**Machine Annotation of   
Traditional Irish Music**

**Bryan2**

**PhD**

**Bryan Duggan MSc, BSc.**

*School of Computing*

*Dublin Institute of Technology*

*Kevin St. Dublin 8, Ireland.*

**Supervisors:  
Prof. Brendan O’ Shea  
Dr. Mikel Gainza**

**Prof. Padraic Cunningham**

**Dublin Institute of Technology, School of Computing**

**December 2008**

**Abstract**

The document contains a discussion of the characteristics of creativity and style in traditional Irish flute music and discusses related work on the problem of feature extraction from monophonic recordings of traditional music. Work on the modelling of musical creativity and the cognition of musical style in software is also presented.

**Keywords: Musical creativity, musical style modelling, traditional Irish music, transcription, signal processing, Machine learning**

**Table of Contents**

[1 Introduction 1](#_Toc199912043)

[1.1 Background 1](#_Toc199912044)

[1.2 Research aims 3](#_Toc199912045)

[1.3 Original Contribution 4](#_Toc199912046)

[1.4 Organisation 4](#_Toc199912047)

[2 Traditional Irish Flute Music 6](#_Toc199912048)

[2.1 Creativity & Musical Style 6](#_Toc199912049)

[2.2 Creativity and Style in Traditional Flute Music 9](#_Toc199912050)

[2.2.1 Ornamentation 9](#_Toc199912051)

[2.2.2 Breathing 12](#_Toc199912052)

[2.2.3 Regional Styles 13](#_Toc199912053)

[2.3 Conclusions 15](#_Toc199912054)

[3 Music Information Retrieval – A Review 16](#_Toc199912055)

[3.1 Software Models of Musical Creativity and Style 17](#_Toc199912056)

[3.2 Conclusions 23](#_Toc199912057)

[4 Transcription 24](#_Toc199912058)

[4.1 Conclusions 28](#_Toc199912059)

[5 Machine Annotation of Traditional Tunes (MATT2) 29](#_Toc199912060)

[6 Machine Annotation of Traditional Sets (MATS) 30](#_Toc199912061)

[7 Conclusions 31](#_Toc199912062)

[7.1 Conclusions 31](#_Toc199912063)

[Bibliography 34](#_Toc199912064)

**Table of Figures**

Figure 1: Wooden flutes (Source: Author) 2

Figure 2: Characteristics required in a human listener for the cognition of musical style (Source: Author based on (Baroni 2006)) 8

Figure 3: An example of a *run* in ABC format (Source: Author) 11

Figure 4: Geographic origin of regional style (Source: Author based on (Keegan 1992)) 14

Figure 5: Waveform plots of a piano (top) and a wooden flute (bottom) playing the notes A to G (Source: Author) 25

Figure 6: the Onset Detection Function (ODF) for a musical phrase calculated using the Onset Detection using Comb Filters implemented by the author in Java (Source: Author) 26

Figure 7: High level diagram of the proposed system using Case Based Reasoning (Source: Author) 29

Figure 8: Three transcriptions from the A part of the tune Ambrose Maloney's in ABC notation (Source: Author) 32

Figure 9: The main sub systems of MATT (Version 1) 34

Figure 10: Screenshot from the current version of the feature extraction system (Source: Author) 36

**Table of Tables**

Table 1: Possible features that characterise creativity in traditional Irish flute playing (Source: Author) 12

1. Introduction

This document presents a summary of work carried out towards a PhD on the topic of modelling the cognition of musical creativity. The work specifically seeks to model the cognition of the creative interpretation of traditional Irish music on the concert flute. Related work proposes that musical performance involves tacit knowledge about interpretation that humans acquire by observation and imitation (DeManteras and Arcos 2002). This research examines the possibility of simulating this observation process using signal processing and machine learning in order to synthesise a novel approach to computationally modelling the cognition of the creative interpretation of traditional Irish music.

This work will have several practical applications in musician and regional style identification (multi-media indexing) in addition to applications in the creation of royalty free music and pedagogical applications in music teaching. Additionally the work will contribute to an understanding of the cognitive processes underlying musical creativity and the cognition thereof and it may lead to better modelling of the regional and cultural context of musical creativity (Csikszentmihalyi 1999). Although this work focuses on traditional Irish music as played on the concert flute, it is hoped that the techniques proposed can be generalised to other genres and instruments.

* 1. Background

Irish traditional music includes several musical forms. In the song tradition, both sean nós (“old style” singing in the Irish language) and singing in English exist. The baroque music of Turlough O'Carolan is also considered part of the tradition (Vallely 1999). This project however, is primarily concerned with traditional dance music, as played on the concert flute. The most common forms of dance music are *reels, double jigs* and *hornpipes*. Other tune types include *marches, set dances, polkas, mazurkas, slip jigs, single jigs and reels, flings, highlands, scottisches, barn dances, strathspeys* and *waltzes* (Larson 2003). These forms differ in time signature, tempo and structure. For example a reel is generally played at a lively tempo and is in 4/4 time (although played and transcribed as 8 quavers in a bar) while a waltz is generally played at slower pace and is in 3/4 time. The time signature, tempo and structure of a tune form are determined by the dance it accompanies. Most tunes consist of a common structure of two parts called either the first and second part or the A part and B part. Tunes are typically arranged into sets. A set consists of a number of tunes (commonly two or three) played sequentially. Each tune in a set is usually repeated two or three times (Vallely 1999).

Instruments used to play traditional dance music include the tin whistle, fiddle (violin), uilleann (elbow) pipes, accordion, concertina, harp and the banjo (Wallis and Wilson 2001). The flute came into common use in traditional music in the 19th Century. The “Irish flute” is also known as the concert flute (because it is in concert pitch), the timber flute (because it is made from wood), the simple system flute or the fheadóg mhór (big whistle). It has six holes tuned such that the lowest playable pitch (all holes closed) is the D above middle C, and the instrument will play a D scale (D, E, F#, G, A, B, C#) as the holes are uncovered sequentially to shorten the resonant length of the bore. The basic flute is often augmented with the addition of up to eight keys (typically made from silver, mounted on wooden blocks) used to play pitches which are impossible to produce on the basic flute. Figure 1 depicts a 6 keyed wooden flute made from African black wood by Eamonn Cotter, an unkeyed made from African black wood flute made by Eamonn Cotter and an unkeyed bamboo flute made by Patrick Olwell in the key of F.



