Timbral Aspects of Orchestration

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A Study of how Timbre can be
used as Primary Parameter in Orchestration

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Introduction

This is a study of timbral aspects in orchestration. It includes looking closer at different composers use of timbre as primary parameter when composing and orchestrating. The study is divided into two parts: one theoretical and one practical composition. The composition will be based on the theoretical and analytical work which I will present through this text. The reason why I have chosen this method is to gain more knowledge of orchestration, and I believe that my execution is a natural and important part of this.

The thesis is divided into four chapters. The first concerns early theories on timbre and how timbre as a term has established its position in the history of orchestration. This part also concerns the development of timbre in orchestration from the beginning of the First Viennese School and towards timbre as a research area for composing, presented by IRCAM. The second concerns methodological approaches, execution of timbral analysis and the importance of acoustics. This part presents how timbral qualities can be analysed by different representations of the music. It also contains a careful review on how I will execute the main analysis, and why knowledge of instrument acoustics is vital to understand digital representations as spectrograms. The third chapter is a mixture, where I analyse how different composers have used timbre as a primary parameter. This part shows examples on how timbre has been used in compositions, and highlights the important connection between acoustics and aesthetics. The forth chapter is a short introduction and review of my own composition. I will present the ideas that has been used, inspiration and how I have executed this in light of the theory, the methodology and the analysis.

Timbre is a musicological field which involves many aspects. This makes it natural to narrow the subject. Because my main goal is to look at timbre in orchestration I think it is the sounding audio that is the most important. What is important is how it sounds, why it sounds like that, which orchestration techniques that are used, how this has an impact on the sound spectrum and how one can recreate sounds by this information. I have therefore chosen not to focus on the acoustical parameters concerning instrument construction, rooms and concert halls, etc. Nor will I in my analysis focus on the technological aspects concerning timbral recreation, by using computers. I will instead foucs on the actual sound, which in this case is recorded CD examples. I will use other acoustical parameters to explain why something sounds the way it does.

The reason I have chosen to primarily look at timbral aspects, is that in a historical context, timbre has been seen as a secondary parameter and I want give this my main focus. Thanks to modern technology and new musical genres that have arisen through the last decades, timbre has become a term which is possible to study in the matter of acoustics and psychoacoustics (sound perception). I intend to use a language where I am not operating with metaphors to describe the sound, but rather try to point out concrete information based on the examples. This is a subject particularly difficult in psychoacoustic research because of how the experience of sound is often described using metaphors. In the bigger picture, I find descriptions as bright, dark, dull, rich, open, covered, hollow and shrill, etc., important as connectors between scientific facts, perception and aural discussions. I will however avoid these descriptions in this context, because I think it is important to be able to describe timbre by concrete facts to develop timbre as a research area.

First of all I want to clarify some of the most important terms in this text. Instrumentation and orchestration, timbre and spectral music as well as some other definitions which will simplify the reading.

What is Instrumentation and Orchestration?

In Rolf Inge Godøy's article *Sketch to an analytical systematics of instrumentation*[1] (1993, my translation), he presents the idea of systemise the analysis of instrumentation. Godøy argues that he is missing concrete terms and concepts regarding instrumentation, in order to conduct a proper analysis (Godøy 1993: 1). Godøy's definition of instrumentation is stated as follows: 'Instrumentation is knowledge of the actual timbral design of a musical composition or an excerpt of a musical work' (ibid.: 2, my translation)[2]. His definition of instrumentation is very wide, which he also points out himself. The idea is to present instrumentation as a term which covers several aspects of the musical substance.

Orchestration is a term which occur in both analytical texts and textbooks which Godøy refers to as instrumentation of that given ensemble (loc. cit.). Instrumentation is according to Godøy a wider term than orchestration and can function as a general concept, independent of size of performers and connection of instruments. Samuel Adler presents a

[1] Skisse til en instrumentasjonsanalytisk systematikk (Godøy 1993)

[2] Instrumentasjon er kunnskap om den faktiske klanglige utformingen av et musikkverk eller et utsnitt av et musikkverk (Godøy 1993).

different opinion on what these terms mean. Only by looking at the contents of *The Study of Orchestration* it seems that under ‘Part One: Instrumentation’ he is concentrating on instruments individually, as groups (strings, wind, brass, percussion) and the connection between them. ‘Part Two: Orchestration’ concerns more of the compositional process like ‘The Distribution of Foreground - Middelground - Background Elements within the Orchestra’, ‘Orchestrating a Melody or Primary Gesture’. These are examples of processing the harmonic, melodic, timbral and textural material (Adler 2002: v-viii). Adler is, however, not particularly concerned with defining the term itself, but he is more interested in the orchestra as an ensemble and the orchestral sound. What he argues is how some aspects of music, as form, can be decided by parameters like timbre and texture. He says: ‘After all, timbre and texture clarify the form as well as the content of a host of compositions’ (ibid.: 3). The difference between Godøy's and Adler's opinion mainly comes from the language. Godøy (originally in Norwegian) is letting the ensemble determine which term to use. Adler (in English) presents instrumentation as knowledge of instruments, and orchestration as how to score the music. Further I will naturally use orchestration as Adler defines it, but I think this shows interesting sides of how the term is used in different languages.

What is Timbre?

Timbre is a musicological concept which I find, like many others, difficult to define. After reading several books, papers and articles, etc., on timbre I still have not found a way of describing the term perfectly. I do not claim that I will be able to do this myself, which is why I think that timbre is a concept that both deserves and demands a more thorough description. I will therefor present different sayings and argue their ability to describe it.

Roy D. Patterson quotes The Acoustical Society of America (ASA) Acoustical Terminology in *Music Perception,* and describes timbre as ‘that attribute of auditory sensation which enables a listener to judge that two nonidentical sounds, similarly presented and having the same loudness and pitch, are dissimilar’ (ASA in Patterson 2010: 37), adding, ‘Timbre depends primarily upon the frequency spectrum, although it also depends upon the sound pressure and the temporal characteristics of the sound’ (loc. cit.). I find this as the most accurate description of timbre. The more common description concerns what timbre is not, rather than what it is. Jeffery Hass from The Centre for Electronic and Computer Music at Indiana University says that ‘It is what allows us to distinguish between two different instruments playing the same note at the same amplitude' (Hass 2013). I have some issues when a term is described by what it is not, rather than what it is. That said, Hass provides an idea of what it can be. When the other parameters (amplitude and frequency) of two different sounds are equal, it is the timbre that separates them. Hass also states: 'Our perception of timbre, or tone quality, seems most closely related to the physical phenomena of unfolding partials in the spectrum of a sound, called the spectral envelope' (loc. cit.). Tor Halmrast presents the principles of a Fourier Analysis in 'Klangen'. 'Jean Baptiste Fourier (1768-1830) showed that any signal can be described as a sum of sine waves with individual amplitude and phase. By different choices of theses parameters one could add for example the most common waveforms: triangle, square and sawtooth'[3] (Halmrast 2014: 27, my translation). Each sine wave is called *Partials.* Rossing, Moore & Wheeler mentions in *The Science of Sound* that partials includes all modes or components of a sound, including the fundamental. *Upper partials*, which is a synonym for *overtones*, exclude the fundamental (Rossing, Moore & Wheeler 2002: 64).

Godøy says that 'It is wrong to say that an instrument's timbre is the overtone spectra of that instrument as one can represent it through a Fourier analysis, because the overtone spectra of an acoustic instrument is never static, it always evolves, and also contains a lot of "noise" or "turbulence" which must be described as chaotic'[4] (Godøy 1993: 11, my translation). Godøy has an interesting point, but there is no contradiction with what he is saying. Fourier analysis is just one way of presenting the overtone spectra of a sound, where the result can vary in time. Godøy further states that 'representations that shows sounds development over time (which also includes the chaotic elements of the sound), constitutes important knowledge in this context. But there will still be a gap between this knowledge and our perception of the sound, if we do not have the opportunity to compare various forms of the sound'[5] (loc. cit, my translation).

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[3] Jean Baptiste Fourier (1768-1830) viste at ethvert (periodisk og egentlig uendelig langt) signal kan beskrives som en sum av sinustoner med hver sin amplitude og fase. Ved forskjellig valg av disse parameterne kan man sette sammen f.eks. de vanligste bølgeformer (Halmrast 2014: 27).

[4] Det er uriktig å si at et instruments klangfare er likt instrumentets overtonespektrum, slik man kan representere det gjennom en Fourier-analyse, all den stund overtonespektra til akustiske instrumenter aldri er statiske, alltid er i utvikling og også ofte inneholder en del 'støy' eller 'turbulens' som må beskrives som kaotisk (Godøy 1993: 11).

[5] Representasjoner som viser lyders utvikling over tid (og som også inkluderer de kaotiske komponentene i lyden), utgjør en viktig kunnskap i denne sammenhengen. Men det vil fremdeles bestå et gap mellom denne kunnskapen og vår oppfatning av lyden dersom vi ikke også har muligheten til å sammenligne flere forskjellige varianter av lyden (Godøy 1993: 11).

Godøy and Hass are both focusing on the spectral envelope of a sound, where they see the development in time as a very important factor. This is because the attack and sustained part of a sound can be widely different. Pierre Shaeffer refers to this as 'cloche coupée'. He figured that the attack and sustained part of a sound is different from each other, but in our perception we create a synthesis combining the two elements, which constitutes a unified timbre (Shaeffer in Godøy 1993: 7). Examples are a piano sound, brass instruments playing ***sfp***, articulation in strings (>) or any impulsive sound. The partials are also not constant in amplitude over time, which means that time must be concerned as an important factor when analysing.

Timbre originally comes from the German word *klangfarbe*, which I will discuss in a historical context in the next chapter. Although the term could not be described by acoustical definitions at the early stages, I think the word itself shows an interesting aspect of how tone quality was considered.

Although the acoustic parameters of timbre are difficult to determine, I think that within a musicological context, these descriptions present the basics of what timbre is. Timbre is used to explain qualities and characteristics of a sound. Analysing timbre shows the complexity of discussing the term. It is difficult to say concrete things about timbre because the term itself is hard to explain. Timbre therefore needs a careful examination and cannot be explained by a simple sentence.

What is Spectral Music?

Spectral music is a musical genre, where analysis of timbral qualities work as a basis for the compositional process. Although spectral music as a genre mainly developed in the 1970s as a result of computers and digital tools, composers as Maurice Ravel, Gÿorgy Ligeti, Olivier Messiaen, Edgar Varese used spectral components as the natural harmonic series in their compositions. The term was, however, not coined until Hugues Dufourt gave this genre a name in his article called 'Spectral Music' in 1979. Doufort, together with other composers, noticed that this musical form directed the focus towards the overtone structure as it developed in time. The American composer and musicologist Anthony Cornicello said that 'various writers have remarked how spectral music eschews traditional melody and counterpoint. The musical surface of a typical spectral work does reveal occasional fragments of melody, but the main focus is the overall timbre' (Cornicello 2000: 2). He continues to argue how the focus and the development of timbre can replace the focus on melody through its ability of recreating the 'tension-release'-feeling. With this, he mentions the spectral process, which is a transformation from one spectrum to another. He argues that the 'relatively consonant and dissonant harmonies enables the composer to create a syntax utilizing them as contrasting states of tension' (ibid.: 3). Cornicello is very concerned with the understanding of where spectral music directs its focus. This is very important considering the way we talk about timbre and spectral music as a musicological concept. Cornicello asks:

> Does the lack of functional harmonic progression and thematic (or motivic) material prevent the listener from clearly understanding the musical intentions of a spectral composer? No, because the spectral composers often utilize musical gestures that reflect the harmonic characteristics. As in tonal music, the tension and release paradigm has a strong influence on the spectral work (ibid.: 4).

The main characteristics of spectral music are often based on mathematical analysis and sonographic representations by for instance a spectrogram. In chapter 3, I will show different ways to compose spectral music through analysis of different works. The first analysis is of *Boléro* by Maurice Ravel, where he uses the natural harmonic series as basis for voicings. Ravel uses rhythm as basis for the composition and the spectral characteristics as secondary. The second analysis is of *Lontano* by Gÿorgy Ligeti. I characterise Ligeti's compositional choice as long, abstract and outstretched components with few or no metric features. The score, however, is extremely precise and every little detail is notated. This is first and foremost to create an illusion of no metric structure. The third and main analysis is of Jonny Greenwood's *48 Responses to Polymorphia: 3 - Overtones.* Greenwood uses 48 string instruments which gives the analysis another approach which concerns timbral differences within one orchestral group. Through these three examples I will discuss different theories and aspects which will be presented in the next two chapters.

Spectral music is closely connected with electroacoustic music, which is also a genre where the timbral design is in focus. Electroacoustic music, in contrast to spectral music, does not necessarily focus on the spectral envelope of a sound, but rather directs its focus towards natural sounds integrated with musical components and technology, as birdsong, car engine and closing doors, etc. I have dedicated some of the theoretic part (chapter 1) towards IRCAM, an institute to support spectral and electroacoustic music research and composing. Many composers who visit IRCAM actively uses technology and electronics as part of their compositions, and connects the spectral and the electroacoustic parameters.

Definitions of Important Terms

There are different ways to present *octaves*. Jurgen Meyer in *Acoustics and the Performance of Music,* presents the American and the German tradition. I will use the American standard where C_4 equals the middle C just below the system using a treble clef.

American	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
German	C_1	C	c	c’	c’’	c’’’	c^4	c^5

Figure 1: Representation of American and German octaves (Meyer 2009: vii).

Rossing, Moore & Wheeler say that *sound* is used to describe two things: ‘1. An auditory sensation in the ear; 2. The disturbance in a medium that can cause this sensation’ (Rossing, Moore & Wheeler 2002: 3). They are clearly only focusing on the acoustical meaning of sound which I intend to do in this text as well. However, to me sound is a very wide and diffused term. I think it is even more incomprehensible than timbre. Sound is used in so many different settings and contexts created by different musical cultures. For example, one can talk about Jonny Greenwood's unique guitar sound, but what does this really mean? A classical educated violinist, a pop singer and a rock drummer would probably have different understandings of the term. That said, I will still use the term, but only in the context as first presented. Only by acoustical means if not told otherwise.

Sound pressure level and sound power level are two acoustical terms which can be difficult to understand, and also to separate. Meyer defines sound pressure level as.

> When we hear music, the perceived tonal impression is caused by sound carried to our ears by the air. Relevant in this context are the minute pressure variations which are superimposed on the stationary pressure of the air surrounding us. The pressure variations propagate as waves in space. These more or less periodic deviations from the stationary mean value, comprise the so called sound pressure variations, for which in practice the shorter term ‘‘sound pressure’’ is used (Meyer 2009: 1).

Sound pressure level is measured using the dB scale. When speaking of sound pressure it is important to separate between ‘absolute’ and ‘relative’ values. ‘So called “absolute” dB values of sound pressure levels are obtained when a reference value of 2×10^{-5} Pa (Pascal) is used. This value was chosen by international agreement’ (loc. cit.). When presenting an absolute sound pressure level it is therefore important to consider the already existing sound pressure in the room (reference value).

Relative sound pressure values is when one value function as a reference for the other. ‘A value of 0 dB, would indicate that the two processes being compared have the same sound pressure, not, however, that they are at the lower limit of hearings’ (ibid.: 2). If One instrument where playing with an absolute sound pressure level of 80 dB, and one with 60 dB, there would be a dynamic difference of relative 20 dB.

When describing sound power level, Meyer says:

> Naturally the measured sound level depends on the strength of the sound source. It is therefore also of interest to determine a characterization of the sound source, which describes its strength independently of spatial considerations and the distance from the listener. This relates exclusively to the sound source itself (ibid.: 3).

Meyer is here concerning the *effect* of the sound. Although the physical unit of power is Watt, a more available dB scale is used. This also simplifies the connection between the sound power of a source and the resulting sound pressure (loc. cit).

Cents denotes the division of semi-tones in the temperated system. Between each semi-tone there are 100 cents, and in contrast to frequency, these are not doubled for each octave. In the natural harmonic series, for example the 11th partial has a cent of - 49, which means that it naturally sounds almost a quarter-tone lower than the written note. In figure 2, the natural harmonic series is presented with the cent number of each partial written above the note.

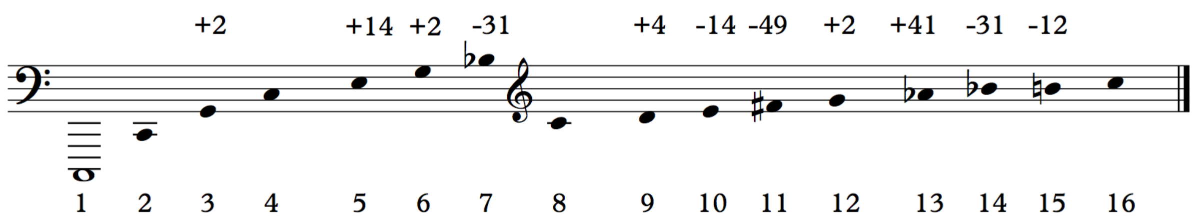

Figure 2: The natural harmonic series with the partial number below and the cents above each note, showing its relation to the temperated system.

Because a lack of musical symbols I will use (+) as a replacement for the ‘quarter sharp’ and the ‘three quarter sharp’ symbol. Example: C, C+, C#, C#+. These are the four quarter-tones between C and D.

To avoid confusion later in the thesis I will also shortly present chords, note (pitch) and form. When a number is adjourned, this indicates a chord symbol (Bb7-chord). When the number is lowered, this indicates the note's pitch (C_5-note). When the number is at the same size as the letter, this indicates a form part (A1-part).

1 Timbre in a Historical Perspective

In this chapter I will give an introduction of timbre in a musical historical context. First I will discuss theories developed by composers, musicians and thinkers in order to present the origin of timbral discussions. I find it important to present how different composers consciously have used timbre as part of their composing from the 18th century, and towards the use of timbre in Contemporary music of the 20th century. I think it is important not to isolate theories in discussions that appear in this thesis. I will therefore begin by presenting a scientific point of view. Then I will continue with presenting an artistic aspect concerning composers relation to timbre. Finally, I will gather the scientific and artistic aspect through IRCAM, and show how they contribute to timbral research and composing.

1.1 Timbre as a Musicological Concept

Through the history of music, many different musicological areas have been discussed by musicologist, musicians, philosophers and scientists, etc. In Emily Dolan's *The Orchestral Revolution,* she discusses how timbre arose as a term in the late 18th century. The focus on timbre has naturally always been in the subconsciousness before, but at this point concrete discussions were starting to develop. The idea of the connection between tone and colour spread amongst musicologists, but it also received massive critique. In the early 18th century, Isaac Newton claimed that colour was analogous to pitch. He presented the idea on how colours could match certain notes in the temperated system. Newton used the Dorian scale where D is the root, and matched a colour with each of the 7 tones in the Dorian scale. The D (the lowest note) was red, since red is the colour with the lowest frequency. Then followed by orange, yellow, green, blue, indigo and violet (Dolan 2013: 24). Newton was not alone in the opinion that there was a connection between tone and colour. Lois Bertrand-Castel was one of those who were fascinated by Newton and decided to ‘paint music’ where he used his own idea of a connection between tones and colours. He also used brightness and darkness to let the colours be valid through all octaves. That is what he called the *ocular harpsichord*, but he never received any great success with it. Castel was always clear that he believed that this instrument would create a new art-form and not just show the connection between colour and sound. Castel's ocular harpsichord helped later thinkers to compare sounds and paintings in discussions of aesthetics and the value of the art. Noël-Antoine Pluche was one of those thinkers, and one of his ideas was that sounds that lacked an object of imitation tired the listener:

> Sound is the object of the ear, as color is of the eye. Beautiful sounds please the ear and beautiful colors please the eye. But as colors are intended to distinguish objects, they do not please one for long if they are not attached to some figure, for they are out of place. Fine marbled paper and lovely Hungarian embroidery are pleasing colours and nothing more. The first glance does not displease: you can even look for useful nuances and good combinations in them. But these are not paintings; and if you wished to prolong this lifeless spectale, even by varying it for a quarter of an hour at a time, you would not care to: the mind does not search for colors, but for colored objects. In the same way sounds, in their variety, help us to identify an infinite number of thoughts and things. But if the sounds come one after the other without beeing attached to an object or thought, we become tired without knowing why (Pluche in Dolan 2013: 40).

Pluche's aesthetic point of view focuses on the connection between sounds and objects in order to entertain a listener. The philosopher Charles Batteux had a similar opinion when he in the 1750s argued that it was important for music to have recognisable mimetic content, in order to be truly beautiful (Batteux in Dolan: 2013: 39):

> Even though a musical composition be the most correctly calculated in all its tones and the most geometric in its harmony, of it has no meaning to accompany these qualities, it can only be compared to a prism which yields the most beautiful colors but which does not produce a picture. It would be like a color-harpsichord which offered colors and arrangements in order perhaps to amuse the eyes, but which would surely bore the mind (loc. cit.).

They both highlight the importance of orchestral knowledge, which Dolan describes as 'the art of manipulating instrumental timbre' (Dolan 2013: 89). Without the ability to transform the knowledge into beautiful musical results, there is no value of knowledge.

Wilhelm Wackenroder was the first to introduce the term *Klangfarbe,* around 1790. The idea of timbre as a musicological concept, challenged aesthetic thoughts by presenting the connection between tone and colour. For musicologist, a whole new musical area appeared. But despite that a lot of treatises being written in this time, orchestration could not be reduced to simple rules. E.T.A. Hoffmann said that 'when it comes to musical color, the musician is left entirely to his own devices; for *that* is orchestration' (Hoffmann in Dolan 2013: 52). With this, Hoffmann also points out the importance of the performer, in discussions of timbre.

In 1863 Herman von Helmholtz wrote a book called *Lehre von den Tonempfindungen,* which was translated by Alexander Ellis in 1885. Because a lack of knowledge of what timbre actually was, Ellis never translated klangfarbe into timbre, but was rather careful in his translation and referred to it as ‘quality of tone’. Although it turned out not to be entirely correct, Helmholtz had interesting thoughts on timbre which are still applicable. In what he called the *form of vibration*, Helmholtz presented the relation between the upper partials of a note. Helmholtz found that a sound's timbre depended on the strength and weaknesses of the upper partials. However, similar to Godøy's statement, presented in the introduction, it is too easy to say that an instrument's timbre is its overtone spectra. What Helmholtz did not mention was that what we think of as timbre, includes a numerous of other sonic elements as well, and it does not only depend on the strength and weaknesses of overtones. Elements as attack, decay, breathing, bow stroke and the performance, which definitely has an effect on the sound, were left out of his text. By only focusing on the upper partials, Helmholtz is forgetting the importance of the fundamental. Dolan also presents what I think is one of the issues with timbre. She quotes W. Dixon Ward, who she calls ‘a founder of psychoacoustics’. Ward, described in 1965 timbre as a wastebasket and that ‘timbre is *everything* that remains after accounting for tone's pitch and dynamic level’ (Ward in Dolan 2013: 54).

In discussions of timbre, there will always exist a relationship between acoustics and aesthetics. The philosopher Johann Gottfried Herder was one of those who criticised the relation between physics, mathematics and music in the late 1760s. When describing what these parameters do, he asked:

> How do they differentiate and determine tones? By the oscillations of the string in a given time, by the proportion of the tensioned force, of the physical constitution and length of the string. And what is it that is calculated from these proportions in the tone? Nothing except proportions. […] as we shall see, they are worthless for the aesthetics of tones (Herder in Dolan 2013: 75).

