who is placed within an interactive control loop.

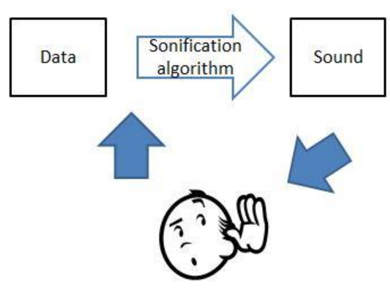

Figure 1. *A listener within an interactive control loop*

The user listens to the sound and through an interface is able to adapt the sonification algorithm. Figure 2 summarizes the effect of having additional listeners within this control loop.

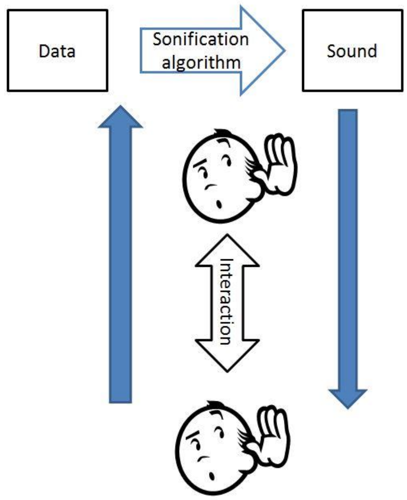

Figure 2. *Two listeners within an interactive control loop*

The addition of a second listener enables the team to interact with each other and the sonification (data and algorithm). It should be noted that there may be a limit to the maximum number of members of the ensemble, since an excessive number of listeners may only distract each other.

2.2. Distributed sonification

Distributed sonification is where a group of users interact with a common data set in isolation, each listener in a separate environment. Each individual forms part of a collective of sonifiers, and each member of the collective brings their own individual qualities to the group. Multiple users may interact with the data in separate environments and at different times. This approach to sonification shares many characteristics of a grid computing system, where a task is implemented on several separate computers. Parallels can also be drawn with a project such as Eric Whitacre's Virtual Choir [6], where thousands of singers separately record their own voices, which are then combined separately to form a choir. Like Whitacre's Virtual Choir, it is anticipated that distributed sonification will require a central administrator or conductor to co-ordinate the collectives' activities. A major benefit of this approach is that because each user is isolated, the effect of environmental influences on the sonification is reduced. For example, one listener may be distracted by a telephone call, but a collection of separate listeners would not be all distracted at the same time.

A distributed approach to sonification will be advantageous where there is a large amount of data to listen to. For example, a data mining task may result in a 20 hour long sonification. A solo sonifier would have difficulty in listening to this in one sitting; they would naturally experience fatigue and distractions which would reduce the efficiency of their work. If this was listened to by a community of 40 sonifiers, each only interacting with 30 minutes of data, the influence of listener fatigue would be reduced. Confirmation of any results could be achieved by multiple sonifiers listening to the same data. The use of a distributed collective, when dealing with large amounts of data, can lead to more accurate results.

3. ENVIRONMENTAL ASPECTS OF MULTI-USER INTERACTIVE SONIFICATION

3.1. Real world interactive sonification

Listening to sound in the real world is more challenging than listening under laboratory conditions. The listener is exposed to sights, sounds, tastes, smells and a gauntlet of additional day to day distractions, such as hunger, noisy neighbors, demanding work colleagues and the internet. Vickers [5] discusses how distraction and fatigue are challenges facing the designer of process monitoring auditory displays. The listener who is placed within an interactive control loop is exposed to multiple sensory stimuli (Figure 3). Some of this sensory data may interfere with the user's ability to perceive sound – for example, a listener with a toothache may be too distracted to effectively interact with the system.

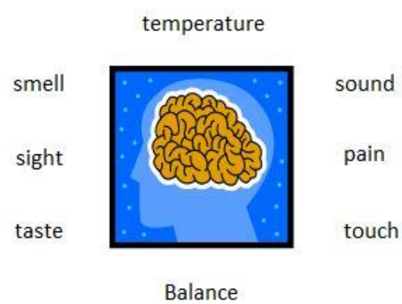

Figure 3. *Stimuli which may distract from effective listening*

The environment that the listener is placed in can have a substantial effect upon listening quality and thus can affect the listener's ability to interact with the sonification system. Interactive sonification is a field of sonification which places emphasis upon the listener interacting with the system that is producing sound [7]. The listener is placed into a control loop which responds to the user's input; Figure 1(which was displayed earlier in this paper) shows a control loop as found in interactive sonification.

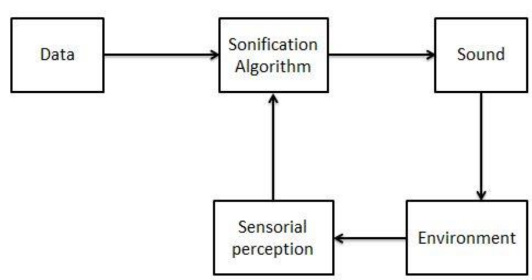

Figure 4. *A perceptual/environmental model of interactive sonification*

A model of interactive sonification that incorporates the environment and the listener's perception is illustrated in Figure 4. The environment that the sound is played in will influence the perception, and as any interaction is caused by sensory input, the environment will influence interaction. For example a noisy environment will diminish the listener's ability to perceive sound, and they may not interact with the system in the same way that they would if listening under ideal conditions.

3.2. Attention and Distraction

Ideally the listener would be placed into a quiet, distraction-free environment; in practice this may be difficult to achieve. This real-world environment will usually contain a level of background noise and disturbances which will distract the listener from interacting with the sonification. It is clear that the environment the sonification takes place in will have some effect upon the listener's attention. The environment provides a rich set of stimuli that is immersive: sights, sounds, tastes and smells all compete for attention. Although people are constantly stimulated, they have the ability to focus upon one set of stimuli at a time, they can pay attention to a single aspect of their environment. For example, when reading one may not be aware of background sounds. However an important characteristic of our attention system is the ability to refocus or move our attention to another stimulus. In the previous example we would stop reading when we heard a loud noise and then pay attention to its source. This is similar to the recognized psychoacoustic phenomenon, the "Cocktail Party" effect [9], where the listener's attention is diverted when they hear their name in noisy environment. Recognizing their name focuses the listener's attention upon conversations that they weren't aware of before. The brain must be subconsciously monitoring sounds in the background all the time.

It has been suggested that the human brain constantly monitors sensory information subconsciously; the brain scanning information in a low-level manner that has been described as a pre-attention phase [8]. In this pre-attention phase the brain may parse aspects of vision into objects, and amalgamate sounds of similar characteristics to form an auditory scene [9]. After this pre-processing, the attention given to the stimuli can be attributed to several factors. There are two forms of attention: automatic and selective [10]. Selective attention is when there is focus upon a stimulus, and a conscious choice is made to focus the attention on one area. Automatic attention is caused either by a change in stimulus, a stimulus that is considered important, or a stimulus that alerts the individual to danger. This is an instinctive response to changes in one's environment. When something triggers automatic attention, there is distraction from the selective attention activity.