Figure : Wooden flutes (Source: Author)

Wooden flutes from the 19th Century were originally designed to play classical music, but with the invention of the Boehm system flute in 1832, wooden flutes became unpopular amongst classical musicians and thus came to be acquired by traditional musicians. Since the 1970’s, there has been a renaissance in wooden flute making and now many musicians play modern wooden flutes based on the 19th Century designs (Vallely 1999).

Music is a creative art form and “individual expression” is a defining component of traditional Irish music (Breathnach 1977). Creativity in traditional music takes three forms:

1. The composition of new tunes.

2. The arrangement of tunes into sets.

3. The individual creativity of a musician in interpreting a tune.

This work concentrates on individual, interpretive creativity. When a traditional musician plays a tune, it is rarely played exactly as transcribed, though unlike with jazz for example, traditional musicians never deviate from the structure or framework of the tune. In fact an experienced musician rarely plays the same tune twice, identically. Interestingly, there is no scope in traditional dance music for rubatto (except for micro-tempo artefacts). Instead, a musician will employ the subtleties of ornamentation and variation to interpret the tune (Larson 2003).

Ornamentation plays a key role in the individual interpretation of traditional Irish music (Canainn 1978). Ornamentation has a different meaning in Irish traditional music than its definition in classical music. In classical music, the expression is achieved by adding notes to the melody. By contrast, with the exception of the slide effects, Irish traditional music ornamentation is played on the beat, and alters the onset of the notes in a manner in which, it is argued, only one note will be heard (as opposed to two notes as in classical music) (Larson 2003). The usage of ornamentation is highly personal and large variations exist in the employment of ornamentation from region to region, instrument to instrument and from musician to musician.

* 1. Research aims

The principal aim of this research is to synthesise an approach to modelling the cognition of musical creativity in traditional Irish flute music. The model will be developed as software that, based on human cognition of musical style can identify and classify creativity and style in digital recordings of traditional musicians.

To achieve this aim, it will first be necessary to understand how humans achieve this task. A literature review will be carried out on the combined subjects of creativity and style in traditional flute playing and the modelling of musical creativity in software. This will be supported by an experiment which will seek to establish definitively the feature set used by domain experts to classify traditional flute styles.

As will be demonstrated, the extraction of high level features from digital recordings of traditional music is a significant and ongoing research challenge. It will be necessary therefore to establish the state of the art in this field and integrate and expand this work into a combined approach to modelling the cognition of musical creativity. Machine learning algorithms will be used to build a classifier from the feature set generated by the analysis of recordings and the aim is to use standard techniques such as cross fold validation to test the model.

* 1. Original Contribution

The attempt to automate the cognition of creativity and musical style in Irish traditional flute music represents a novel contribution in the field, since modelling this type of music cognition has never been attempted previously. In addition, the main specific contributions to knowledge are listed as follows:

1. The identification of a set of creative features that distinguish the interpretation of a piece of traditional music by one musician from another.
2. The development of new algorithms for high level feature extraction from recordings of traditional music.
3. The synthesis of new similarity metrics for automating the comparison of digital recordings of traditional flute music.
4. The synthesis of a novel approach to the automation of musician, style and region of origin identification from digital music recordings.
5. The synthesis of novel frameworks for musical style modelling that uses signal processing techniques to infer high level stylistic features that can be modelled by a machine learning system.
6. The validation of all frameworks proposed.
   1. Organisation

The remaining sections of this document are organised as follows:

Section 2 discusses creativity and style in traditional Irish flute music. Firstly, musical creativity and style are defined and related. Requirements for the cognition of style in a human listener are proposed. This section also summarises the characteristics of style in traditional flute playing, discussing ornamentation, breathing and regional styles.

Section 3 describes related work in two areas. In the field of feature extraction, signal processing techniques, using filters and Fourier analysis to determine note onset and offset times and pitches of notes in traditional Irish music are described. This section continues by reporting on a selection of systems that use machine learning to either model musical creativity or the cognition of musical style in software. Most of the systems discussed operate in the domain of classical music, though one of the systems discussed uses a corpus of traditional reels to learn from.

Section 4 discusses the proposed approach. A high level system diagram is presented illustrating how signal processing will be used to extract features from digital recordings of flute music in order to build a training corpus for a machine learning system. Four high level problems are identified in this section as needing to be addressed for the overall project aim to be achieved.

Section 5 presents the work carried out to date. Three musicians are identified who have agreed to assist in this project. The MATT (Machine Learning Articulation of Traditional Tunes) project developed by the author is described and discussed in this section as is current work on the problem of feature extraction.

Section 6 presents the work plan for the remainder of the PhD and identifies six high level tasks that will be carried out.

1. Traditional Irish Music

(Williamson, Thompson et al. 2006) identify reasons why authors have had difficulty characterising creativity. They suggest that it has been impossible to offer an unambiguous and broadly agreed on definition. Further they propose that creativity is difficult to isolate empirically and finally they suggest that creativity has an entrenched mythology especially in the arts world where it is construed as a mysterious, unknowable process. In this section, the problem of defining style in traditional flute playing is divided into two sub-problems. Firstly the concept that style is related musical creativity is proposed. Secondly, this section summarises approaches to the problem of what characterises style in traditional flute playing.

* 1. Creativity & Musical Style

(Götz 1981) relates creativity to “making” and defines creativity as “the process or activity of deliberately concretising insight”. (Boden 1996) is extensively cited by authors seeking to understand creativity. Boden distinguishes two types of creativity. Psychological creativity (P-creativity) occurs when an individual has an idea which is novel to that individual, regardless of how many other individuals have had that same idea. Historical creativity (H-creativity) defines ideas that are novel not only to an individual, but also novel in the history of human endeavour. P-creativity is therefore judged by an individual. H-creativity is judged by society at large. The concept of two levels of creativity is also proposed by (Gardner, 1993b), who distinguished between “little c” and “big C” creativity.