There is no secret that Herder was critical to the physical features connected to musical aesthetics. His relation to physicists was tense and he was concerned that a fewer people focused on how the music had an affect on human beings. While he was searching for answers on how the music had an impact on humans, their soul and affections he also said that ‘[…] physicist, […] knows it [tone] only as resonance’ (loc. cit.). A problem with Herder's thoughts was that he referred to timbre as the quality that remains beyond the pitch and volume. And as everyone else, Herder was forced to describe timbre in a negative way by presenting what it is not. Herder did not see timbre only as the third parameter of what a sound is, but he separated timbre from pitch and volume. While pitch and volume where measurable, timbre were only immediately perceptible. To Herder, ‘timbre wasn't a quality, but it was the direct experience of the tone itself’ (Dolan 2013: 78). It is very interesting how

Herder draws the focus away from timbre being a quality and towards it being something spontaneous. However, if looking at it from that point of view, all three parameters (pitch, loudness and timbre) are spontaneous, because sound can only exist in time. It is not possible to mark an area of the sound and just hear that part isolated from a time domaine. I think that Herder's thoughts highlight the importance of how music is experienced and how listening plays an important role even when discussing qualities.

Timbre highlighted different areas in musicology in many ways. First of all, timbre is not as clear as the quantitative parameters as melody, harmony and rhythm, etc. An issue that arose was how to talk about this. The vocabulary all of the sudden became important, and the use of metaphors to describe this, needed great attention. Dolan asks: ‘What would it mean to treat orchestration on the same level as form and harmony? Analytical systems, by definition, must reduce; but how does one reduce sonority?’ (ibid.: 102). Both timbre and orchestration did at that time demand a whole other value system in thoughts of musical analysis. Dolan says:

> If timbre thwarts systematic analysis, if it refuses to be disciplined, it is precisely because timbre stands at the inauguration of modern musical discourse. It cannot be easily analyzed as a parameter because ultimately timbre is not a parameter at all: it is aesthetic attention itself. The birth of the attention to timbre is also a condition of possibility for orchestration, for […] orchestration is the art of manipulating instrumental timbre (ibid.: 89).

Dolan draws the attention of timbral aesthetics towards the exploitation of timbre in the orchestra. She highlights the importance of discussing the concrete use and development of this in a historical context, in order to connect the theories to actual music and orchestration techniques.

1.2 Historic - Aesthetic Transition in the 18th and 19th Century

In the middle of the 18th century, as the Baroque era ended and The First Viennese School started, the music history went through some drastical changes which gave a whole new dimension to composing music and experimenting with timbre. Orchestration did also become a musical parameter which gained a greater focus than before. In addition to timbre becoming a term, the transition from smaller and undefined ensembles to a more standardised orchestra opened for a new way of focusing on orchestration. In contrast to the Baroque where the contrapuntal composing technique were heavily used and where the instruments operated more as individuals, the early orchestra gave the composer more opportunities to let one instrumental group accompany the other. In the beginning, strings and woodwinds were most frequently used, but also elements of brass as the French horn and trumpet were used as part of the symphonic orchestra. However, brass did not function as an independent group at these early stages.

There is a reason why Dolan said that orchestration is the art of manipulating timbre. The more conscious relation to instruments timbre was with no doubt a result of compositions for the symphonic orchestra's and its development as an ensemble. This connection of instruments and groups naturally led to a greater possibility to experiment with timbre. For example in Joseph Haydn's 93rd symphony, second movement, there is a great example of where he uses timbre as primary parameter, and harmony, melody and rhythm as secondary. In measure 73-79, the harmonic, melodic and rhythmic progression are more or less static and the focus are directed towards combinations of instruments where motives are played and responded to by other instruments. In the same composition there are also several examples of how Haydn combines different instruments in order to change the timbre, both in the melody and accompaniment.

Concrete orchestration techniques based on timbre were naturally created as a result of the new way of compositional thinking. In contrast to for example the Baroque's fuges where there were mostly two tones playing simultaneously with the same instrumental timbre, the orchestra gave opportunities to double the melody with great timbral variations. It was an opportunity to combine woodwinds with strings, or for example a melody played in unison by bassoon and French horn accompanied by the strings. The melodic development received more attention than before, but because of the quantum of performers, the harmonic distribution also became an important concern in this era.

1.3 German and French View on Orchestration

In the second half of the 19th century, different use of timbre became more clear in thoughts of concrete ideas on how to orchestrate. This lead to different directions of orchestration. Two of the main directions were the German and French orchestration.

The German direction is described by Richard Strauss as symphonic and polyphonic (Strauss in Berlioz 1991: I). This direction was, according to Strauss, a continuation of the symphonic works of Haydn and Mozart. He presents a line from them, through Beethoven, towards Brahms and Schumann, who were representatives for this direction. What Strauss refers to as polyphony in the German, symphonic direction, is the musical texture. Elements as harmony and timbre had a less dominant role.

The French direction was described as dramatic and homophonic. (loc. cit.). From Händel, Haydn and Gluck's operas, this direction were lead by Carl Maria von Weber and Hector Berlioz. Strauss highlights colouristic elements and timbral innovations as important factors. He also sees this direction as monotone and primitive music in the matter of texture (Strauss in Møller 2011: 86-87).

In *Studia Musicological Norvegical,* Thomas E. Møller states that ‘Strauss touches a central issue on how we consider orchestration when he focuses on different aspects in the comparison of orchestration styles’[6] (Møller 2011: 86, my translation). Strauss preferred the German direction, and when looking at the strings, he is more focused on the polyphonic qualities rather than the instrumental timbre. Møller presents Strauss' view on the German orchestration:

> The extensive doubling across the instrument groups and propensity to employ the semitutti-sound causes the sound spectrum to be characterized by continuity, but also uniformity. The instruments and the instrument group's pure timbre obscures, through a high level of mixing, that the timbre remains more or less constant and without contrasts[7] (ibid.: 90, my translation).

The two directions represented two widely different views on orchestration. The German direction tried to create an overall unified sound, while the French were looking for contrasts. Both directions had a focus on timbre, but they had different timbral ideals. Møller claims that ‘without judging the musical quality, one can still say that it was the French, dramatic orchestration style lead by Berlioz, that through works and text as *Traiteè d'Instrumentation,* brought the orchestration further, before and partly parallel with R. Wagner’[8] (ibid.: 92-93, my translation).

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[6] Strauss berører en helt sentral problemstilling for hvordan vi betrakter orkestrering overhodet når han fokuserer på ulike aspekter i sammenligningen av orkestreringsstilene (Møller 2011: 86).

[7] Den utstrakte doblingen på tvers av instrumentgrupper og tilbøyeligheten til å anvende semitutti-klangen fører til at klangspekteret preges av kontinuitet, men også ensformighet. Instrumentenes og instrumentgruppenes rene klangfarger tilsløres gjennom så stor grad av sammenblanding at klangen forblir mer eller mindre konstant og uten kontraster (Møller 2011: 90).

[8] Uten å vurdere musikkens kvalitet, må det likevel være plausibelt å hevde at det var den franske, dramatiske orkestreringsstilen anført av Berlioz som, både gjennom verker og tekstbøker som *Traité d'Instrumentation*, ledet orkestreringen fremover før og delvis parallelt med R. Wagner (Møller 2011: 92-93).

Adam Carse in *The History of Orchestration* said that:

> Berlioz kept the three main groups of the orchestra well separated; their functions are not allowed to rob one another of their distinctive features, to cancel their individuality by being too constantly combined, or to develop into neutrality of tone-colour by over-blending. Thus his contrasts are strong, clearly coloured and well spaced (Carse 1925: 259).

Carse's choice of words presents a critical view towards the German orchestration, where he clearly favours the French. In contrast to Møller, Carse is judging the musical quality with this statement, where he constantly describes the German characteristics in a negative way. I think that Møller is presenting the development of orchestration in a more objective way which shows a better picture. One must not forget that music from the German direction is often performed by orchestras today. Probably even more than music from the French. I think that both directions represent important elements in the development of timbre in orchestration. Both in the matter of techniques, but also in thoughts of it being an important compositional aspect.

1.4 Wagner, Debussy and Stravinsky

Richard Wagner, Claude Debussy and Igor Stravinsky have all had a huge impact on the music history and they developed orchestration even further. I think it is important to present how these composers have focused on timbre in the history of orchestration. They all represented different directions and timbral ideals.

In the preface of *Treatise of instrumentation* Strauss says that Richard Wagner (1813-1883) represents a mixture of the French and German orchestration which surpasses all that previously have been done in both directions (Strauss in Berlioz 1991: II). Møller says that: 'Strauss is of the opinion that a synthesis of dramatic and symphonic orchestration was also the target of Berlioz in his dramatic-symphonic works, but that it failed as a result of the French composer's lack of polyphony'[9] (Møller 2011: 86, my translation). Wagner restrained the synthesis of the German and the French direction, and was according to Strauss, in many ways regarded as a genius in the ways he did this (Strauss in Berlioz 1991: I). Not only did Wagner combine the two directions brilliantly, but he also developed the orchestra as a whole.

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[9] Strauss er av den oppfatning at en syntese av dramatisk og symfonisk orkestrering også var målet for Berlioz i hans dramatisk-symfoniske verker, men at dette mislyktes som følge av den franske komponistens mangel på polyfoni (Møller 2011: 86).

It is first with Wagner the brass as an independent group is used in its full potential. He also often extended the brass group from how it previously was used, by sometimes using 8 horns (4 playing Wagner tuba), 4 trumpets, 4 trombones or 5 tubas, etc. According to one of history's most idiomatic composers, Nikolay Rimsky-Korsakov, the orchestrater should if using 8 horns; use 3 trumpets, 3 trombones, tuba, 4 flutes, 4, oboes, 4 clarinets, 4 bassoons (including secondary instruments) to remain a proper balance between the groups (Rimsky-Korsakov 1964: 13, 22). Wagner maintained this balance brilliantly and frequently created timbral variations, between and across all three groups together with the percussion.

In 1874, the painter Claude Monet presented his *Impression; soleil levant*, which can be seen as the beginning of the Impressionism of art. As a reaction to the previous direction, the impressionists intended to paint the immediate and spontaneous impression directly on the canvas. The musical Impressionism, however, did not begin until about 1890 and lasted until 1915. It was first and foremost connected with Claude Debussy (1862-1918), who can be seen as the creator of this direction.

Nils E. Bjerkestrand said that 'the musical impressionism was not a revolutionary movement which distanced itself from the past, but rather an evolution where elements from previous styles were reshaped and combined with new ideas'[10] (Bjerkestrand 1998a: 9, my translation). Not only did they distance themselves from form and tonality, but extended them by using modality, the pentatonic scale and the whole tone scale. Most importantly, the relation between consonance and dissonance did not function as previous. The harmonic function from the major-minor-tonality disappeared, and a dominant-7 was no longer meant to lead towards the tonic. It would rather be sequenced a whole-tone up or down (example: G^7 moving towards either a F^7 or a A^7 chord, instead of a C). Debussy's harmonic structure could often be categorised in four groups. 1: Chords by thirds, 2: Enlarged chords by thirds, 3: Chords by fourths, 4: Chords by seconds (ibid.: 18-22). The relation between the chords were in Debussy's work often characterised by the distance of a perfect 5th.

It is interesting how the connection between tone and colour is present in the Impressionism, and how painting pictures and composing music suddenly got an obvious connection with the spontaneous impressions. This connection exists just as much in the analytical perspective as it does in the compositional. Both Debussy's, Ravel's and Stravinsky's work were often compared with art-forms and styles. I find that the most

[10] Musikalsk impresjonisme kastet ikke over bord verken tonaliteten eller gamle formtyper, men videreforedlet dette gjennom en symbiose av tradisjon og nye stiluttrykk (Bjerkestrand 1998a: 9).

interesting aspect about this, is how composers might have thought when translating a visual art-form into a musical art-form. Debussy's choice of harmonic, melodic and rhythmic base for the genre is not random, and has a connection with the pre-existing visual artform. There is a clear link to Newton's analogy. Although the connection between tone and colour does not appear as Newton suggested, the thoughts are still present. Not as a tone-colour link, but as a link between music and art.

The Russian composer Igor Stravinsky (1882-1971) is one of the composers of the late 19th- and the 20th-century who experimented with timbre, and 'extended' the instrumental range by creating voices and melodies beyond their comfort zone. Stravinsky took private lectures with Rimsky-Korsakov. The traces of Rimsky-Korsakov's ideas, instrumentation and form principles is first and foremost present in Stravinsky's early works. His eager to constantly change his composing led him to break with some of these principles in his later years. Although Rimsky-Korsakov's frames of composing were too strict for Stravinsky, this basis was very important for him, and the new impulses for developing he could easily get from elsewhere. Stravinsky later became a great admirer of Debussy's works and impressionistic composing style, a style which Rimsky-Korsakov distanced himself from. Bjerkestrand claims, in *The Instrumentation in the Music of Igor Stravinsky*[11] (my translation), that there are also traces of impressionistic elements in the works of Rimsky-Korsakov and other Russian composers at that time (Bjerkestrand 1998b: 8).

During Stravinsky's Russian period, he worked closely with Sergej Djagilev, the leader of *The Russian Ballet.* At this time, he composed his most famous work, *The Rite of the Spring.* In any discussion of this composition, the opening bassoon solo is always a topic. Stravinsky used the instruments extremes in ways never heard before, which created new timbres. Bjerkestrand characterises the work as dualistic. He says that the pentatonic based melody accompanied by surrounding voices with a chromatic character creates this effect. He also compares this to the Cubism where Pablo Picazzo visualises two dimensions (the profile and front) at the same time (ibid.: 27). Although Stravinsky's use of poly chords where frequent used in this work with for example a Eb^7 over a Fb, which has a distance of a 1/2 tone between the root notes, Bjerkestrand claims that it was the rhythmic structure that took the main focus. This is however a great example of how Stravinsky's use of harmony is directly compared with Cubism as an art-form. The relation between tone and colour does not only exist in the matter of timbre but also composition styles and in this example harmony.

[11] Om satsteknikken i Igor Stravinskijs musikk (Bjerkestrand 1998b).

1.5 IRCAM

In the 1970s Pierre Boulez (1925-2016), encouraged by the French president George Pompidou, established a research institute named IRCAM (Institut de Recherche et Coordination Acoustique/Musique). The institute was meant to focus on electronic music with Pierre Boulez as a leader, a position he held until 2002. Today, IRCAM 'is one of the world's largest public research centres dedicated to both musical expression and scientific research' (IRCAM: 2016). The centre was completed in 1977. It is located at the *Place Igor Stravinsky*, in Paris, and closely connected with the *Centre Pompidou of Art and Culture.*

IRCAM is part of the post World War II development of Contemporary music, with a focus on electroacoustic and spectral music. IRCAM presents the three main areas which they focus on: *research, creation,* and *transmission.* These musical areas contains everything from developing software programs, composing, lectures, projects and artistic research, etc. The British academic, anthropologist and musician Georgina Born, did as a result of her Ph.D. a study of IRCAM, Boulez and the avant-garde music. She mentions in her introduction that 'the institute is best known as a centre that hosts visiting commissioned composers, who come to produce a piece using IRCAM research and technologies, aided by IRCAM assistants' (Born 1995: 2). She also mentions Boulez's thoughts of the purpose of this centre:

> According to Boulez, the basic aims of IRCAM are to bring music, science, and technology into a new kind of collaborative dialogue in order to produce research and technologies that will aid the progress of musical composition (loc. cit).

IRCAM's great influence on the musical history in the second half of the 20th century is first and foremost represented by the French composer Pierre Boulez. Pierre Boulez, as his predecessors in Contemporary music, Pierre Schaeffer and Edgard Varèse, made many contributions in developing the electronic and computer made music. In the introduction of *The Musical Language of Pierre Boulez,* Jonathan Goldman says that 'Pierre Boulez could not unreflectively accept the forms handed down to him by tradition' (Goldman 2011: 1). Boulez argued that post-war music needed to accept that the musical form was not a permanent schema where to fill in musical content. He further argued that the form needed to reflect the microscopic elements on a macroscopic level (loc. cit).

I will further in this subchapter present IRCAM's role in the development of spectral music, electroacoustic music, timbre research and their focus on the process of composing music, using IRCAM technology. This contains everything from creating softwares, combining it with acoustic instruments, to the performance. But also IRCAM's contributions in developing timbre as an important aspect of both composing, creating and orchestrating. I will present this through stories from IRCAM, where the connection between research and art are presented.

1.5.1 Research

One of IRCAM's main dedications is musical research. In the development of electronic and spectral music, IRCAM provides a framework for these studies. The chart below presents the different musicological research areas that IRCAM focus on.

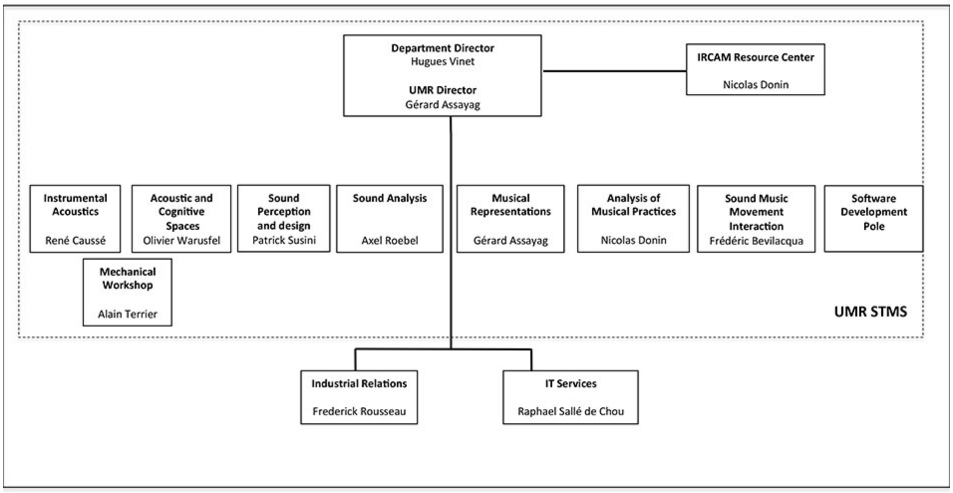

Figure 3: Chart of IRCAM's research areas (IRCAM 2016).

In the late 1950s, experimenting with computer synthesis and recreation of timbre were problematic in many ways. First of all, there were technical issues because the sound-synthesis technique had extremely heavy computing demands (Born 1995: 181). A bigger issue was the timbral recreation. Because of a lack of acoustical analysis, these recreations were not particularly good, and as a result of this, the psychoacoustical research were starting to grow. Further in the 70s and 80s, music computer languages as what Born refers to as ‘patch’ languages were emerging. The development of sound synthesis made with computers has without a doubt been an important factor in the development of timbre. Although the early attempts on recreating instrument timbre were bad, it led to a greater understanding of what the sound consists of. These programs demanded a high level of detailed information of acoustical parameters in order to recreate a proper timbral result. The importance is, however, that this research led to improved sonic results.

Born presents an IRCAM incident where a student was using this technology when composing (ibid.: 182). During an internship, the composer used the *Cmusic* patch program, in order to produce complex synthesised sounds. The student had written extremely high amplitude levels unwittingly, and as a result, he had made a distorted sound. The student also tried to recreate the same sound, using exact same values, but did not experience the same result. This showed that there was a certain amount of instability with the program.

IRCAM's technology research in the 80s distanced itself from the commercial aspect. 'Consistent with Boulez's own ideology, it was held that IRCAM had nothing to learn from commerce' (ibid.: 184). IRCAM believed that the commercial industry had nothing to offer them, which might sound like a paradox because of their intense curiosity towards that part of the industry. There was tension between IRCAM and leading commercial companies as Yamaha corporation, although in 1984 Yamaha visited IRCAM to present their new CX synthesiser. IRCAM were amused by the small size, and when the question of what was inside was raised, the answer was 'Ah … Japanese air!' (Yamaha in Born 1995: 184). And the mystery was maintained. An important difference between IRCAM and the commercial technology research was that IRCAM did not have a focus on user friendliness or man-machine interface. They did not prioritise that aspect because they did not think it was fundamental for the research. Through IRCAM's years of existence there has been a lot of changes which has led to new research areas, and the focus of marketing has increased over the years. That said, 'the basic social, theoretical, and aesthetic dimensions of IRCAM appear largely to be continuous with the past, as do some of the central problems and contradictions of music research and production' (Born 1995: 314).

1.5.2 Creation

The second area IRCAM focus on, is creation. Within creation, IRCAM further divides it in *Concerts/Performances*, *ManiFeste* and *On tour*. IRCAM offers a series of concerts, where composers present their electronic Contemporary music. ManiFeste is a festival which lasts about a month, where different composers, performers, directors and actors, etc., are brought together for the same purpose. IRCAM also tours around the world to present the music, with the purpose of spreading their music. There is no doubt that IRCAM is very active in widening this musical genre, and develop the focus on timbre in music.

IRCAM do not only have visitors whose purpose is research, but also those who create music. Born presents a story of how a visitor whom she refers to as 'AV' in 1980 visited to learn about the IRCAM technology, and in 1982 returned to create music. In two months AV had managed to produce one minute of music based on a timbral transition from a simulated voice and a Chinese oboe (ibid.: 235). AV also revisited IRCAM in 1984 with the purpose of extending the compositional idea from 1982. This was a failure, because his work demanded a great deal of computer resources. The technology gave AV problems because of the need for memory and computing power. The computers needed this in order to produce the length of files that was needed to maintain an organic sound. It could take weeks to transform a patch into an audio clip, and when producing music at that time, two issues were raised: time and collaboration. Time became an issue simply because of the technical aspect, where much time were spent on fixing programs instead of creating music. The issue on a daily basis was the ratio. With a ratio of 30:1, it should have taken 30 minutes to compose a minute of music. Based on AV's composition of 72 seconds in three months, Born presents a ratio of 54'000:1 (ibid.: 238). In other words it was not an efficient process.

This shows the difficulties in recreating timbre at these early stages, and there was certainly a need for acoustical and psychoacoustical research. Many issues needed to be problematised, including psychoacoustics, acoustics, development of synthesis programs and time efficiency, etc. In light of spectral music and mathematical created music, further development was essential. IRCAM's development of technology has been important for these areas, and are therefor one of their main areas of focus.

1.5.3 Transmission

The last of the three areas IRCAM focus on, is what they call transmission. In this category they focus on teaching and learning by providing different courses and lectures. They also provide softwares and plug-ins for download. One of the most used synthesis programs, *Max*, was created at IRCAM in 1988. This program can create sounds from the very bottom by connecting different sinus tones with each other. Adding several sinus tones into a new waveform is what we refer to as *Additive synthesis.*

Comparing today's Max-technology with the technology presented in the 'AV-example', there are, naturally, major differences. Without going too far into the functions and the possibilities with Max, there has been some great changes as results of the research that has been done. The time issue is no longer present and makes it much easier to work. This is because of the immediate auditive feedback from the program. For composers who are inexperienced with the use of technology such as Max, Pure Data (PD) and similar programs, the aspect of finding solutions by trial and error is much easier than before. Of course some knowledge about the creation of a sine wave, and development towards more complex sounds are needed. However, by these technological innovations, where IRCAM are great contributors, they are surely developing the spectral and electroacoustic music further.

