Portfolio of Compositions with accompanying Written Commentary

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by

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Written Commentary

Contents

Introduction 1

Part 1: Consonance and Dissonance

1.1 Semantic shift **5**

1.2 Multiple perceptual factors **7**

- 1.2.1 Sensory consonance **8**
- 1.2.2 Affinity of tones **11**
- 1.2.3 Root-relationship **13**

1.3 Localised templates **16**

1.4 Domain specificity **20**

1.5 Between consonance and dissonance **21**

Part 2: Portfolio of Compositions

Compositional Context **24**

Note on microtones and intonation **25**

2.1 *I would go home but my house on fire,* for Pierrot sextet **26**

2.2 *Rabbit Hole,* for solo cello and electronics **31**

2.3 *Two Systems* – introduction **35**

- 2.3.1 Melodic consonance and dissonance **36**
- 2.3.2 *Two Systems,* for solo tenor trombone and electronics **39**

2.4 *An intense and unpleasant excitement*, for solo flute and electronics **44**

2.5 *Dear Henry* – introduction **47**

- 2.5.1 Rhythm harmony **47**
- 2.5.2 Perceptual factors of rhythm harmony **49**
- 2.5.3 *Dear Henry,* for Pierrot sextet **53**

2.6 *Yes and No*, for 22 solo strings **57**

2.7 *Concerto for Piano and Electronics* **62**

2.7.1 Movement 1: Maestoso-Vivace **62**

2.7.2 Movement 2: Adagio sostenuto **66**

2.7.3 Movement 3: Rondo Allegro **68**

Conclusion 72

Appendix I: Recordings and resources on USB 75

Appendix II: Chronological list of pieces completed during PhD 76

Appendix III: Sources for *Concerto for Piano and Electronics* 77

References 87

Introduction

The initial focus for this project was to create a series of original compositions exploring the use of consonance and dissonance within elements of music other than harmony, i.e. rhythm, melody, timbre, etc. My interest in this topic came from reading Henry Cowell's *New Musical Resources* (1996) in which he sets out his theory of rhythm harmony:

> The familiar interval of a fifth represents a vibration of 2:3. Translating this into time, we might have a measure of three equal notes set over another in two… Corresponding to the tone interval of a major third would be a time-ratio of five against four notes; the minor third would be represented by a ratio of six against five notes, and so on. If we were to combine melodies in two (or four) beats, three beats, and five beats to the measure, we should then have three parallel time-systems corresponding to the vibration speeds of a simple consonant harmony.
>
> (Cowell, 1996, p. 51)

This idea that there are other kinds of consonance had an influence on my compositional approach for two main reasons. Firstly, there was the issue of redundancy, that is the ability to create tension and release when harmony was either missing or functionally redundant. As a composer in the 21st century I am writing after what Schoenberg called 'The Emancipation of the Dissonance' in which composers were no longer using consonance and dissonance in the ways traditionally prescribed:

> One no longer expected preparations of Wagner's dissonances or resolutions of Strauss' discords; one was not disturbed by Debussy's non-functional harmonies, or by the harsh counterpoint of later composers. This state of affairs led to a freer use of dissonances comparable to classic composers' treatment of diminished seventh chords, which could precede and follow any other harmony, consonant or dissonant, as if there were no dissonance at all.
>
> (Schoenberg, 1975, p. 216)

For some this abandonment of functional tonality was just the first step towards a new style in which structural tension and release was entirely absent, for example Stockhausen's concept of Moment Form which sought to remove the use of climax and relaxation in compositional structures (Stockhausen, 1963). However, I wanted to be able to use the new harmonic freedoms of the emancipation of the dissonance, but without entirely rejecting the use of tension and release.

The second reason for my interest in exploring the use of consonance and dissonance outside of harmony was the possibility of writing pieces which had a sense of ambiguity or contradiction. If there are different types of consonance and dissonance, it should be possible for them to function independently, and the movement between tension and release could occur in different directions simultaneously, e.g. a piece could resolve rhythmically whilst becoming harmonically more dissonant.

However, as I began to explore these ideas it became clear how fragmentary my knowledge was, both in terms of my theoretical sources being limited to only a few writers, and also in terms of my somewhat partial understanding of the perceptual processes involved. Furthermore, from what I did understand, it seemed that the existing literature on this topic also contained some confusions. For example, different writers were not using the terms consonance and dissonance in the same way which meant that their different types of consonance and dissonance did not relate to each other coherently. It was clear that further research would be beneficial to broaden and clarify my understanding. Therefore, the initial aims of this research project were:

1. Undertake critical research into the psychoacoustic causes of harmonic consonance and dissonance.
2. Apply the findings of this research in a critical review of the existing literature on non-harmonic consonance and dissonance.
3. Apply the findings of this review in a series of original compositions.

Initially it had been my aspiration to establish a single coherent definition of consonance and dissonance and then apply this across the different musical elements. However, it soon became clear how varied the use of the terms *consonance* and *dissonance* are, as Tenney states:

> There is surely nothing in the language of discourse about music that is more burdened with purely semantic problems than are the terms consonance and dissonance. A comparison of some of the definitions of these words to be found in current dictionaries, harmony textbooks, and books on musical acoustics indicates that there is considerable confusion and disagreement as to their meaning - if indeed there is any meaning still to be attributed to them.
>
> (Tenney, 1988, p. 1)

This is not surprising considering that these terms have been around for over 2000 years, and in that time both their meaning and the context in which they have been applied have changed significantly. Furthermore, as these changes have occurred, remnants of the older concepts have remained, resulting in consonance and dissonance becoming both perceptually and conceptually multi-dimensional:

> A new interpretation of 'consonance' and 'dissonance' began to supersede an older one. But the aspect of musical perception denoted by these terms in their earlier interpretation did not, in either instance, simply disappear, or become any less real than it had been before. Although the changes in their descriptive language during these transitions may have involved the replacement of one set of meanings by another, the perceptual and conceptual changes which this language had to accommodate involved a cumulative process of addition of a new perceptual/conceptual acquisition to the earlier ones.
>
> (Tenney, 1988*,* p. 65)

In light of this, instead of trying to establish a single definition of consonance and dissonance to be applied across the different elements of music, the aim of this project became to clarify the multi-dimensional nature of consonance and dissonance and to delineate some of its distinct elements. From this it would then be possible to develop a more coherent understanding of consonance and dissonance that could then be used to clarify some the confusions in the existing literature. Furthermore, it also became clear that these different elements could be important compositional resources which could be used to create redundancy and ambiguity: redundancy as the different components of consonance and dissonance could be used at different times; and ambiguity as they could also be used against each other.

Therefore, the ultimate objective of this project became the development of a multi-dimensional approach to consonance and dissonance that includes both their use in relation to multiple elements of music, and also their different perceptual and conceptual components. Part 1 of this commentary (1.1-1.6) will discuss some of the different components of consonance and dissonance, including how the meaning of these terms has changed over time, the occurrence of multiple perceptual processes, and how individual's emotional responses to consonance and dissonance differ. This is not an exhaustive survey of these issues, as this would be well beyond the scope of this project but will instead focus on those which played significant roles in my compositional thinking. Part 2 (2.1-2.7) then discusses how these different factors relate to other elements of music and how they shaped the composition of my pieces.

Part 1: Consonance and Dissonance

1.1 Semantic shift

The terms *consonance* and *dissonance* have changed their meaning significantly over time. In the earliest texts they were used to refer to the auditory phenomenon of perceived unity between different notes:

> [Intervals] are concordant when the notes which bound them are different in magnitude, but when struck or sounded simultaneously, mingle with one another in such a way that the sound they produce is single in form, and becomes as it were one sound. They are discordant when the sound from the two of them is heard as divided and unblended.
>
> Nicomachus, *The Manual of Harmonics,* 262.1ff (c. 100 CE).

> People give the name "concordant" … to those [intervals] which make a homogeneous impression on the hearing, "discordant" to those that do not.
>
> Ptolemy, *Harmonics* 10.25–8 (c. 130 CE)

It is this definition which gives the etymology of these terms: *consonance* meaning 'sounding together' or 'sounding as one'; *dissonance* meaning 'sounding apart' or 'sounding as two'. Later there occurred a shift towards a conception of consonance as pleasant or agreeable combinations of notes:

> Philomathes: What is a concord?
>
> Master: It is a mixt sound compact of divers voices, entering with delight in the ear…

> Philomathes: What is a discord?
>
> Master: It is a mixt sound compact of sounds naturally offending the ear.
>
> Thomas Morley, *A Plain and Easy Introduction Practical Music*, 1597, p. 70

> Consonance: this is an interval the union of whose sounds is very pleasing to the ear... Dissonance: thus is the name for intervals which, so to speak, offend the ear.
>
> Jean-Phillipe Rameau, *Treatise on Harmony*, 1722, xli-xlii (Table of Terms)

This shift has led to disagreement between theorists. In one camp, we find those who adhere to the older definition, seeking to explain consonance and dissonance in terms of perceptual unity, for example, Stumpf's theory of *Tonverschmelzung* (tonal fusion) proposed in the second volume of his *Tonpsychologie* (1890). In contrast to this, we find theorists who treat consonance and dissonance exclusively as a matter of pleasantness or unpleasantness without any reference to unity. This is either because they were unaware of the earlier meaning, or because they saw the change as being a complete paradigmatic shift. One example is Helmholtz who proposed his *roughness* theory of dissonance in *On the Sensations of Tone* (1895). Both approaches have their followers, with Boomsliter & Creel (1961) and Ebeling (2008) arguing for tonal fusion, and Plomp & Levelt (1965), Bregman (1990) and Vassilakis (2001) following Helmholtz's approach. Additionally, both groups have collected data which supports their particular position while raising objections which they claim disproves the other (e.g. Plomp & Levelt, 1965, pp. 549-552).