There are examples in traditional music of both P-creativity and H-creativity as defined by (Boden 1996). Individual expression (P-creativity) is in fact a defining component of traditional Irish music (Breathnach 1977). When a traditional musician plays a tune, it is rarely played exactly as transcribed, though unlike with jazz for example, traditional musicians never deviate from the structure or framework of the tune. In fact, experienced musicians rarely play the same tune twice, identically. In the introduction to the revised edition of O’ Neill’s Music Of Ireland (originally published in 1906), Krassen describes a typical scenario:

“*It seems that on this particular occasion Touhey wanted to learn a tune from McFadden. He had McFadden play it for him several times and then tried his own hand at it. Of course McFadden had to play it again, pointing out several "errors." This happened a number of times until Touhey finally gave up, for McFadden was playing the tune a little differently each time through!*”

- (Krassen 1975)

A traditional musician will usually employ subtle variations, ornamentation, timbre and phrasing to interpret a tune (Larson 2003).

H-creativity by definition, more rarely occurs in traditional music. Some examples might include the introduction of the concert flute in the nineteenth century, the development of the ceili band form in the 1920’s, the renaissance of traditional music led by Sean O’ Riada and Ceolteori Cuailann in the 1960’s and the introduction of the Bouzuki in the 1970’s (Wallis and Wilson 2001).

The cognition of individual creativity implies that an individual musician demonstrates a style that can be recognised. (Meyer 1989) defines musical style as:

“*a replication of patterning…that results from a series of choices made within some set of constraints”*.

- (Meyer 1989)

(Keegan 1992) again associates the concept of style with creativity and claims that the technique and creativity of an individual and their musical style are one and the same thing.

(Baroni 2006) suggests that a listener can have different approaches to music which influences their perception of style. A listener’s approach can be:

*“a mere abandon to the flux of sounds where music is lived as an emotional stimulus and a source of immediate pleasure”*.

- (Baroni 2006)

He suggests that in this context a listener has little appreciation of the style of the musician. He continues by proposing that a listener must have an *objective approach*, *a precise knowledge* of the cultural conditions where the music was produced and must have *competence* to distinguish one style of music from another. He suggests that examples are categorised by comparing them to *prototype models* that represent its fundamental characteristics.



Figure : Characteristics required in a human listener for the cognition of musical style (Source: Author based on (Baroni 2006))

(Baroni 2006) describes an experiment carried out to establish the features used by a group of both experts and amateurs in a musical domain to categorise a piece of music. A group of 13 subjects listened to a recording of a fragment of a little known piece of music by the composer Donizetti. The subject group contained musicologists, professional and amateur musicians. Each subject was provided with a tape recorder to record the cognitive paths followed in order to identify the composer. The experiment demonstrated that those subjects who possessed “prototype models” or “stored memories” were able to identify the century and genre, form and instruments in the piece of music, in other words to classify the style. The experiment also demonstrated that those subjects who possessed a “lexicon” of music terminology were better able to classify the piece. The author concludes by explaining that the subjects used:

*“prototype, conceived as a hierarchical organisation of memorised listening experiences, orientated by historical knowledge”*

*-* (Baroni 2006)

to classify the music.

* 1. Creativity and Style in Traditional Flute Music

There are a number of authoritive sources that describe characteristics that can define an individual musician’s flute style. These include Valley’s, “Timber: The Flute Tutor”, and his PhD thesis, “Flute Routes to 21st Century Ireland” (Vallely 2004), Larson’s “The Essential Guide to Irish Flute and Tin Whistle”, McCormack’s, “Fliúit: Irish Flute Tutorial”, Keegan’s MPhil thesis “Words of Traditional Flute Style” (Keegan 1992). In addition there is Casey’s “Traditional Irish Flute Music from East Galway A Regional study and Documentary Field Collection”. Additionally Tansey’s “The Bardic Apostles of Inishfree” (Tansey 1999), a profile of Sligo musicians contains references to ornaments not described in any of the other literature, (*bark*, *backstitch, run* and *pop*). In personal interviews (Tansey 2006) he has elaborated on the meaning of these terms. Although there are some disagreements in definitions of certain features, the literature generally agrees that flute style can be characterised by features that include use of ornamentation, phrasing (where a musician takes a breath), use of variation, staccato or legato playing (with throating/tounging attacks), the timbre a musician achieves with an instrument, tempo, choice of tune and choice of tune type.

* + 1. Ornamentation

(Larson 2003) defines ornamentation as:

“…*ways of altering or embellishing small pieces or cells of a melody that are between one and three eight-note beats long. These alterations and embellishments are created mainly through the use of special fingered articulations*.”

- (Larson 2003)

Fingered articulations are a defining characteristic of traditional Irish music. The sound of most articulations is very brief. Although generated by inserting additional notes, (Larson 2003) argues that the notes are played at such speed that they are not perceived as having a discernible pitch or duration. There are differing opinions as to the origins of ornamentation in traditional Irish music. (Larson 2003) suggests that ornamentation is derived from the playing of the *píob mór*, a mouth blown bagpipe that predated the development of the modern uilleann pipes. The  *píob mór* had no capacity for momentary interruptions to the flow of air and thus melodies were played as unbroken streams of sound. In order to generate a perceived stop between two notes of the same pitch, a musician would play a third note momentarily between the two notes.

(Tansey 1999) argues that ornamentation developed as an attempt to mimic the sounds of nature. He compares for example the sound of a *cran* to that of a sheep’s “baa” and postulates that the ornament was developed by shepherd’s who played wooden flutes while tending sheep:

“*I put it to you therefore that it had to come from the throats of birds, the wild animals, the ancient chants of our forefathers, the hum of the bees and the mighty rhythms of the galloping hooves of wild horses all moulded together…*”

- (Tansey 1999)

The main components of wooden flute ornamentation are now identified:

A *cut* is defined as an articulation used to separate two notes. A cut is articulated by playing a middle note momentarily at a higher pitch than the second note. The overall length of the two notes does not change when cutting and so the length of the second note must be shortened very slightly to accommodate the cut.

A *tap* (referred to in some sources as a *strike* or a *bounce*) is an articulation also used to separate two notes. A tap is articulated by playing a middle note momentarily at a lower pitch than the second note.

A *long roll* is articulation used to separate three notes. The second note in the sequence is cut and the third note is tapped. Again, the overall length of the three notes does not change. A *short roll* is similar to a long roll, but the first note in the sequence of three is dropped.

Concert flutes are usually pitched in D. As there is no note lower than a low D on the instrument, a tap on the low D is not possible. Instead, to execute a “roll” type ornament on a low D, a musician will play a *cran*. In order to play a cran, the musician replaces the tap with a second cut. The second cut uses a different note, usually higher than that of the first cut. This creates a “bubbling” sound typical of the playing of Matt Molloy. Not all musicians use crans, for example Catherine McEvoy does not play crans at all. Although (Larson 2003) suggests that crans can be done on any note, most other sources suggest that crans are only played on the low and middle D and E. They can be played long or short as with rolls.