1.6 Summary

There has with no doubt been massive changes in the history of music from the 18th century where the Baroque era ended and towards today's Contemporary music. Haydn represents the early orchestral view on timbre with a symphonic thinking where one orchestral group could accompany the other, and doublings in either unison or octaves can be seen as a symbol and the greatest innovation of this time. In the 19th century the German and the French views on orchestration represents the two main directions. The German represented the conservative direction, and the French represented the innovative and progressive. The two directions were further developed and combined by Wagner, where he also introduced the brass as an independent orchestral group, often by extending the brass ensemble. The French direction was further developed by Debussy with his impressionistic compositions where he introduced new relations between chords and harmonic development based on previous techniques. Together with Stravinsky, new principles and ideas for developing the orchestration were truly present by extending the instrumental range. Post World War II, the technology started to play a central role for Contemporary music composers. As a result of the new compositional directions, IRCAM was founded and opened in the late 1970s with Boulez in the lead. IRCAM are still focusing on promoting the electroacoustic and spectral music through concerts, tours, research, courses, software development and by inviting and closely work together with different composers using IRCAM technology.

There has been great changes in the focus on timbre and orchestration over the years. This has lead to new opportunities for composing. The present, and the previous three decades, development in technology has opened up for new methods of timbral analysis and the use of this in creating new spectral music. The understanding of timbre have also increased greatly on a microscopic level which have resulted in greater knowledge of why certain instrument combinations function as they do, and how this directly can be used in thoughts of developing the orchestration even further. In the next chapter I will look closer into the analytical aspects of timbre in orchestration.

2 Methodology

The methodology in my thesis combines various analytical approaches. Analysis can be conducted in many different ways, but I have chosen to narrow this down to *score analysis, auditive perception (listening)* and *sound analysis* through spectrograms and other digital representations. When analysing timbre, it is the actual sound that is interesting. The main focus is therefore at the vertical aspect of the music, which means the structure of tones played at the same time.

Whether conducting a sound analysis, score analysis or aural analysis there are certain ways to approach these methods. I find that ideas from both Fourier analysis and Shenkerian analysis can be useful in this matter. Shenkerian analysis derived from Shenker's final works where his desendance further developed his analytical ideas. Nicholas Cook says that ‘it aims to omit inessentials and to highlight important relationships’ (Cook 2009: 28). The principle is based on a hierarchically categorising of the harmonic material based on what is relevant and what is not. He also says that ‘any linear motion in a Shenkerian analysis that doesn’t form part of a harmonic aggregate cannot be considered as of genuinely significance’ (ibid.: 38-39).

It is first and foremost the idea of separating musical elements that I find interesting. although Shenkerian analysis is directed towards harmonic structures I think the categorisation based on importance is useful. I will not use these methods per se but when analysing timbre it is vital to understand the most important aspects of what you are looking for, if not the result will not be properly presented.

In contrast to analysing harmony, melody, rhythm, pitch, frequency and amplitude, etc., timbre is difficult to describe precisely. For example, one can say that a trombone is playing a C_4 with a frequency of 261 Hz, with the sound power level of 85 dB. Both amplitude and frequency are presented, but the timbre needs a more thorough description. The three parameters are, however, not independent from each other. A change in either amplitude or frequency will have an effect on the timbre. A good example of this is the overtone structure of a clarinet, where the odd partials dominate in the lower and middle register, while the even partials become just as dominant when playing in the upper register. The instrumental timbre therefore changes as a result of changing frequency. A similar example can be presented for amplitude. In one of my previous work of research while creating a spectral composition, I analysed the spectra of two audio files. Both files were a

French horn playing, but with different sound power level. The audio file with the highest sound power level did clearly produce more overtones. It is also important to remember that one would percept the distribution of frequencies differently when listening, if the recording is amplified.

As a contrast to frequency and amplitude, timbre as a qualitative is, however, impossible to present as a concrete unit like the quantitative. Therefore, there is a need to represent the timbre in various forms to be able to understand some of the timbral qualities of a sound. This also clarifies the difficulties in describing timbre as a term in one sentence as discussed in the introduction. After reading this chapter, the different representations will also show how complex timbre is. I will highlight the importance of connecting different analytical forms and methods to be able to get a proper representation of timbre.

2.1 Score

To be able to use a score in the analytical work, a definition of what it really is, is necessary. First of all it is a form of visualising music with concrete values to act as a guide for the performer. It is traditionally not meant as an analytical tool, but can rather be seen as a form of musical language. However, because it is used in both the compositional process and the performance, it will also function as an analytical tool to understand some aspects of the music in retrospect.

As mentioned in the introduction, some musicologists describe timbre as what separates two sounds with the same amplitude and frequency from each other. Both amplitude and frequency can at some level be represented by the score. Amplitude is of course relative in relation to the dynamic symbols as ***f*****,** ***p*****,** etc, and frequency in relation to notes. The score has more difficulties with presenting the timbral qualities of a sound. However, I do not see this as a major issue, because when working with a score, I think that knowledge of instruments should be taken for granted. When writing a composition for a string quartet it is necessary to know the instruments, their strengths, weaknesses and functions, etc. As a qualitative measurement, the timbral aspects of different instruments, their blend and orchestration, is far more difficult to gain control over than for instance the range of each instrument. At that level, a score will not be particularly useful to understand instrumental timbre. Spectrograms and other visual representations of sound, and of course listening, would provide more information. I think, however, that discussions of score in the relation of timbre, a certain knowledge of instrumental qualities, how they sound and what their main functions are in the orchestra is a matter of course. Therefore, these discussions are absolutely relevant.

I believe there are many different thoughts on the importance of the traditional score when analysing timbre. I think this comes from the intention on how to use it. I will argue that score analysis separated from all other musical aspects is ill suited to represent timbre, and there would be easy to raise many arguments of why it is.

> A musical score is a symbolic, or discrete, representation - the score assumes that the music can be abstracted to a sequence of isolated events, or notes. The score is ill suited to visualizing electroacoustic music because it is often characterized by complex time-varying spectra that defy attempts to be abstracted to discrete events (Adams 2006: 14).

When looking at the analytical aspect of electroacoustic and spectral music, there are some similarities in what is relevant. When analysing electroacoustic music, the process of composing can be just as important as the music itself. This can also be important in spectral music, but the main thing these two genres have in common is the focus on the timbral qualities of a sound. As Adams is stating in the quote, the score is ill suited because it cannot say anything about the actual sound. The concrete frames the score provides, can be an issue for electroacoustic music.

In discussions of spectral music, I think the score can play a more significant role as part of the analysis. First of all, the score is highly relevant in the compositional process, which means that the timbral aspects of the music are, or at least should have been taken into account before creating the score. By this, the score is also relevant in the analysis. A more interesting question is whether it is possible to read any concrete information about the sound without knowledge of how it is supposed to sound in advance. Like spectrograms, spectrums and waveforms, etc., the score is just a representation of the sound. In contrast to for instance a spectrogram, a score can only tell us which note, which instrument is playing that note, and at which dynamics, and nothing about the character of the sound.

2.1.1 Timbral Readings of the Score

The data that can be read from the score is valuable before reading the spectrogram, especially if looking at separating sounds from each other. This can be difficult by listening, and also by looking at the spectrogram. In the following example there are eight instruments playing the same melody in different octaves. Through listening and spectral analysis it can be difficult to transcribe the music, especially when concerning the instrumentation, and not only the played tones. This is because it is hard to separate different sounds when they are played at the same time. The score is therefore in this context well suited, but only to simplify the upcoming analytical process, and not to say anything concrete about the musical timbre.

Figure 4: Excerpt of measure 40-43 from *Peter Pantonal* (transposed score), by Mathias Langfeldt. The melody is accompanied by strings playing a sustained Badd⁹ chord. (Langfeldt 2015).

Here is an example of both; what can be read in score, but also an example of a clear conscious choice of orchestration to gradually change the sound from one timbre to another through the use of doublings and pitch. With exception of the first note (Gb), the rest of the notes are the whole-tone scale from B to B. The melody in this composition is primarily based on this series of tones, where the timbre and harmony plays a greater role than the melody. Other than the most obvious facts, what timbral aspects are there to be seen? All instruments are playing in either unison or in octaves, and the dynamic is ***p***, which means that amplitude and frequency are established in relation with dynamics and pitch (there is of course no exact dB or Hz values).The timbre is however only represented in our imagination, but that is also how the choice of doublings and blends are created. An orchestrator does not analyse every single chord with a spectrogram when composing, but uses previous knowledge to orchestrate in a way that sounds good.

The choice of doublings as in the example above is often decided by different aesthetic points of view presented by an experienced composer's idea of what is good and bad orchestration. Adler is very clear in his aesthetic point of view, which I will show in the upcoming spectral analysis (2.3.3). He often uses definitions as *good* and *bad* orchestration to describe different spacings. I also think that Adler often presents the extremes in his examples to give the student orchestrator a clear idea of what is working and what is not. No matter what aesthetic opinion, it will have a clear effect on the choice of timbre when orchestrating. When a composer repeatedly uses almost the same orchestration methods, it is much easier for the listener to recognise the musical timbre. The composer uses timbre as base for what is good and bad orchestration, which means that previous knowledge on how things sound, will help in understanding timbre in scores where by acoustic means it is not possible to read timbre.

2.2 Auditive Perception

Listening is with no doubt necessary and important when analysing music. Not necessarily if focusing on harmonic, rhythmic or melodic structures from the score, but to understand the sound and perceive instruments blend. By looking at a spectrogram, it is very hard to see which instruments are playing if there are two or more playing at the same time. By listening, a musician should have no problem with separating widely different instruments as for instance a tuba with an oboe, given that the listener has some idea on how they sound separately. Listening is also the source of judging music. As I will show in chapter 2.3.3, Adler presents his opinion of good and bad orchestration through two simple C major chords distributed differently. The examples are primarily judged by listening and Adler's idea on how different instruments act together. In other words, they are judged by Adler's aesthetic point of view. Both the score and spectrogram would work as tools for underpinning the arguments, but it is the listening which gives the judgement in the end.

Godøy presents what Pierre Schaeffer sees as the main methodological approach.

> To Schaeffer, the repeated listening to a fragment, which he called “sillion fermé” (which denotes […] a “loop” […]), that was the main methodological approach. Through this process of repeated listenings, one could constantly focus on new aspects of that sound and then discover new things with the sound which one was not aware of, and one could also eventually arrange the different aspects in a more systematic way[12] (Godøy 1993: 7, my translation).

[12] For Schaeffer var den gjentatte lyttingen til et fragment, det han kaller “sillion fermé” (som betegner en [“lukket fure” på et fonogram, eller senere en lydbåndsløyfe, og nåtildags en] “loop” [ved avspilling av en digital lydfil]), det metodiske hovedprinsippet. Gjennom en slik prosess av gjentatte lyttinger ville man da kunne fokusere oppmerksomheten på stadig nye aspekter ved lyden, og dermed både oppdage nye ting i lyden som man ikke var klar over, og man kunne også etterhvert ordne disse forskjellige aspektene på en mer systematisk måte (Godøy 1993: 7).

What Schaeffer argues is that a sound is never static. One cannot measure a sound at one point because it exists in time. Therefore, it is the repeated listening that allows us to discover new aspects of certain parts of a sound. With spectrograms one can focus at microscopic time periods and see the spectrum at that given point. The whole envelope of the sound must, however, be considered to get a proper understanding of the sounds development in time, which is important because a sound is never static.

It might be an issue to distinct one sound from another when they are played together. If a C major chord is played by two clarinets and two oboes interleaved, which is found in Adler's example of good distribution of tones within a chord (chapter 2.3.3), it might not be easy to separate the different timbres from each instrument. One would achieve greater results in this context if the auditive perception was connected with a score. Overtones are also an issue with the listening method. To actually hear each overtone which is presented by the C major chord, would almost be impossible. Instead of one series of natural harmonics, there are four. In these cases, the listening works best together with a spectrogram. In this next subchapter I will also present why spectrograms work best together with listening and that knowledge of instrument acoustics is very important to be able to read spectrograms properly.

2.3 Digital Visualisation of Sound

2.3.1 Spectrogram - Sonic Visualiser

Spectrograms are one of the main tools in the understanding of timbral qualities of different sounds. A spectrogram is a tool used to visualise audio signals. It presents a picture of the sound where the *time* domaine is presented on the x-axis, and *frequency* domaine on the y-axis. The amplitude is shown by colours, but exact values can be read via the additional toolbox. By using the spectrogram as an analytical tool, it provides a lot of additional information that cannot be read in the score. Examples of this can be the overtone structure, amplitude level of each overtone and pitch deviation from the temperated system. This information is crucial to understand instrumental timbre, and it also provides the analyst with valuable information above the melodic range.

> The fundamental of the oboe sound is relatively weak especially in the low registers, since the sound power level below the formant maximum drops by 4–6 dB/octave. The fundamental thus lies up to 15 dB below the main formant. Its vowel character is therefore enhanced (Meyer 2009: 70).

Jürgen Meyer presents the reason why the oboe sounds similar to the vowel 'a(ah)', but also underpins the importance of the information provided by the spectrogram. What he calls *formant*, is an important term in research of acoustics and speech. Gunnar Fant described it as 'The spectral peaks of the sound spectrum |*P*(*f*)| are called formants' (Fant 1960, in Wolfe). Later in the methodology chapter I will discuss the term more closely, and present how it can be used in timbral analysis. The formant character which is special for the oboe comes from its overtone structure, and that the fundamental is not the strongest partial. In the chart below, Meyer presents the main formants (spectral peaks) of the double reed instruments. The oboe clearly has its peak around 1100 Hz, which is important knowledge and defines its instrumental timbre. Meyer also mentions that the bassoon does not reach its maximum sound power level until the 8. or 9. partial, which is about three octaves above the fundamental. However, its main character lies around 500 Hz, and therefore gives it an o(oh)-character, in the same way as the oboe gets its a(ah)-character around 1100 Hz. In one of the upcoming examples by Adler, I will show how this knowledge is useful when analysing the timbral qualities of a mixed sound between numerous instruments.

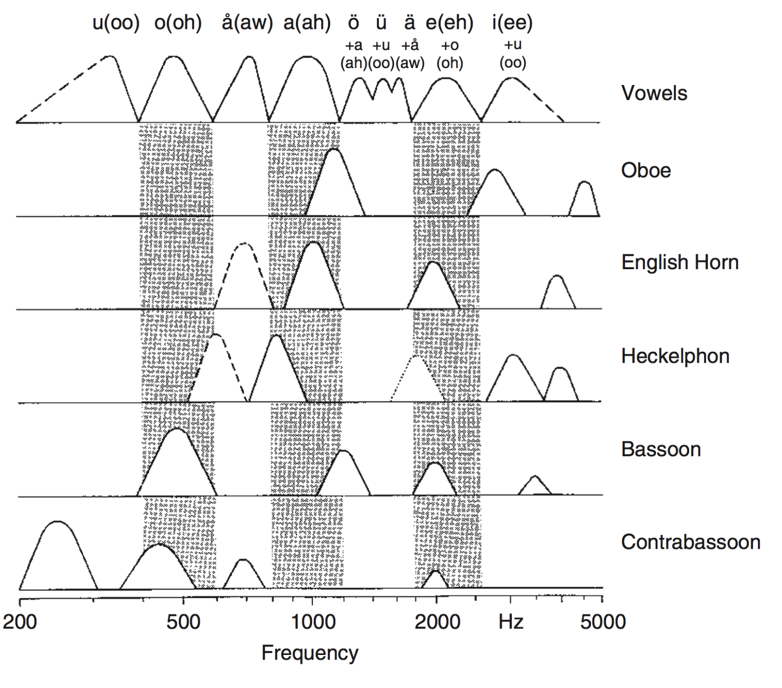

Figure 5: Chart of formants in woodwind instruments. (Meyer 2009: 71).

There are a lot of different analysis programs that can be used in the matter of timbre, and in addition, all of these programs have extremely wide options of plug-ins. They all are meant to analyse a variety of elements, and aim to give different representations. To narrow this, I will only use three programs: *Sonic Visualiser, Praat* and *Spear.* The main focus will be the spectrogram, melodic range spectrogram and spectrum in Sonic Visualiser, but I will also use Praat as a tool to show the concentration of formants in different instruments. Spear will be used to manipulate the overtone structure of the sound.

Before analysing, it is very important to be aware of the quality of the audio file. There are differences between a mp3-file and a waw-file, which will also have an effect on the spectral analysis. With an mp3-file some information is meant to be left out, and this information can be important in the analytical process. Tor Halmrast presents in 'Klangen' an example where waw quality can show frequencies up to 20 kHz, while mp3 quality can vary from 15 kHz (high quality) to about 500 Hz which is extremely poor quality (Halmrast 2013: 358). Noise can also be an issue when analysing. If the recording quality is bad, then there might be a lot of noise which will disguise the overtone structure, and particularly the weak ones. The quality of the audio file will also have an effect on the frequency range that is shown in the analysis. If an audio file only provides information from 20 Hz-10 kHz, it would be impossible to read anything above 10 kHz.

In Sonic Visualiser one can choose between different ways to represent the spectra of a sound. This includes colour, scale, window and bins. Except from spectrums (which I will describe later), all spectrograms are presented with *time* on the x-axis and *frequency* on the y-axis. *Amplitude* is shown by colours. This is only an indication of which partial is the strongest. One can read exact values from an additional toolbox. There are also different colour sets which are used to get the best possible representation of the sound. Thorough this text I will use several of these sets which will present how colours can be changed to get the best result.

There are two main *scales* that are used to present frequency; linear and logarithmic. The linear scale shows an even scale where the distance between the frequencies is proportional. The logarithmic scale is practical to represent relative values. The most important is that a doubling in frequency has the same width at any point at the scale. For example: The human ear percept the distance between octaves as evenly wide, no matter if it is from C_2-C_3 or from C_5-C_6. This is because the ear is 'logarithmic by nature'. In a linear representation one can see that 2000 Hz equals 1/10 of the scale. From C_2 (65,4 Hz) - C_3 (130,8 Hz) there is a distance of 65 Hz. Between C_5 (523,25 Hz) - C_6 (1046,5 Hz) the distance is 523,25 Hz. The sizes are proportional because the frequency is doubled for each octave, but the width is different as a contrast to the logarithmic presentation. In most of my examples I will use the linear representation because I think this shows the best result in my analysis.

The *window* size is deciding the visual quality of the spectrogram. A high value equals good quality, and low value equals poor quality. This does not mean the good quality represents the sound better than the poor. It is only a matter of what you are looking for. One can choose between three ways of presenting *bins*. All bins, frequency and peak bins. These show different sizes of the frequency width. In figure 6 I have presented 'all bins', while in figure 10 I have presented 'frequencies'.

2.3.2 Analysing One Note

The simplest form of spectral analysis is to analyse one note played by one instrument. By only analysing one note, the overtone structure of that instrument will appear. When using this method the information of which partial that is the strongest, the sustainability of each overtone and their pitch can be read.

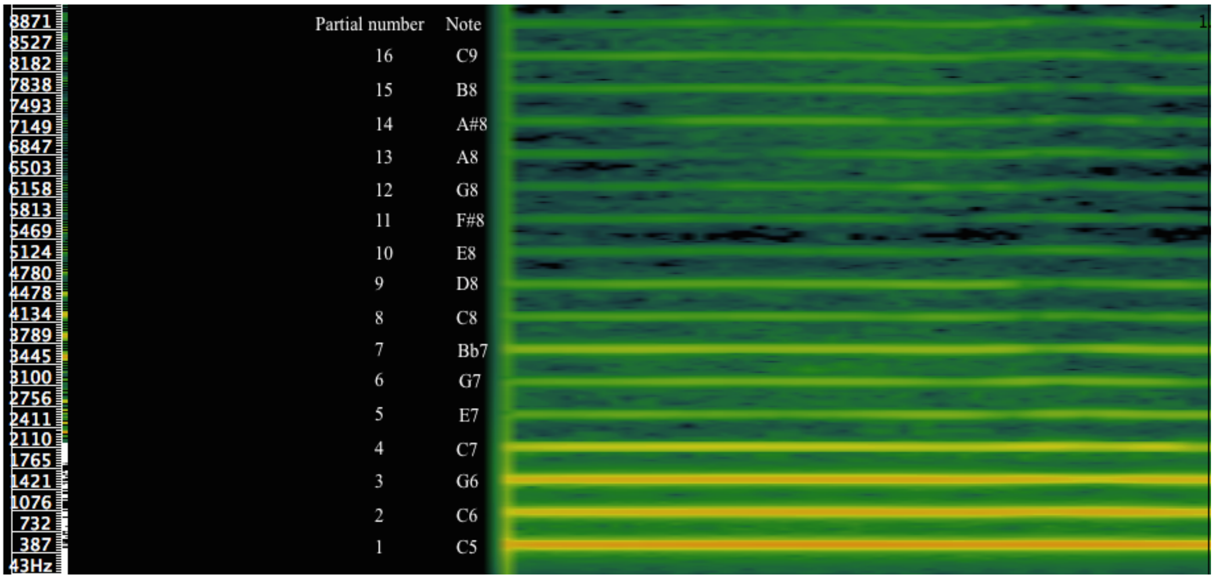

Figure 6: Spectrogram showing the overtone structure of a bassoon playing a C_5 note (523 Hz) at the dynamics of ***mf***. Scale: linear. Quality: mp3, (LPO 2013).[13]

Figure 6 presents a bassoon playing a C_5-note and the next 15 overtones. The window presents about one second of the sound. This is one aspect on how instrument acoustics are

[13] All pictures marked with (LPO 2013) = Performed by London Philharmonic Orchestra. The sound examples are taken from Youtube with mp3 quality.

discovered. The bassoon's first three formants are centred around the first four partials, and the fourth one around the 7th partial (Bb$_7$). Shown by colours, these notes are the strongest partials in this audio. If the same note were played by for instance a flute, the overtone structure would look totally different, because of their differences in the overtone structure. While the bassoon is rich in overtones, the flute is poor. If a bassoon would have played a much deeper note, for instance a C$_3$-note, and at the same time changed dynamics to ***f***, the overtone structure and amplitude-level would have looked totally different as well. This is because a sound with more power will create more overtones, and there is room for more overtones when playing in a deeper register. The formant peaks would, however, be at the same frequency area.

The spectra in figure 7 presents some significant readings. My main argument was that in some cases there is more room for overtones when playing in a lower register. Although the C$_5$ (right) note has a higher sound power level than the Bb$_2$ note (left, almost 20 dB), the Bb$_2$ still creates more overtones across the whole frequency area 20 Hz-20 kHz. It is also possible to see that the formant character in the first audio clip around 500 Hz is particularly strong (this is shown by the yellow in contrast to red).

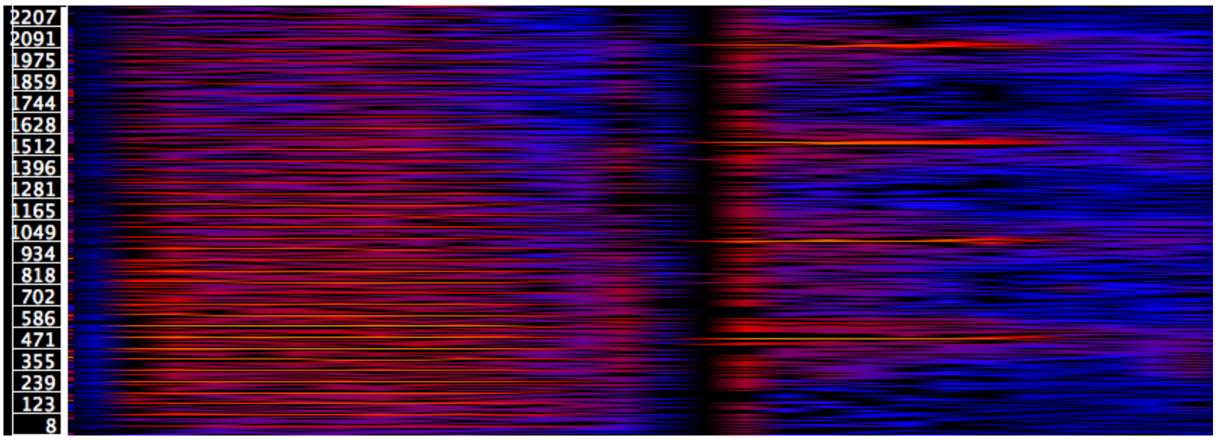

Figure 7: Spectrogram showing the overtone structure of a bassoon playing Bb$_2$ (left, 116 Hz), and C$_5$ (right, 523 Hz). Scale: linear. Quality: mp3, (LPO 2013).