4. EXPERIMENTAL WORK ON MULTI-USER SONIFICATION

An experiment was set up to explore if a distributed approach could be applied to a large data mining problem. This problem was related to the audification of radio astronomy data produced by the Search for Extra-Terrestrial Intelligence (SETI) [11]. This project audifies SETI data, as the default background data is generally random Brownian noise, and so the audified version has similar characteristics to white noise. Any potential candidate signals would be heard as glitches, tones, pulses or chirps within the noise. As the data is noise-based in nature it is presented to the listener as background white noise. Many listeners are familiar with noise-masking, and several internet sites such as [12] and apps, such as [13] now exist to mask environmental noise. For example, people in open-plan offices often report an improvement in productivity if they mask out distractions using white noise [14].

In this system, if a listener hears a candidate sound within the noise-like background data they can press a button on an interface that reports this information back to a centralized database. The user interface will include interactive controls to allow the listener to repeat sections of the data, which is important to enable them to confirm if there was a signal.
A single SETI observation generates a large amount of data, and once audified will generate 35 hours of audio. This is impractical for solo listening; however a distributed listening methodology would be beneficial. The audio is broken down into smaller packets and then distributed to a team, who individually interact with their own data. After the team has listened to this data, the incidents of button presses are collated; a number of hits from several individuals at the same time would indicate the presence of a signal, whereas false positives (where individual listeners have pressed the button in error) would not show a similar grouping.

4.1. Experiment

The objective of this experiment was to establish whether a team of listeners would be able to detect sinusoid signals mixed into white noise whilst taking part in a distraction activity.

An audio file, 14 minutes in duration, was created containing noise at -30 dB, generated from a SETI radio observation of the Moon [15], and which has Brownian noise characteristics. Mixed into the noise are 5 test tones that are 10 seconds in duration. These tones occur at various times throughout the test, and details of their frequency, amplitude and start times are shown in table 1. Start times listed are the number of seconds from the beginning of the test file that the signal starts.

Signal start time(seconds)	Frequency	Amplitude (dB)
56	200Hz	-30
137	200Hz	-50
251	1Khz	-40
446	1Khz	-30
788	200Hz	-54

Table 1. *Signal frequencies, amplitudes and start times*

These listening tests took place in an acoustically isolated room, where each listener was fitted with a pair of DT 100 Beyerdynamic headphones and asked to read a section of the novel The War of the Worlds [16] whilst listening to the audio file containing noise and signals. Listeners were asked to concentrate on the reading activity. If they perceived a signal, they reported this to the examiner by pressing a button, whereupon the examiner would log the time. The button was not connected to any devise but acted as an indicator that the listener had heard something. After the audio file was played, each listener was asked to complete a short questionnaire on the reading material, which was intended to establish if each listener was taking an active part in the reading task. All resources for this are available to download from the sonicSETI website [17].

4.2. Results

There were 9 participants, aged between 29 and 61, 8 males and 1 female. A table has been collated of the times that each candidate registered a signal and pressed the button (Table 2). The leftmost column (ID) is the candidate number and each time in seconds that the listener reported a signal is listed in the rows to the right (for example candidate 4 indicated 5 signals at 59, 140, 250, 447 and at 789 seconds. Several candidates reported more than 5 signals, with candidate 7 reporting nine signals.

	Time of report (seconds)								
ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	59	147	253	448	790				
2	57	60	140	172	252	447	792		
3	59	145	252	449	790				
4	59	140	250	447	789				
5	57	140	227	253	450	800			
6	57	141	254	450	793				
7	54	60	140	254	449	611	729	784	791
8	57	140	253	449	792	838			
9	58	140	253	310	448	789			

Table 2. *Times of signal detection reports for each candidate*

Table 3 indicates the number of correct reports per candidate. A report is identified as being correct if the candidate presses the button during the time that the signal was present. The correct column indicates the number of correctly identified signals, and the false column is the number of false positives – button presses when the signal was not present. The data appears to show some anomalous data – candidate 2 appears to identify signal 1 twice, candidate 4's identification of signal 3 is before the signal started, this could either be a false positive or an error when the time was written down. Candidate 5 identified signal 5 after the signal ended.

There is a high incidence of correct detection of the signals mixed in with white noise; the majority of listeners correctly detected all 5. Out of the 59 signal reports, 11 of these were false (18%), this would indicate that listeners are able to detect the presence of signal mixed into white noise whist distracted by a reading activity.

Evaluating these collated results as a group, it is clear to see that the real signals can be identified. When a listener falsely reports a signal, they do so in a random manner. A histogram which plots the number of reports against the time of report is shown in Figure 5.

ID	Sig 1	Sig 2	Sig 3	Sig 4	Sig 5	Correct	False
1	1	1	1	1	1	5	0
2	2	1	1	1	1	5	2
3	1	1	1	1	1	5	0
4	1	1	0	1	1	4	1
5	1	1	1	1	0	4	2
6	1	1	1	1	1	5	0
7	1	1	1	1	1	5	4
8	1	1	1	1	1	5	1
9	1	1	1	1	1	5	1

Table 3. *Table of correctly identified signals per candidate*

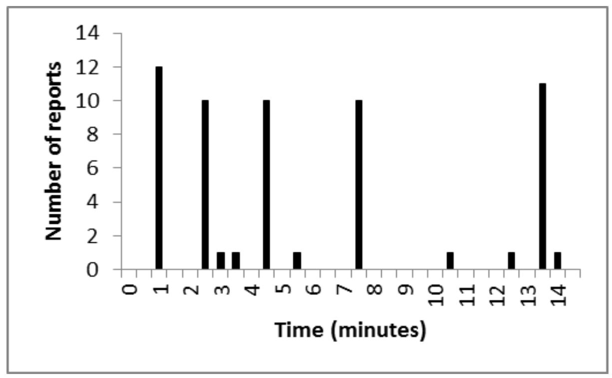

Figure 5. *Histogram showing incidence of reports against time*

Figure 5 shows that this team of sonifiers were able to correctly identify the presence of the five test signals presented; this is demonstrated by the five peaks on this histogram. The single points on the histogram are erroneous reports. By inspection of the graph it is easy to distinguish between clustering of hits when a signal occurs and the low incidence of errors.

5. CONCLUSIONS

In the real world, a listener in an interactive control loop is subject to a variety of stimuli – all vying for the listener's attention. The listener may become fatigued or distracted by their environment. There are other considerations such as the individual's hearing ability or competency to interact with the sound. A multi-user approach to sonification can help resolve some of these issues. Distributed sonification in isolated environments should reduce the effect of distraction. As demonstrated in the sonicSETI case study, individual errors can be ignored when plotted against a majority of results. Any results gained from a team of sonifiers are confirmed by a majority of listeners. When dealing with large amounts of data, where solo sonification would be time prohibited, a team of sonifiers could be a workable solution.