However, taking Tenney's approach, as discussed in the Introduction, it is possible to see this change as part of a process of aggregation, and rather than outright rejecting one position or the other, seeing the concept of consonance as consisting of both unity and pleasantness. An awareness of this is important for these terms to be used coherently and is something which had a significant influence on my compositions, for example in pieces such as *Yes and No* (see 2.7).

1.2 Multiple perceptual factors

Another important influence on my compositional thinking is the theories of Ernst Terhardt who, like Tenney, takes a multi-dimensional view of consonance and dissonance:

> There evidently exists one aspect of musical consonance that becomes apparent in tonal music: it is termed *harmony* (note that in this context the term is given a specific meaning). Moreover, there exists another aspect which appears even to dominate consonance evaluation of isolated chords; this aspect is termed *sensory consonance*… Musical consonance is thus composed of two principal components: sensory consonance and harmony.
>
> (Terhardt, 1984, pp. 281-2)

To clarify Terhardt's terminology, *harmony* here is not referring to the general practice of sounding notes together, but rather: "Harmony (in its specific sense used here) represents the principles mentioned already: tonal affinity, compatibility, and fundamental-note relation. It is pertinent to pitch relationships." (ibid., p. 282). While Terhardt defines sensory dissonance as "the more or less complete lack of annoying features of a sound (i.e., on the physical side, amplitude fluctuations and presence of spectral energy at high frequencies)." (ibid., p. 282). Terhardt is clear to distinguish that by sensory consonance he does not mean the same thing as *musical consonance*, but rather the more generalised theories concerning perceived unpleasantness or annoyance in sound: "The first component is called sensory consonance; it represents the graded absence of annoying factors and is not confined to musical sounds, that is, not music specific." (ibid., p. 276). Terhardt's approach can be seen as related to the concepts of unity and pleasantness discussed in 1.1 as his concept of *harmony* concerns the occurrence of perceptual unity between notes, while his concept of *sensory consonance* deals with pleasantness.

Terhardt also specifies the perceptual processes which he claims underpin these two concepts. As mentioned in 1.1, various theorists have developed different theories regarding the perceptual causes of consonance and dissonance. Terhardt's approach is to bring together the different theories which he believes to be valid, including one of his own, into a unified framework. In the course of my research I have found Terhardt's approach to be the most coherent and with the most rigorous evidential basis. The following is a discussion of his framework.

1.2.1 Sensory consonance

For the perceived pleasantness of certain combinations of notes, Terhardt initially defers to Helmholtz's theory of *roughness* which states that the sensation of unpleasantness between certain combinations of notes is caused by acoustic beats:

> When two or more simple tones are sounded at the same time, they cannot go on sounding without mutual disturbance, unless they form with each other certain perfectly definite intervals. Such an undisturbed flow of simultaneous tones is called a consonance. When these intervals do not exist, beats arise, that is, the whole compound tones, or individual partial and combinatorial tones contained in them or resulting from them, alternatively reinforce and enfeeble each other. The tones then do not coexist undisturbed in the ear. They mutually check each other's uniform flow.
>
> (Helmholtz, 1895, p. 204)

Helmholtz then argues that at slow speeds beating is not particularly unpleasant to hear, but when the frequency of the beats is more than 20 per second, the sound becomes unpleasant:

> The ear easily follows slow beats of not more than 4 or 6 in a second. But when the interval between the two tones increases to about a semitone, the number of beats becomes 20 or 30 in a second… such rapidly beating tones are jarring and rough. A jarring intermittent tone is for the nerves of hearing what a flickering light is to the nerves of sight, and scratching to the nerves of touch. A much more intense and unpleasant excitement of the organs is thus produced than would be occasioned by a continuous tone.
>
> (Ibid., pp. 168-70)

Helmholtz then claims that beating is strongest at close intervals such as the semitone, and gradually weakens as the interval widens, meaning that it is weaker in whole-tone intervals and non-existent in thirds (ibid., p. 171).

Beating can also occur spectrally which means that roughness can be heard in intervals wider than a third. Ex.1 below shows three intervals, with the lower stave showing the fundamental frequencies, and the upper stave showing the overtones. The first bar shows a minor second which will have beating between all frequencies. The second bar shows a major seventh which will have beating between some frequencies, for example the first overtone of the first lower pitch (C4) will beat against the fundamental pitch of the upper note (B3). The third bar shows a tritone which will also have beating between some frequencies, such as the second overtone of the lower note (G4) and the first overtone of the upper note (F#4).

Ex.1: Occurrence of spectral beating in complex tones.

As overtones tend to be lower in amplitude than fundamentals, the roughness caused by spectral frequencies is weaker. However, this can depend the spectral characteristics of the particular instruments in use. For example, tritones and major sevenths will sound more dissonant when played by instruments with stronger spectral components such as trumpets and oboes, and weaker when played by instruments with weaker spectra such as flutes (Lerdahl, 1987, p. 141).

Since Helmholtz first proposed his theory, research has been produced which both supports and extends it, such as Plomp & Levelt (1965) and Vassilakis (2001). In particular one issue with Helmholtz's theory that Plomp & Levelt's work clarifies is how the occurrence of roughness relates to musical intervals. As mentioned above, Helmholtz states that beats of 20 to 30 per second occur at intervals of about a semitone. However, Plomp & Levelt's work demonstrated that maximal roughness occurs at approximately 25% of the critical bandwidth, and then gradually subsiding (see Ex.2).

Critical bandwidths correspond to ranges of frequencies, and due to the logarithmic relationship between frequency and musical pitch (Heller, 2013, p. 90), the critical bandwidth corresponds to different musical intervals across the audible range of frequencies. This means that the exact intervals in which roughness occurs is not fixed, as Helmholtz states, but depends on the specific pitch range in use. Roughness occurs in larger intervals lower in the frequency range, and in smaller intervals higher in the frequency range. For example, at A4 maximal roughness occurs at the interval of a minor second: A4 = 440Hz, A#4 = 466.16Hz, resulting in

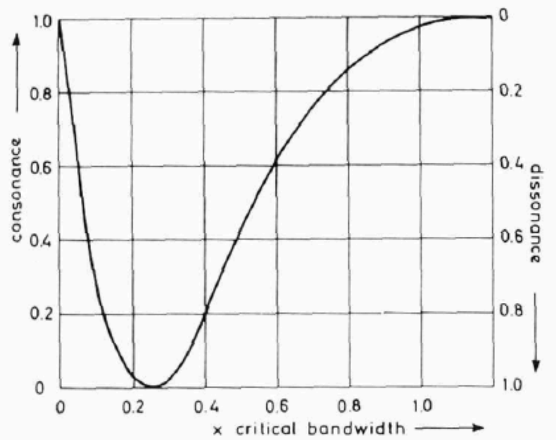


FIG. 10. Standard curve representing consonance of two simple tones as a function of frequency difference with critical bandwidth as a unit. The curve is based on the data points of Figs. 1–7. The consonance and dissonance scales are arbitrary.

Ex.2: ‘Fig. 10' from Plomp & Levelt, 1965*,* p. 556

26.16 beats per second. However, in the lower range the interval of maximal roughness can be as wide as a perfect fifth, for example, A1 = 55hz, E2 = 82.41Hz, which results in 27.41 beats per second.

One reason that this is significant is that it provides evidence against the theory of harmonic ratios which states that harmonic consonance is caused by simple ratios between different frequencies (e.g. Galileo, trans Crew & De Salvio, 1963, p. 100). According to this theory, a Just major third with a harmonic ratio of 5:4 should be more consonant than a semitone which has a ratio of 17:16. However if both of these intervals are created starting from A2, the major third will have significantly more roughness than the semitone: A2 = 110Hz, C#3 = 138.59, which results in 28.59 beats per second. While A#2 = 116.54 which heard against A2 results in 6.54 beats per second.

Alongside roughness, Terhardt also argues that sensory dissonance is caused by *sharpness,* that is the occurrence of high frequency spectral energy in a sound. This is also known as *shrillness* - a tonal characteristic of some high-register instruments such as piccolo and Eb clarinet (Adler, 2002, p. 211). In this respect, Terhardt is incorporating into his framework the work of Cardozo & van Lieshout who in their paper *Estimates of annoyance of* *sounds of different character* (1980) demonstrate that perceived unpleasantness in sounds is related to occurrence of both roughness and sharpness. To be clear, sharpness does not relate specifically to harmonic consonance and dissonance as it is not caused by combinations of notes, but, as will be discussed later, it is a significant factor in timbral consonance and dissonance, which is explored in pieces such as *Rabbit Hole* (2.2) and *An intense and unpleasant excitement* (2.4). In order to avoid confusion with the idea of sharpness in terms of intonation, I will refer to this specific phenomenon as *tonal sharpness.*

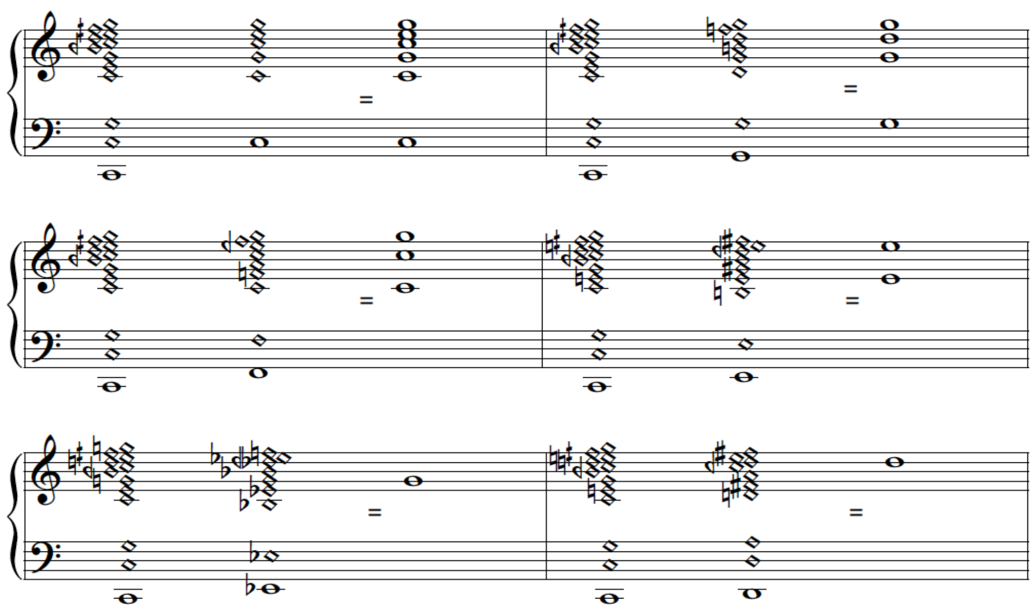
1.2.2 Affinity of tones

Terhardt argues that the second component, harmony, consists of two distinct perceptual processes: *affinity of tones* and *root-relationship*. *Affinity of Tones* is a theory which was also first proposed by Helmholtz, and it states that two complex tones with different pitches are heard as highly unified if they share a significant number of spectral frequencies. As discussed in 1.1, Helmholtz himself did not consider perceptual unity to be part of the concept of consonance, however he did establish a strong theory as to its cause. Part of Terhardt's approach is to show that Helmholtz had failed to coherently link his different psychoacoustic theories into a fully consistent framework.