2.3.3 Analysing Simple Chords with Few Instruments

Most important, but also the most difficult, when using the spectrogram is knowing exactly what you are looking for and where to look for it. To be able to argue that a chord spacing is either good or bad, there has to be an idea of how to make them so. Here is an example of how a spectrogram is used to understand timbre and orchestral instruments blend. The following example is sourced from Adler's *The study of orchestration* (Adler 2002: 253).

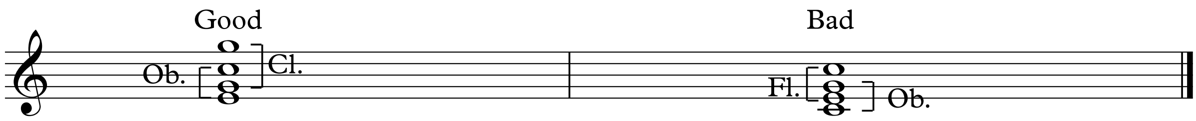

Figure 8: Adler's opinion on good and bad orchestrating shown in a compact score.

In the following spectrogram, three panes are added. There are, from top to bottom, waveform, melodic range spectrogram and spectrogram. When analysing timbre, we mainly focus on the two spectrograms. Amplitude is shown by colours, where in the lowermost spectrogram red indicates high amplitude, green is low or none and the colours between these two (yellow, orange) show the scale between them.

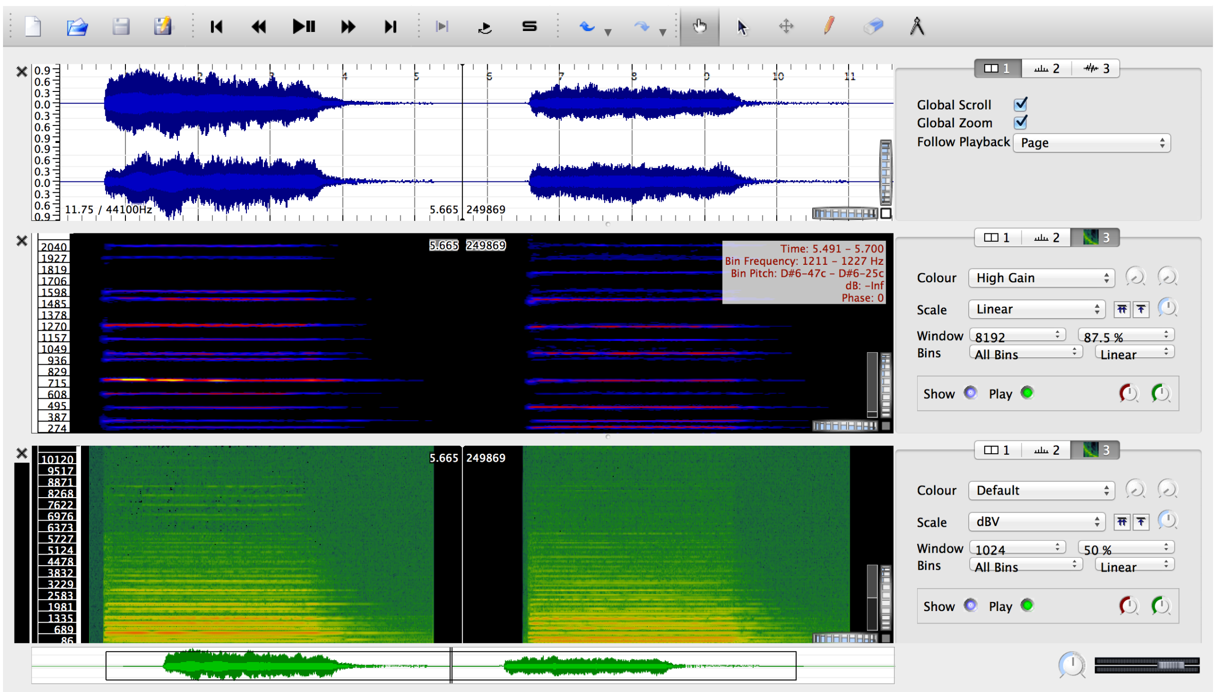

Figure 9: The chords from figure 8, shown as waveform, melodic range spectrogram and spectrogram in Sonic Visualiser. Scales: linear. Quality: waw, (Adler 2002).

Good:

Notes	Instrument	Amplitude in dB	Time in seconds
G_5	Clarinet	-9	1,539
C_5	Oboe	-19	1,539
G_4	Clarinet	-21	1,539
E_4	Oboe	-18	1,539

Table 1: Table presenting the relative sound pressure level of the played tones in the good distribution.

Bad:

Notes	Instrument	Amplitude in dB	Time in seconds
C_5	Flute	-15	7,339
G_4	Oboe	-17	7,339
E_4	Flute	-13	7,339
C_4	Oboe	-20	7,339

Table 2: Table presenting the relative sound pressure level of the played tones in the bad distribution.

It is important to be critical to Adler's choice of examples before concluding anything. By only looking at the score one can already assume that the good chord will sound brighter and clearer than the bad one because of the range. The interesting part is however how the choice of instrumentation will effect the sound. As a first thought when looking at the bad chord, the oboe would overpower the flute in this range, but by looking at the amplitude level the flutes seem to overpower the oboes. This is where the melodic range spectrogram reaches an issue if it is isolated. The knowledge of instrument acoustics and the listening ability is therefore very important. It would be wrong to make any conclusions on what makes this chord bad, when a large part of the information is left out. Meyer describes the overtone structure of the flute as following: ‘the fundamental is the most strongly developed of all partials for the entire range of the instrument’ (Meyer 2009: 64-65). And he continues with describing the oboe: ‘As determined by the different process of generating vibrations and the conical nature of the bore, the oboe has a totally different tonal character than the flute. Acoustically this is borne out in the spectrum which is rather rich in overtones’ (ibid.: 70). In other words, the flute has a few number of overtones, the fundamental is the strongest partial and the oboe has a very high number of partials and the fundamental is weak. This means that there is a lot of important information that lies above the melodic range.

With the resolution in the spectrogram (figure 10), the C_4 and G_4 notes which are played by the oboes cannot be seen. The overtones above C_5, have in contrast a more dominant role in this picture. If the window size is expanded, then the C_4, G_4 and more partials will be possible to see.

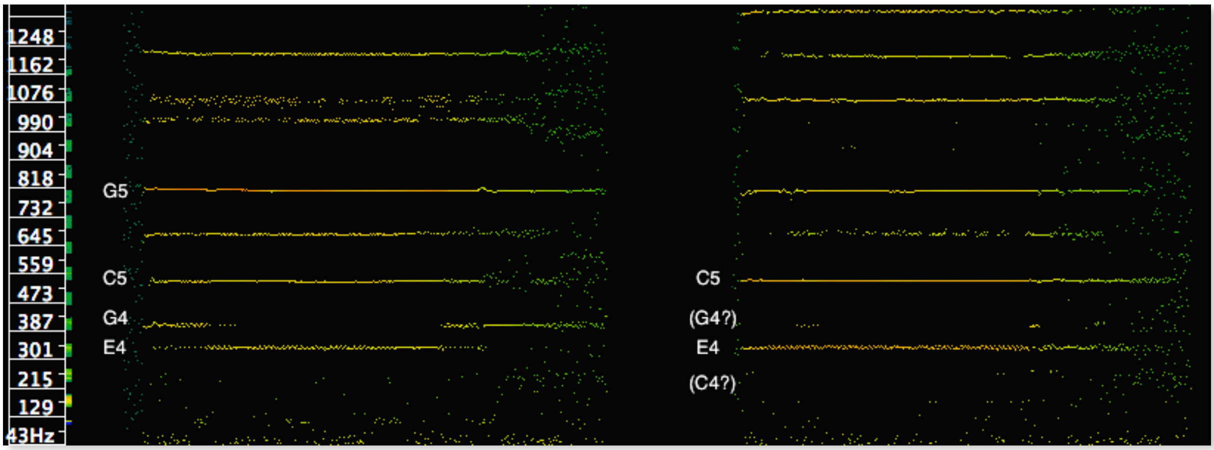

Figure 10: Zoomed version of the spectrogram shown in figure 9. The good chord (left) and the bad chord (right), Scale: linear. Quality: waw, (Adler 2002).

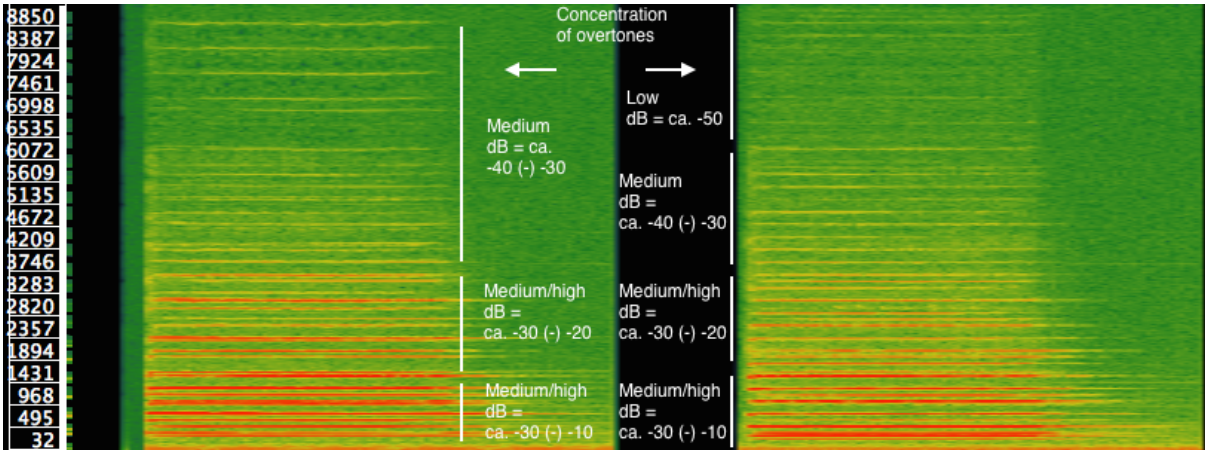

Figure 11: The Good chord (left) and the bad chord (right) shown in the spectrogram. Scale: linear. Quality: waw, (ibid.).

In the spectrogram in figure 11, the linear frequency scale is from ca. 32 Hz to 8850 Hz. Above this, the overtones are too weak to give a clear colour in the spectrogram. By only looking at this representation it can be hard to read anything useful at all, but it gives an indication of where the concentration of overtones are at the strongest and weakest.

In a way, these two chords look very much alike, but there are some differences. The most obvious thing to notice is the difference between the two chords in the upper frequency area from 6-9 kHz. In the good chord, the overtones are much clearer and creates more brilliance to the sound. In the bad chord, this area is almost empty in this representation. In the area below, around 4-6 kHz, both sounds have a higher concentration of overtones. The main difference is the number of overtones which is higher in the good chord, but these are very weak as well. In the frequency area from 20-1500 Hz, there is a high number of overtones in both examples where they also are strong. As Meyer describes the clarinets range: 'In the region from approximately Eb_4 to G_5 the 1st and 3rd partials are decidedly more strongly pronounced than the octave partial, from the 4th harmonic on upwards the odd and even contributions are, however, equally developed' (Meyer 2009: 75). This means that both the clarinet and the oboe at this range will contain a high number of overtones. This stands in contrast to the flute in the bad chord which has its main energy at the fundamental.

Although a lot that can be said about this reading, there is no argument of concluding if the one chord is good and the other is bad. It is also a matter of context that has not been taken into concern. What if this was accompanying a singer who sung in the same register as the clarinet in the good chord. Would it still be a good way to orchestrate? It is also a matter of aesthetics, which in this case is only decided by Adler's opinion. There are nonetheless some technical aspects which I think Adler is taking into consideration. I think the difference in sound power level between the oboe and the flute will be too big. The oboe will overpower the flute and create unbalance in the chord. The flute will also have problems when it comes intonation at this range (especially E_4). The connection of tones will therefore often sound out of pitch.

2.3.4 Analysing Complex Chords, with Complex Orchestration

When analysing more complex chords with a complex orchestration, the principles are the same as in the previous examples. The issue is the amount of information that the spectrogram has to process, and what there is to be read. When I speak of complex chords and complex orchestration, this does not necessarily mean advanced harmony or more difficult orchestration methods, but rather more tones and more instruments playing at the same time.

I prefer using Adler's examples when demonstrating the spectrogram. This is because Adler presents clear thoughts on what he thinks is good and bad. This gives the opportunity to show if there is any possibility to prove that one chord is good while the other is bad by the use of spectrograms. In the end it is a matter of aesthetics, but it is important to understand the limits of the spectrogram, especially when looking forward towards real musical analysis.

> The student orchestrator must give special consideration to spacing within first-inversion chords, particularly when the third (in the bass) is doubled by a lower (rather then upper) chord member. This spacing will perserve the open sound of the first inversion chord (Adler 2002: 255).

Adler's idea of a first inversion chord as open is crucial to why he spaces the chord the way he does. I want to argue why Adler might think this way, and at the same time present some ideas on what might make the one chord good and the other bad.

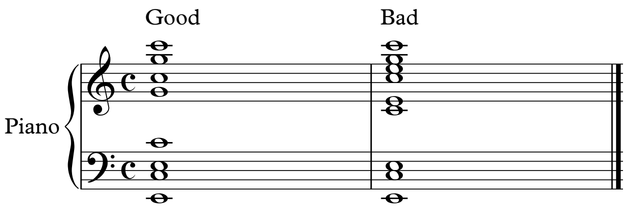

Figure 12: Compact score of Adler's first-inversion chords.

In Adler's instrumentation he has chosen to extend the use of primary instruments in the orchestra, and has therefore added a bass clarinet and an English horn. Before looking at the score, we can easily see in the piano sheet (figure 12) that the four deepest notes are the same in the good and the bad distribution of the chords. For some reason, Adler have chosen to put the C_4 in the bass clef in the good spacing and in the treble clef in the bad one, but this has no actual effect on the sound. Both C_4 notes are played by the second clarinet. Below we can see this example spaced out by Adler where he uses the orchestration technique called superposition/overlaying.

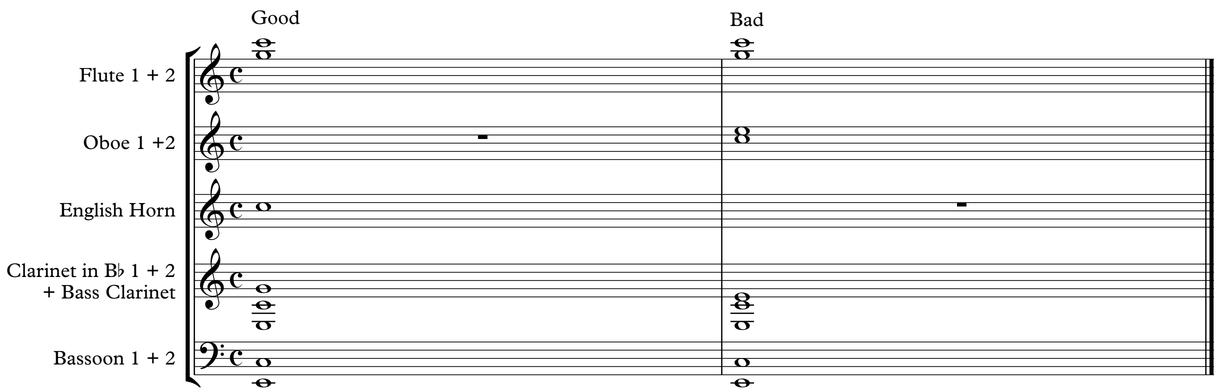

Fig. 13: Minimised score of Adler's first-inversion chords.

These two examples where the first one is good and the second bad, look very similar as expected after looking at the score. The open spacing in the first example are exclusively constructed on an open sound with a lack of thirds. The open sound of the first-inversion chord gets its balance by exactly this, and it comes from the function of the chord. A first-inversion chord is not meant to be a stable chord, but it is supposed to lead somewhere. If the chord was a tonic, the third in the bass would be used to lead towards a subdominant. If the chord was a dominant, it would have been used to lead towards the tonic.

The G_4 and G_5 notes in the good spacing and the E_4 and E_5 notes in the bad one, are the main differences in the distribution. Because of the E_2 note played by the bassoon, the E tone will be established by the natural harmonics in both examples. In the bad spacing where also E_4 and E_5 is present in addition to E_2 and E_3, there will be a lot higher concentration of thirds in the overtones above the melodic range. In the good spacing only E_2 and E_3 is played which means that the overtones created from these two tones will not be as powerful as in the bad spacing. The natural harmonics create the presence of both E_4 and E_5 in the first example, but they sound weaker than the actual played notes. Because of these two notes and the fact that E_5 is played by an oboe which sounds quite thick in this register, the bad chord sounds more as a C major chord. The third in the bass tries to lead the chord forwards, while the thirds in the upper range (E_4 and E_5) try to stabilise it.

When listening to this example again, it is obvious that the bass note in the bassoon (E_2) has a greater role in the first chord rather than the second. The English horn also helps the chord in keeping balance with its C_5 note, with the flutes playing G_5 and C_6 above. In the second example, the E_5 occupy a much bigger part of the sound which is also easy to hear, especially if listening to both examples right after each other. With this, one can argue that the good spacing is good because of two main things. The first is that thirds might be difficult to intone, and it is easier when there is only two thirds instead of four. It is also easier to intone the thirds in a lower range rather than the upper. The second, is concerning the function of the chord. By omitting the thirds in the middle and upper part of the chord, the space between each note in these areas become bigger. This enhance the open sound character which Adler argues that this chord should have.

The spectral analysis of the two chords raises a lot of issues. First of all, Adler's music recordings are in many ways poor when analysing the timbre. This audio clip contains a very high level of noise which makes it even harder to analyse the two chords. Figure 14 shows only the peak frequencies, similar to figure 10. By looking at this, the two chords may seem similar, which is natural because of the similar choice of spacings. It is, however, possible to see that the overtone structure is different, which is already presented here. In my short analysis of these two chords, where I have zoomed in on this picture and more closely looked at the overtone structure, it is possible to see that the thirds in the bad chord are strongly represented through the whole spectrum. This is in contrast to the good chord, where the first and fifth plays a greater role. I also think that this picture underpins my opinion that timbre cannot be shown by only one representation, simply because it is hard to claim why that particular spacing is good while the other bad, without connecting it with the aspect of listening.

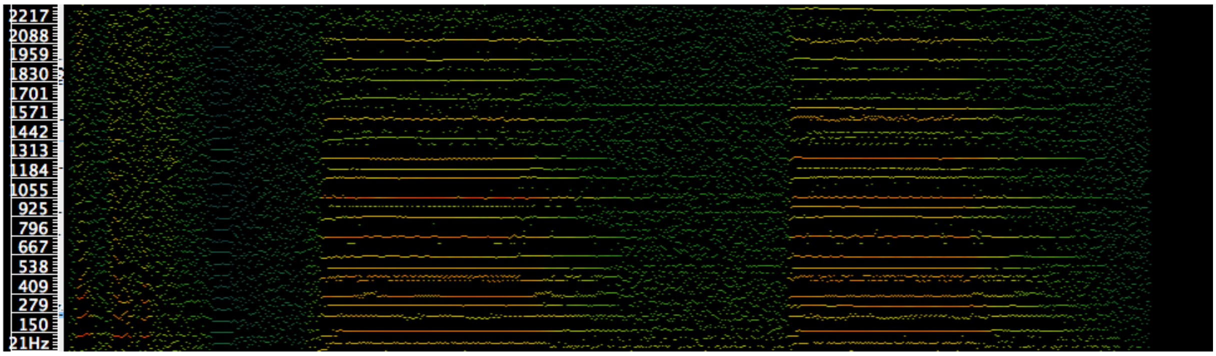

Fig. 14: Spectrogram showing the chords in figure 13. Good chord (left), and bad chord (right). Scale: linear. Quality: waw, (Adler 2002).

2.3.5 Spectrum

The spectrum is an analytical representation of sound where the frequency peaks are much easier to see in time. It is actually just another way of presenting the same musical content as one can with a spectrogram. With spectrograms, the whole information can be shown as a static picture. The spectrum can present it both as a static picture, but also as a developing figure. The difference is mostly decided with the choice of window. In my analysis of Boléro, I will show how the relation between the melody and accompaniment evolves during the piece. This representation (figure 20) is made by the average amplitude and frequency values of one melody representation. With this one can see which frequencies that dominates the spectrum of that given time. With these representations one must not forget the compromise between time and frequency. If one wants to see the development of frequencies over a longer time period as I do in my analysis, the amount of details in the frequency spectrum will decrease. If only one measure was analysed one could have seen more details in the frequency development. Figure 15 shows the spectral development of overtones in a bassoon playing a

C5 note. The x-axis shows frequency in a logarithmic representation and the y-axis shows amplitude. Although amplitude is shown in an axis instead of just colours, it is only meant to create the peaks which we most clearly can see in the bottom spectrum.

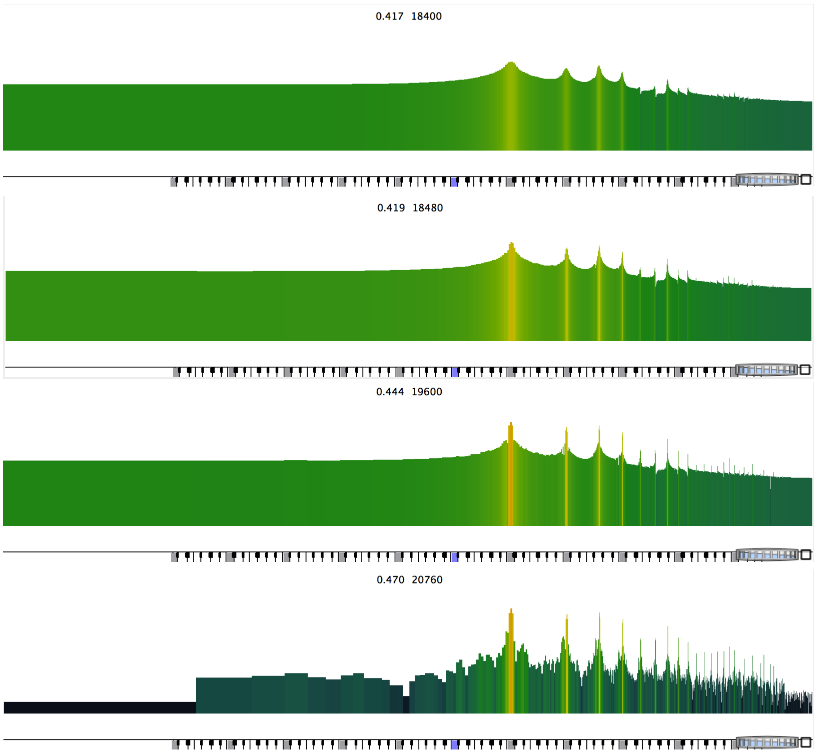

Figure 15: Four slices of the spectrum of a bassoon playing a C_5-note Scale: logarithmic. Quality: mp3, (LPO 2013).