With all of the above articulations, the actual pitch of the “extra” notes may vary depending on which finger the musician feels most comfortable lifting at speed (Keegan 1992). Using different fingers to perform the ornamentation also gives the ornament a specific character which can be part of a musician’s unique sound. An interesting example of this can be found Seamus Tansey’s 1975 recording “The King of the Concert Flute” (Tansey 1975).

(Larson 2003) suggests that trills are not common in Irish flute music, however an analysis of the corpus described in section 6 finds this not to be the case. A trill is defined as a rapid alteration of the principal note and the note above it. A trill may begin on either the principal note or on the higher ornamental note. Trills are usually played for short durations in traditional music, with longer duration trills being considered too much of an allusion to classical music.

A *tight triplet* alsocalled a *treble* in (Tansey 1999) is a stepwise rising or falling sequence of three notes played in quick succession in the rhythm of two notes. A specific type of tight triplet mentioned in (Tansey 1999) is a *back stich* which he describes as a treble using the notes BCD. A *run* as described by (Tansey 2006) is a descending sequence of two tight triplets as illustrated in Figure 3. In the note sequence, the first four notes are played without the use of a run while the second sequence of six notes are two tight triplets, in other words a *run* on the four note sequence.

K:D

M:Reel

=cABG (3=cBA (3BAG

Figure : An example of a *run* in ABC format (Source: Author)

Switching between octaves on a wooden flute is achieved using a technique known as *overblowing*. (Hamilton 1990) describes how overblowing can be used as a technique to add variation to a performance by overblowing a phrase meant to be played in the lower octave of the instrument.

Overblowing is also used as a technique in the sounding of a *hard D*. A *hard D* is achieved on a wooden flute by overblowing the D in the lower register to the extent that the note is perceived as a group of harmonics of D that can be impossible to distinguish (Keegan 1992).

* + 1. Breathing

Phrasing in traditional flute music is easily identified as the timings in a performance of a tune where a musician takes a breath.

|  |  |  |
| --- | --- | --- |
| Ornamentation | Single-note | Cut |
| Tap |
| Multi-note | Roll |
| Cran |
| Triplet |
| Run |
| Breathing | Phrasing |  |
| Throating (attacks) |  |
| Overblowing |  |
| Timbre |  |
| Variation |  |  |
| Repertoire | Reels |  |
| Jigs |  |
| Hornpipes |  |
| Polkas |  |
| Slides |  |
| Scotisches |  |
| Strathspeys |  |
| Mazurkas |  |
| Tempo |  |  |

Table : Possible features that characterise creativity in traditional Irish flute playing (Source: Author)

Traditional music scores are not annotated with breath marks and it is up to an individual musician to decide where a breath should be taken. Taking a breath usually means leaving out a note or several notes from the score in a performance. Phrasing is therefore more obvious in music played on the flute than on any other traditional instrument (Keegan 1992). (Keegan 1992) in his interviews establishes that phrasing (and in particular the length of phrases) is a strong indicator of a particular regional and individual style.

In traditional Irish flute playing, *tounging* as used as a note attack by classical flute players is rarely used. Instead a technique called *throathing* is often used (the stop is produced by the throat rather than by the tongue) (Hamilton 1990). This can often result in the note following the attack to be overblown, (sometimes one of the harmonics of the fundamental rather than the fundamental itself is perceived).

On the flute, the timbre achieved by a musician can vary widely between a broad/breathy sound and a sharp/clear sound and naturally, volume also can characterise a style.

Table 1 summarises the possible features elaborated upon in this section.

* + 1. Regional Styles

(Canainn 1978) describes regional style as the common features which distinguish the majority of performances by musicians from a particular area. Until the 1940’s there existed distinct regional styles of flute playing attributed mainly to the isolation of rural communities prior to the advent of mass communication. Similarly the country as a whole was largely preserved from the influence of other cultures due to its geographic position and the isolationist economic policies of the early Irish Free State (Keegan 1992). (Keegan 1992) describes his work in understanding the cognition of regional styles of Irish flute music by conducting a series of interviews with prominent musicians. He reports that four regional styles were identified by his subjects, though his work suggests that the characteristics that distinguished these styles varied somewhat. The regional styles identified in his work are: The West Clare style, the Ballinakill/East Galway style, the Fermanagh/Northern style and the Sligo/Roscommon style. Figure 4 shows a map of Ireland with the locations of the four regions identified by (Keegan 1992).

The West Clare and Ballinakill/East Galway styles he describes as demonstrating much use of ornamentation and accidentals, with the melody played at a relatively slow pace. These styles differ in repertoire and use of breath articulation, with The West Clare style being characterised by the use of throathing to emphasise rhythm. The Ballinakill/East Galway style developed from the playing of the musicians in one of the first ceili bands (The Ballinakill Traditional Players). (Keegan 1992) suggests that the Ballinakill/East Galway sound is more legato, with an emphasis on melody rather than rhythm. This is evident in the repertoire played by musicians in that style, which contains tunes with several parts. The suggests that in the past a substantial group of East Galway musicians have adopted the Boeme system flute or other fully keyed instruments, which are more suitable for the repertoire which involve tunes in unusual keys and with accidentals.



Figure : Geographic origin of regional style (Source: Author based on (Keegan 1992))

The Fermanagh/Northern style he describes as being sparsely-ornamented, but with heavy stress on breath articulation techniques. He states that there exists two styles of phrasing. In some examples, there is an emphasis on natural-phrasing (regular two-bar phrases), while other musicians demonstrate short irregular phrasing, characteristic of the music of North Leitrim (and hence similar to the Sligo-Roscommon style).

There is a strong concentration of flute players in the Leitrim/Sligo/Roscommon area which (Tansey 2006) attributes to the prevalence of coal mining in the region. He argues that the flute was considered good for the development and health of the lungs of coal miners, constantly exposed to high levels of coal dust in their profession. Although (Keegan 1992)’s subjects reported contradictory opinions on many aspects of the Sligo/Roscommon style, they agreed that the style is very rhythmical because of the use of breath articulation and emphasis. They also suggest that the overuse of ornamentation is not characteristic of many musicians of the Sligo/Roscommon style (though he points out several notable exceptions).