In regards to specific musical intervals, Helmholtz argues that octaves have the highest degree of affinity. This is because all of the frequencies in the upper note correspond to frequencies in the lower one:

> The resemblance of an Octave to its root is so great and striking that even the dullest ear perceives it; the Octave seems to be almost a pure repetition of the root, as it, in fact, merely repeats a part of the complex tone of its root, without adding anything new.
>
> (Helmholtz, 1895, p. 253)

Helmholtz then argues that this sense of affinity is dependent on how many matching frequencies two different tones share. Example 3, below, shows the amount of overtone matching in different intervals. In each bar the first two chords show two separate complex tones with the fundamental written in a round note head and the overtones written in diamond note heads above. Taken together these first two chords represent a musical interval, that is the fundamentals of each chord are spaced a specific musical interval apart. The third chord in each bar, which is written entirely in round note heads, shows the frequencies which the two first chords have in common, thereby showing the matching frequencies for each interval.



Ex.3: Overtone matching in different dyads

As can be seen the greatest amount of overtone matching occurs with the octave, the next strongest being the fifth, and then the fourth, and so on, with the effect gradually weakening. Helmholtz states that the sense of affinity is strongest in octaves, fifths, and fourths, and is sufficiently weak in thirds to be imperceptible: “the interval of a Third is by no means so clearly defined by easily appreciable partial tones.” (ibid., pp. 254-5). And as with his theory of roughness, more recent empirical data has been collected by researchers such as Kallman (1982) and Terhardt (1991) which strongly supports this viewpoint, showing that when asked to compare the similarity between different complex tones test participants showed a clear statistical preference for perfect intervals such as octaves, fifths and fourths.

Terhardt argues that this occurrence of perception fusion is an example of the gestalt law of similarity (Koffka, 1935, p. 106, cf. Medin, Ross, Markman, 2005, p. 79) and that different sound-objects are perceived as related due to a high degree of similarity in their component features.

1.2.3 Root-relationship

The other perceptual factor of *harmony* that Terhardt identities is *root-relationship*, also known as *fundamental bass*. This is a long-established theory which states that a chord is consonant if all of its notes are related to the same harmonic root, for example as Rameau stated in his *Treatise on Harmony* (1722):

> The source of harmony does not subsist merely in the perfect chord or in the seventh chord formed from it. More precisely, it subsists on the lowest sound of these two chords, which is, so to speak, the harmonic centre to which all the other sounds should be related.
>
> (Rameau, trans. Philip Gossett, 1971, p. 141)

In Example 4, below, the first chord shows the harmonics of the note C3. The second chord is dissonant as it does not match these harmonics, while the third chord does match and therefore is consonant:

Ex. 4: The overtone series (chord 1) compared with a dissonant chord (chord 2) and a consonant chord (chord 3).

What is also important to note about this theory is how it relates to theories of pitch perception. As has been observed (Bregman, 1990, pp. 232-3), if the component frequencies of a complex tone are harmonically related, the tone will then possess a clear and singular sense of pitch. Bregman calls this *harmonicity*. Terhardt argues that the occurrence of root-relationship in harmony is an extension of pitch perception, and that both are examples of harmonicity. Terhardt's explanation for this phenomenon is his theory of *virtual pitch* (1974), in which he argues that listeners possess a template of the harmonic series in their long-term memory. All incoming auditory signals in short term memory are then compared to this template, and those which match it are perceived as perceptually fused in accordance with the gestalt law of past experience (Koffka, 1935, p. 106). As Terhardt argues, this template is initially acquired by the auditory system for the purposes of pitch perception as this is a necessary component of auditory communication, and it then later extends into harmony:

> "J.P. Rameau was the first who, in his *Traite de l'Harmonie*, explicitly treated the fundamental notes as an auditory percept. He regarded the *basse fondamentale* as an "implied" or "inferred" auditory feature of sound which nevertheless has psychological reality and is of crucial significance in tonal music. And this is exactly what the *basse fondamentale* actually is: An auditory percept, though a virtual one. Any pitch corresponding to any fundamental note merely is a virtual pitch. So, the theory of virtual pitch can be employed as a universal tool to determine the roots of any type of musical sound."
>
> (Terhardt, 2000)

One of the strengths of Terhardt's theory is that it is able to address problems with Boomsliter & Creel's long pattern hypothesis of harmonicity (1961). This is essentially a modern extension of the theory of harmonic ratios that claims that simple ratios are not only the cause of harmonic consonance but also pitch perception:

> "In a consonance, such as the fifth, 3:2, every second wave of the lower frequency corresponds with every third wave of the higher frequency (although we do not know the neural form of this correspondence). We can hear that 17:13 is dissonant, and can readily understand the lack of fusion, since only every 13th wave of the lower corresponds with every 17th wave of the higher frequency."
>
> (Boomsliter & Creel, 1961, p. 26)

> "Irregular frequencies produce sensations of noise, while sensations of pitch are associated with repeating frequencies…in normal hearing of a complex tone, such as a human vocal tone, with many partials, we integrate the entire complex, perceiving it through one sensation of pitch… the capacity to organise a complex by common long wave patterns is an essential for efficient perception

> of even a single normal complex tone. If this is the case, then auditory organisation of harmonies by common long wave patterns would appear to be a simple extension of the normal auditory process required in successful hearing of single tones."
>
> (Ibid., p. 9-12)

The significant problem with this theory is that listeners have been observed to tolerate deviations from true harmonic ratios without noticeable loss of either a sensation of pitch (Ward, 1954) or harmonic consonance (Plomp & Levelt, 1965). In the case of harmonic consonance, this can be seen in two specific examples. Firstly, few acoustic signals generate exactly periodic sound waves as most have naturally occurring frequency variation such as vibrato (Sundberg, 1994). Secondly, in the case of an ensemble of singers or instrumentalists playing in unison, we see the chorus effect in which not all players will be generating exactly the same frequency (Heller, 2013, p. 85). Yet in both of these cases the sense of harmonic consonance is not weakened as long as the frequency variations remain within certain thresholds.

Pitch and harmony are both highly robust phenomena that can withstand a certain amount of deviation. This suggests that harmonicity is not caused by the exact mathematical relationship between different frequencies, but rather the relation of the signal to a template, the matching of which need not be exact. The theory of harmonic ratios has had a long and illustrious history, having been argued for by individuals no less than Plato (*Timaeus,* 80b) and Galileo (ibid*.,* p. 100). Yet ultimately the relationship between harmonic consonance and frequency ratios is one of correlation rather than causation. The harmonic series naturally consists of frequencies that are related by simple ratios, but the occurrence of these ratios is simply a product of how fixed bodies vibrate and generate modes (Heller, 2013, p. 174).

In summary, Terhardt's theory of consonance and dissonance consists of *harmony* and *sensory consonance*, and these are caused by four distinct perceptual processes: the occurrence of roughness; the occurrence of sharpness; the perception of affinity between complex tones; the perception of root-relationship in harmonic chords.

Terhardt's ideas have had a significant influence on my compositions. Firstly, because his work address problems with the theory of harmonic ratios which I discuss in my pieces *I would go home but my house is on fire* (2.1) and *Dear Henry* (2.5). Secondly because Terhardt's work also demonstrates that when attempting to apply the concepts of consonance and dissonance to other elements of music it is necessary to determine the different perceptual factors involved. This is something that can be seen in my discussion of melodic consonance and dissonance in 2.3 and rhythmic consonance in 2.5. However, while I find Terhardt's approach to be the most coherent, there are two significant issues that I have with it, both of which relate to the role of template recognition. This is the topic of the following chapter.

1.3 Localised templates

The influence of learning in the perception of consonance and dissonance has been noted by a number of theorists, for example:

> It is a notable fact that certain combinations accepted as satisfactory by one listener are found to be unsatisfying to another, and this acceptance or rejection of a given chord depends very largely upon the familiarity of the ear with the chord in question - that is to say, upon the musical experience of the listener.
>
> (Cowell, 1996, p. 10)

And research has collected evidence for this, for example:

> There are long-term memory templates for common chords and when recognition mechanisms based on these templates fail this leads to cognitive incongruence and the negative affect of dissonance… The cognitive incongruence theory of dissonance was rigorously tested in Experiment 2, in which non-musicians were trained to match the pitches of a random selection of 2-pitch chords. After 10 training sessions, they rated the chords they had learned to pitch match as less dissonant than the unlearned chords, irrespective of their tuning, providing strong support for a cognitive mechanism of dissonance.
>
> (McLachlan, Marco, Light, & Wilson, 2013).