6. FURTHER WORK

As mentioned in the opening paragraph – this is a position paper which presents the novel concept of sonification in groups to this conference. This work in progress is expected to continue into several distinct areas.

The pilot study on distributed sonification was conducted under acoustically isolated conditions. The study's results suggest that collectively a group of sonifiers can accurately detect these signals, but further work needs to be undertaken to establish the effect of real-world conditions. This test needs to be repeated in a distracting and noisy environment to clarify whether distributed sonification can reduce the impact of the environment.

This work requires further study on ensemble sonification, with a particular emphasis upon the interaction between team members during a sonification experiment.

This team intends to conduct a live interactive ensemble based sonification during the presentation of this paper at the conference, which will incorporate live feedback of results obtained during the test, a technique that was suggested by Penelope Griffiths [18].

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Appendix D

Listening tests feedback forms

SETI Noise/artefact Experiment 1

Subject Number	
Age	
Sex	
How good are you at listening (1 to 10)	

On a scale from 1 to 10, please score whether you can detect a signal within the white noise in the following samples. In the second box please indicate what type of signal you heard – Tone, Chirp, Pulse, Squiggle, None or Other

10 = I definitely can hear a signal in the noise,

1 = I could not detect any signal in the noise

	Score	Signal type
Sound 1		
Sound 2		
Sound 3		
Sound 4		
Sound 5		
Sound 6		
Sound 7		
Sound 8		
Sound 9		
Sound 10		
Sound 11		
Sound 12		
Sound 13		
Sound 14		
Sound 15		
Sound 16		
Sound 17		
Sound 18		
Sound 19		
Sound 20		

Comments:

SETI Noise Experiment 2a – With Preview

Subject Name	
Age	
Gender	
Please rank your musical ability (1 = None to 10 = Virtuoso)	
Please rank your hearing ability (1 = very poor to 10 = excellent)	

On a scale from 1 to 10, please score whether you can detect a signal within the white noise in the following samples. In the second box please indicate what type of signals you heard – Tone, Chirp, Pulse, Squiggle, None or Other.

10 = I definitely can hear a signal in the noise, 1 = I could not detect any signal in the noise

	Score	Signal type/s
Sound 1		
Sound 2		
Sound 3		
Sound 4		
Sound 5		
Sound 6		
Sound 7		
Sound 8		
Sound 9		
Sound 10		

Comments:

SETI Noise Experiment 2b – No Preview

Subject Name	
Age	
Gender	
Please rank your musical ability (1 = None to 10 = Virtuoso)	
Please rank your hearing ability (1 = very poor to 10 = excellent)	

On a scale from 1 to 10, please score whether you can detect a signal within the white noise in the following samples. In the second box please describe what type of signal you heard.

10 = I definitely can hear a signal in the noise, 1 = I could not detect any signal in the noise

	Score	Description of signal
Sound 1		
Sound 2		
Sound 3		
Sound 4		
Sound 5		
Sound 6		
Sound 7		
Sound 8		
Sound 9		
Sound 10		

Comments:

Please don't turn over this page until you have completed the listening test!

Subject Name	
Age	
Gender	

Q1 - Are you a musician?

Q2 – If the answer to Q1 is yes, which of the following terms describes your level of musicianship?

1 – Beginner

2 – Intermediate

3 – Advanced

4 - Virtuoso

Please don't turn over this page until you have completed the listening test!

Instructions

Please circle the correct answer

1) ______ **Which Century was the War of the worlds set?**

   a. 18th
   b. 19th
   c. 20th

2) ______ **Which publication reported the first sighting of the disk to English readers?**

   a. Punch
   b. The Sunday Times
   c. Nature

3) ______ **What island is mentioned in the book has having been nearly swept out of existence by Europeans?**

   a. Galapagos
   b. Tazmania
   c. Jamaica

4) ______ **Which activity was the author teaching himself to do?**

   a. Swimming
   b. Cooking
   c. Riding a bike

Any Comments on this test?

Please don’t turn over this page until you have completed the listening test!

Subject Name

Age

Gender

Q1 - Are you a musician?

Q2 – If the answer to Q1 is yes, which of the following terms describes your level of musicianship?

1 – Beginner

2 – Intermediate

3 – Advanced

4 - Virtuoso

Please don’t turn over this page until you have completed the listening test!

Instructions

Please circle the correct answer

1) **Which Century was the War of the worlds set?**

a18th

b19th

c20th

2) **Which publication reported the first sighting of the disk to English readers?**

2) ______

a. Punch

b. The Sunday Times

c. Nature

3) ______ **What island is mentioned in the book has having been nearly swept out of existence by Europeans?**

a. Galapagos

b. Tazmania

c. Jamaica

4) ______ **Which activity was the author teaching himself to do?**

a. Swimming

b. Cooking

c. Riding a bike

Any Comments on this test?

Appendix E

Multi-listener workshop presentation

Multi-listener Sonification:
An exploratory workshop

Your Host : Paul Lunn

Please download MAX MSP from https://cycling74.com/downloads/

About Me

- Senior Lecturer in Music Technology at Coventry University in the UK
- PhD Researcher at York University, supervised by Dr Andy Hunt
- Investigating applying sonification techniques to big data

Why teams?

International **Community** for Auditory Display

Introducing The Lone Sonifier

Sonifies in isolation

Does not verify any findings

Interacts with the sound

Bias

Was he paying attention all the time?

Did he get distracted?

Hearing fatigue

Hearing ability?