These ‘slices’ are pictures made from the ‘developing figure’ which in Sonic Visualiser will be seen as a ‘video clip’, and not as a static figure. The ‘tool box’ which is presented in the melodic range spectrogram in figure 9, is of course available to get exact amplitude and frequency values. The four windows above present the development of partials in a short amount of evolving time. In total they represent about 0,5 seconds of the sound. This means that one is able to read detailed information about the frequencies.

The first spectrum shows that the fundamental and the next three partials are quickly developed, while the 5th-9th partial are starting to present themselves. In the second spectrum, which is only 0.002 seconds later, the fundamental has managed to increase its sound power level with almost 6 dB. In the third spectrum, the overtones from ca. 4300 Hz - 1400 Hz are creating peaks. It is also interesting to see the high concentration of noise which is represented in the first three spectrums in contrast to the fourth. This is, however, not unusual in any of the three main orchestral groups when playing legato, because of how the sound is produced (blowing, bow stroke). In the fourth spectrum, the overtones are all clearly represented, which in this example can be seen as a representation of how the sound acts in most parts of the sound clip. This is because there is no rhythmic structure presented and there is only one note being played.

The sound's release is in a way similar to its attack, where the upper partials from about the 10th (E_8) are slowly decreasing in sound power level, while the first nine partials are still stable in power. The fundamental and the next three partials, which are concentrated around the formant, fades at last, and the partials above (5th-9th) gradually fades out from top to bottom. The spectrum is a good tool to understand the envelope of the sound of each instrument. The audio clip for this example is about 1.6 seconds long. It is possible to see that, especially in the upper partials from 10th and above, that they are not constant in power and will therefore vary which partial is the strongest. They are still not close to the sound power level of the main partials.

Rimsky-Korsakov claims that if orchestrating the woodwinds and the strings together where one group play sustained notes while the other staccato, he would let the strings play the staccato part (Rimsky-Korsakov 1964: 111). This comes from the different possibilities to manipulate the envelope of the sound. Presented in the figure below, there is the four main parts of an envelope: attack, decay, sustain and release.

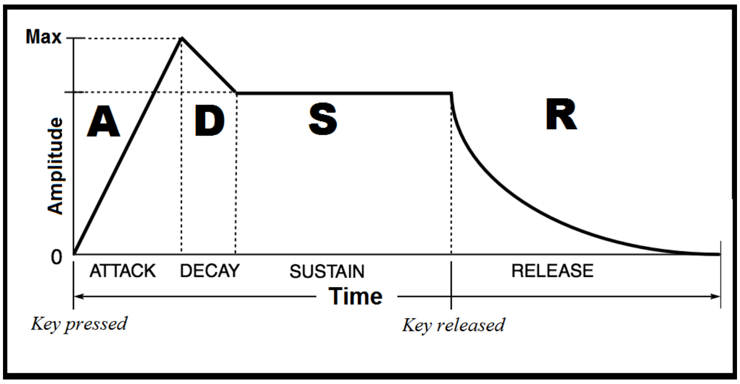

Figure 16: The four parameters of an envelope filter. As seen, primarily meant for keyboard or synthesiser, but the principles are the same for all sound (Newjazz 2014).

The attack is how fast the sound goes from a minimum to a maximum amplitude level. The decay is the drop from the maximum amplitude to the sound stabilises. When the sound is stabilised it is called sustain, and when the instrument stops playing and there is still sound, it is called release. This chart is commonly used with synthesisers and digital music production tools to manipulate sound, but it is also very useful to understand the development of the instrumental timbre. A fine example to clarify this is to imagine a trombone playing ***sfz***, which means powerful attack and quickly drop in amplitude. The attack and decay is in this case very short, while the sustain has no limit other than the performers breath. The release will mostly be the reverb which comes from the instrument. In a graphic representation, it would look a lot like figure 16. This information is easily provided by the spectrum, but it can also be shown in a spectrogram. If looking at figure 9 or 11, it is possible to see how the overtones gradually fades out, although the flutes and oboes stop playing at the same time.

2.3.6 Formants

As I mention in the introduction, formants are described by Fant as the spectral peaks of a sound spectrum. James Jeans said that it means 'the collection of harmonics of a note that are augmented by a resonance' (Jeans 1938, in Wolfe). Benade writes: 'The peaks that are observed in the spectrum envelope are called formants' (Benade 1976, in Wolfe). They are all basically saying the same, but there is one thing that is left out which I find important. Characteristic for formants is that although the pitch is changed, the character of the voice or an instrument stays the same. This is why an oboe contains its unique timbre all over its range and not just around its formant peak (see figure 5). There are, however, some formants that are extra dominant in certain frequency areas. For example the vowels *I, Y* and *E* are all more dominant in the brighter range. This also helps explaining why the instrumental timbre have some characteristic differences depending on the range. The change in instrumental character is much easier to hear in the instruments with a clear formant like the woodwinds, partly brass, but are more difficult to hear in instruments with diffuse formant or no formant like the strings. It is easy to picture the *u(oo)*-character in the tuba, the *o(oh)* in the bassoon, and the *a(ah)* in the oboe, but it is harder to picture a clear formant in the violin, especially when played in tutti as they usually do in an orchestral context. This comes from a lack of formants to define the character, that the envelope peak is too narrow to detect a clear formant and that the sound producing element (the bow) is a significant part of the violin sound.

The value of instrumental timbre was in the 18th century often classified by its possibility to imitate the human voice. In this aesthetic opinion the oboe was seen as an instrument with high value. This was because the formant peaks of the oboe's timbre were concentrated around the vowels.

2.3.7 Analysing Formants in a Spectrogram - Praat

Praat is like Sonic Visualiser a sound analysis program which is used to give different representations of a sound. Presenting formants is one of the programs strength, and it is a useful tool when focusing on instrumental characteristics. Based on the statements above, I want to exercise this into looking at the formant structure of an oboe and a cello. Both sound clips are taken from Youtube, played by performers from the London Philharmonic Orchestra. When using audio downloaded from Youtube it is important to consider the mp3 quality which cannot present the whole spectrum from 20 Hz-20 kHz. In the examples where I have used audio from Youtube, I am only searching form information below 10 kHz. Sometimes it can be hard to decide at which frequency area the formant actually lies. Praat, however, does this calculation and provides an exact frequency where the formant is concentrated.

Oboe

F1 Hz	F2 Hz	F3 Hz	F4 Hz
1100.280565	1881.749913	3115.955637	4145.600657

Table 3: List of formants in the oboe. The calculation is automatically done by Praat. F = Formant.

Cello

F1 Hz	F2 Hz	F3 Hz	F4 Hz
undefined	undefined	undefined	undefined

Table 4: List of formants in the cello. The calculation is automatically done by Praat. F = Formant.

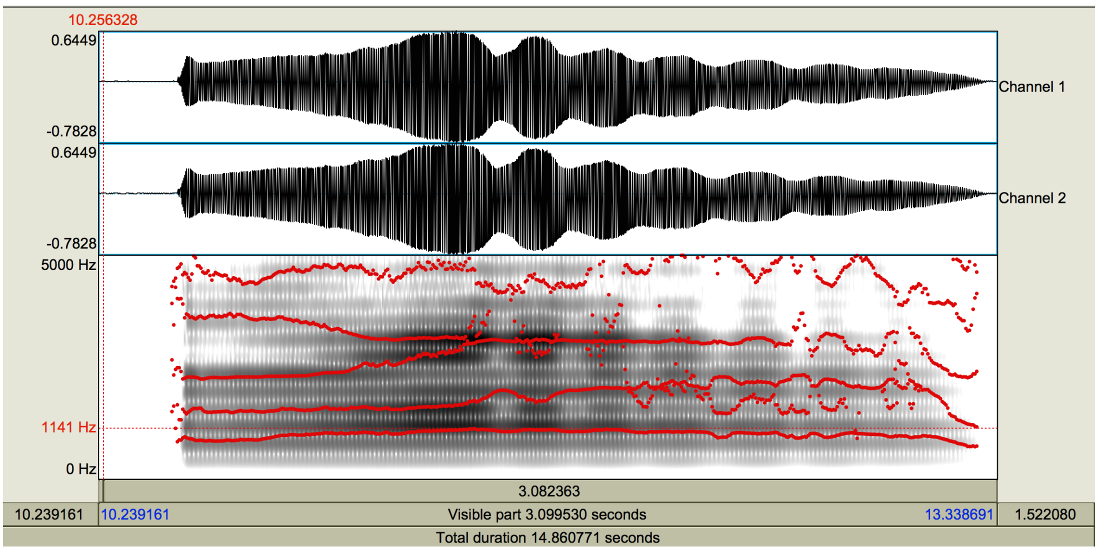

Figure 17: Oboe formants shown in Praat. Quality: mp3, (LPO 2013)

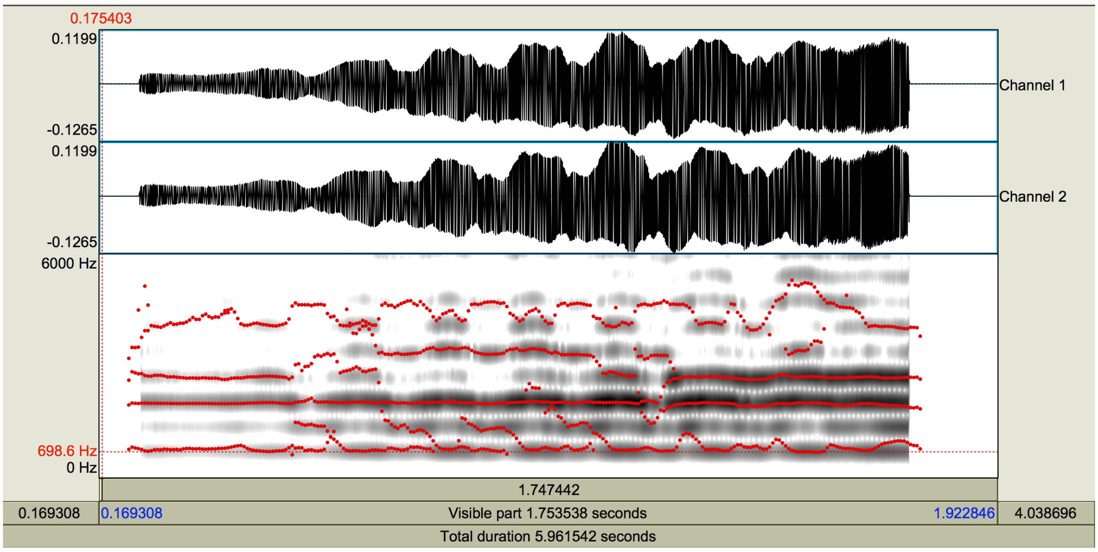

Figure 18: Cello formants shown in Praat. Quality: mp3, (LPO 2013)

The formant spectrogram shows some interesting factors. In the analysis of the oboe, the first three formants are relatively easy to see. The fourth one is more undefined, but Praat's self calculation function provides this information. In the cello analysis, it is much harder to find the formants. All four potential formants are widely spread. With some adjustments there would, however, be possible to find some formants in the cello as well, because there is a clear indication that the formants exist. As the analysis shows, the frequency is very unstable over time. In figure 5, we can see that the formant character usually is stretched out in frequency. If the envelope peak is too narrow, it can be hard to detect a concrete formant. If it is to wide, then there would also be difficult to detect a formant. Praat might therefore not find a representative frequency of the formants. If this note was played by several cellos, the lack of formants in the instruments unison character might increase. In the analysis of Lontano, I will try to detect a formant character in a cluster created by the woodwind section. This is to see if there will be a clear formant when a numerous of instruments are playing together. Also, it will be possible to see which instruments dominate the spectrum.

Analysis of formants are one of the analytical forms where it is possible to present concrete information about instrument characteristics. By comparing instrumental timbre to the human voice and by looking at the formants, it is easier to connect the undefined timbre to something more concrete and it also explains why an instrument keeps its characteristics through its range.

2.3.8 Manipulating the Overtone Structure - Spear

Spear is like Sonic Visualiser and Praat, a digital program for spectral analysis but also resynthesis. Spear provides a possibility to manipulate the overtone structure of a sound. It is possible to remove overtones, only play certain overtones and resynthesise this into a new audio file. Spear allows us to research the sound on a microscopic level, and with the add/remove function, new data which cannot be found in the other programs are suddenly available. I find this first and foremost useful when analysing one or two instruments, or in the compositional process. If analysing one tone played by one instrument it is interesting to experiment with the instrumental character. An example can be to remove the strongest partials and see what is left of the sound, or remove some of them to see how this will effect the sound's character. When analysing two instruments it is interesting to try separating the overtone structure of each in order to examine the two different timbres. With this it is possible to look at which instrument that is concentrated in what part of the spectrum. In the example in chapter 2.3.3 this function could be useful to separate the flute from the oboe and argue why the flute seemed more powerful than the oboe in the melodic range spectrogram, but by listening the oboe would overpower the flute.

2.4 Summary

I have in this chapter looked at what we can read from different analytical representations. The spectrogram has shown the overtone structure and the concentration of overtones in different frequency areas. The melodic range spectrogram provides information about the fundamental, and only a few number of the first overtones, which naturally lies within the melodic range. The formant spectrogram provides information about which frequencies the different formants are concentrated at, the number of formants and if there even is a formant character there at all. This is significant when comparing instruments to for example the human voice. The spectrum gives information about frequency peaks and is especially good to show the development through time.

All of the examples given in this methodology chapter are taken out of context to present simple versions on how these tools and methods can be used in analysis of timbre in orchestral music. There are, however, so much more information in the soundscape when analysing an actual musical piece. By doing a spectral analysis of a full composition, what is actually there to be analysed? In a tutti passage for instance, there are more than 50 performers playing at the same time. One must also consider the intentions of the composer, especially if judging music and timbral qualities of the sound.

The choice of methodology is important to get the best possible representation of the timbral qualities. I believe that by showing different sides of the same music using different analytical tools, the knowledge of instrumental timbre and the orchestral timbre will be better, rather than with only one point of view. I think it is crucial to understand the complexity of timbre and that there are many factors which plays a role. I think that by using these methods there will be easier to gain a greater knowledge of composers active use of timbre when composing. In the next chapter I will execute these methodological approaches in actual musical analysis to show different timbral aspects of orchestration.

3 Timbral Analysis of Three Works by Different Composers

In chapter 1 I gave a short introduction of how some composers developed the use of timbre in orchestration through the last three centuries. In chapter 2 I presented different methodological approaches on how to analyse timbre in order to gain a greater knowledge on instrument acoustics. In this third and final theoretical chapter, the historical and analytical theories will be conducted in three analysis. Through this chapter I will show how these composers actively have used timbral knowledge when composing their pieces. All three compositions represents a contemporary focus on orchestration, from Ravel's *Boléro* (1928) through Ligeti's *Lontano* (1967) and towards Greenwood's *48 Responses to Polymorphia* (2011). In these three compositions the differences in scoring, the use of timbre, different textures and orchestration techniques are presented by examples. Between the time when *Lontano* and *48 Responses to Polymorphia* were composed, the technological revolution with analysis programs as spectrograms, spectrums and formant analysis, etc., were developed. This gives Greenwood a whole other base than Ligeti and Ravel. However, his composition is based on *Polymorphia* by Krzysztof Penderecki which was composed in 1961, and is in many ways the base for how Greenwood composes.

I have decided to direct my main focus towards Greenwood's composing and the use of timbre when composing in present time. This is because I have used his composition as primary inspiration source for my own composition. Through the analysis I will present the importance and orchestration potential when there is an active use of timbre as base for composing and orchestration. These analysis naturally has its main focus directed towards timbre, and will therefore not be an analysis of the whole composition but rather fragments that represents the use of timbre. I will however discuss how the form can be decided by timbral development and then present a view of the whole picture.

3.1 Ravel - Boléro (1928)

Ravel, Impressionism and Timbral Orchestration

Maurice Ravel (1875-1937) was, together with Debussy, the most well known impressionist. He was for a long time a great admirer of Debussy but he refused to be undermined by his importance. Therefore, he needed to distance himself from Debussy, and in 1922 he declared to *The Morning Post* that he was an 'anti-Debussyist'. He thought that Debussy lacked a discipline, especially regarding form. He also said that 'I started the reaction against him in favour of the classics because I craved more will and intellect than his music contained' (Ravel in Kelly 2000: 14-15).

Ravel's composing style has taken inspiration from many sources. His composing is often characterised by a great clarity in the orchestration as in the 19th century French direction. He often used elements from earlier musical periods as Baroque, Neoclassicism and also some elements from jazz, which was a genre that was starting to develop during Ravel's later years. He was a composer who created his music at the piano which is why many of his compositions exist in two versions, for orchestra and for piano. Each period of his life had a great impact on his development as a composer, and in the late 1920s he composed what was going to be his most famous work, Boléro. It is an orchestral work which is experienced as a long crescendo, with a straight form where he lets a numerous of instruments present the melody in turn with their unique timbre.

Analysis of Boléro

[Note[14]: The sound quality of this analysis is standard CD format. Boléro is performed by The Berlin Philharmonic Orchestra, conducted by Pierre Boulez, published in 1994. The track has a full length of 14 minutes and 58 seconds. The score is collected from imslp, where it is offered for free[15].]

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[14] Internet links to full scores of both Boléro, Lontano and 48 Responses to Polymorphia are present in the bibliography. The links can also be found in a footnote.

Boléro, score: http://imslp.org/wiki/Boléro_(Ravel,_Maurice)

There are some different features which I intend to present in this analysis. The use of various doublings to develop and create timbral variations in an otherwise static musical piece, the relation between the melody and the accompaniment in the light of timbral changes and the use of overtones as basis for creating secondary voices. I will also discuss Meyer's idea of Ravel's intention with these voicings, in order to explain how he might have thought and his relation to the use of the natural harmonic series.

I think Boléro is an early work where the idea of using the overtone structure is the basis for creating voicings and the wanted timbre. I will not say that Boléro is a true example of a spectral composition, but I think it is inspired by the overtone structure and instruments character. If Boléro was a true spectral composition, based on mathematical calculations, one can easily argue that Ravel have not maintained this in the idea of spectral composing. In this analysis of Boléro I will first and foremost present how Ravel has used these techniques in this composition, but also argue why it is distanced from the principles of spectral music.

3.1.1 Score and Auditive Perception

The score's representation and the auditive experience has a close connection. This comes from the music's strict form and only one natural way of scoring the music. The spectral representation is, however, partly distanced from these two, which I will show later. The score shows two melodies which gradually increase in the number of instruments and dynamics. This is also how the music is percepted.

The main topics that I intend to discuss is difficult to represent by the score and listening, at least alone. The timbral analysis of Boléro is therefore dependent on the spectral representation. That said, I will argue how the gradual densification of overtones might not have a direct link with the score. I will also argue against letting acoustical analysis represent the music alone. These discussions are part of proving the importance of connecting the spectral research with the representation of the music and the experience of the music.

3.1.2 Overview and Form

Note: The melody in (A) starts at C, and the melody in (B) starts at Bb. They will still be named after their function to the root (C). Example: C=1, E=3, G=5, Bb=b7, etc.

Form shown in table and spectrogram:

Part	Instruments playing the melody	Tones/ second voices
A1	Flute	1st = C
A2	Clarinet	1st
B1	Bassoon	b7th = Bb
B2	Eb clarinet	b7th
A3	Oboe d'amore	1st
A4	Flute, trumpet (muted)	1st
B3	Tenor saxophone	b7th
B4	Sopranino Saxophone	b7th
A5	2 Piccolo, French horn, celesta (in octaves)	1st, 3rd, 5th (C, E, G)
A6	Oboe, cor angles, oboe d'amore, 2 clarinets	1st, 5th, (C, G)
B5	Trombone	b7th
B6	Piccolo, 2 flutes, 2 oboes, cor a., 2 clarinets, tenor saxophone	3rd, 5th, b7th
A7	Piccolo, 2 flutes, 2 oboes, 2 clarinets, 1. violin in divisi	1st
A8	Piccolo, 2 flutes, 2 oboes, cor a, 2 clarinets, ten sax, 1.+ 2. vls. in div	1st, 3rd, 5th
B7	Piccolo, 2 flutes, 2 oboes, cor angles, trumpet, 1. + 2. violins in div.	b7th
B8	Pic, 2 fls, 2 obs, cor a, 2 cls, s. sax, trb, 1.+ 2. vls. in div, vla, vc.	3rd, 5th, b7th
A9	Piccolo, 2 flutes, s+t sax, 3 trumpets, 1. vl. in divisi	1st, 3rd, 5th,
B9*	Piccolo, 2 flutes, s+t sax, 3 trumpets, trombone, 1. vl. in divisi	3rd, 5th, b7th

Table 5: Form of Boléro shown in a chart.

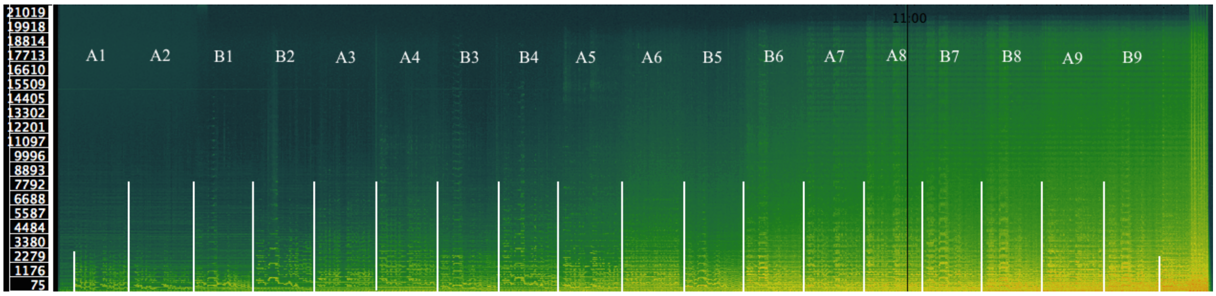

Figure 19: Form of Boléro shown in a spectrogram. Scale: linear. Quality: waw, (Ravel 1994).

There are a couple of significant things one must consider with this representation. First of all, this is a spectral representation of the whole composition, which means that the x-axis is representing Bolero's 15 minute long development. This means that it will not be worth much more than a rough representation of the spectral development. Connected with the chart above, it is however possible to get an idea of how the different instrument combinations will effect the overtone structure. By looking at the score and listening to the music, one can see that there is a close connection between the written dynamics and the experienced sound. However, the connection between the densification of overtones, and the dynamic development has a gap. One can see that in B1, B3 and B4, where the melody is respectively played by bassoon, tenor saxophone and sopranino saxophone, there are a high number of overtones. These structures stand out in the spectrogram, and this can mean that some of the instruments are playing at a range where none of the others are disturbing their individual timbre. One can also see in B2, B5, A1-A7, that the overtone structure is less present which comes from the acoustical qualities of the instruments. It is also interesting with this spectrogram how all ‘B-parts’, no matter what combination of instruments, have a clear showing of overtones in the beginning of the melody. When it moves further down in the register it seems that the accompaniment overpower the overtones in the melody.

If Ravel's idea was to compose a musical piece based on a gradual densification of overtones, I think he would have orchestrated it differently. I do however think that the densification is a secondary parameter in Boléro. I think his use of timbre concerns other aspects which I will present at in the end of the analysis.