Again, we see the role of templates except this time relating to localised features such as common chords. In his paper *The Concept of Musical Consonance: A Link between Music* *and Psychoacoustics* (1984) Terhardt does not discuss the extent to which cultural learning plays a role in the perception of consonance and dissonance, stating "in the frame of this definition, a discussion of whether the consonance phenomenon is subject to cultural development (i.e., more or less arbitrary) is of little relevance" (ibid., p. 278). It seems that Terhardt would rather limit the scope of his enquiry in order to establish one universal template which determines harmonic unity. However, I would argue that it is incongruous to only partially accept the role of template learning. A more coherent position would be to accept the broader role of template learning so that it also applies to localised features such as common chords, but nonetheless maintain a special position for the harmonic template. The harmonic template will always be the primary template due to the continuous reinforcement and precedence it gains from its ubiquitous occurrence in pitch perception (Terhardt, 2000). However, other localised templates can and often are acquired, and so can also be recognised and heard as consonant. Clearly this sets up some potential conflicts: firstly, as localised templates can be inharmonic, and secondly if certain intervals that are otherwise consonant are avoided for certain stylistic reasons, do they then become unfamiliar and therefore jarring to the listener?

In regard to the first conflict of inharmonic chords becoming localised templates, there are two issues which might determine how this is resolved. Firstly, localised templates have to work within the context set by the harmonic template due to its ubiquity. This would perhaps explain why the use of chords such as the major triad seem to have developed as typical stylistic features of Western music even without composers being explicitly aware of the existence of the harmonic series (Tenney, 1988, p. 65). It would also explain why attempts by composers to establish inharmonic chords as the basis for functional harmony, for example Ives's primary sonority which he created for his *Three Quarter-Tone Pieces* (Ives, 1999, p. 112) have met with more resistance. Secondly, it does seem that there needs to be sufficient spectral density in order for either harmonicity or affinity of tones to occur. Evidence for this can be seen by comparing the results of two different experiments which both tested individual's ability to tune musical intervals. In Moran & Pratt's paper *Variability of Judgements on Musical Intervals* (1926) individuals were asked to tune two sine tones to different musical intervals and were found to be more likely to tune them to the equally tempered scale. Whereas in *Perception of Musical Interval Tuning* (1984) by Hall & Hess the same experiment was carried out by using complex tones and individuals showed preference for Just intervals. It seems that in the absence of sufficient spectral content in the sine tone experiment, the individuals relied upon localised templates. This would in turn suggest that more sparse use of harmony, such as two or three-part writing, may tend to rely more on localised stylistic template matching rather than harmonicity. This is explored in *Yes and No* (2.6).

In regards to harmonies which could become classed as dissonant if they are typically avoided for stylistic reasons, this is most likely what has happened with the perfect fourth. In terms of Terhardt's three perceptual processes set out in 1.2, the perfect fourth is consonant: it lacks roughness, the two pitches have an audible degree of affinity, and it is an interval which is part of the harmonic series and therefore shares a common root. Outside of the Western classical tradition fourths are widely used as points of stability or resolution, for example in the tuning of the Mongolian *morin khuur*, a two stringed instrument in which the strings are tuned to a perfect fourth and used as a drone (Zhang, 2009). Nonetheless numerous guides on harmony and counterpoint, such as Fux's *Gradus ad Parnassum* and Rameau's *Treastise on Harmony* classify the fourth as a dissonance. This is most likely due to the localised template effect, that is that fourths were omitted for specific stylistic reasons concerning the use of suspensions and then became atypical for this style. In isolated listening tests for measuring subjective levels of dissonance (e.g. Hutchinson & Knopoff, 1978) perfect fourths consistently rate as highly consonant, which would suggest that when context dependent factors are removed fourths are not perceived as dissonant.[1]

The second issue with Terhardt's theory is the idea that the sensation of unpleasantness, which Terhardt relates to sensory consonance, could also be caused by the absence of template matching. As Zajonc argues (1968), individuals are more likely to have a negative emotional reaction to unfamiliar stimuli. In a familiar surrounding an individual will recognise, i.e. template match, most of the objects around them. The sudden introduction of an unfamiliar object into this environment however will have a jarring and unsettling effect. It is only with repeated exposure to this stimulus that this reaction will become more positive:

> Mere repeated exposure of the individual to a stimulus is a sufficient condition for the enhancement of his attitude toward it. By "mere exposure" is meant a

[1] I would also add, from purely personal and anecdotal experience having taught species counterpoint to beginners, that the perfect fourth is the interval that students take the longest to learn to avoid. Seconds, tritones and sevenths immediately sound dissonant to them, but it seems to take longer for them to acquire the aural expectation that fourths should not occur.

> condition which just makes the given stimulus accessible to the individual's perception.
>
> (Ibid., p.1)

Repeated exposure allows individuals to acquire the necessary template to recognise the stimulus so that it becomes less jarring. The question then becomes: to what extent is it possible for template recognition to override the jarring sensation related to roughness? If a chord which has roughness becomes familiar, does it lose its jarring and unpleasant quality? As both Zajonc (1980) and Fodor (1983, p. 43) have argued, template recognition is often used instead of fully conscious cognition. For example, it is possible for an individual to navigate and interact with a familiar location without being fully aware of what they are doing. Therefore, an individual may acquire a template for a chord that allows them to recognise that chord but without having to listen closely enough to hear any roughness. Furthermore, template recognition also occurs very quickly - fast enough to be prior to conscious cognition. It may be that chords can change at such a rate that there is only enough time for the listener to recognise the templates without actually hearing any beating as this necessarily takes a certain amount of time to occur. For example, the following quote by Kyle Gann discusses J.S. Bach's use of well temperament, which Gann specifies is not an example of true equal temperament:

> [In] well temperament… each key, however, was a little different, and Bach wrote *The Well-Tempered Clavier* in all 24 major and minor keys in order to *capitalize* on those differences… In keys with poor consonances, like F# major, Bach will pass quickly by the major third, and the slight touches of dissonance give the prelude a bright, sparkly air. In more consonant keys, as in the C major prelude, the tonality is much more mellow, and Bach can afford to dwell on the tonic triad.
>
> (Gann, 2017)

Gann argues that in keys like F# major Bach uses short amounts of dissonance, but perhaps what is happening here is that the short amount of time that the imperfectly tuned major third in F# major is sounded is enough for the template to be recognised, but not long enough for the beating to be sufficiently heard.

Because they are just quickly recognising the familiar chords while also focusing on other musical elements, it could be possible for a listener to hear harmonies with roughness but not be fully aware of it. As Terhardt himself notes, sensory consonance: “tends to dominate evaluation of isolated chords” (1984, p. 281), and most studies which have generated support for the theory of roughness (see 1.2.1) used sustained and isolated chords outside of musical context. The above examples would suggest that context weakens its effect.

The tension between localised cultural learning and the more universal physiological factors is something which is explored in my pieces such as *Two Systems* (2.3), *Dear Henry* (2.5), and *Yes and No* (2.6).

1.4 Domain specificity

Another issue that has caused confusion is that individual perceptual processes only apply to certain types of signals. Fodor (1983) argues that perception and cognition are not a single linear process but involve multiple independent and parallel processes which he calls *modules*. One important feature of these modules is the concept of *domain specificity*, which proposes that individual modules are restricted in the kind of information they can process:

> I imagine that within (and, quite possibly, across) the traditional modes, there are highly specialised computational mechanisms.... The specialization of these mechanisms consists in constraints on the range of information they can access…. Candidates might include, in the case of vision, mechanisms for color perception, for the analysis of shape, and for the analysis of three-dimensional spatial relations.
>
> (Ibid., p. 47).

If this modularity also applies to auditory perception, then the perceptual processes which underpin consonance and dissonance are also domain specific. As mentioned in 1.1, there has been some disagreement regarding the unity and pleasantness concepts of consonance and dissonance, and the two sides of this debate have collected evidence in favour of their particular theories and against the opposing theories. However, this is usually due to both of these groups choosing very specific kinds of musical material which best suits their particular theory. For example, as mentioned in 1.3, most studies which support the roughness theory of dissonance focus on isolated chords and so minimise the effect of context dependent factors such as template recognition. However, cherry picking the kind of material used does not actually disprove that a particular perceptual process occurs, but rather demonstrates that it may not necessarily occur in all circumstances, as Lerdahl argues:

> To assert that a rule is universal is to claim that it represents a natural propensity of the musical mind. But even a universal principle cannot apply if the input does not trigger it. A totally non periodic rhythmic sequence will not lead to the inference of a metrical grid, nor will drum music bring principles of pitch organisation into play.
>
> (Lerdahl, 2001, p. 4)

Different perceptual processes exist but they are waiting to be engaged by the right kind of information; understanding that they are domain specific provides a means for them to co-exist. Furthermore, awareness of the territory of these domains gives the composer the potential to move between them, using different musical materials to bring different perceptual processes in and out of play. This is explored in pieces such as *Rabbit Hole* (2.2), *Dear Henry* (2.6), and *Yes and No* (2.6).

1.5 Between consonance and dissonance

Another issue which has played a significant part in my compositions is the possibility of an intermediate position between consonance and dissonance. My interest in this came about from a contradiction in the literature in which theorists have stated that consonances are to be preferred over dissonances, but then have also argued that perfect consonances are less preferable than imperfect consonances. For example, Johann Fux in *Gradus ad Parnassum* gives the following rule for two-part counterpoint:

> The rule concerning the beginning and the end is to be explained this way: the beginning should express perfection and the end relaxation. Since imperfect

> consonance specifically lack perfection, and cannot express relaxation, the beginning and end must be made up of perfect consonances.
>
> (Fux, trans Alfred Mann, 1971, p. 28).