Team Sonification

Sonification in a team

Results can be independently verified

Interacts with both the sound and each other

Share the workload

Impact of distractions reduced

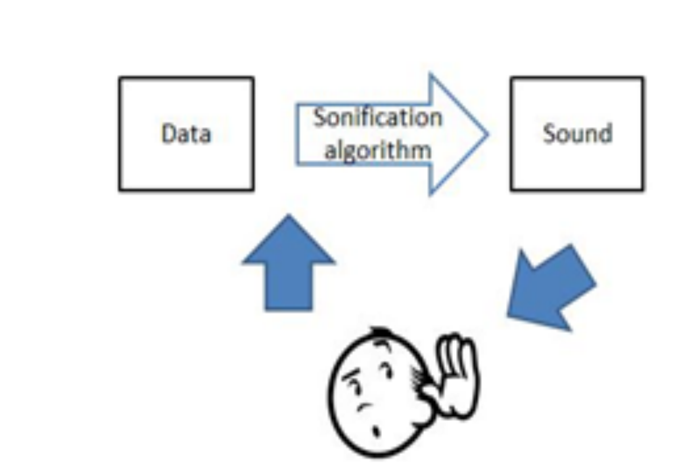
Several perspectives

The group ear

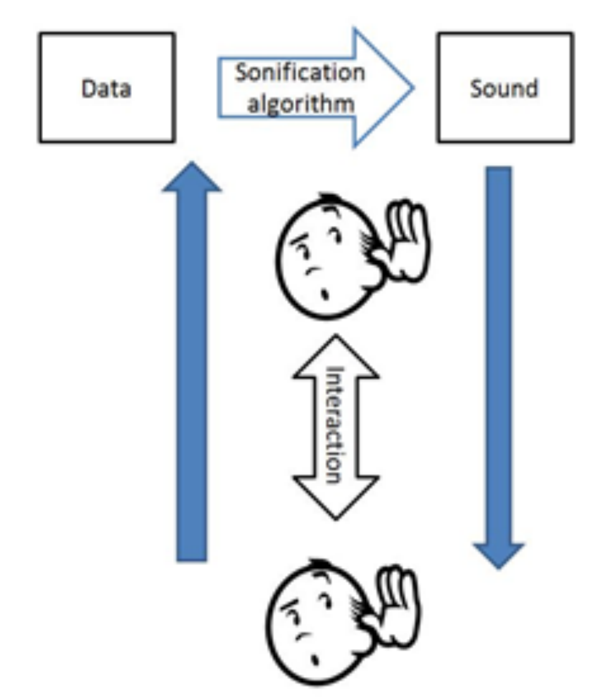
The Group ear

Is this automatic peer review?

Team sonification = Interaction^2



Solo listener within an interactive control loop



Two listeners within an interactive control loop

Sonification in teams

- Have identified several approaches to team based interactive sonification
- Ensemble sonification
- Distributed sonification

Ensemble Sonification

- A team of sonifiers within the same environment
- Each interacts with the data
- Each interacts with each other
- Possibly requires a conductor to lead the ensemble

Distributed Sonification

- Sonification "work" is distributed to a team
- Each member interacts with the data in isolation
- Different environments
- Different distractions
- Results are confirmed by multiple hits

- Eric Whitacre's Virtual Choir

Crowd Sourced Science

- Distributed Sonification enables many users to interact with data
- Public engagement
- This could be the basis for sonification based citizen science
- E.g Galaxyzoo, frogwatch, weather detective
- If it is based on a topic that catches the publics imagination, this could be an excellent way of promoting the subject
- E.g. Astronomy, Medical, ecological, environmental

Session Set Up

- Make sure that Max msp is installed on your computer
- https://cycling74.com/downloads/
- Unzip the file I sent to your email address to your desktop
- No looking!

Exercise 1

- Please open seti_demo.matpat

- If you think that you can hear a tone within the white noise – press the lower button!

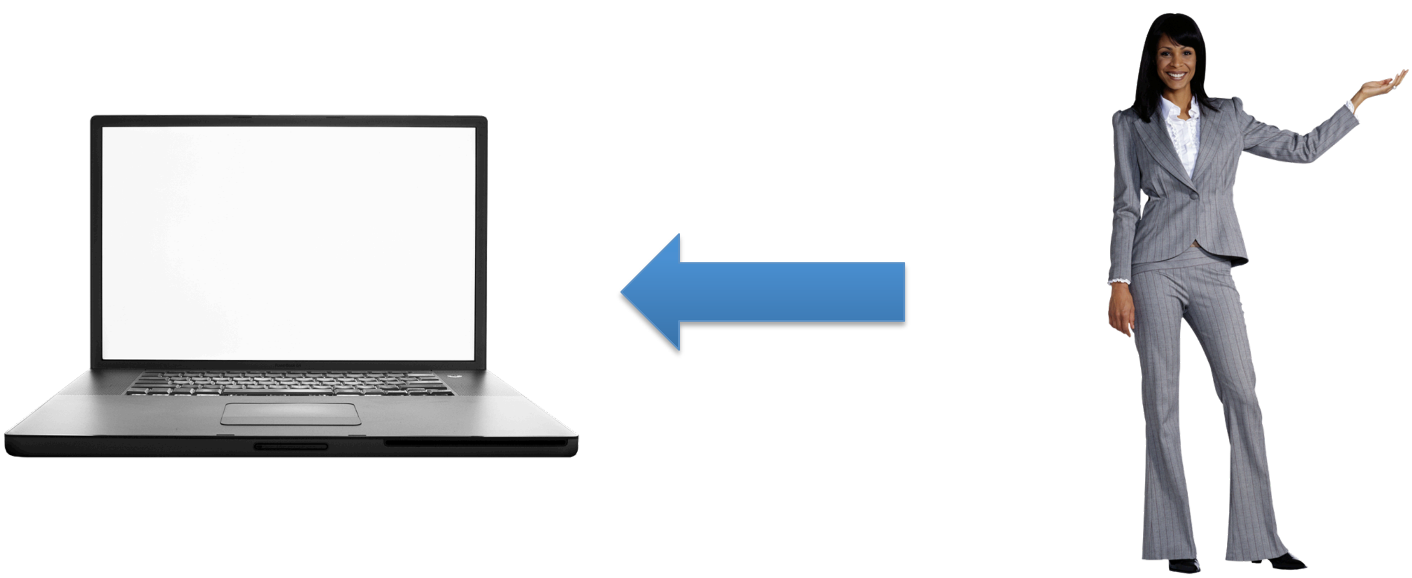
Short break!