* 1. Conclusions

From this section, it is possible to conclude that the concept of style and creativity are strongly related. A musician’s style can be described as the creative choices made in the performance of a piece of music. From the perspective of traditional flute playing, these choices include the use of ornamentation, phrasing, use of variation, staccato or legato playing with correspondingly different attacks, the timbre a musician achieves with an instrument, tempo, choice of tune and choice of tune type. It is clear also that flute style has a regional context and how a musician interprets tune is often strongly influenced by the cultural context the musician has emerged from. The cognition of musical style requires competence, objectivity and knowledge of this cultural context in listeners. Finally, it is proposed that the cognition of style involves the listener comparing an unclassified piece with prototype models.

Support for queries on traditional instruments or lilted queries

Ornamentation

Variation including scattering

Phrasing (breathing)

Sets

Legato playing (hard to detect onsets)

Repetition & Structure (no reason for short queries or incipit's)

Tempo variation

Any phrase (not just the incipit)

Transcription errors (false positives, false negatives, pitches)

The importance of the problem in the domain of cultural heritage preservation

Transposition?

1. Content Based Music Information Retrieval

The approaches proposed in this work form part of a content based Music Information Retrieval (MIR) system for traditional Irish music. Music Information Retrieval can be defined as “the task of extracting from a large quantity of musical data, the portions of that data with respect to which some musicological statement is true” (Kassler 1966). The term Music Information Retrieval is first mentioned in the literature in (Kassler 1966). In this work the author presents MIR, an assembly like language for formulating musical queries and navigating scores. He suggests that MIR could form part of a “library of the future” although he recognises the limitations of the language proposed.

More recently (Typke, Wiering & Veltkamp 2005; Typke 2007) suggest that there are three main classifications of MIR systems: those for searching symbolic representations of music, those for searching audio data and systems that combine both approaches by first converting audio data to a symbolic representation and then searching for a match in a corpus of symbolically notated music. (Downie 2003) proposes analytic/production systems and locating MIR systems a classification analogous to the first two classifications. This section presents related work in each of the three classifications of system and concludes with an analysis of the suitability of existing approaches to perform MIR for traditional Irish music.

* 1. Searching symbolic representations

Symbolic MIR has its roots in dictionaries of musical themes such as Barlow [1]. Monophonic music can be represented as a one-dimensional string of characters, where each character represents a musical note. String can be made up of characters representing pitches, pitch intervals or melody contours. In systems that use this format, standard string matching algorithms such as Knuth-Morris-Pratt, Boyer-Moore, Levenstein (Edit) Distance, longest common sub-sequence or regular expression searching have been applied (Navarro & Raffinot 2002).

GuidoMIR is a symbolic MIR system that has a native corpus of melodies in the Guido/XML music notation language. The authors claim that using a symbolic musical score language such as Guido/XML has a number of advantages over MIDI, a format designed for playback. They cite the ability to store meta-data with the melody as the main advantage, but list several others. They also do not use any form of database engine and instead their system in built entirely in Perl and uses a database of flat files. Although their corpus is text based, the authors use a probabilistic matching algorithm based on first order Markov chains to match queries to corpus strings. Their system supports queries based on both pitch and rhythm. (Hoos 2001).

TunePal is an MIR system whose main advantage is that it runs on a mobile device such as PDA or smartphone and so can be used in traditional music sessions and workshops. TunePal has a corpus of approximately five thousand traditional Irish dance melodies in ABC format. The system supports text queries on melodies or any of the meta-data such as tune name, type or composer. For melodic queries, the system requires a knowledge of the ABC language. It has an elementary query normalisation algorithm that normalises text queries into the same register and removes ornamentation from corpus strings, but otherwise it requires to exactly match strings from the corpus .

Orpheus

Themefinder

* 1. Searching audio data

Shazam

* 1. Hybrid approaches

MELDEX has a pitch tracking interface that allows users to sing queries. The system depends on the user separating each note by singing *da* or *ta*. The articulation of the consonant is used to detect the onset of each note. As queries were generated by humans, they naturally contained errors. has classified the errors into four types: Expansion, Compression, Repetition, and Omission.

MELDEX has a database of approximately 10,000 folk songs, compiled from the Essen collection (ref). The system uses the approximate string matching methodology of . This methodology was designed explicitly for the musicological analysis of melodic strings. Melody contour searches use interval direction method (section x.x). Matching melodies are ranked based on the degree of similarity between query and the items returned. Initially, MELDEX supported queries based on incipit’s , however subsequent improvements facilitated the matching of queries where the match occurs not only in the incipit, but also anywhere within a melody . Reported performance of the system is quite poor, with simple, exact match searches, taking an average of 500 ms to perform and 20 note approximate search pattern, requiring approximately 21 seconds.

Musipedia (previously known as Tuneserver) is a web-based MIR system that supports queries entered by whistling, playing on a virtual piano keyboard, tapping the rhythm on the computer keyboard, or entering the melodic contour . For whistled input, the audio is first sampled and a Fast Fourier Transform is then used estimate pitch. Onsets are noted using a combination of *silence windows* and pitch changes between consecutive frames of audio. The audio is then converted to Parsons’ code (section X.x) and a melodic contour search calculates the weighted edit distances between the query and strings from the corpus. Results are ranked in order of ascending distance from the query. The authors report a success rate of approximately 80% for queries with an average of 16 notes, where the correct melody was within the top 40 matches. The correct melody was returned as the closest match in 44% of queries. The authors ascribe mistakes to transcription errors and queries that were too short to discriminate similar representations of different melodies. The front end to Musipedia is also known as Melodyhound. Interestingly, although Musipedia contains traditional Irish dance tunes as part of its corpus, it does not generate positive results when queries are presented in the form of melodies played on the tin-whistle or wooden flute.

A later implementation of Musipedia supports a pitch and onset time-based search by representing the query into a weighted point set and calculating the Earth Mover's Distance (Section X.x) for each query point set and pre-computed point sets representing segments of melodies from the database. The "query by tapping" method that only takes the rhythm into account uses the same algorithm as the pitch and onset time method, but assumes all pitches to be the same. The system accelerates searches using an indexing technique based on vantage objects .