However, he then follows this by saying:

> The imperfect consonances, then, are more harmonious than perfect ones… …Therefore, if a composition of this species, having only two parts and being otherwise very simple, too, should contain very many perfect consonances, it would necessarily be lacking in harmony.
>
> (Ibid. p. 28)

To some extent this avoidance of perfect intervals is due to the necessity of maintaining the independence of the voices as perfect intervals tend to result in a higher degree of perceptual fusion. Huron (1991) argues that the harmonic style of J.S. Bach is intended to occupy just such a position: "An analysis of 30 polyphonic keyboards works by J.S. Bach suggest the choice of harmonic intervals is governed by two predominant goals: (1) the pursuit of tonal consonance and (2) the avoidance of tonal fusion." (Huron, 1991, p. 135)

However, this avoidance of perfect consonances is also due to their difference in sonority compared with imperfect consonances. Returning again to *Gradus ad Parnassum,* Fux later on uses an interesting term when discussing the use of resolutions of dissonances in fourth species counterpoint:

> It remains to be explained which dissonances may be used if the cantus firmus occurs in the upper voice, and how they are there to be resolved. I should like to say, therefore that one may use here the second resolving to the third, the fourth resolving to the fifth, and the ninth resolving to the tenth… I have intentionally omitted the seventh… one might say, perhaps, that this resolution of the seventh is not good because it moves into a perfect consonance, the octave, from which it gets too little euphony.
>
> (Ibid, pg. 58-9)

The OED describes euphony as meaning "the quality of having a pleasant sound" (OED online, article: euphony), which by some definitions (e.g. Rameau's in 1.1) would make it synonymous with consonance. Yet euphony is the very quality that Fux claims perfect consonance lack, therefore making these terms distinct from consonance.

Similar advice to avoid perfect consonances can be found in MacPherson's instructional work *Melody and Harmony,* which also identifies a difference in quality between perfect and imperfect intervals:

> Only concordant intervals should (at present) be used. Of these, only 3rds and 6ths should be used with any frequency . . . The 8ve generally has a "thin" effect . . . The 5th being bare and empty, should be almost entirely excluded.
>
> (MacPherson, 1920, p. 9)

I would argue that this quality of euphony is a small degree of dissonance: not enough to be jarring or unpleasant, but enough to give the sound a subtle amount of intensity or excitement. In this way, the bareness of perfect intervals is their complete lack of any dissonance. With this in mind, an important feature of my compositional thinking became drawing a distinction between *consonance* and *euphony*, with the later meaning a quality of sound somewhere between consonance and dissonance.

In this way euphony can be understood as relating to the *Goldlilocks effect* (Colman, 2015), that is the idea of a point of equilibrium between two extremes. One application of this idea is that it explains how levels of complexity determine attention. Kidd, Piantadosi, & Aslin (2012 & 2014) have argued that attention is best maintained when both visual and auditory stimuli are neither too simple nor too complex. In the same way, I would argue that it can be preferable for a piece of music to occupy an intermediate position in which it is consonant enough to give it a sense of coherency and stability, but also dissonant enough to make it exciting and engaging.

This idea of an intermediate point between or a combination of both consonance and dissonance is explored in some of my pieces, including *Yes and No* (2.6) and *Concerto for Piano and Electronics* (2.7).

Part 2: Portfolio of compositions

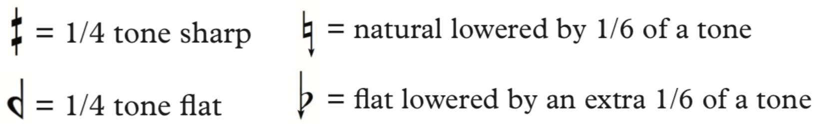
Compositional Context

As discussed in the Introduction (pp. 1-2), it had initially been my intention to establish a single coherent definition of consonance and dissonance and then apply this across the different musical elements. Underlying this intention was the belief that it would be possible to set out objective perceptual criteria on which my compositions could be based. In this way my initial approach was strongly influenced by the work of spectralist composers such as Tristan Murail and Gérard Grisey, both of whom sought to use evidence regarding how sound is typically perceived and organised by the human mind to create more rigorous compositional procedures (Fineberg, 2000). One example of this can be seen in early pieces in this portfolio such as *I would go home but my house is on fire* (2.1) and *Rabbit Hole* (2.2) which both make use of the overtone series as a basis for harmony; the reasoning for this being that this natural phenomenon provided an objective basis for harmonic consonance.

However, as is discussed in chapters 1.3-1.5, it became clear in the course of this research that defining the perception of consonance and dissonance solely in terms strictly objective criteria was not a viable approach, especially in light of the clear evidence in favour of the role of learning. The audiences learning creates expectations about the typical kinds of sounds they should expect to hear, and a desire to explore this is what ultimately led my compositional style to move away from spectralism towards two distinct areas. Firstly, there are works such as *Two Systems* (2.3) which, rather than using one objective standard of intonation, instead uses two different intonation systems and explores the tension between them. This was strongly influenced by the work of Georg Friedrich Haas, in particular his work *In Vain* (2000) which juxtaposes 12-tone equal temperament which Just intonation. Another area that the later works in this portfolio moved towards is the polystylistic and referential approach of composers such as Luciano Berio and John Oswald, both of whom explore the use of the listener's familiarity with specific styles of music in order to play with their expectations. The influence of this can be seen in the use of mash-up technique in the first movement of *Concerto for Piano and Electronics* (2.7). While this shift from spectralism to polystylism was somewhat unexpected, not least to myself, it was a logical and necessary outcome of the direction in which this research had taken me.

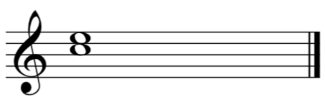
Note on microtones and intonation

This portfolio makes extensive use of harmonic tunings including extended Just intonation tunings of the 7th, 11th, and 13th harmonics. These intervals are notated to the closest sixth or quarter-tone using the following accidentals:



Due to limited availability of microtonal notation in standard word fonts, these will be referred to in the text using a combination of text and musical symbol. For example, quarter-tone intervals will be referred to as F-quarter-# or G-quarter-b, while sixth-tones will be referred to as or C-sixth-# or D-sixth-b.

Just intervals within the 5-limit system are notated using standard twelve-tone accidentals. This is because of the relationship between Just intonation and the traditional Western diatonic system, both historically and in terms of typical performance practice of non-tempered instruments (Sanchez, 2006), and is also in keeping with the notation methods used by composers such as Ben Johnston and Georg Friedrich Haas. In this way the following interval can be interpreted as either a Just or an equally tempered major third:



When one or the other is specifically required, instructions are given to make this clear, such as 'this section is to be played in just intonation'. The difference between equal temperament and Just intonation is explored in some of these pieces, for example *Two Systems* (see 2.4) requires the player to switch between both, and also the second movement of *Concerto for Piano and Electronics* (see 2.8) uses Just intonation in the electronics against the equally tempered piano.

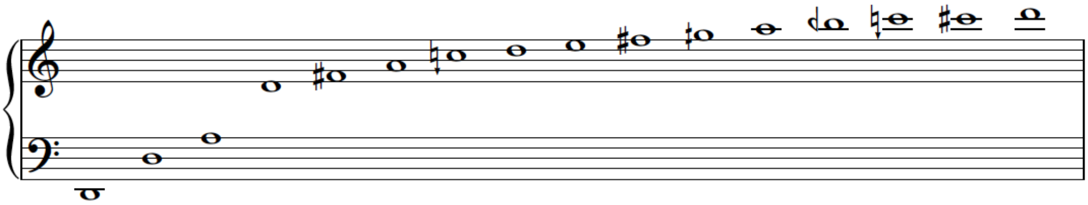
2.1 *I would go home but my house is on fire,* for Pierrot sextet

I would go home but my house is on fire is a work for violin, flute, bass clarinet, cello, piano, percussion and live electronics. The intention for this piece was to explore the use of both harmony and timbre to create consonance and dissonance, in particular to use them against each other to create opposing movements between tension and release. Timbre is defined by two distinct elements: spectrum and envelope. Spectrum relates to the frequency content of complex tones, while envelop relates to a sound's dynamic profile over time. In the following discussion timbral consonance and dissonance is used in relation to spectra and the occurrence of roughness and inharmonicity between different frequencies with a single pitch.

This piece was written at a point during my research when my theoretical understanding had not yet fully developed. For this reason, this piece is based on some erroneous ideas and its use of consonance and dissonance is not entirely coherent. In particular, I was not aware of the occurrence of multiple perceptual processes within consonance and dissonance. As can be seen in Appendix II, there are also four earlier works to which the same problem applies. However, it was through writing this particular piece that these issues were further explored and clarified, and this led to a significant development in my theoretical understanding. It is for this reason that this work has been included in this portfolio. The following discussion will present the ideas behind this piece as they were conceived at the time and then the critical assessment of them will come afterwards.

As discussed in section 1.2.3, there is a strong connection between the theories that explain the perceptual causes of harmony and pitch. Helmholtz even argues that the very practice of harmony itself developed out of the awareness of spectral frequencies in complex tones (ibid., pg. 253). As these elements are so closely related, it is possible that the same applies to their perceptual causes of consonance and dissonance. The composition of this piece was strongly influenced by Boomsliter & Creel's approach to this issue (see 1.2.3) and treats timbral consonance and dissonance as being determined by periodicity. In this way, timbral consonance is understood as being clear tones with unambiguous sense of pitch, while dissonance comes from adding noise to these sounds using techniques such as flutter tongue and the addition of distortion by the electronics.

In regard to harmony, this is a role substantially taken by the electronics. Although the piece is written for Pierrot sextet, it does have an enhanced role for the bass clarinet and piano, both of which have their signal taken via two microphones and sent through a Max/MSP patch for live processing. This processing consists of 16 separate delays which use very short delay times (between 0.45-6.81ms) and high feedback levels (90-96%) to create resonances which are then mixed with the direct signal. The timing of these delays are set so that the resonances they produce correspond to the first 16 frequencies of an overtone series starting on D2:



Ex.5: first 16 partials of harmonic series on D2.