- Next on the agenda is Pair Sonification

Pair Sonification

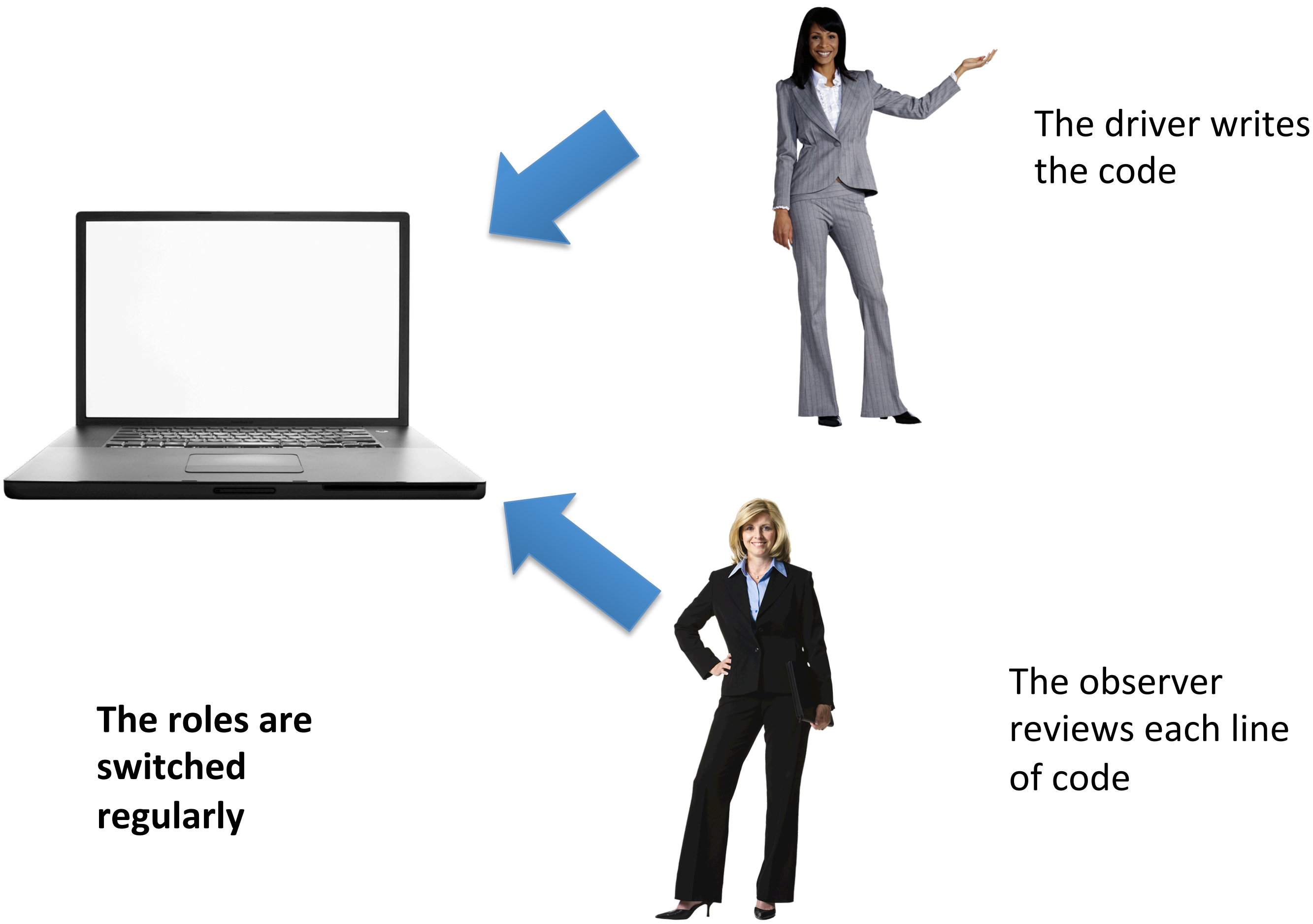
- Pair sonification is based upon principles developed for “Pair Programming”
- Agile Software Development
- Agile software techniques were introduced to improve code quality and productivity

Solo Programming



Programmer

Pair Programming



Pair programming benefits

- The pair need to think/plan before they design
- Discourages bad habits
- Mentoring
- Sharing best practice
- Forms mutual understanding of design

Pair Sonification Example

The driver interacts with the sound

The roles are switched regularly

The observer provides feedback to the driver

Exercise 2

- Work in pairs
- Please open task_2 folder
- Run pair_radio_1
- The driver does what the observer tells them
- Find the best setting

- Now swap roles with pair_radio_2

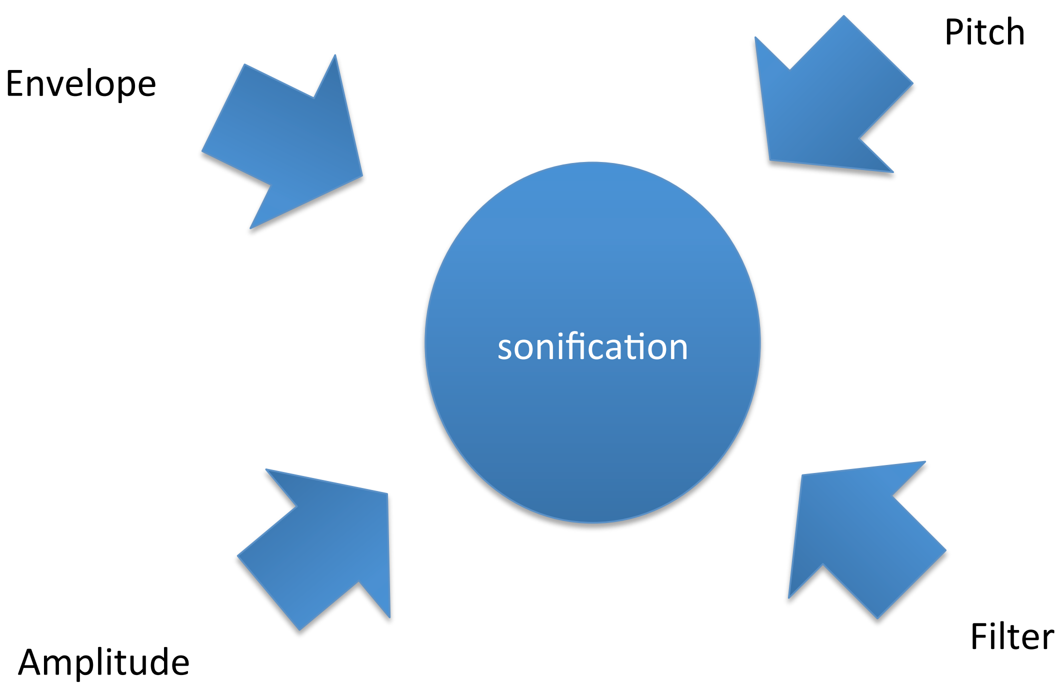
Short break!

- Next on the agenda is Ensemble Sonification

Ensemble Sonifcation

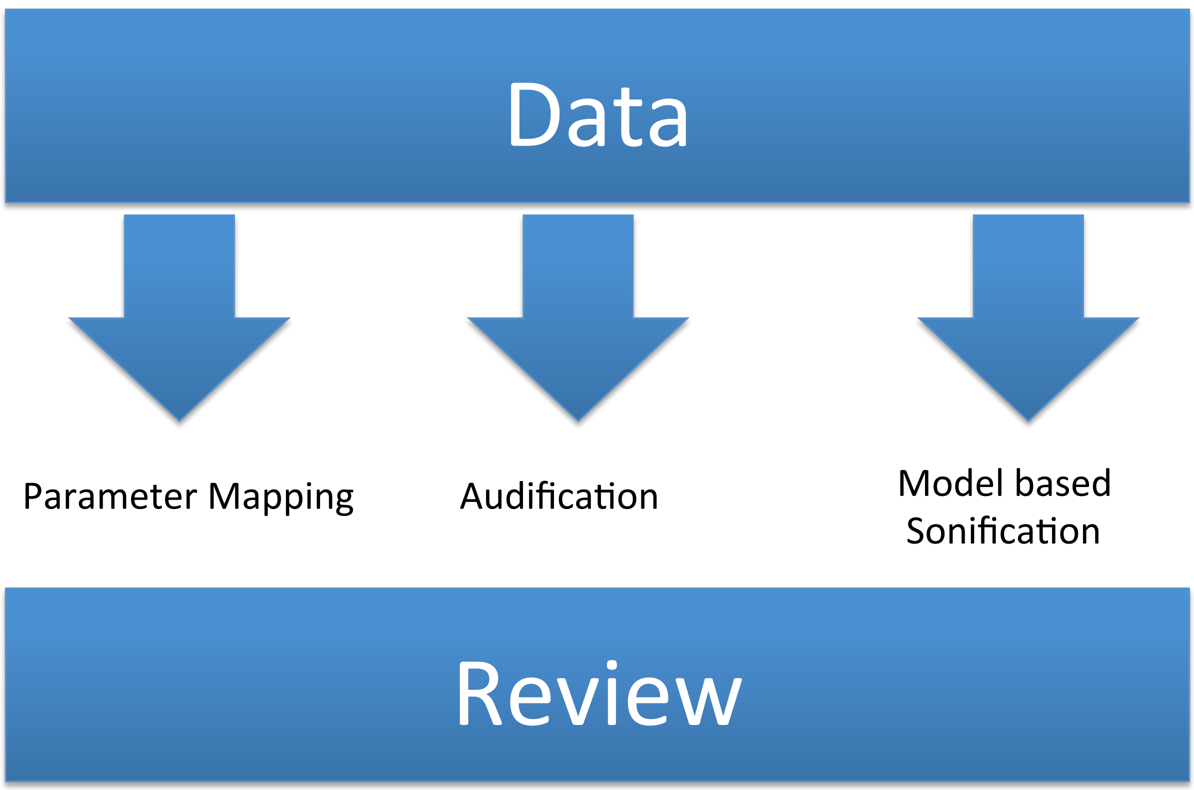
- 3 or more in a team
- Working concurrently or in parallel
- Again this encourages planning and discussion before the work is progressed
- Team dynamics may come into play