3.1.3 Timbre

Further in this analysis I want to focus on certain areas of Boléro in order to present the spectral development between the melody and the accompaniment. As I roughly discussed above, there is not a causality between sound power level, number of instruments and the number of overtones created. In B3, where the tenor saxophone plays in solo, proves this. This is the first time the overtones are visible in the frequency range of 20'000 Hz. In the next two parts, A4 and A5 there is a much smaller spectrum despite that there are more instruments playing. The next time the overtones are visible at this frequency range is in B6, which also is the first example of Ravel's active use of the overtone structure in theme B. As we can see from the spectrogram in figure 19, the spectrum of overtones does increase when there is a higher sound power level and more instruments playing together, but in comparison with B3, the structure is not particularly wider. Because of the development in the accompaniment as well, where there are more instruments playing than in B3, the overtones will be at a smaller distance from each other. This is because the overtones are created from several fundamental tones.

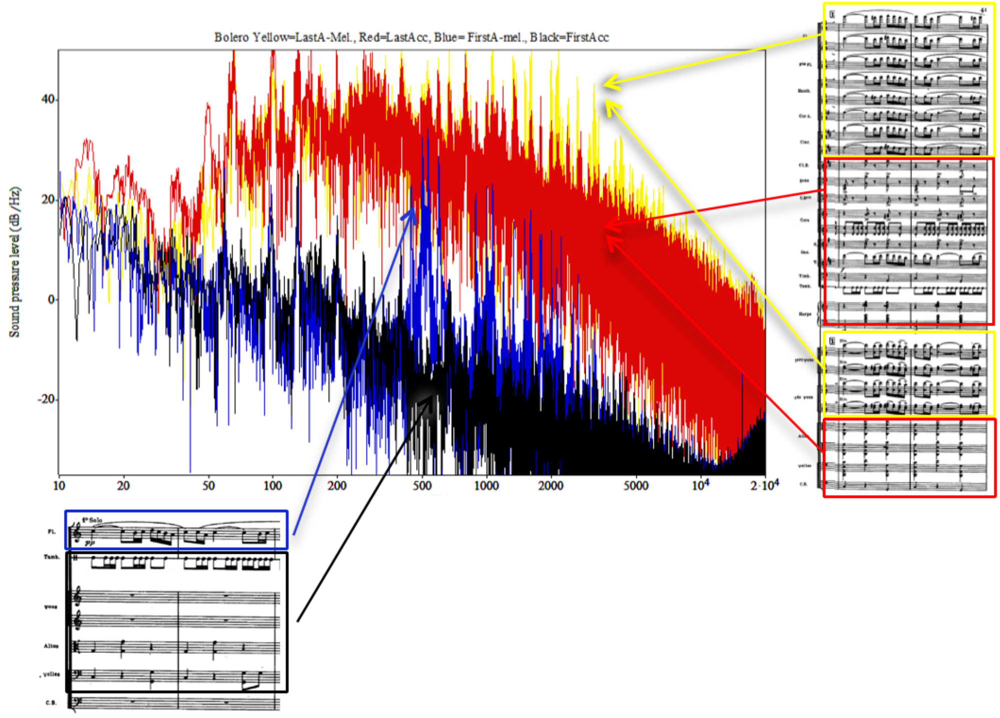

Figure 20: Spectrum of melody and accompaniment in Boléro, first and last A-melody. Quality: waw, (Halmrast 2016, Edited with permission)

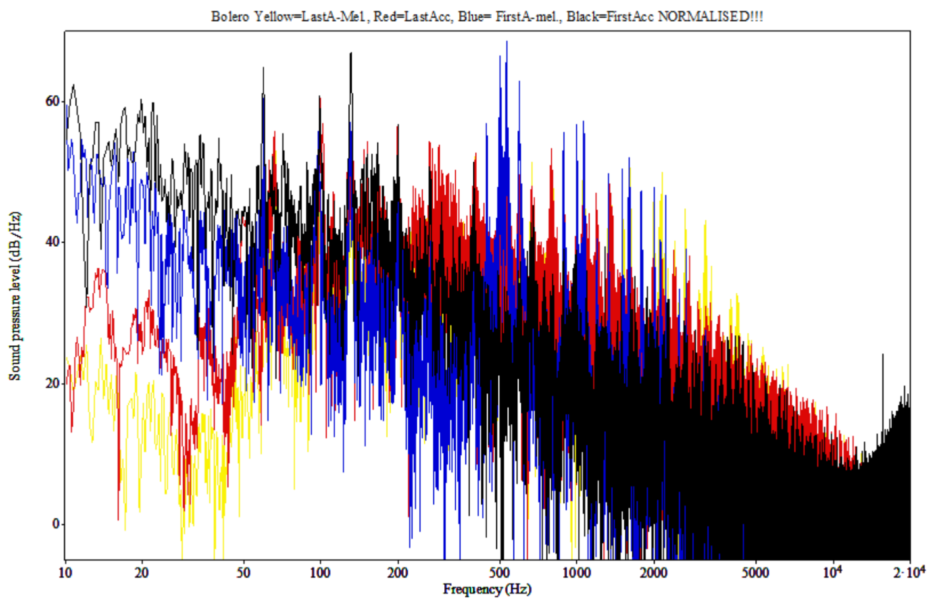

Figure 21: Normalised Spectrum of melody and accompaniment in Boléro, first and last A-melody. Quality: waw, (Halmrast 2016)

Figure 20 is a spectral representation which shows the differences between the first and the last A-melody. Figure 21 shows that the sound files are normalised, which means that, although the dynamics have changed in the original track, the maximum amplitude (dB) in both sound clips are equal. Both spectrums present the average sound pressure level and frequency during the time of one A-melody. The first figure shows that there are relatively big dynamic differences between the two presentations of the melody. It is with this representation easy to see which frequency the melody contributes with. In the first melody, presented by the blue (melody) and black (accompaniment) colours, the frequencies from 500-5000 Hz have a much higher sound pressure level in the melody than in the accompaniment. Below 500 Hz the accompaniment is the strongest. By the blue peaks presented, one can see something that reminds of the overtone structure of the flute playing the melody which is concentrated around 500 Hz. In the frequency area around 10 kHz there is almost no sound present according to the analysis which is in great contrast to the last A-melody. In the last melody, the accompaniment seems more dominant from 10-1000 Hz, while from that point and upwards the melody is the strongest. Because there are several instruments playing the melody in the last presentation, and from different tones, it is easy to see that the relation between melody and accompaniment are more even in the last presentation than in the first. Ravel's orchestration of the melody by using odd overtones (parallel chords) creates a higher number of overtones. This is clearly visible, especially in figure 20.

By normalising the audio files, it is easier to compare the two versions. In the frequency range between 10-100 Hz there is very little energy in the last A-melody[16] (yellow), and also in the last accompaniment (red) while the melody and accompaniment in the first A-melody[17] is rather powerful. In both presentations of the melody, the accompaniment dominates at this frequency range. From about 100-500 Hz, the accompaniment is still the most powerful in both presentations, but from 500-2000 Hz, there is a transition where the melody is becoming the strongest. The flute's low number of overtones is very clearly represented as the first presentation has very little energy above 2000 Hz, especially in the melody. There is no doubt that the last A-melody presentation has a lot more energy at that area. It is important to remember that Boléro will be experienced as it is represented in figure

[16] The score does not operate with measure numbers, and is therefor easier to follow the page numbers. Last A-melody: page 55 - 58 (measure 293-310).

[17] First A-melody: page 1-3 (measure 5 - 21).

20, and not 21. The differences in energy in the frequency areas will be experienced as even bigger when listening. It is however interesting that the first presentation of the melody has a greater dynamic spectrum despite the last presentation is being more powerful. The representations in figure 20 and 21 show that the development between melody and accompaniment in Boléro is quite interesting, both in the matter of dynamics, energy and relation.

Figure 22: Boléro measure 131-134 (A5). Excerpt without harp and strings (Ravel 1929).

Another interesting aspect of Boléro seen from a timbral point of view, is how Ravel uses the natural harmonic series to create second and third voices. He clearly breaks with the tradition by using spectral components as base for creating voices instead of more traditional harmonising methods as block harmonisation (choral style). I think this is Ravel's greatest contribution of a timbral aspect in the history of orchestration.

As I argued in the methodology chapter, the relation between score, listening and spectral analysis is very important in the relation of timbre, and this is an excellent example why. The snare drum, tambourine and the 1st flute are playing the rhythmical accompaniment which is the base for the whole composition. The bass clarinet, oboe, harp and strings are playing the second layer of accompaniment, and the harmonic basis on each fourth. The melody is first and foremost represented by the French horn with octave doublings in the celesta. The piccolo flutes are creating the second and third voice with a distance of a major

3rd and a perfect 5th to the root note (C). Meyer presents a clear parallel between instrument acoustics and orchestration with this example which is interesting. According to Meyer, individual partials can stand out within a spectrum or not be heard at all. In the low register of a clarinet we find this example where the odd partials dominate and creates a lack of the octave partials (2nd and 4th). 'This leads to a covered and occasionally hollow tone, in this the absence of the octave components […] also supports the dark timbre' (Meyer 2009: 32). Meyer clearly states that a gap between partials creates a hollow sound. He continues by saying that this effect also can be achieved synthetically with proper instrumentation. In Boléro, Ravel presents this synthetical representation of a hollow sound by choosing exactly the 3rd (E), and the 5th (G), as starting tones for the second and third voices. In the natural harmonic series we can see that these are both odd partials (3rd and 5th partial). I think, however, that Meyer's opinion is too focused on the hollow sound created by for instance a clarinet and how the odd partials dominate. If looking at this in the point of view of spectral music and Meyer's idea of this hollow sound, I think his explanation is too simple and vague. First of all, by listening to Boléro, and particularly this presentation of the melody (A5), my experience is that it does not sound typically hollow, especially if comparing it to A2 where the clarinet presents the melody in solo. I believe there are several arguments against Meyer's synthetically presented hollow sound. By looking at the natural harmonics and the first 20 partials, both the 3rd and 5th appears three times. The fifth appears with partial numbers: 3, 6 and 12, and the third appears with the partial numbers: 5, 10 and 20. This shows that both the 3rd and the 5th appears as an odd partial once. Because of this, I think that in order to create this hollow sound, the octave spaces from the fundamental needs to be taken into account. The French horn is playing a C_5, which means that in order to create the proper balance between the partials, the piccolos needs to play G_6, and E_7. The piccolos actually do this which is an argument for Meyer's opinion (Both piccolos and celesta sound and octave above written note). However, the celesta plays an important part in this matter. It plays the melody from C_6 and C_7, which in one way creates the balance between the odd and even partials. It is therefor interesting to look at the spectrum of the celesta which have a non-harmonic overtone series. As mentioned before, the fundamental is the strongest partial in the flutes. As the only impulsive melodic instrument present in Boléro, the celesta is very easy to hear and has a clear role in the soundscape.

Partial	Note	dB
-1	C7	- 26
1	E7	- 14
2	E8	- 48
3	A8	- 26
4	B8	- 38
5	C9	- 42
6	D9	- 29
7	E9	- 44

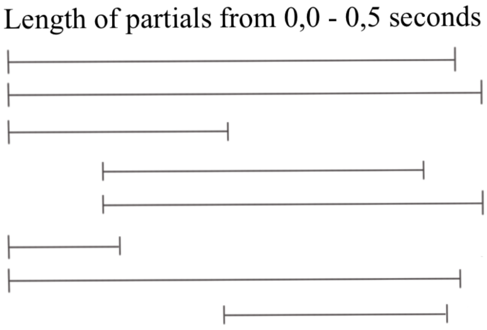

Figure 23: A rough representation of the amplitude level, organisation of overtones and their sustainability in a celesta playing an E_7 (The length of E_7 equals 5 seconds, and the chart is only meant to show the lack of stability in the instruments overtones).

The fundamental of the celesta is very strong and is the partial with the longest sustainability. The -1, 3 and 6 partial is also strong, but lacks a certain amount of sustainability. This means that when the celesta is playing both C_5 and C_6 in Boléro, this will at some level even out the dominance from the odd partials created by the flutes. I am not claiming that Meyer's opinion is wrong in this case, especially since Ravel uses the best possible orchestration in order to create this hollow sound. I am rather arguing that this assumption is directing too much focus towards the acoustics, and has a lack of the auditive perception and the connection between those.

In a conversation with Tor Halmrast, we discussed Ravel's melodic structure and the tones relation to the natural harmonic series. If Boléro purely was meant as a composition based on overtones, the melody would probably contain other tones more related to the overtone structure. This is also an indication of how Ravel only uses the overtones as a secondary parameter to create tension and release in the vertical aspect of the music.

I also think this highlights the connection between the opening tones of each melody (C and Bb). In the natural harmonic series, these tones have a different relationship than in the temperated system. Because the seventh partial has a difference from the temperated system of -31 cents there will not be a dissonance or tension created by this. In the temperated system, the relation between these two tones is to create exactly this. In B6 an interesting connection between the first (C) and the seventh (Bb) appears. The melody starts at the tone Bb, and the second and third voices at E and G, while the accompaniment is playing the root, C. With this, a C^7 chord is present. Ravel does not relate to the natural harmonic series, but to the temperated system instead. I also think that this proves that his idea of creating voices based on the natural harmonic series may not be his main intention whit this scoring. Ravel's only use of tones from the temperated system is therefore important to have in mind.

In theme A, he uses the following tones: C, D, E, F, G, A, B, which are the tones of a C major scale. In theme B, he uses the following tones: C, Db, D, Eb, E, F, G, Ab, A, Bb. The second melody (B) is closer to the natural harmonic series than the first (A). But with the fundamental of C, one can argue that Eb, F, A, and Db are not among the first 16 partials which is where the main overtones are (from the 16th partial and upwards, all overtones are with a distance of a 1/2 tone from each other). Olivier Messiaen said that these are ‘Nearly all the notes perceptible to an extremely fine ear, in the resonance of a low C, figure, tempered in this chord’ (Messiaen 1956: 50).

Figure 24: The resonance chord (loc. cit.).

I find it a bit odd how Messiaen presents what he sees as the perfect resonance chord but, according to his own example, does not mention the tones pitch deviation from the temperated system. I think if orchestrating this chord with the use of mathematical calculation, it would be more correctly to translate this information over to quarter-tones. In the example above, the Bb which is the 7th partial of C has a cent of -31 (figure 2), which gives the chord a drastic change. The first four tones creates a C^7 chord, but with the low natural Bb it would be more correctly to lower the Bb a quarter-tone (50 cent) in order to remove the tension that is not present in the overtones, but which is in Messiaen's example. Although I think this creates a better example of how it is supposed to sound, it will not be fully correct since there are needed 19 cents more to create a full quarter-tone (figure 2). The same principle is applicable for the natural F# (11 partial) which is 49 cents lower than the temperated F#. The natural G# is 41 cents higher than the temperated tone, which also should be altered. In the analysis of the bassoon sound in the methodology chapter (figure 6) the fundamental is not played in a correct pitch. This means that I have written A instead of G# as the 13th partial.

There are no quarter-tones present in Boléro, and Ravel's use of a more correct handling of tones in relation to the natural harmonic series is excluded. That said, there is no doubt that Ravel presented a new way of actively consider timbre in the matter of orchestration in his time. If Ravel's intention was to synthetically recreate the hollow sound by the use of second and third voices playing the odd partials is difficult to say. I do however think that Ravel was inspired by organ mixtures where upper partials could be added to create brilliance to the sound. If using a certain connection of pipes and pressing a singel tone on the organ, the 3rd and 5th partial would sound as well, as in Boléro. Ravel's consideration of octaves and the use of piccolo's pure timbre, in order to recreate the 3rd and the 5th partial shows a fine understanding of instrument acoustics already at this point. Although I argued that the B-melody has a closer connection to the natural harmonic series than the A-melody, I think it has a closer connection with Ravel's influence from jazz, where the alteration of tones were common.

3.2 Ligeti - Lontano (1967)

Ligeti and the Use of Electronics

Gÿorgy Sándor Ligeti (1923-2006) was a Romanian/Hungarian composer who is most known for his contributions in Contemporary music. After World War II, Ligeti was first and foremost inspired by the great Hungarian composer Béla Bartók and partly Stravinsky, but had no experience with The Rite of the Spring or music by Arnold Schönberg. There was no possibility for Ligeti to compose electronic music in Hungary, but after a meeting with Herbert Eimert and Karlheinz Stockhousen he received a scholarship and left the country in 1957. He composed three electronic pieces; *Glissandi, Artikulation and Atmosphéres.* The latter was not the same piece as the orchestral *Atmosphéres.* Ligeti did not further continue with the electronics, although he was still greatly influenced (Griffiths 1997: 3-18).

Analysis of Lontano

[Note: The sound quality of this analysis is standard CD format. Lontano is performed by The Berlin Philharmonic Orchestra, conducted by Jonathan Nott, published in 2008. The track has a full length of 11 minutes and 45 seconds. The score is available for free[18].]

[18] Lontano, score: http://vk.com/doc21393690_153932355?hash=fdde8eeec7316b5666

In this analysis I will look at how Ligeti uses timbre as base for other parameters. This includes form, harmony and melody. I will also present the connection between the sounding audio and his score. I will conduct a spectral analysis as well, where the focus is directed towards his creation of tension and release, open and closed orchestration and the creation of formants.

As a contrast to Ravel's Boléro, Lontano represents another active use of timbre in orchestration. This means that there are other aspects that is more important. Boléro's strict relation to form, harmony, melody and rhythm which defines the composition, is not present at the same level in Lontano. Lontano is what I will define as a more abstract composition with no particularly melodic, harmonic or rhythmic perceptible structure. The focus is purely directed towards timbre and the vertical aspect of orchestration. Ligeti focusses on the development of timbre over time at a very high level, where he slowly evolves his ideas.

3.2.1 Score - Representing the Music

I think it is interesting how Ligeti scores his music. In order to maintain the illusion of no rhythmic structure at all, he notates the rhythm very accurate. In the first six measures, he is only using the woodwind section which plays an Ab_4 + cello playing an artificial harmonic from Ab_2 which sounds like Ab_4. All instruments are presented this way:

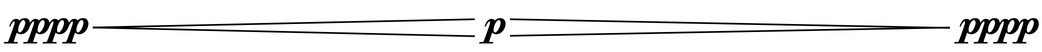

Figure 25: The dynamic development of all instruments in the opening of Lontano.

Lontano begins with all instruments playing in unison. It further develops into a cluster with a space of a 1/2 tone between each note. In the score below, the cluster is starting to develop. The first flute plays Ab - G - Bb, and is followed by the other instruments. Further the tones A - F# - B - E - C# - C - D# - D - E# are presented (from measure 5-18). In this cluster the whole chromatic scale is present in a partly sustained chord in the en of measure 18 (C, C#, D, D#, E, E#, F#, G, Ab, A, Bb, B).

Figure 26: Score of Lontano, measure 5-8 (Ligeti 1967)

3.2.2 Auditive Perception

The experience between reading the score and listening to the music gives two widely different impressions. The score presents the music as rhythmically complex. This is also contrasting in relationship with the spectrogram, which does not indicate a complex rhythmic structure. This means one thing; Ligeti has mastered the transition from the score into the auditive perception brilliantly. His complex rhythm is meant to create an idea of no rhythmic structure, and this is how it is percepted and shown in the spectrogram (fig. 27).

Listening to Lontano demands a great amount of patience in order to understand how Ligeti is using timbre. It seems to me that his focus is directed towards the timbral tension-release effect which I mentioned in the introduction. There are some similarities with Boléro at this point. Boléro has a gradually increasing dynamics from the beginning to the end, but also a densification of the overtone spectrum. The latter is the main contrasting element in Lontano. He creates long, sustained tensions, where the overtones are at a close distance (in frequency) to each other. In one quick move, the overtones are suddenly widely apart (fig. 28). In the next subchapter I will also argue how these contrasting elements are deciding the form.

3.2.3 Form, Harmony, Melody and Rhythm in Light of Timbre

The form is primarily based on three dynamic peaks. The densification of overtones, tension and energy is what I use as grounds for this devision. Each A-part can be characterised as rich in overtones, while the B-parts are poor (fig. 27). This also creates contrasts in energy and in tension. Although neither the rhythm, melody nor the harmony is necessarily similar in the different parts, the timbre can decide the form structure. The form is primarily decided by listening and spectral analysis.

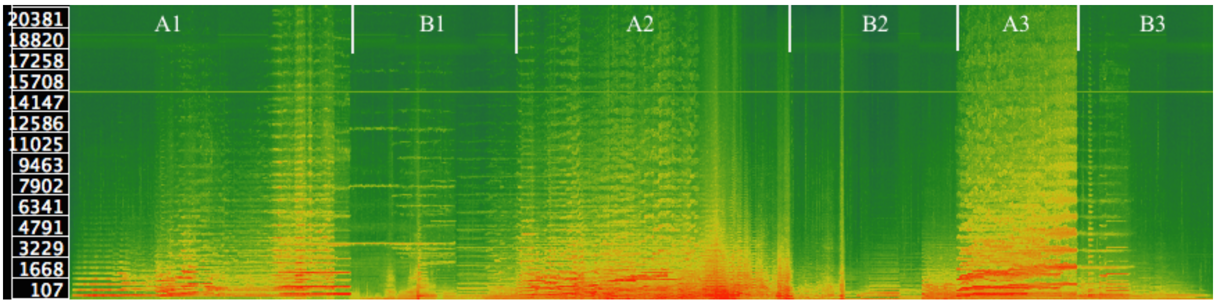

Figure 27: Form shown in a spectrogram. Time: 00.00 - 11.45 minutes. Scale: linear. Quality: waw, (Ligeti 2008).

The parts are not even in either length, strength or orchestration, but there are three clear peaks which by a timbral judgement can be seen as parts with the same purpose. A1 is almost a mixture of A and B because the main tension is gradually built up from the beginning. There is, however, no concrete separation in the listening process, only a gradual increase of intensity. This subdivision of parts are purely based on timbre, as there are few directly repeated elements in these parts.

He is also contrasting thick and thin orchestration between each part. In the end of A1, he uses the whole woodwind and string sections. He gradually develops them towards a peak, where he introduces a contrasting element by letting a single violin play artificial harmonics. B1, which is introduced by that violin represents how the B-parts have a slowly increase of overtones, which leads towards the next A-part. At this point, he is also creating contrasts between the registers. It is almost impossible to see, no matter how far one zooms in on the spectrogram, but the violin is actually accompanied by a tuba playing in its deepest register. Afterwards this is doubled in contrabass and contrabassoon. Because the frequency system works in such way that a tone's frequency is doubled for each octave upwards (A_3= 440, A_4= 880, etc), this creates a massive area in the spectrum which is 'empty'. Within the hearing range of a human ear (20 - 20'000Hz) the violin playing a C_8 (artificially made from C_6) only creates C_9, G_9 and C_{10}. Although the tuba, contrabass and contrabassoon creates a great number of overtones, the main energy will be concentrated at a low frequency area, below 3000 Hz, which can be seen in the bottom right corner.