The Max patch also includes a volume tracker which monitors the volume of the signal from the bass clarinet and the piano and uses this to control the volume of the resonant delays. This means that they are only heard when the bass clarinet and piano are playing, making them act as an accompanying background drone. The reason for using the electronics like this was because it allowed the piece to explore the idea of abstract harmony, that is the role that harmony can play in music even when it is not actually present. For example, as Rosen argues:

> Modulation in the eighteenth century must be conceived as essentially a dissonance raised to a higher plane, that of the total structure. A passage in a tonal work that is outside the tonic is dissonant in relation to the whole piece, and demands resolution.
>
> (Rosen, 1997, pg. 26)

This idea of residual harmony allows harmonic dissonance to play a functional role even if it was not actually present. It can also be related to Fred Lerdahl's concept of *tonal pitch space*, in which he argues that melodic tension is determined by a note's relation to a tonic: "In a hierarchical view, tonic orientation establishes the point of stability against which the instability of other events is measured." (Lerdahl, 2001, pg. 142).

In my previous experiences using electronics alongside live players it has often seemed that the electronics occupy a peculiar role: they are audibly there, yet physically absent, almost as if they exist abstractly apart from the live players. In this way, the role of the electronics was to be this kind of abstract harmony with everything that the bass clarinet and piano play being heard against the 16 drones tuned to a harmonic series on D.

The other role taken by the electronics that also creates a type of dissonance in this piece is a hard clip distortion effect which adds significant amounts of noise to the signal played by the bass clarinet and the piano. The Max patch was designed so that this distortion would not be added to all of the signal, but only those frequencies which relate to the harmonic series on D. This was achieved by adding a comb filter EQ before the distortion, the peaks of which were tuned to the frequencies of the D harmonic series so that only those frequencies would be loud enough to be distorted. The intention here was to create a conflict between harmony and timbre - when the bass clarinet or the piano play notes which do not relate to the harmonic series on D, harmonic dissonance is heard, but when they play notes which do relate to the harmonic series on D harsh distortion is heard.

The first main section of the piece (bars 1-38) begins with the bass clarinet playing an extended solo melody which creates tonal tension against the electronic drones by moving between various degrees of the chromatic scale. The specific degrees of the chromatic scale were chosen in order to gradually build the tension throughout bars 1-9, eventually reaching the greatest level of harmonic dissonance in bar 9 where the bass clarinet plays the notes Db3 and Eb3. This then resolves in bars 10-11 as the bass clarinet returns to D, and then in bars 12-15 the rest of the ensemble reinforce this by sounding notes of the D harmonic series.

At bar 16 (letter A) the piece then begins a second movement towards harmonic dissonance, this time with the bass clarinet playing even more dissonant quarter-tone intervals against the electronic drones. Then at bar 21 the bass clarinet introduces the first use of timbral dissonance in the piece by playing flutter-tongue which adds noise to its tone, and this is supported by the percussion which uses a pair of maracas to create pitch-less noise. Eventually at bar 28 the piece resolves again by moving back to the tonic, and the bass clarinet and the piano play an extended section in which they sound only notes from the harmonic series (see bars 28-38). Harmonically this section is consonant, however due to the frequency selective distortion effect this section is timbrally dissonant.

The second main section of the piece starts at bar 39 (letter B) and lasts until bar 62. The main idea of this section was to explore Rosen's idea of modulation as dissonance. It primarily consists of the flute, violin, cello, piano and percussion playing simple repetitive which are harmonically consonant and, even though this piece was primarily intended to explore harmonic and timbral consonance and dissonance, it was also decided to make these ideas melodically and rhythmically consonant by making the figures melodically repetitive and limiting the rhythms to demisemiquavers in all parts. However, despite being consonant in themselves, these figures are dissonant in relation to the electronic drones as they are in a natural G# minor scale. The second section then continues repeating these figures but uses the dynamic changes in the piano part (e.g. bars 45-50) to raise the level of the electronic drones making them increasingly clash against the live instruments. This continues to bar 58 where the music reaches a dynamic climax and the piano begins to play triplet quavers against the other parts to add some rhythmic dissonance. This climax coincides with the return of the bass clarinet, at first playing a C#4 in harmony with the other instruments, and then in bar 59 moving to D4 to instigate a return back to the key of the electronic drones.

This section (bars 63-70) acts partly as a re-transition which reaffirms the original tonic of the piece, but it is also the most dissonant part of the piece in which the instruments fight most strongly against this tonic. The bass clarinet uses two main notes, D4 and A4, but bends their pitch in order to create harmonic dissonance against the drones, as well as using harsh flutter-tongue to create timbral dissonance. Underneath this in bars 67-69 the flute, violin and cello add their own pitch bends to create further harmonic dissonance, and the maracas again create noise.

The final section of the piece (bar 71/letter D to the end) then focuses once more on the opposition between the harmonic drones and the frequency selective distortion effect. The piano first plays a series of broken chords, some which clash against the drones (bars 71, 72, 74, and 75) and some which trigger the distortion effect (bars 73, 76, and 77). Then from bar 78 the bass clarinet plays a series of melodic phrases all of which start off from a point of tonal tension and therefore clash against the drones, and then move towards the tonic and so eventually arrive on a note that creates distortion and timbral dissonance. The ending of the piece was intended to be ambiguous with the bass clarinet playing a final F-quarter-#4 which is not harmonically related to the electronic drones, but also avoids triggered the distortion effect.

As mentioned earlier, the composition of this piece was the cause of significant development in the understanding of consonance and dissonance of this project, and one particular element of this piece that brought this about was the use of the maracas in bars 21-24 and 67-70 to create noise. As discussed above the use of noise in this piece was intended to be a form of timbral dissonance. However, on hearing the piece in performance the use of maracas did not come across as particularly dissonant or jarring, in fact they sounded fairly calming. For example, in bars 67-69 the ensemble plays a chord which becomes more harmonically dissonant through the use of pitch bending, and the maracas playing white noise along with it. After this (bar 70) the maracas play solo for one bar, and this sounds much more like a consonant resolution than a continuation of the dissonance. It was through further research and in particular through reading the theories of Helmholtz and Terhardt (see 1.2) that it became more clear that the sense of dissonance created by distorted or noisy sounds is not solely due to the fact that these sounds are aperiodic, but also because these sounds also have an audible amount of roughness caused by the beating of closely related frequencies. The pitch-less noise created by the maracas is inharmonic but cannot be considered to be dissonant as it lacks roughness.

Another issue with this piece is the inconsistent use of 12-ET and just intonation. For example, as mentioned above in bars 12-15 the entire ensemble sound pitches from a harmonic series on D. The strings and woodwinds play pitches which are correctly in tune with the harmonic series, in particular the cello and the flute both play non 12-ET pitches. However, against this the piano and the vibraphone, due to their fixed 12-ET intonation, both play pitches which are only approximate the true harmonic tunings. In the case of the piano this includes a C6 which is 33 cents sharp of true harmonic tuning, and a G# which is 49 cents sharp. 12-ET approximations of just intonation have a different quality to true just intonation, as the composer Kyle Gann has commented:

> I've had interesting experiences playing just-intonation music for non-music-major students. Sometimes they will identify an equal-tempered chord as "happy, upbeat," and the same chord in Just intonation as "sad, gloomy." Of course, this is the first time they've ever heard anything but equal temperament, and they're far more familiar with the first sound than the second. But I think they correctly hit on the point that equal temperament chords do have a kind of active buzz to them, a level of harmonic excitement and intensity.
>
> (Gann, 1997)

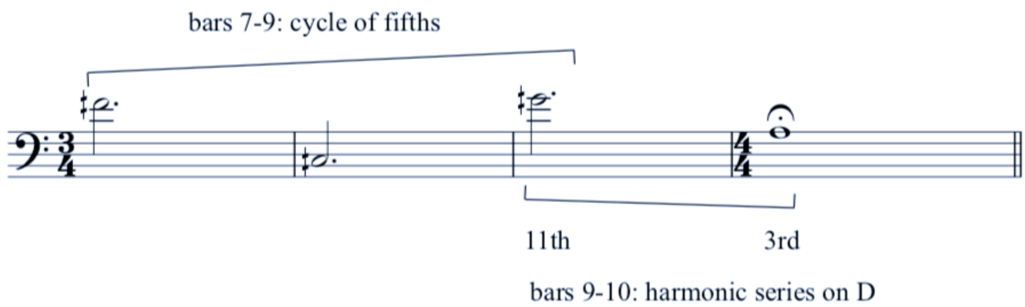
This means that the chord in bars 12-15 has a mixed quality to it as it combines elements of both just intonation and 12-ET. The same also applies to the piano part in bars 28-36 in which it plays rising figures based on harmonics 8-12 (D4-A4). Again, some of these pitches, F# and G#, are only approximations of the true harmonic tunings, while the electronic drones underneath it are tuned to just intonation. While being enjoyable to listen to, this mixed quality was not something I was fully aware of when composing this piece, and another lesson learned from this was that in future pieces closer attention should be paid to differences in intonation when using both equal temperament and just intonation.

2.2 *Rabbit Hole,* for solo cello and electronics

The second composition completed during this project was *Rabbit Hole* for solo cello and electronics. As with *I would go home but my house is on fire* (2.1) this piece explores the use of timbral consonance and dissonance in relation to spectra, however this time with a clearer understanding of the multiple perceptual factors involved. The first factor is roughness which Lerdahl argues can occur within a single tone (1987, p. 141). Tonal sharpness (see 1.2.1) also plays a role, with the cello using very high piercing tones with strong high frequency spectra. Another factor is the use of harmonicity with the cello using clear pitched tones played ordinario to create timbral consonance, and then later using sul ponticello to make the sense of pitch more ambiguous.