Ensemble Parameter Mapping



Each member controls one aspect of the sonification in a shared environment

Ensemble parallel sonification



Each member applies a different sonifcation technique to the same data

Who's in charge?

Task 3

- Please open ensemble radio.matpat
- Work as a team – audio contains background noise + random spoken words (fruits)
- How many fruits can you hear?
- You have 15 minutes

The end

Thank you for attending!

Appendix F

Virtual auditory display team

Virtual sonification teams

Paul Lunn

May 1, 2018

Contact Details

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Introduction

This document describes the setup of a virtual sonification team. The objective of this experiment is to research what can be learned about data through a team of people interacting in a virtual environment.

Virtual teams

A virtual sonification team is a group of people in different geographical locations who collaborate on a common task. This virtual team will interact through digital communication systems such as email and video conferencing. Any video conferences will be recorded for monitoring purposes, but the recordings will be private and not released outside of the team. For this short experiment I will be taking the role of team leader, and also contributing to the task.

Protocol

For this experiment I would like to set up a virtual team consisting of members of the sonification community. The team will be formed for one week where each member will be asked individually to sonify the same data set. The team will be introduced by having a joint video conference to introduce everyone to the task. Once everyone has submitted their task, I will distribute everyone's solution and we will have a video conference where everyone can feedback on everyone's results.
At the end of the experiment I will ask each participant to fill out a confidential questionnaire concerning their attitudes to team working.

Data

The data for this experiment is a chemical analysis of 1600 Portuguese red wines. Each wine has been analysed and separately evaluated for quality. Quality is a number between 0 and 10 (0 is poorest, 10 is best). The goal of this task is to use sonification techniques to model wine quality based on chemical tests.
The data is in CSV format, which is an open source spreadsheet. Information concerning each column of data is enclosed in Table 1 below.

Attribute	**Maximum**	**Minimum**
ID	1	1599
fixed acidity	15.9	4.6
volatile acidity	1.58	0.12
citric acid	1	0
residual sugar	15.5	0.9
chlorides	0.611	0.012
free sulfur dioxide	72	1
total sulfur dioxide	289	6
density	1.00369	0.99007
pH	4.01	2.74
sulphates	2	0.33
alcohol	14.9	8.4
quality	8	3

Table 1: Attributes and quality of red wine

This data is sourced from
https://archive.ics.uci.edu/ml/datasets/Wine+Quality
Please feel free to choose any sonification algorithm for this task.
At the end of the task can you please submit an audio file containing an example of your results and any source code/application patches that you have used to implement your algorithm - these will be distributed to the team for feedback.

Participant No.

INFORMED CONSENT FORM:
Virtual Sonification Teams

You are invited to take part in this research study for the purpose of collecting data on Virtual sonification teams].

Before you decide to take part, you must **read the accompanying Participant Information Sheet.**

Please do not hesitate to ask questions if anything is unclear or if you would like more information about any aspect of this research. It is important that you feel able to take the necessary time to decide whether or not you wish to take part.

If you are happy to participate, please confirm your consent by circling YES against each of the below statements and then signing and dating the form as participant.

1	**I confirm that I have read and understood the Participant Information Sheet for the above study and have had the opportunity to ask questions**	**YES**	**NO**
2	**I understand my participation is voluntary and that I am free to withdraw my data, without giving a reason, by contacting the lead researcher and the Faculty Research Support Office at any time until the date specified in the Participant Information Sheet**	**YES**	**NO**
3	**I have noted down my participant number (top left of this Consent Form) which may be required by the lead researcher if I wish to withdraw from the study**	**YES**	**NO**
4	**I understand that all the information I provide will be held securely and treated confidentially**	**YES**	**NO**
5	**I am happy for the information I provide to be used (anonymously) in academic papers and other formal research outputs**	**YES**	**NO**
6	**I am happy for the meetings to be recorded**	**YES**	**NO**
7	**I agree to take part in the above study**	**YES**	**NO**

Thank you for your participation in this study. Your help is very much appreciated.

Participant's Name	**Date**	**Signature**
Researcher	**Date**	**Signature**

Virtual Sonification Team Questionnaire

1. **Where did you work on this task, i.e. which city/town?**

   ____

2. **Please indicate your experience with Auditory Display research prior to the experiment**
   Mark only one oval.

	1	2	3	4	5	
I have no experience of sonification	⬭	⬭	⬭	⬭	⬭	I am very experienced in sonification

3. **Please indicate your experience of working within a team on sonification tasks prior to this experiment.**
   Mark only one oval.

	1	2	3	4	5	
I have no experience of sonification teams	⬭	⬭	⬭	⬭	⬭	I am very experienced in sonification teams

4. **The team had a meaningful, shared purpose.**
   Mark only one oval.

	1	2	3	4	5	
Disagree	⬭	⬭	⬭	⬭	⬭	Agree

5. **My involvement in this team reduced my creativity**
   Mark only one oval.

	1	2	3	4	5	
Disagree	⬭	⬭	⬭	⬭	⬭	Agree

6. **We communicated effectively within our team**
   Mark only one oval.

	1	2	3	4	5	
Disagree	⬭	⬭	⬭	⬭	⬭	Agree

7. **This was a worthwhile experience for me**
   Mark only one oval.

	1	2	3	4	5	
Disagree	⬭	⬭	⬭	⬭	⬭	Agree

8. **I would like to incorporate virtual teams in my future research**
   Mark only one oval.