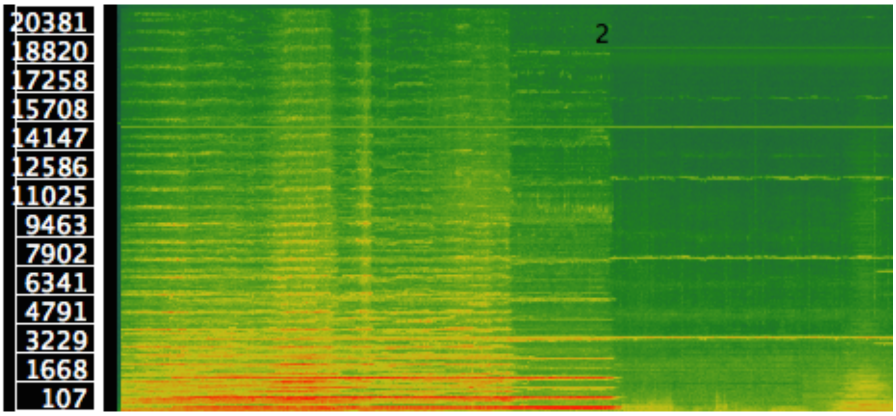

Figure 27: Overtone structure of the first peak in Lontano (time: 1:59-3:18). Scale: linear. Quality: waw, (Ligeti 2008).

Even though the woodwinds are only playing in unison at the area shown in the spectrogram before **2**, and the strings supplementing them with a whole-tone below, this will function as a timbral tension-release. This proves that the tension-release concept is not depending on the harmony. It is interesting to see how Ligeti uses timbre as a primary parameter and connects the melody, harmony, rhythm and form directly with it. The progression in all secondary parameters are created in order to manipulate the timbre.

The melody in Lontano is interesting to look at, despite its absence. It is how Ligeti progress his harmonic development which is the reason for this.

Figure 29: Melody in Lontano in a compact score.

This compact score shows about the first minute of Lontano, where these are the first seven tones to appear. While one instrument moves towards the next note, the other stays and then creates a cluster which function as base for the harmonic structure. This is a composing method which gradually introduces different instruments, and the development in melody which creates the harmony. The melody seems to me as a compositional tool to slowly evolve a harmonic basis. Beginning with one tone, it slowly expands into a harmonic layer. This harmonic layer is then a secondary parameter to manipulate the timbre.

Ligeti further develops this towards a singel tone played in octaves, before entering part B1 with a single violin playing C_8. Towards the end of B1, the same melodic idea is presented to create a cluster. A2 is based on a constant change in this cluster. There is no harmonic or melodic release, but rather short melodic motives which slowly moves from one instrument to the other with a gradually increasing dynamic. The motivic idea continues in B2 as well, but the harmonic tension created by the constant dissonance is more or less gone, until the development towards A3 starts. In A3, the same melodic idea is again base for the harmonic progression. If one manages to see melody and harmony as results of the timbral development, one can say that these two factors also have an impact on the form. B3 has in a way the same relation to A3 as B2 has with A2. The ideas are progressed but slowly disappearing, both in energy, instrumentation and melodic and harmonic development.

When one orchestrate as Ligeti does in Lontano, with no recognisable attack in any of the sounds, the similarity with vowels increase and the similarity with the consonants decrease. Analysing formants is therefore a great way to see the envelope peak of this complex sound. By doing this we can see the main four formants and then see which vowel that dominates in this cluster and combination of tones in woodwinds and strings.

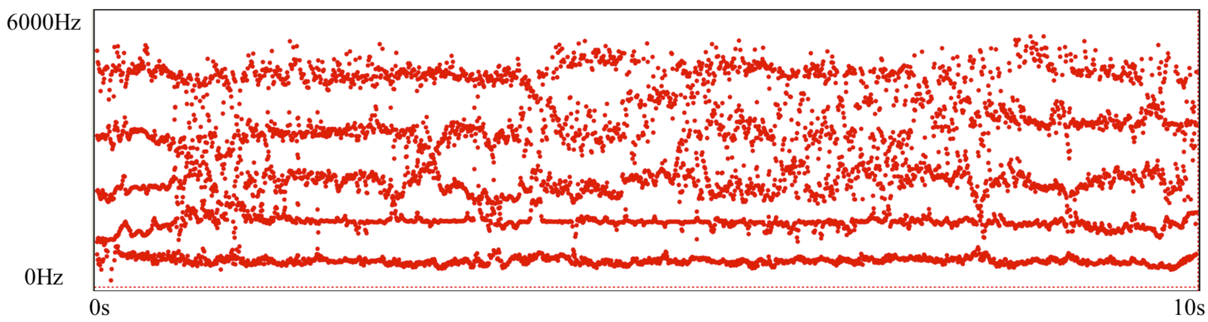

Figure 30: Formants of the woodwind-strings cluster in Lontano at measure 5-18. Quality: waw.

Formant	F1 = 500 - 700 Hz	F2 = 1100 - 1500 Hz	F3 = 2000 - 2500 Hz	F4 = 3100 - 3600 Hz
Vowel	o(oh) - å(aw)	a(ah) - ö +a(ah)	e(eh) + o(oh)	i(ee) + u(oo)

Table 6. Table of formants and their vowel.

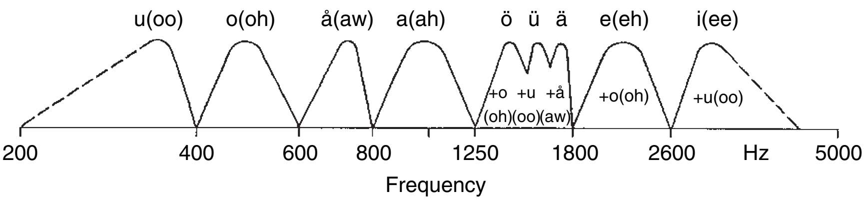

Figure 31: Vowels with exact bandwidth (Meyer 2009: 31).

In figure 30, the formants are presented in Praat where there is a lot of variation in the spectral envelope. In table 6, the first four formants are presented with an approximately bandwidth, and in figure 31, the vowels are presented with a more accurate frequency range than in the methodology chapter. By looking at the formants we can see at which frequency area the sound has its main energy and discover which instruments that are more dominant. Naturally the oboe and bassoon will be dominant because they have all of their formants presented in the sounds spectral peaks. The flute and the clarinet will be less dominant, both because of the formant peak and that they have less definable formants. In a spectrogram one can see that when the double reed instruments become more and more present as the overtone spectra increases. The increasing vowel character in the opening of Lontano seems to me as a deliberate compositional choice considering the orchestration. Beginning with flute, then clarinet, bassoon, cor angles and then oboe, he is starting with an instrument with few overtones and gradually expands this into the instruments with a high number of overtones.

As a conclusion, I will say that it is how Ligeti uses timbre as primary parameter and all other as secondary as the main aspect of the music. By changing the roles of all parameters he manages to highlight a whole other timbral aspect than what Ravel presents in Boléro. His complex scoring also presents a gap between the representation and the experience of the music.

3.3 Greenwood - 48 Responses to Polymorphia: Overtones (2011)

Greenwood, Radiohead and Penderecki

Jonny Greenwood (1971-) is a British composer and guitarist who is most known for his contributions in the alternative rock band Radiohead. Greenwood has for a long time been known for his unique guitar sound and playing style. As a composer Greenwood focuses more on the Contemporary music, where his enthusiasm for the strings are truly present. During his solo career he has composed music for films as *There Will Be Blood, The Master, Norwegian Wood* and *Bodysong,* and has also published a CD together with Krzysztof Penderecki including compositions as *48 Responses to Polymorphia*.

In Radiohead's many arrangements it is easy to hear the influence and contributions of Greenwood, especially in the string arrangements. In *Kid A (2000)* Greenwood's arrangements are truly present, especially in the song *How To Disappear Completely.* With the pure voice of Thom Yorke in front ground accompanied by the acoustic guitar in the middle ground, there is room for Greenwood's arrangement in the background. The bright, but weak chord which is presented from the very beginning can in many ways remind of the first chord represented in his work Overtones[19] which I will analyse later. In the following track, *Threefingers,* Greenwood also presents the ondes martenot, an instrument rarely used in a popular music context, and are more known for its presence in works of Olivier Messiaen (1908-1992), as in the *Turangalîla Symphony*.

In Greenwood's Contemporary works there are many traces of Messiaen's characteristics, not only the use of ondes martenot. Both the harmonic progressions, the use of symmetric scales and most of all the timbre. The timbre, or the sound (in form of composers/ artists uniqueness) is very similar in the two composers works. This is especially recognisable in the strings. An example of this is Messiaen's *Louange à l'Éternité de Jésus,* from 'Quartet for the end of time' and Greenwood's *Prospector's Quartet* from 'There Will Be Blood'.

In 2010 Jonny Greenwood and Krzysztof Penderecki initiated a collaboration, which resulted in a record including Penderecki's *Threnody for the Victims of Hiroshima* and *Polymorphia,* and Greenwood's *Popcorn Superhet Receiver* and *48 Responses to Polymorphia* where the two latter respectively are inspired by the two former compositions. There are

[19] Greenwood has two compositions named Overtones. One is from 48 Responses to Polymorphia, and the second from The Master. These two are very much alike, but in this text I will consequently speak of the former.

traces of both of Greenwood's work in some of the films he has scored for, as The Master and There Will Be Blood.

Penderecki - Polymorphia

Krzysztof Penderecki (1933-) is with no doubt one of the greatest living composers from Poland. In 1961 he composed a work called *Polymorphia*, where he used 48 strings (24 violins, 8 violas, 8 cellos, 8 basses) which naturally is the reason for Greenwood's name of his composition. Penderecki tried to categorise timbre in the orchestra into materials, where he called metal, wood and leather primary materials, and felt and hair as secondary materials because their lack of producing sound themselves when vibrating. He also divided the sound producers into two; inciters and vibrators. The vibrators were also called the sound source and the body that agitates the vibrator was an inciter (Mirka 1997: 63). In Polymorphia he tried to create a timbral opposition between wood and metal.

Penderecki used a lot of contrasting elements to create variations in timbre, an idea that is also captured by Greenwood in his work. Examples of this are (ibid.: 229):

High register vs. low register	Temporal mobility vs. temporal immobility
Middle register vs. extreme registers	Temporal continuity vs. temporal discontinuity
Spatial mobility vs. spatial immobility	Maximal time-span vs. minimal time-span
Spatial continuity vs. spatial discontinuity	Loud dynamics vs. soft dynamics

Penderecki also created this chart of how to articulate throughout the composition in order to create variations in playing techniques, and then change the timbre by only using the same instruments.

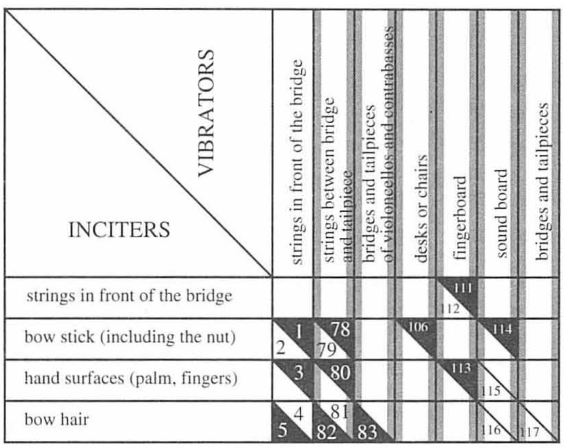

Figure 32: Chart presenting Penderecki's use of articulation in Polymorphia (loc. cit.).

Mirka is more occupied with systemising the work into categories in order to look at the techniques, rather than to look at the actual sonority of the music. I do find this useful as well, especially to understand the intention of the composer. Connected with the auditive perception, it is much easier to understand concrete elements of the music that creates the variations in timbre. This is very difficult to observe through for instance a spectrogram. Mirka's systemising of Polymorphia will function as a great tool to measure Greenwood's response with the actual ideas Penderecki used when composing.

Analysis of 48 Responses to Polymorphia: Overtones

[Note: The sound quality of this analysis is standard CD format, and it is the original soundtrack which is used. The music is performed by AUKSO Orchestra. The track (Overtones) has a full length of 2 minutes and 33 seconds. There is no available score for download. Faber music has however released the score as a preview on their website, which is not to be used in performance[20].]

3.3.1 Score - Representing the Music

Greenwood's choice of representing his music is quite different from the strict ways presented in Boléro and Lontano. The score relies on little information and more on coincidences created from a lack of this. This will naturally create more differences from each performance of the piece, but also give the conductor a greater role in the shaping of the piece. With almost no rhythmical elements, the note values rarely exists in their written form.

I think his choice of scoring has both some strengths and weaknesses in thoughts of functionality. First of all, I find his use of keys a bit odd. He has chosen to start the music in Ab major, but none of the played material has anything to do with that key. From the very beginning the first violin plays an E_5, while the other violins play quarter-tone stepwise from B_4 and upwards. This ends in an extreme complex cluster chord including all the 24 tones except A# and A #+. In measure 7, when this idea is repeated, the first violin still plays E_5 and the other violins play chromatically sixteenths as the first time, but without the quarter-tones. This creates a cluster including all of the chromatic tones from B_4-Bb_5. In the middle of this

[20] 48 Responeses to Polymorphia, score: http://scorelibrary.fabermusic.com/48-Responses-To-Polymorphia-23785.aspx

long sustained cluster, he changes the key into a C major key, which is more natural for the continuation. From measure 1 to 17 Greenwood actually scores his music quite ordinary, while the last part acts more freely. From measure 18-35 the rhythmic space between the measures and notes are rubato although this is not written in the score. In this part he is creating long sustained passages where he leaves a lot of the musical development into the hands of the performers. In measure 19-21 Greenwood introduces what he calls *I.R.I. trem* which means 'Independent, Random and Intermittend notes added to a held pitch - like a fingered tremolo but with only occasional use of the second note' (Greenwood 2011). This orchestration method contains both positive and negative aspects. The negatives are naturally that the composer and conductor looses some of the control over the orchestra by not knowing how intense each individual will play, which will have a huge effect on the timbral result. It might also be difficult for the performer to know how much he should play, which can lead to a mess rather than beautiful music. The positive effect Greenwood gains by giving the performer a more free role is the creativity which is very hard to imagine by yourself. By combining 48 performers, and letting them play a free rhythmic structure between the two tones, a more natural execution will occur. In the replay the same idea is presented, only with a ***sfp*** accents on random bow changes.

Greenwood said in an interview with *The Quietus*:

> Strangely, it can be a disadvantage to be a semi-semi-competent string player when you're writing for them. I still tend to underestimate what real players can do. I'm always dragging them down to my level... [it] makes my stuff easier to play, at least (Greenwood 2014).

I think Greenwood's unexperienced mind with playing the violin has led him to orchestrate in the way where experienced performers have a greater role. He has an idea of how it is supposed to sound, and since he also plays a part in the recording of the music he can easily change what he is not delighted with. From measure 23 to 35 there is for instance no dynamic symbol even though the orchestra clearly variates. From a timbral point of view, the score tells little about the development in contrast to Lontano where everything is scored to its finest level. This does also have a connection with the time era where the music is composed. In the 1950-60s Contemporary music, the orchestra was used to play with strict scores as with Lontano. It has however become more common to score with less information as Greenwood does in today's Contemporary orchestration.

3.3.2 Auditive Perception

As I have previously argued, there will always be a gap between the experience of music when it comes to studying a score, listening and spectral analysis. In Overtones, the relation between listening and the score will definitely have this gap, which mostly comes from Greenwood's choice of giving each individual performer a free rhythmic role. For example in measure 23-25, it is hard to imagine how it is supposed to sound, and it looks like a static sound, which it is not. When listening to the same piece, it sounds like there is a lot of movement in both rhythm and tones that are played. This comes from the attack created by random bow changes. Meyer said that 'The three influential quantities to be modified by the performer are: the speed of the bow, the pressure exerted by the bow hair on the string, as well as the point of contact at which the bow touches the string' (Meyer 2009: 88). He continues to explain their function by quoting Bradley and Cremer: 'The bowing speed influences fundamental and overtones equally, it is, therefore, the most important means of influencing dynamics. In contrast, bow pressure has no influence on the fundamental, assuming equal bowing speed, an increase in bow pressure primarily raises the intensity of higher overtones' (Bradley, 1976; & Cremer, 1981 in Meyer 2009: 88). 'The point of contact, on the other hand, influences the entire spectrum. Thus, the closer the contact point is to the bridge, the more bow pressure is needed' (Meyer 2009:88). This means that a change in bowing speed which have a great influence on the attack will have a dynamic impact. When one string instrument creates a new random bow change, it will therefore stand out and create more attention to that tone. This will create the illusion of a change in tones.

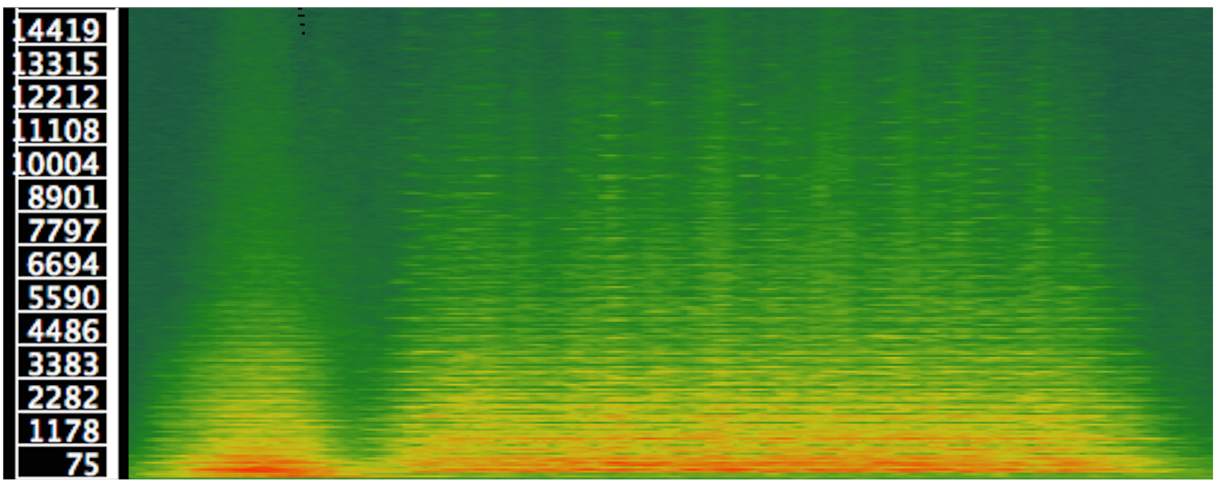

Figure 33: Spectrogram showing the overtone structure of bar 22-25. Scale: linear Quality: waw, (Penderecki, Greenwood 2011).

By looking at the spectrogram in figure 33 one can see that it has little effect on the actual overtone structure, which is more or less constant. But, because bow pressure and the point of contact also have some small changes, there will be some differences. Both the spectrogram and the score will have difficulties to represent the sound properly in this case, and it is a great example of the importance of listening. In a composition as Overtones, where only strings are used, playing techniques are often the key to variations. When there is only a variation in technique it can be difficult to understand the relation between what we hear, what we read from the score and the spectrogram. Instrument acoustics will therefore be even more important in order to understand the timbral development.

3.3.3 Form, Harmony, Melody and Rhythm

Before discussing the timbre in this composition I find it useful to briefly present other parameters which have an impact or is influenced by the focus on timbre. When it coms to form, it has no clear structure, but I do, however, experience two main parts. Part 1 (1-17) are based on rapid sixteenth movements which are developing into a long sustained chord, and are then repeated with another tonal material. Part B (18-35) can almost be seen as a call & response technique where Greenwood uses the final chord from Polymorphia, and creates short responses as I.R.I trem and random accents with the bow. These contrasts are developing in both timbre, dynamics, harmony and rhythm.

The harmonic structure is also divided into two, with the same measure numbers as the form. In part A, there are two main chords. The first is a cluster containing 22/24 quarter-tones and the second is containing all 12 semi-tones. They are both developed from the sixteenth movement. In part B the quarter-tones disappears and the harmonic structure is based on a sequenced cluster movement, where he is using a traditional superposition/overlaying technique. After presenting the main C major chord in measure 18, he responds with the diatonic cluster from F_3-B_4 playing I.R.I trem. From measure 18-29 he keeps a steady timbral thickness, which he expands to the counterpoints by creating a cluster from G_1-E_8 as the final chord.

Melody and rhythm are almost absent, or have at least no particular purpose. The first violin, however, has at some level a solistic role in part A and in the beginning of part B. The rhythm also has a secondary function, and does only work as a systematisation tool for the timbral development.

3.3.4 Timbre

The remaining part of the analysis will focus purely on Greenwood's active use of timbre when orchestrating. Previously I have only discussed how this focus has had an impact on the other parameters, and how the music is percepted by looking at the score and listening. In this final part I will look at how the playing techniques affect the overtone spectrum, the distribution of tones within chords, and how some frequencies dominate more than other in a complex timbre. I will also focus on the compositional process.

In part A, I find three main timbral topics that I intend to discuss. The first is to look at the differences in playing technique in the first violin. The second is to look at the spectrum of the quarter-tone chord from measure 4, to see which frequencies dominates. The same is also interesting to look at in the semi-tone cluster in measure 10-13 (where there is no other disturbing elements except from the 'melody' in the first violin). The third is to compare these two chords and see how the use of quarter-tones has an impact on the sound.

1).

The first violin has in many ways a solistic function. First of all, it is separated from the other instruments by playing a whole other rhythmic pattern. Second of all, it uses another form of playing technique, which is what is interesting to look closer into. The great thing about this example is that the only difference between the two tones played by the first violin is the technique, and this only effects the timbre. The violin is only playing an E_5, with no particular rhythmic pattern and no harmonic function. The first tone is an E_5 played with vibrato, which means that it has to be played at the A-string with either fourth finger in first position or first finger in forth position. The next time the first violin plays this E_5 note (measure 2) it is written *sul ponticello,* and a '0' above the note. This means that the performer is supposed to play the note on an open E-string with the bow as close to the bridge as possible. There is no doubt that this technique has an auditive effect and that it is easy to hear the difference between these two tones, but the spectral differences are also rather interesting.

As shown in the spectrogram in figure 34, there are major differences between the two ways of playing. In the first introduction of 'E_5 II' the first violin plays alone, not disturbed by anything. In this case the instrument manage to produce a clear overtone structure. As we can see, the partials become thicker in the middle of its length which comes from the vibrato that makes the binary frequency wider. When E_5 II is presented the second time, the other 23 violins are all playing the quarter-tone cluster, but these barely creates any overtones above 13'000 Hz. The E_5 II does therefore manage to produce more energy into the upper frequency area. However, from the seventh partial and upwards the sound power level drops with over 10 dB from B_7 - D_8. E_8 is over 15 dB lower than the B_7 as well. The frequency width of the B_7 tone is from -33 to +46 cents, which means that the vibrato effect is masking a clear overtone structure. In addition to this the playing technique is similar to all the other 23 violins, where all instruments are playing using the left hand fingers on the neck.

The first time Greenwood presents the 'E_5 0', is in the middle of the most intense rhythmic and harmonic part of the composition. Only sixteenths are played in the remaining 23 violins, and all quarter-tones are played. The use of open strings and the sul ponticello technique are therefore used to greatly separate the first violin from the rest. Looking at the first E_5 0 in the spectrogram, there is a very clear overtone structure which is present through the whole spectrum. There are some reasons why this happens. First of all, when playing an open string it is a greater chance that the overtones resounds after moving the bow, because there is not the same natural way to dampen the strings as if the left hand fingers are used.