Fast melody Finder (FMF) is a web based music information retrieval prototype whose key feature is that it indexes the corpus according to a scheme known as FAI (Frequently Accessed Index) . The principal behind FAI is that a piece of music is often identifiable from a few specific melody segments of the overall melody. In FAI, segments are automatically induced from previous user queries. Each entry in the FAI structure has four variables: Access Count, Age, Repetition and Size. The authors propose an index maintenance system that, for example, supports merging of similar indexes.

Their prototype system has a corpus of 12000 MIDI files, which they pre-process to extract meta data in XML format such as time and key signature. Melodies are represented as pitch (U, D, S) and time contours (L, S, S) (Section X.x). Queries can be input by humming or by drawing the melody on a graphical representation of a 5 line stave. The system presumably incorporates a transcription subsystem, but this is not discussed in the paper. Matching is achieved using the Boyer Moore algorithm initially to search for an exact match and if an exact match is not found the system falls back to calculating the edit distance using dynamic programming. Index entries are searched in order of access count. The authors present results which indicate that queries using both pitch and time contours

(Blum

et al., 1999). Foote (1997) has designed a music indexing

system based on histograms of MFCC features derived

from a discriminatively trained vector quantizer.

Cornells Query By Humming

Super MBox

SoundCompas

* 1. Feature Extraction
     1. Note onset
     2. Pitch
     3. Loudness
     4. Chroma
     5. Timbre
     6. Mel-Filtered Cepstral Coefficients
  2. Melodic Similarity
     1. Parsons’ Code

Parsons showed that a simple encoding of tunes that ignores most of the

information in the musical signal can still provide enough information for distinguishing between a large number of tunes. The Parsons code reflects only

the directions of melodies. Each pair of consecutive notes is coded as “U” (“up”)

if the second note is higher than the first note, “R” (“repeat”) if the pitches are

equal, and “D” (“down”) otherwise. Rhythm is completely ignored. Thus, the

first theme from the last movement of Beethoven’s 9th symphony (“Ode to Joy”)

would be coded RUURDDDDRUURDR.1 Note that the first note of any tune is

used only as a reference point and does not show up explicitly in the Parsons

code at all.

Lemstorm et al. (1998) used the suffix-tree as the index

and presented a coding scheme of music that is

invariant under different keys and tempos, and investigates

the application of two approximate matching algorithms

to retrieve music.

* + 1. Intervals
    2. Earth Movers Distance
    3. Edit Distance

Hidden Markov Models

Longest Common Subsequence see (Rho & Hwang 2004)

String matching algorithms

Boyer–Moore algorithm: This is based on the idea

that more information can be obtained by matching

the pattern from the right than from the left and shows

very good performance. It scans the pattern characters

for a match starting from the last character in the string.

During the search, the pattern characters are scanned

for a match starting with the last character in the

pattern.

* 1. Conclusions

MIDI – No support for meta data or structure (Hoos 2001)

Contours/intervals – Too many false positives (Schlichte 1990) (Adams, Bartsch, & Wakefield 2003)

current UDR string cannot describe sudden

pitch transitions

EMD – (No ornamentation compensation, cant use for segmentation - TYPKE 2007)

Musipedia, Melody hound etc (No support for query by playing)

None of the systems support segue melodies

None of the systems address ornamentation

1. Feature Extraction

in two areas. In the field of feature extraction the work of (Gainza, Coyle et al. 2005; Gainza 2006; Gainza 2006) is reported. This work describes signal processing techniques, using filters and Fourier analysis to determine note onset and offset times and pitches of notes in traditional Irish music. The work will subsequently be used as a basis for feature extraction in this project.

Work on the problem of high level feature extraction from monophonic recordings of traditional music is reported in (Gainza, Coyle et al. 2005; Gainza 2006; Gainza 2006). This work mainly deals with the problem of transcription from digital sources using signal processing techniques. Transcribing a source will provide several, (but not all), of the features proposed in section 2.2 for use in classifying traditional flute styles. The authors divide the problem into three separate problems: identifying note onset and offset times, identifying the pitch of notes and transcribing ornamentation.

To address the first problem, the authors propose an approach they refer to as Onset Detection using Comb Filters (ODCF). ODFC discovers harmonic characteristics of the input signal and is therefore more tolerant to energy changes in an input signal and is also better at detecting onsets in legato playing, where there is no significant change in energy at the onset of a new note.

Add to this chapter:

Fourier Analysis

MFCC

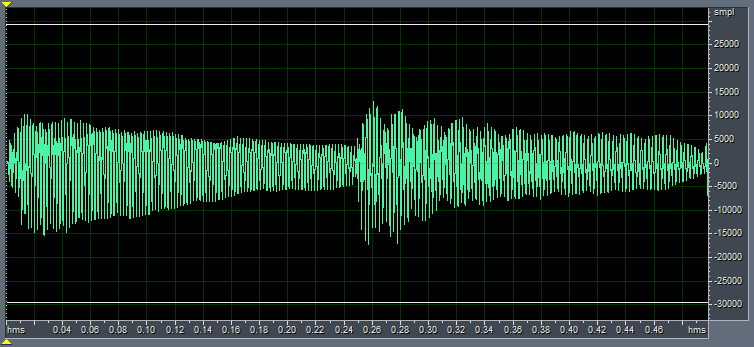
Wavelet analysis

Onset detection

Pitch detection

Spectral Centroid

Spectral Flux



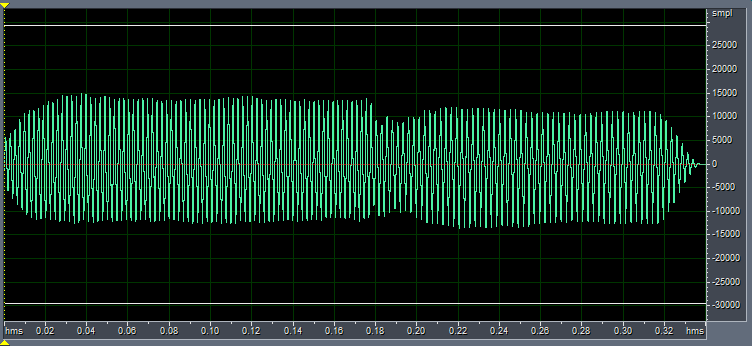


Figure : Waveform plots of a piano (top) and a wooden flute (bottom) playing the notes A to G (Source: Author)

Figure 5 compares waveform plots of a wooden flute playing the notes A to G legato with waveform plots of the same notes being played on a piano. As can be seen from this figure, there is a significant and detectible energy change in the plot from the piano between the offset of the first note and the onset of the second note, whereas with the notes played legato on the wooden flute there is a less detectable energy change from one note to the next.