	1	2	3	4	5	
Disagree	⬭	⬭	⬭	⬭	⬭	Agree

9. **This experience had a positive effect upon my understanding of Auditory Displays**
   Mark only one oval.

	1	2	3	4	5	
Disagree	⬭	⬭	⬭	⬭	⬭	Agree

10. **Working in teams can be an effective approach to auditory displays?**
    Mark only one oval.

	1	2	3	4	5	
Disagree	⬭	⬭	⬭	⬭	⬭	Agree

11. **Working in teams can be an efficient approach to auditory displays**
    Mark only one oval.

	1	2	3	4	5	
Disagree	⬭	⬭	⬭	⬭	⬭	Agree

12. **Any comments on this experiment?**

____

____

____

____

____

Virtual Sonification Team Questionnaire

3 responses

Where did you work on this task, i.e. which city/town?

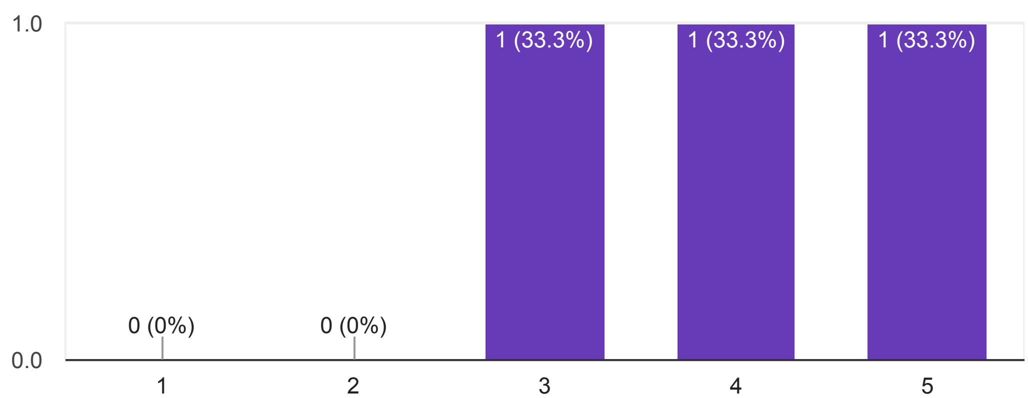
2 responses

Vancouver

Coventry

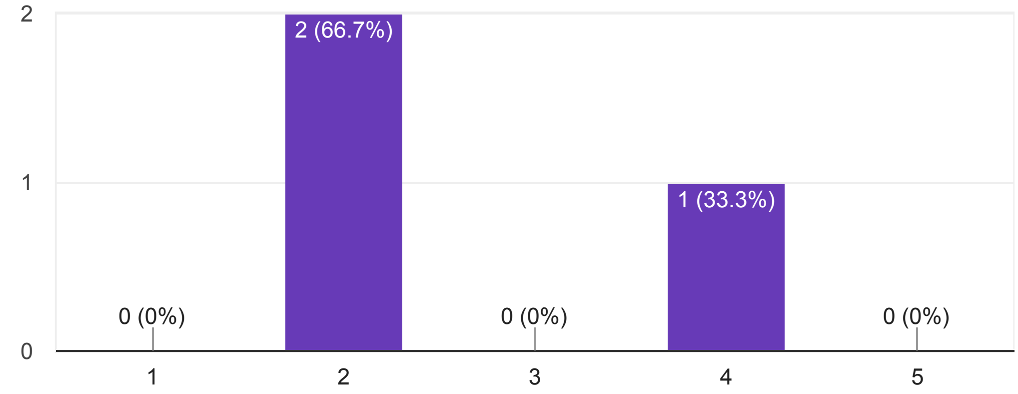
Please indicate your experience with Auditory Display research prior to the experiment

3 responses



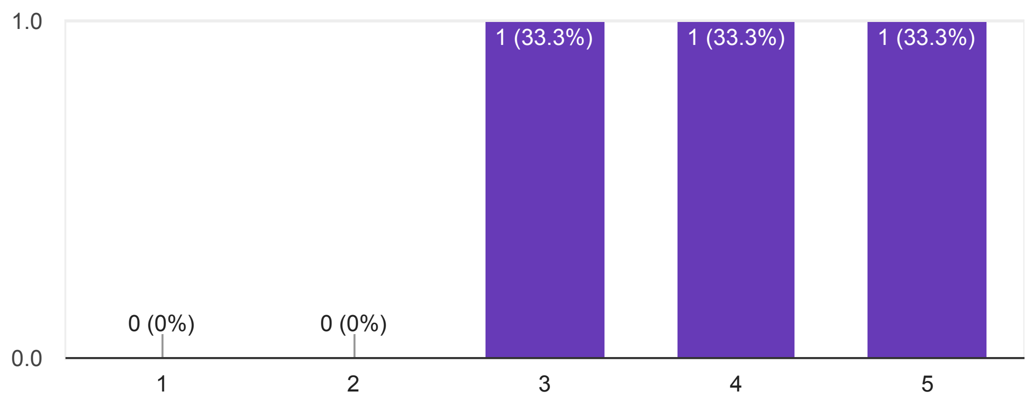
Please indicate your experience of working within a team on sonification tasks prior to this experiment.

3 responses



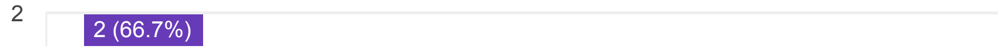
The team had a meaningful, shared purpose.

3 responses



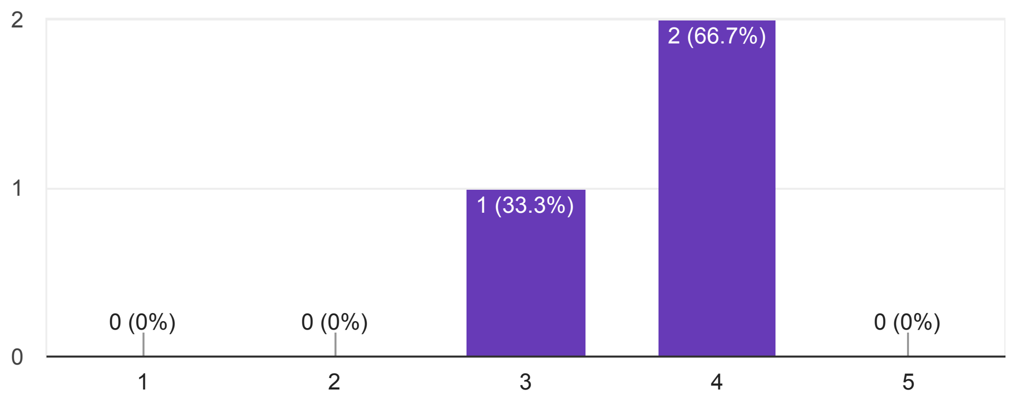
My involvement in this team reduced my creativity