The electronics in this piece consist of live processing of the cello in Max/MSP, in this case 8 oscillators whose pitch and volume are taken from live readings of the cello using the object [fiddle~]. The original plan was to have a single oscillator which would follow the cello using the readings, the idea being that the similarity between the cello and electronics would be a type of consonance. However, it soon became clear that [fiddle~] was too sensitive to create a consistent imitation of the cello part. It would rapidly respond to small variations in pitch, or even occasional bits of noise such as when the cellist changed bow direction, and this would result in the oscillator fluctuating unpredictably. In order to avoid this, I decided to slow down the rate at which [fiddle~] output its readings by adding a trigger to the patch which would only send the readings through to the oscillator at a regular interval, e.g. every 700ms. This fixed the unpredictability, but it then meant that the single oscillator would now jump awkwardly from reading to reading. A pitch glide effect was tried in order to create smoother transitions between the different pitches, however this just sounded comical. So instead, I decided to have multiple oscillators each of which would in turn receive a reading from [fiddle~] and then fade in and out to introduce their new pitch. This created two effects: firstly, it a freeze effect in which single notes in the cello's melody line were suspended in time, albeit in a digital imitation; and secondly it turned melody into harmony as the oscillators held different pitches from the cello's melody.

The opening section (bars 1-33) starts with the cello playing a melody which moves between fermatas. The electronics take a reading from the cello once every 700ms resulting in pitches from the melody being sustained and creating harmony. The intervals of the cello's melody were specifically chosen to create different degrees of harmonic dissonance, for example bars 1-3 create consonance because the sustained notes all relate to the harmonic series on D, whereas in bars 5-6 the D4 and Eb3 are more dissonant. In bars 7 the cello then moves to F-quarter-#4 in bar 7 which is dissonant against the Eb3 from the previous bar. However, as shown in example 6 below, the following bars are also in quarter-tones and proceed in a cycle of fifths. This moves the harmony of these bars back towards consonance and acts as a quarter-tone modulation, shifting the tonal orientation away from D. However, the G-quarter-#4 in bar 9 then acts as a pivot note as it is also part of the harmonic series on D, and from this the cello moves back to its opening note of A3 which is part of the same series.



Ex.6: cycle of fifths starting on F-quarter-#4, and pivot back to harmonic series on D

As mentioned above, one of the types of consonance explored in this piece is the relationship between the cello and the electronics, and up to this point it has been fairly symbiotic. However, the main narrative of this piece is that the cello increasingly sees the electronics as an intrusion and tries to evade them by playing material that [fiddle~] is less able to accurately follow. This includes multiple notes at the same time, rapidly changing notes, and noisy or distorted timbres, which means that the next section begins to move more towards dissonance.

At bar 11 the cello plays rapid broken chords, first as two note tremolos, then as arpeggios in bars 13-15. These broken chords are related to the same harmonic series, so there is some degree of consonance in the harmonies created by the electronics. However, due to the decreased accuracy of the [fiddle~] readings, these harmonies will contain some random frequencies caused by reading errors. Now there are two types of dissonance working together to create an overall sense of tension: firstly the cello and the electronics are dissonant in relation to each other as the harmonies in the electronics do not accurately relate to what the cello is actually playing; and secondly the harmonies are dissonant due to the occurrence of inharmonicity.

Next, in bars 19-23, the cello plays a continuous glissando centered around the note A3. As this is a single note the electronics can follow the pitch much more accurately, so in this sense the music is now consonant. However, as the cello is playing only within a very small interval, the resulting harmonies created by the electronics have audible roughness. Now the two different types of dissonance are working against each other. This then leads to harmonic consonance in bars 25-33 as the cello plays an open harmonic glissando along the D string, and the electronics turn the frequencies of this glissando into a harmonic chord. Now the two different types of consonance are reinforcing each other, as the relationship between the two parts is consonant and so are the harmonies.

In the next main section (bars 34-58) the cello once again tries to evade the electronics, this time with timbral effects such as sul ponticello and tremolo to add noise and distortion to the sound. Part of the intention of this section was to explore the grey area between timbre and harmony which is a typical feature of spectralist composers such as Gérard Grisey and Tristan Murial:

> The opening sonority of *Partiels* [by Grisey] is similarly a harmonic spectrum on fundamental E, with the open E string of the double bass very prominent… The resultant object is much more than just a chord: it is a timbre, or a sonority which is ambiguously somewhere between harmony and timbre.
>
> (Anderson, 2010, pg. 8)

In bars 34-46 the cello plays single notes while gradually transitioning between sul tasto and sul ponticello and also occasionally adding tremolo. This is timbrally dissonant, firstly because the sul ponticello makes the cello's pitch less clear, and secondly because it adds noise and distortion. These timbral effects also mean that the [fiddle~] object cannot accurately follow the cello, and so once again the readings include errors which cause inharmonicity. At bar 47 the cello once again begins to play more than one note at a time, starting with double stops, then tremolos on different notes, and then arpeggios across all four strings. In each case it further confuses [fiddle~] so that the harmonies created by the electronics become more dissonant.

The next main section of the piece is bars 59-81. Having had some success at evading the electronics, the cello then tries to go even further and begins playing rapid bursts of notes. The electronics respond accordingly and increase the rate of readings from the [fiddle~] object to once every 18ms. The cello then tries less clearly pitched techniques such as percussive ricochet in bars 72-75, and left-hand tapping on the fingerboard in bars 75-77 in order to further confuse the electronics. Both of these techniques reduce the accuracy of the [fiddle~] object to some extent, but not enough that the electronics are completely lost.

In bars 82-108 the cello tries yet another approach and begins to play very high harmonics at such a low volume that it is below the detection threshold of the [fiddle~] object. Due to the difficulty in accurately finding very high harmonics the notation was made partly indeterminate in this section, specifying only the string on which the harmonics should be played and an approximate sense of melodic contour. In particular this section was inspired by Sofia Gubaidulina's use of harmonics in her piece *Rejoice! Sonata for violin and cello* in which their use was intended to be a form of transformation:

> The theme of my work *Rejoice!* is the metaphorical presentation of the transition to another reality, expressed by means of the juxtaposition of normal notes and harmonics. The string instrument's ability to produce notes of different pitch at the same position on the string cab be experienced musically as a transition to another level of reality… it is a question of experiencing these sounds not merely as a timbre, a colour effect, a veil before something, but also as that thing's very essence, the essence of its form as a "transfiguration".
>
> (Cholopov, 1993)

The cello is trying to reach a place where it cannot be followed by the electronics, however it is unable to maintain this extreme position and gradually begins to play loud enough to detected. Due to the high position of the cellist's left-hand fingers, the position of the bow is molto sul ponticello, which means that the timbre of these high pitches is distorted and harsh. This then means that there is audible dissonance in the timbre of these sounds, and also the harmonies produced by the electronics are inharmonic due reading errors by [fiddle~].

At bar 109 the cello returns to the rapid bursts of notes from bars 59-81. This time they build to a climax in bar 122 as the cello plays a rising scale up to a sustained D5, which due to its position high on the top string has a great deal of tonal sharpness. In bar 124 the cello then restates this D5 but then begins to apply overpressure until the sound becomes heavily distorted. As the [fiddle~] object is designed to detect pitch, its only response to the cello's overpressure is to output a stream of random frequencies. In terms of their relationship, the cello and the electronics are consonant as they are both producing highly dissonant sounds. The cello then continues to play sustained notes moving in and out of overpressure until bar 143, with occasional reprises of the rapid bursts of notes from bars 59-81. All of these are followed by the electronics, with the overpressure causing it to output random frequencies.

The coda of the piece starts at bar 144 and acts as a final resolution to the preceding drama. The cello bows very lightly on the strings and the body to create soft noise that is consonant because, although it is inharmonic, it lacks roughness. Underneath this the electronics gradually return; however, these remain highly chaotic because once again they are trying to find pitch in a signal that only contains noise. Now the relationship of the cello and the electronics is dissonant because the cello has moved to a different perceptual domain in which pitch is no longer a relevant factor while the electronics remain stuck in the pitch domain and therefore cannot read the cello's signal. This is the rabbit hole of the title: the cello has finally managed to reach a place where it cannot be followed by the electronics, and in this place it is able to achieve a resolution by moving towards consonant noise.

2.3 *Two Systems* - introduction

The third piece completed in this project is *Two Systems* for tenor trombone and electronics which explores the tension between melodic and harmonic consonance and dissonance. To some extent melodic consonance and dissonance has already been explored in *I would go home but my house is on fire* (see 2.1)*,* however this use of melody was focused on what I would call *harmonic melody,* that is a melody moving against a perceived tonal centre which creates various degrees of tension. The intention for this piece was to also focus on melody in its own right, rather than just as an extension of harmony. Here the factors explored are melodic contour, pitch set, and intervallic self-similarity. The context for these factors is discussed in the following section 2.3.1, how these ideas are explored in the piece is discussed in section 2.3.2.