To generate the Onset Detection Function (ODF), the input signal is first sampled at 44100Khz. The input signal is then segmented into overlapping frames of 2048 samples (approximately 46 milliseconds). Each frame overlaps with the previous frame by 75%. Each frame is then passed through a bank of twelve FIR comb filters.

A FIR comb filter works by summing the input signal with a delayed version of the same input signal. The delay of the filter is calculated as being 1 / frequency being filtered (the length in time of a single period of a waveform at the frequency). This has the effect of amplifying the frequency (or a harmonic thereof) in the input signal that matches the frequency being filtered. Thus, the energy of the input signal is doubled only if the peaks of the signal coincide with the peaks of the FIR comb filter. This will only occur for a given delay and its integer multiples.

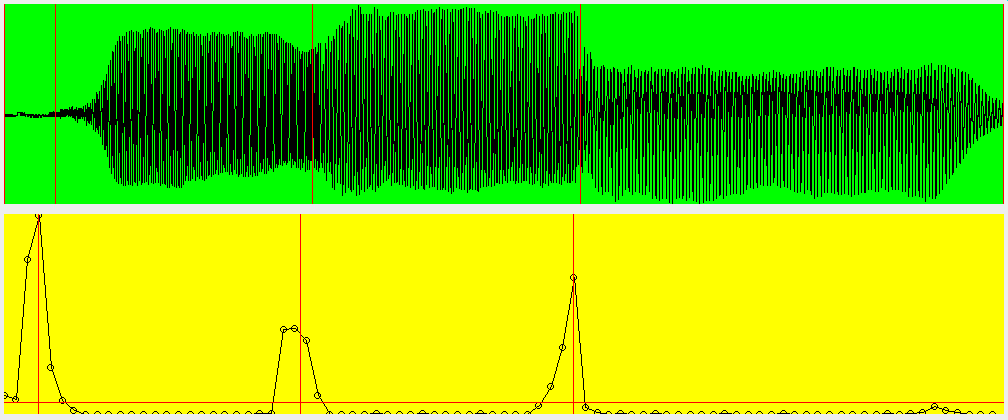


Figure : the Onset Detection Function (ODF) for a musical phrase calculated using the Onset Detection using Comb Filters implemented by the author in Java (Source: Author)

Twelve filters with different delays are used corresponding to the twelve semitones in the key of D3. For each frame of audio examined, the outputs of the audio passed through each of the twelve filters are calculated. A value for the ODF is then calculated as being the sum of the difference between the outputs of each of the twelve filters in successive frames, squared. In the case where the input signal changes from one note to another, this results in a peek in the ODF graph.

Using statistical techniques (average and standard deviation), a threshold is then calculated above which peeks in the ODF are recognised as being candidate note onsets. Figure 6 shows the ODF calculated in this way (using the system developed in Java and described in section 6) with an input signal of a wooden flute playing the notes D, E and F legato.

As illustrated, the onsets detected correspond to the onsets of each new note. The authors also propose that the ODF is filtered using a low pass filter to smooth the ODF, removing spurious onsets caused by noise in an onset.

To detect pitch, a Short Term Fast Fourier Transform is carried out on frames in the input signal to produce a frequency spectrum. There are various techniques possible to establish the perceived frequency from a frequency spectrum, but the author’s use an approach, based on (Brown 1992) which uses pattern matching augmented with a parabolic interpolation of the frequency spectrum to refine their pitch estimation.

To detect ornamentation, the algorithm use heuristics derived from standard descriptions of traditional ornamentation (summarised in section 2.2.1 of this document). For example, to transcribe a cut on the note G, the algorithm looks for two consecutive G notes, separated by a momentary note at a higher pitch. The authors report a 60% success rate with single note ornament and a 40% success rate at detecting multi-note ornaments.

(Dixon 2004) describes BeatRoot and the Performance Worm, two systems that the author claims, extract expressive features from a digital recording of a piece of music played by a human musician. They propose that although expression is contained in the physical features of the audio signal, such as amplitudes, frequencies and onset times, it is better understood when viewed from a higher level of abstraction, that is, in terms of musical constructs such as tempo, rhythm, pitch and timbre. These features are not directly measurable and the signal must be analysed to extract them.

BeatRoot models the perception of beats in a piece of music. BeatRoot first analyses the input signal to extract note onsets. Their first attempt to extract note onsets used a time domain algorithm that looked at the energy changes in successive frames. The authors claim that this approach worked well for percussive instruments such as the piano, but admit that the algorithm often detected false onsets and also failed to detect onsets for simultaneously sounding notes.

Their second attempt improves accuracy by separating the signal into frequency bands and looking for onsets in each band. (Gainza, Coyle et al. 2005) algorithm discussed earlier, which uses time domain comb filters seems more promising for detecting onsets in traditional music played legato on wind blown instruments as it is less sensitive to amplitude modulation in the signal. The system then uses an array of agents initialised with a tempo hypothesis. The agent then predicts further beats and is evaluated according to how well the predicted and actual beat times correspond. The system was evaluated against a corpus of Mozart sonatas and popular music and the authors claim a success rate of 90%.

* 1. Conclusions

This section described related work in the field of feature extraction and the work of (Gainza, Coyle et al. 2005; Gainza 2006; Gainza 2006) was summarised. This work reported on the use of signal processing techniques to determine note onset and offset times and pitches of notes in digital recordings of traditional Irish music. Although the authors of this work report success rates in transcribing multi-note ornaments of 40%, it will be possible to increase this success rate by adopting the suggestion of (Dixon 2004; Widmer and Goebl 2004) which is to augment bottom up information extracted from the signal with top-down domain specific rules of music theory. The work described in this section will subsequently be used (sections 5 and 6) as a basis for feature extraction in this project.

1. Machine Annotation of Traditional Tunes (MATT2)
2. Machine Annotation of Traditional Sets (MATS)
3. Conclusions

The following are the list of publications from research carried out in the pursuit of this PhD.