3 responses



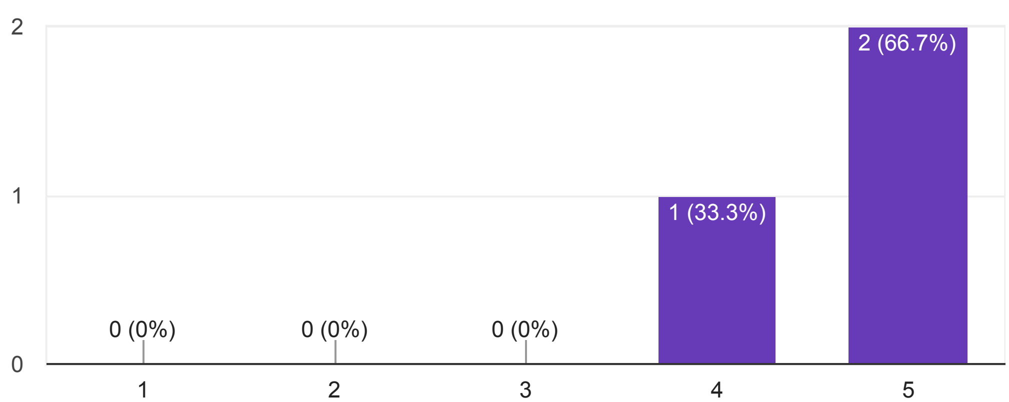
We communicated effectively within our team

3 responses



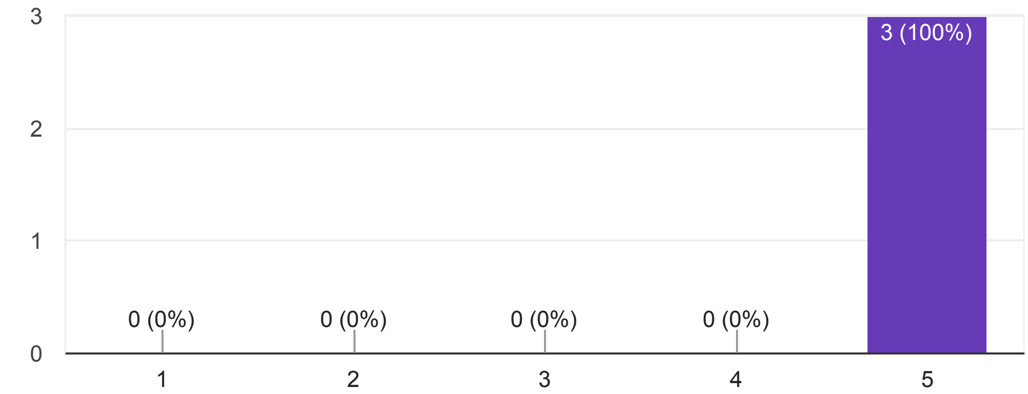
This was a worthwhile experience for me

3 responses



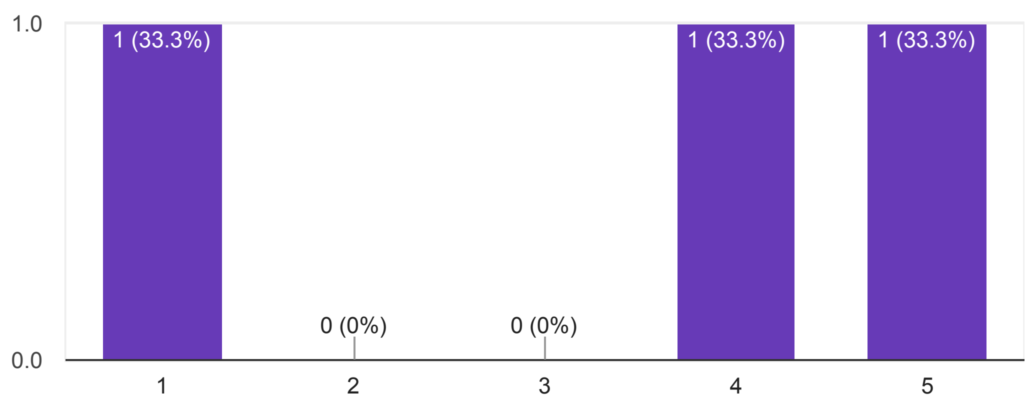
I would like to incorporate virtual teams in my future research

3 responses



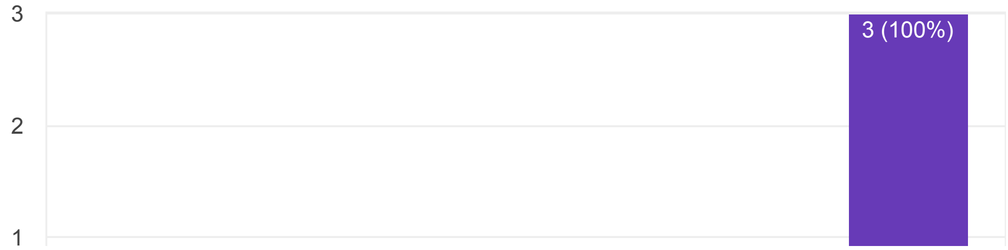
This experience had a positive effect upon my understanding of Auditory Displays

3 responses



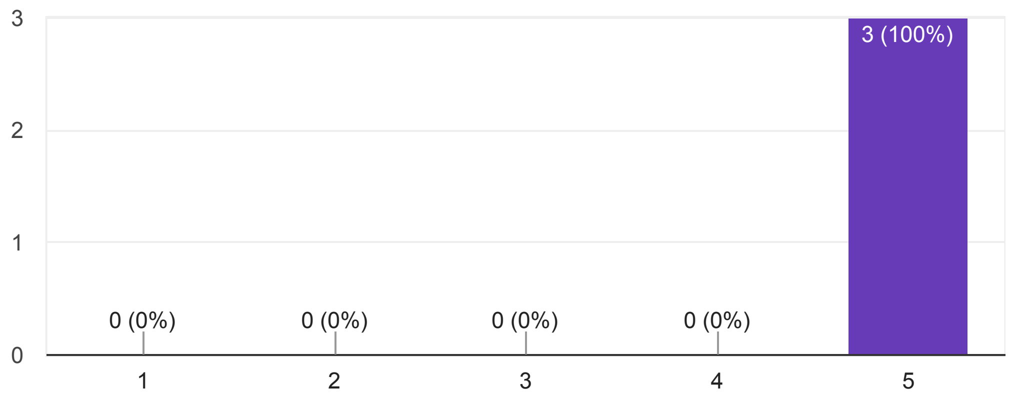
Working in teams can be an effective approach to auditory displays?

3 responses



Working in teams can be an efficient approach to auditory displays

3 responses



Any comments on this experiment?

1 response

It's good to meet people from different academic backgrounds. I would like to continue this type of work in the future. Thank you.

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