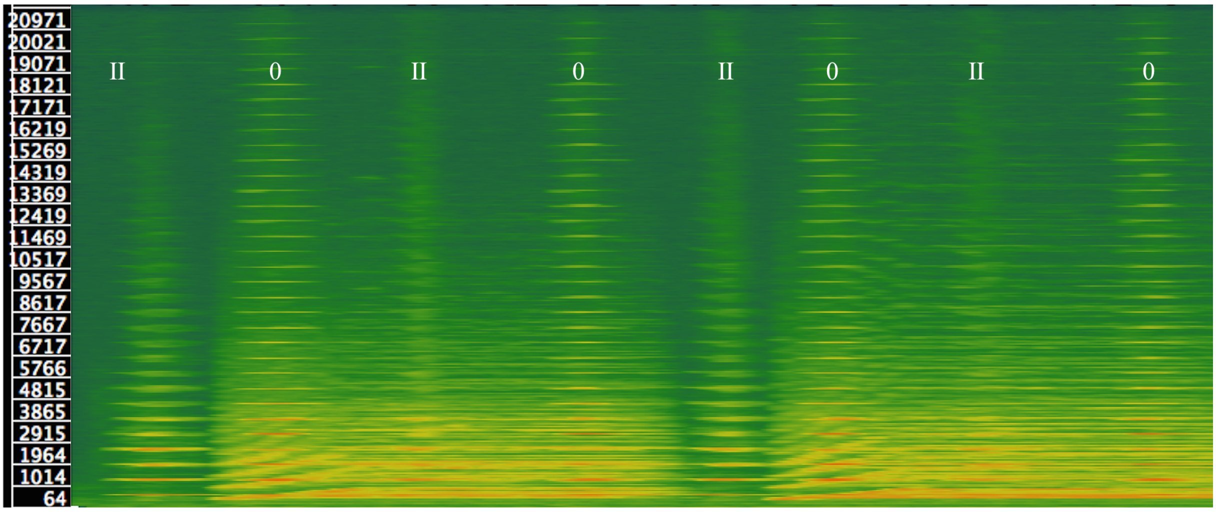

Figure 34: Spectrogram showing the first violin playing an E_5 using two different techniques. II = ord. 0 = sul pont. (as shown in the score). Scale: linear. Quality: waw, (Penderecki, Greenwood 2011).

This is especially easy to hear if the note is played staccato. Meyer says that 'The point of contact, on the other hand, influences the entire spectrum. Thus, the closer the contact point is to the bridge, the more bow pressure is needed' (Meyer 2009: 89). He also says that 'the closer the contact point lies to the bridge, the brighter and louder the sound becomes' (loc. cit.). Meyer also presents an interesting point on how the bow is a significant part of the violin sound:

> The fact that this hissing noise is a specific component of the tonal picture has become particularly evident in experiments with electronic imitation, where the harmonic spectrum alone could not create the impression of a string instrument (loc. cit.).

This also proves Godøy's point, presented in the introduction, that an instrument's timbre is not purely the overtone spectra of that instrument. By reading a spectrogram the bow would not be presented in an obvious way, but will rather be shown as noise between the overtones. It will therefore always exist a gap between listening and reading spectrograms. That said, one can still read a lot on how the sound acts.

Another reason why the structure is so clear is that there is no vibrato or touch of any kind on the string other than the bow, that can camouflage the pitch. In the following example the frequency width is shown in the two different playing techniques. In E_5 II there is a width of 73 cents (-30 (-) + 43) and in E_5 0 there is a width of 10 cents (+10 (-) +20). In the upper frequency area (10 kHz - 20 kHz) these differences results in one (II), having a vague overtone representation while the other (0) has a very clear overtone structure.

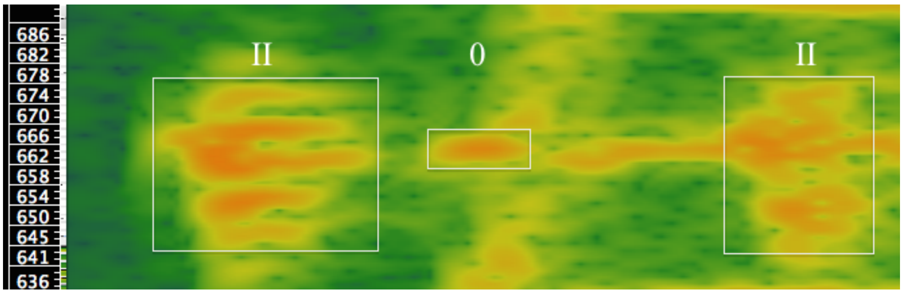

Figure 35: Spectrogram showing the frequency width of E_5 using different playing techniques. Scale: linear. Quality: waw, (Penderecki, Greenwood 2011).

2).

In order to present an overview of the quarter-tone cluster and the semi-tone cluster presented from measure 1-17 which defines part A, I find it necessary to categorise the tones based on their presence in the sound. The tones are categorised using spectral analysis. With the first chord the categories are *strong, medium* and *not present.* This is because some of these tones have no presence in the spectrogram. In the second chord I have chosen to categorise them into *strong, medium* and *weak*, because all tones are present. The chords will be mentioned as A1 (quarter-tone chord) and A2 (semi-tone cluster).

A1.

Strong:	Medium:
A+, G+, F#+, F, (E), D#	B, G, F+, D#+, D+, C#+, C#, C+
Not present:	Not played:
B+, A, G#+, G#, F#, E+, D, C	A# (weak), A#+ (medium)

It is interesting how he choses to double both E_5 in the 1st and 16th violin and F#+ in the 10th and 11th violin, but omits A# and A#+. When presenting the whole quarter-tone scale, I would rather give the melodic tone (E) a free space and not double any particular tone. It is, however, also interesting how A#+ still can be experienced through spectrograms even though it is not played.

Some of these tones are much more present in a spectrogram than others, when all tones are played at the same time with the same dynamics. It is in this case important to remember the mixing process, where equalisers probably are added to improve the final results.

A2.

Strong:	Medium	Weak
Bb, E, D#, C	A, G#, F#, D	G, F, C#, B

All tones in the second chord are present, and the relation between the number of instruments playing the same note and their sound power level has a clear connection. With the exception of F, all weak tones are played by only one instrument. All medium tones exept D are played by two or three instruments. All the strong notes are played by two instruments exept D# which is played by three. But the E notes are doubled in the ‘melody’ by the first violin, the Bb is the top note and the C is the bottom because the B has no sustainability (figure 36).

3).

One might think that using quarter tones in orchestration would create a wider spectrum, but after looking at the two chords from part A it seems like this is not the case at all. If anything, it seems like it is the opposite, but only with a slight margin. It is of course interesting to look at the whole spectrum, but since the main power in the violin lies at its fundamental, that is the most important area. The spectrogram in figure 36 shows the presence of fundamentals in the two chords. In A1 it is easy to see that there is not 22 different tones present, which I think might come from that certain tones overpower others in a close frequency area. There is, however, issues with this theory. In the frequency area between 810-881 Hz shown in the spectrogram in figure 36 there is a gap in A1, where the tones G#, G#+ and A are played, but none seems to be visible. The second chord which only contains semi-tones has a much more even structure and balance based on this figure, although there is a lack of sustainability.

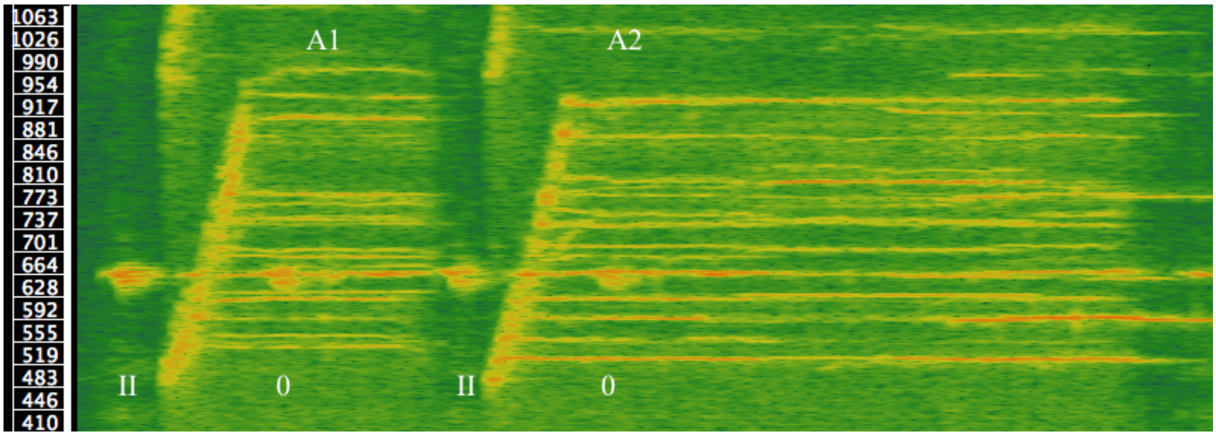

Figure 36: Spectrogram showing the fundamentals of the two chords from part A, and the first violin's presence. Scale: linear. Quality: waw, (Penderecki, Greenwood 2011).

In part B, there are more, but shorter passages that in a way repeats itself. This part is primarily based on the four C major chords which appears in measure 18, 22, 25 and 30. Both the idea of that C major chord and the instrumentation is directly taken from Penderecki's final chord in Polymorphia. I think Penderecki's way of introducing this chord is odd because his long, abstract composition has no connection with this chord, but it appears after the composition sounds like it is finished. In a way it is strange that Greenwood uses this as base for the most of his composition (all 9 parts), but on the other hand the way he develops it is brilliant.

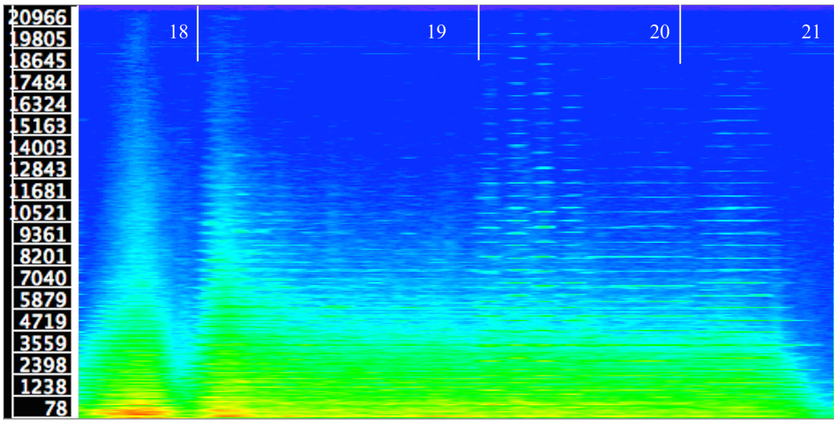

Figure 37: Spectrogram showing the spectral development of measure 18-21. Scale: linear. Quality: waw, (Penderecki, Greenwood 2011).

The spectrogram in figure 37 shows an interesting connection between dynamics, range, intensity and technique. With this way of representing the spectra I am not focusing on each individual partial, but rather the concentration of energy, how this is affected by the dynamics, range and technique that is used. I think this example can be representative for the most of the remaining music in regards of timbre. It also represents the gap between all of my three methodological approaches.

In measure 18 there is the C major chord which I previously have referred to as 'call', while in measure 19-21 there is the 'response' with the use of I.R.I. trem. In measure 18 the dynamic level is ***p*** with a crescendo towards measure 19 with the dynamic level of ***ff*** with a decrescendo towards measure 20 with a dynamic level of ***mp***. In measure 21 there is a decrescendo towards measure 22, where the next C major chord appears again with the dynamic level of ***p***. In addition, the first violin plays ***pp*** in measure 20. The repetitions also follow this pattern although it is not written in the score.

In the spectrogram (fig. 37) the sound power level scale is (from high to low) red - yellow - green - turquoise - blue. Based on this, the fundamentals of the C major chord (C - E - G) is the most dominant which is neither a surprise nor separated from the listening experience. Its main energy (red - yellow - green) drops around 5000 Hz. Above this we can see that the higher (in frequency) the overtones are, the shorter sustainability they have got. The overtones are present through the whole spectrum, but the energy is low. In the beginning of measure 19 the energy quickly increase, but also quickly decrease. It is interesting that although the dynamics moves from ***ff - mp - p*** in measure 19-21 the main energy is stable in sound power level, it only drops from the attack to the sustained sound where the main energy reaches up to 4000 Hz. The overtones above this area does however decrease gradually with the dynamics. In measure 20, the first violin is once again introduced with a tiny motivic element. Although it is playing in ***pp*** while the rest are playing in ***mp***, it sounds much louder and it also looks that way in the spectrogram. This can come from two things. First of all, it seems that the dynamics has changed in the mixing process of the track in order to make it even more in focus. The other is the use of bow technique, where he clearly uses sul ponticello even though it is not written in the score. Based on the score, the rhythmic element is the only thing which should separate this sound from the rest, but in the spectrogram and by listing it is the timbre that does this. In the spectrogram the four even eights followed by two longer sustained tones are separating itself from the rest of the sound by creating new energy into the upper frequency area. These can be seen in turquoise which mean that they are not as powerful as the accompaniment, but it brings a brightness into the sound by the first violin which gives it this quality.

3.4 Summary

Throughout this chapter, I have shown a various of both timbral aspects in orchestration and different analytical approaches to this. There is no doubt that these three composers have used widely different approaches in their compositions, which is also the reason why I have presented different analytical aspects. It has been shown that as a qualitative parameter, timbre is definitely difficult to discuss and analyse. If I would have used other plug-ins which shows other sides of the sound, these analysis could have contained a whole other set of information.

In the analysis of Boléro, I have shown how Ravel has used the overtone structure to create secondary voices. I also drew the conclusion that I think his idea comes from the organ mixtures. This was meant to give the organ timbre more brilliance, which I also think Ravel achieves. With this I also presented his relation to the natural harmonic series and the temperated system. He has obviously chosen not to relate the seventh partial to the natural harmonic series. I have also discussed how characteristics as ‘hollow’ in theory can be achieved synthetically through statements by Meyer. In the discussion of the form, I presented how Ravel might have thought in relation with the densification of overtones. I showed that there is a gap between the gradual crescendo that the music relies on, and the densification of overtones. And finally, I presented the relationship between accompaniment and melody by showing the contrasts between the first and the last melody.

In the analysis of Lontano I mainly focused on how timbre can decide other musical parameters. This includes form, harmony, melody and rhythm. It has been shown that these parameters has a secondary function, and are meant as tools to manipulate the timbre. Most importantly, I have discussed how traditional aspects of music, as tension-release, can be decided by timbre. Based on the quote by Cornicello which I presented in the introduction, this shows how directing the attention towards other aspects can give the musical substance a whole other value.

In the last analysis I focused on how Greenwood manipulates the string timbre by using various techniques. I have shown that small changes in playing techniques can change the whole spectra of that sound. Also in this analysis I have shown how timbre function as primary parameter, and that the secondary parameters are meant as tools to manipulate it.

The methodological approaches are presented with different connections. In Boléro, there is an obvious connection between the auditive perception and the score. The spectral analysis is not distanced, but there are some differences which for example is the densification of overtones. In Lontano there is a gap between the auditive perception and the score. When listening to the music it sounds abstract, with no metric features. When looking at the score it looks rhythmically complex. In this analysis I think there is a closer connection between listening and reading the spectrogram. The spectrogram gives a better representation of the important aspects, as the tension-release. In the analysis of 48 Responses to Polymorphia: Overtones, there is a gap between all of the methodological approaches. The score is just partly presenting what the music will contain. This comes from Greenwood's choice of giving the performer a greater role. The spectral analysis will not manage to represent the sound properly concerning the I.R.I trem, and ***sfz*** with random bow accents.

As a total, these analysis have shown different timbral aspects of orchestration. They are also just representations of how one can execute timbral analysis. Because timbre is a term which cannot be analysed using one method, it shows its true complexity. It also shows how timbre has an extreme potential in orchestration.

Conclusion

Timbre is without a doubt a complex term. It contains many aspects and demands a careful study to understand it properly. Already in the 18th century thinkers were discussing the term, but with a whole other set of premises than how we discuss the term today. I think these early discussions were important to highlight timbre as a parameter in music. The attention directed towards timbre, were part of the further development of orchestration. Through the next centuries composers chose different timbral aesthetic ideals. However, I do not think timbre functions as a primary parameter until the middle of the 20th century. With composers as Ravel, Ligeti and Penderecki timbre became a musical parameter which was used to experiment. Closely connected with increasing evolvement of technology, the focus on different aspects of a sound became important. It also became an interesting aspect to many Contemporary composers. With this historical aspect of timbre, it has been a gradual development, as it has been used as both primary and secondary parameter.

In most classical music performed today, whether it is Contemporary, Romantic or Baroque music, etc., timbre still function as a secondary parameter. I think this first and foremost comes from it always being an underlying parameter. This does not mean that timbre is not important in certain classical compositions. It is always important because music cannot exist without it, but it is a matter of how much attention the composer directs towards it.

The development in technology has played a major part in acoustical and psychoacoustical research. Regarding timbre, this research is vital in order to start understanding the term. As I have shown in this thesis, timbre is very complex. Although acousticians have come a long way in understanding how sound and instrumental timbre works, there is still a long way to go to fully understand it. Elements as noise also makes it very difficult to understand the whole spectra of a sound. Nonetheless, I must say that by listening to software samples of instruments, a lot of the sonic elements of the sound spectra are present. This means that the acoustical research shows improving results.

My main approach with this text has been to show the use of timbre in orchestration. Based on previously composed music I have shown examples of this. These are meant to show how earlier composers might have thought in the creation of their music. The analysis has also provided examples on how to create musical ideas based on theoretical, acoustical and aesthetical principles. I also think that the analysis have managed to show how widely different timbre can be used in orchestration.

I think that music as an artform deserves a great amount of attention directed towards the aesthetical aspect. I do not see a gap between timbre being a primary parameter orchestration and it being an acoustical research. However, I think there is a balance which the composer or orchestrater must take into consideration. If not meant for research, I think a composition with a lack of foucs on the aesthetic aspect, looses its value. As I quoted in the beginning of this text, and as I will finish this theoretic part:

> Even though a musical composition be the most correctly calculated in all its tones and the most geometric in its harmony, of it has no meaning to accompany these qualities, it can only be compared to a prism which yields the most beautiful colors but which does not produce a picture. It would be like a color-harpsichord which offered colors and arrangements in order perhaps to amuse the eyes, but which would surely bore the mind (Batteux in Dolan 2013: 39).

4 Practical Component: A Review of My Composition

4.1 Idea and Inspiration

The practical component of my thesis is an orchestral work. The composition is a direct response to Greenwood's *Overtones.* Similar to Greenwood, I have only used the string group and composed a piece using 24 violins, 8 violas, 8 cellos and 8 contrabasses. In the composition I have used several theories, which I have discussed in the theoretical part of the thesis. I will further present the inspiration for the composition, ideas that has been used and how I have used them.

My main inspiration for creating this piece comes from Greenwood's music. I have huge respect for his artistic works, both in Contemporary music and in band related music. One of the reasons is that I think he manage to execute his ideas using the orchestra in beautiful ways. Although my composition is a partly theoretical based piece, I relate the aesthetic attention closely to Greenwood's music. I think this is shown with a calm and structured development, where instrumental timbre is in focus.

4.2 Overview and Form

My composition is divided into four parts, which in the score is marked with A-D. It has a total duration of about 4 minutes, where each part is based on one main idea. Part A is what I will define as a summary or a repetition of the essence in Overtones. My composition begins with the final chord (C major) from Penderecki's *Polymorphia.* Which I mentioned earlier, Greenwood base his composition on this chord. In *Overtones* it introduces the second part, and I have intended to present my composition by using the same chord and voicing. In the next measures, I continue with Greenwood's call & response technique. In these measures I use the analytical approach of *Polymorphia* presented by Mirka, with ‘high register vs. low register’ (Mirka 1997: 229). As a response to the first chord, the violins play the tones which is part of the first sixteen partials. At this point I do not relate to either quarter-tones or octaves to present the partials correctly. The response contains the tones from the resonance chord presented earlier by Messiaen. I have orchestrated this chord from the first (C), third (E) and the fifth (G). This is to present the ‘resonance’ of all the three tones present in a C major chord. Part A ends with the C major chord plus its resonance together before it drops into silence.

Part B is at some points similar to Part A, and I see this as a process of moving away from Greenwood's composition. I do however use techniques which are similar. The first eight violins create a transition between the different timbre created by each string on a violin. In the beginning the brightest is the strongest, and at the end, the darkest is the strongest. The next eight (9-16) violins create an open chord with the distance of a perfect 5th between each note (Bb-F-C-G). The last eight (17-24) violins create a cluster from G_3-G_4 where the lowest note jumps an octave for each measure. This ends in the same cluster one octave above (G_4-G_5). In this part I am using playing techniques to create timbral variations. These are presented in three ways; sul ponticello, artificial harmonics and ordinary playing technique. The idea is to separate certain frequencies from the other by constantly changing dynamics and pitch.

Part C is based on the lowest C of the viola. The first measures of this part only contains this long sustained tone. I mentioned in the analysis of Boléro that Messiaen claimed that the first 16 partials are possible to percept for a very fine ear. I do not think this is easy, but by presenting the C-note on an open string in the viola it is for me possible to percept the overtones quite clearly, at least the first 12 partials. To achieve this, I think that the listener has to use the method I presented through Schaeffer earlier. The idea is to repeatedly listen to the same area of the music to discover new aspects. I also think it is important to know where in the frequency area (at which octaves) one must direct the attention. If not, it will be very difficult to discover the overtones. Further I develop this tone into a massive and dark C major chord as a response to the opening chord. This chord evolves into a cluster, which enhances the string character. It is also a reminder of Greenwood's scoring, where he creates the similar effect.

Part D is a recreation of the lowest C in the viola. The difference from part C is that the overtone structure is orchestrated using the 24 violins. It is also a response to Messiaen's resonance chord. Beginning from the root, all tones are gradually introduced. This is the first time in the composition where I am using quarter-tones. I think it is necessary in this part, because of the relation between the natural harmonic series and the temperated system. In the aesthetic opinion, this also creates a nice contrast to the first time I presented the resonance chord (measure 2-4).

4.2 Harmony, Melody and Rhythm

The harmony presented in the composition is meant to create variations. The main harmonic structures used are: major chord, cluster, open 5th (based on violin tuning), quarter-tones and the resonance chord. Both melody and rhythm only functions as secondary. There might be some fragments of a melody, but it is the timbral qualities this brings that is important. The rhythm has the same function. It is similar to the use in *Lontano* and *Overtones.*

4.3 Timbre

The composition is meant to reflect some of the timbral aspects of orchestration which I have presented. The focus has been on creating music based on my analysis, inspired by techniques and ideas as the resonance chord. The use of quarter-tones has always been in focus, but I am occupied with the thought of being careful and frugal with this. I think it only should be used with a concrete intention as I do in the last resonance chord. When presenting one tone at the time, the quarter-tones might sound out of pitch, but when the whole chord is presented it sounds as a harmonic presentation of the viola timbre.

The timbre is naturally the primary parameter of my composition. I want the listener to direct the main attention towards this aspect. I also want the listener not to be stressed out by complex secondary parameters. In Boléro I think melody, harmony and rhythm have a dominant presence in the composition, and the attention to timbre seems to me reduced. The secondary parameters are therefore carefully used. I have also created space with the use of pauses, but also by an economic orchestration style.

It is also important to me when composing that the mathematical aspect is not overpowering the aesthetical. In spectral compositions which I presented with IRCAM and 'AV', the mathematical calculations are necessary with the intention of recreating the sonority. In my composition the aesthetical aspect is also very important and will reflect my intention of combining scientific and acoustical research with aesthetics, with the purpose of creating beautiful music.

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Appendix

1: *Resonance*[21] - Mathias Langfeldt

[21] The full score of *Resonance* is only avilable in the printed version of this text. This is due to copyright of the music.