Duggan, B: TunePal: A Portable Tune Teaching Tool for Traditional Musicians, DIT Annual Showcase of Learning & Teaching Activities, January, 2007

Duggan, B., Zheng, C., Cunningham, P.: MATT - A System for Modelling Creativity in Traditional Irish Flute Playing, Third Joint Workshop on Computational Creativity, ECAI'06, Italy, August 2006

Duggan, B.: Learning Traditional Irish Music using a PDA, IADIS Mobile Learning Conference, Trinity College, Dublin, Ireland, July 2006

* 1. Conclusions

Bibliography

Baroni, M. (2006). Hearing Musical Style: Cognative and Creative Problems. Musical Creativity Multidisciplinary Research in Theory and Practice. I. Deliége and G. A. Wiggins, Psychology Press.

Boden, M. A. (1996). Dimensions of creativity. Cambridge, Massachusetts, MIT Press.

Breathnach, B. (1977). Folk Music and Dances of Ireland.

Brown, J. C. (1992). "Musical fundamental frequency tracking using a pattern recognition method." JASA 1992 **3**: 1394-1402.

Canainn, T. O. (1978). Traditional Music in Ireland. London, Routledge and Keegan-Paul Ltd.

Cotter, E. (2006). Interview notes.

Coyle, L., D. Doyle, et al. (2004). "Representing Similarity for CBR in XML, Department of Computer Science, Trinity College Dublin."

Coyle, L., C. Hayes, et al. (2002). "Representing Cases for CBR in XML."

Cristianini, N. and J. Shawe-Taylor (2000). An Introduction to Support Vector Machines and other Kernel-based Learning Methods, Cambridge University Press.

Csikszentmihalyi, M. (1999). Implications of a

Systems Perspective for the Study of Creativity. Handbook of creativity, Cambridge University

Press**:** 313–335.

Dannenberg, R. B., B. Thom, et al. (1997). A Machine Learning Approach to Musical Style Recognition. 1997 International Computer Music Conference, International Computer Music Association.

DeManteras, R. L. and J. L. Arcos (2002). "AI and Music: From Composition to Expressive Performance." Ai Magazine.

Dixon, S. (2004). "On the analysis of musical expression in audio signals."

Dixon, S., W. Goebl, et al. (2002). Real time tracking and visualisation of musical expression. Music and Artificial Intelligence: Second International Conference, ICMAI2002, Edinburgh, Scotland.

Duggan, B., Z. Cui, et al. (2006). MATT - A System for Modelling Creativity in Traditional Irish Flute Playing. Third ECAI Workshop on Computational Creativity, Riva Del Garda, Italy.

Eck, D. and J. Lapamle (2006). Learning Musical Structure Directly from Sequences of Music, University of Montreal

Department of Computer Science

CP 6128, Succ. Centre-Ville

Montreal, Quebec H3C 3J7 Canada.

Furnkranz, J. (1999). "Separate-and-conquer rule learning." Articial Intelligence Review **13**(1): 3-54.

Gainza, M. (2006). "Automating Ornamentation Transcription."

Gainza, M. (2006). Music Transcription within Irish Traditional Music. Faculty of Engineering. Dublin, Dublin Institute of Technology. **PhD**.

Gainza, M., E. Coyle, et al. (2005). Onset Detection Using Comb Filters. IEEE Workshop on Applications of Signal Processing to Audio and Acoustics, New Paltz, NY.

Götz, I. (1981). "On Defining Creativity." Journal of Aesthetics and Art Critism(39): 297-301.

Hamilton, C. (1990). The Irish Flute Players Handbook. Cork, Breac Publications.

Hurley, B. (2005, April 2006). "An Interview with Eamonn Cotter." from <http://www.firescribble.net/flute/cotter.html>.

Keegan, N. S. (1992). The Words of Traditional Flute Style. Music Department. Cork, University College Cork. **Masters Degree**.

Kohonen, T. (2001). Self-Organizing Maps, Springer Verlag.

Krassen, M. (1975). O' Neil's Music of Ireland, Waltons.

Larson, G. (2003). The Essential Guide to Irish Flute and Tin Whistle, Mel Bay Publications, Inc.

León, P. J. P. d. and J. M. Iñesta (2004). "Musical style classification from symbolic data: A two-styles case study." Lecture Notes in Computer Science **2771**: pp. 166-177.

Mandel, M. I., G. E. Poliner, et al. (2005). "Support vector machine active learning for music retrieval." ACM Multimedia Systems Journal.

Meyer, L. B. (1989). Style and Music. Theory, History and Ideology. Philadelphia, University of Pensylvania Press.

Quinlan, J. R. (1986). Induction of decision trees.

Repp, B. H. (1992). "Diversity and Commonality in Music Performance: an Analysis of Timing Microstructure in Schumann’s ‘Traumerei’." Journal of the Acoustical Society of America(104).

Roni. (2005, March 2005.). "The Amazing SlowDowner." from <http://www.ronimusic.com/>.

Salton, G. and C. Buckley (1988). "Term-weighting approaches in automatic text retrieval." Information Processing and Management **5**(24): 513-523.

Smith, E. and D. Medin (1981). Categories and Concepts, Harvard University Press.

Tansey, S. (1975). King of the Concert Flute.

Tansey, S. (1999). The Bardic Apostles of Innisfree, Tanbar Publications.

Tansey, S. (2006). Interview Notes. The Cobblestone Pub, Dublin.

Vallely, F. (1999). The Companion to Irish Traditional Music, New York University Press.

Vallely, F. (2004). Flute Routes to 21st Century Ireland, National University of Ireland. **Doctor of Philosophy**.

Wallis, G. and S. Wilson (2001). The Rough Guide to Irish Music. London, Rough Guides.

Widmer, G., S. Dixon, et al. (2005). "From Sound to `Sense' via Feature Extraction and Machine Learning: Deriving High-Level Descriptors for Characterising Music." Sound to Sense:Sense to Sound: A State-of-the-Art.

Widmer, G. and W. Goebl (2004). "Computational Models of Expressive Music Performance: The State of the Art." Journal of New Music Research **33**(3): 203–216.

Williamson, A., S. Thompson, et al. (2006). Creativity, originality and value in music performance. Musical Creativity Multidisciplinary Research in Theory and Practice. I. Deliége and G. A. Wiggins, Psychology Press.

Wright, M. and E. Berdahl (2005). "Machine Learning of Expressive Microtiming in Brazilian and Reggae Drumming." CS229.