2.3.1 Melodic consonance and dissonance

Dowling (1978) argues that melodic perception can be separated into two distinct elements: scale and contour. In regards to contour, Heise and Miller (1951) have shown that a sequence of tones which follow a simple contour, such as an ascending or descending scale, will be heard as perceptually unified. In particular, this research demonstrated that if one tone was detuned so as to deviate from its expected position in a contour it would be heard as a separate 'pop' that stands out from the rest of the sequence:

> This effect is quite marked, as if the isolated tone came from a separate sound source completely independent of the background pattern. If the frequency of the variable tone is now gradual changed so as to bring this tone back into the pattern, the 'pop' becomes progressively less distinct until the tone finally merges into the pattern, losing its separate identity.
>
> (Ibid, p.72)

Bregman argues that this is an example of *schema-based stream integration,* that is the perceptual fusion of separate tones or events according to some form of regularity, such as repeated patterns, regular spacing in time, and simple contours (1990, pp. 395-453). In this way a consonant melodic contour is one which follows a clear and simple trajectory, whereas a dissonant contour is more irregular and unpredictable, for example the following excerpt from Pierre Boulez's *Dialogue de l'ombre double*:

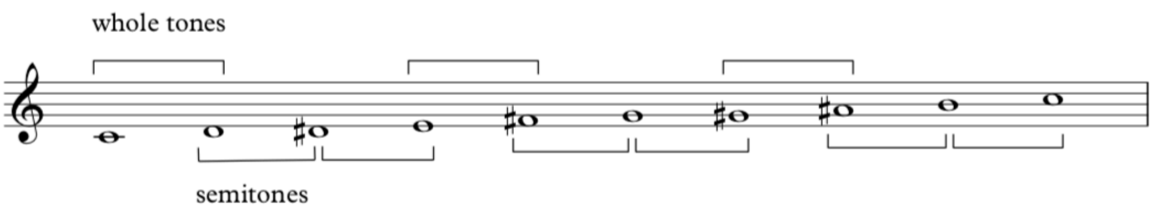
Ex.7: Boulez, P. *Dialogue de l'ombre double,* bars 25-27

Consonance in melodic contours does not only occur within individual contours but can also occur between different melodic phrases. At its strongest this would consist of two phrases with the same or highly similar contours, as well as those with related contours such as inversion or retrograde. Therefore, dissonance would be two melodies with completely unrelated contours.

Dealing next with scale, Dowling uses this term to refer to the set of pitches that make up a given key or mode. However, following on from Forte's work on set theory (Forte, 1977) I will separate scale into the two distinct elements of *pitch* and *interval*, as these are able to function separately.

For pitch, the most basic type of consonance is a repeated pattern such as a motif. A repeated pitch pattern forms a localised template which is stored in the listener's memory, and any subsequently melodic phrases will be compared to it. After this, the next type of pitch consonance is different melodic phrases which belong to the same pitch set (ibid., pp. 1-2), as these are likely to be perceptually related. Pitch set dissonance is caused by the introduction of pitches from outside the established set which are likely to be heard as surprising and jarring. This can occur either as contrasting phrases made from different pitch sets, for example Schoenberg's use of complementary hexachords to create contrast in his *Drei Klavierstücke,* Op. 11 (Forte, 1972); or it can occur as a single note, for example the sudden occurrence of a C# in the context of an A minor which would sound jarring and like a 'wrong' note. In regard to the size of the pitch set, Dowling argues that consistency of pitch set is strongest in sets of around 7 notes or less (ibid., p. 343). This idea is supported by the research of Krumhansl (1990, pp. 241-253), which shows that above this limit listeners are more likely to lose a sense of orientation in a pitch set and are therefore less likely to be able to discriminate between members and non-members. In this way, pitch set consonance is more likely to occur in smaller sets.

In regards to intervals, once again a repeated pattern of intervals is a type of consonance. As Perle argues (1992, p. 81) every musical interval has a distinct character or *identity*, and in this way repetitions of distinct intervals can give a melodic line a sense of unity. This can be seen, for example, in interval cycles such as the cycle of fifths. The distinction between a pitch pattern and an interval pattern can be seen in the difference between a tonal sequence and a modulatory sequence. Both are examples of a transposed repetition of a melodic pattern, however the tonal sequence maintains the pitch set but changes the exact pattern of intervals, whereas the modulatory sequence moves out of the established pitch set but maintains the exact intervallic pattern. It is possible that this is why the use of sequence is so common as a means of modulation in the Classical and Baroque styles: the sense of consonance created by the interval pattern compensates for the pitch set dissonance created by the change of key. A similar effect can also be seen in Messiaen's modes of limited transposition (Messiaen, 1956, pp. 58-63) in which scales are created by the use of repeated intervals. In some cases, these modes contain large pitch sets of 8 or more notes, however the lack of pitch set consonance is ameliorated by the use of repeated interval patterns:



Ex.8: Messiaen's third mode of limited transposition with a repeated interval pattern

In this way, sequences and the repeated patterns of Messiaen's modes can be seen as double schemas, consisting of a repeated pattern and a simple rising trajectory on which that pattern is repeated.

As well as patterns, interval consonance can also occur in terms of sets, that is groups of one or a few distinct interval identities. Forte uses a similar idea in his interval vectors (Forte, 1977, pp. 13-16), the purpose of which is to identify the intervals which can be created by all possible permutations of a pitch set. For example, the pitch set [C, C#, E, F#] has an interval vector of [111111]: it contains each interval once and therefore has a high degree of intervallic variety. In contrast to this the whole-tone scale has the interval vector [060603]: between all of the possible combinations of notes in the whole-tone scale there are 6 different major seconds or minor sevenths, 6 different major thirds or minor sixths, and 3 tritones. This means that the whole-tone scale has a high degree of intervallic self-similarity.

However, I am proposing to use interval set as a distinct concept from interval vector. An interval set is not all of the possible permutations of intervals in a fixed pitch set, but rather a collection of distinct interval types which are used in successive melodic motion. In this way, a melody which proceeds only in semitones then has an interval set of 1, even though it may contain all 12 pitches. A melody that uses only whole-tones and semitones therefore has an interval set of 2, and so on. Small interval sets contain fewer distinct identities in melodic movement and are therefore more self-similar and more consonant than large interval sets. An example of the use of interval set consonance can be seen in the tone row for Webern's *Concerto for Nine Instruments,* Op.24 (1934) which is a derived row consisting of four segments, each of which moves only using the same two melodic intervals:

Ex.9: Row from Webern, *Concerto for Nine Instruments,* Op. 24 (1934)

Schoenberg's original intent in developing Serial technique was to find a means of creating perceptual unity in twelve-tone music. However, as Krumhansl has shown (1990, pp. 241-253) twelve-tone melodies are difficult for listeners to memorise and recall. Each segment in Webern's row above consists of the same two melodic intervals, and so a sense of interval set consonance between the individual segments compensates for the sense of pitch set dissonance.

2.3.2 *Two Systems,* for solo tenor trombone and electronics

As mentioned above, the intention of this piece was to explore the tension between melodic and harmonic consonance and dissonance. This is achieved through the use of two different scales, one for melody and one for harmony. The idea for this approach came from my own training as a string player in which I was taught to use different intonation systems for melody and harmony. This is a technique used and taught by a number of string players, including Casals (Cherniavsky, 1952), Sassmanhaus (2012), and Kimber:

> We continually urge our students to listen intently, but it is not usual to ask them to "listen melodically" of "listen harmonically", since it is not commonly understood that these two ways of listening differ. When playing melodically, we are listening to notes one at a time in succession… Melodic intonation tends to follow the pattern of *Pythagorean tuning,* derived from a succession of perfect fifths that includes our open strings. When tuning harmonically, we are listening to more than one note at the same time… The tuning of harmonic intervals is influenced by harmonics, present in every note we play… Tuning every interval to simple harmonic ratios is known as harmonic tuning.
>
> (Kimber, 1992, p. 59)

The difference between these two tunings, the Pythagorean and Just intonation, is that the Pythagorean has a higher degree of intervallic consistency, as Richter states:

> The derivation of the major third F# [above D] via a natural third leads to a small interval and smaller whole-tone step E-F#. If the scale intonation is constructed in this way, we will indeed face a heterogenous structure within the two tetrachords. The Pythagorean scale has the advantage of being based on homogenous tetrachords and does dispense with two type of whole-tones… If we play [plays example - major third] as a stand-alone aspect of harmonic texture (e.g. a repeated major chord), we will instinctively and justifiably lower the major third (F#) to avoid the resulting beat from a wider (impure) third and adjust to produce an interval close to the just major third. If however we play the same interval in a melodic context, that is, in the context of a melodic progression of some kind, we will be inclined to treat the F# as a leading tone and accept the out-of-tuneness of the major third which suffers from a sharpening of the F#.
>
> (Richter 2006, p. 4)

The Just intonation diatonic scale has two different types of whole-tone interval: a wide whole-tone between the first and second scale degrees which corresponds to the ratio of 9:8, and a narrow whole-tone between the second and third scale degrees which has a ratio of 10:9.

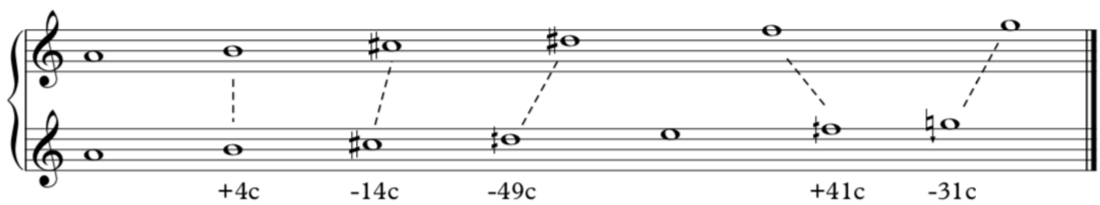
Both of these have distinct identities. In contrast to this, Pythagorean intonation only has one type of whole-tone interval and therefore is made up of a more limited interval set. I propose that this is why Pythagorean intonation is preferred for melodic playing over Just intonation: it is melodically more consonant.

The intention of this piece was to use two different systems for melody and harmony but extending it beyond just different intonations of the same scale to actually having two different scales. The melodic material of this piece is based on a whole-tone scale starting on A; this was chosen firstly because it is based on a limited pitch set of only 6 notes, and secondly because it is based on a limited interval set. In order to ensure intervallic consistency, the player is specifically asked to play this scale in equal temperament. In contrast to this the harmony of this piece is based on the harmonic series, also starting on A, which due to the asymmetry has little intervallic consistency. When playing in this scale the trombone is specifically requested to use Just intonation.

The opening section (bars 1-10) consists of an unaccompanied trombone melody based on the whole-tone scale. The contours of the trombone's phrases are written so that they are audibly related, for example in bar 1 opens with a two-note ascending figure which is then immediately answered by its inversion. The same idea is then repeated in bar 2 but this time with a simple extension which turns it into a three-note figure, and then again in bar 3 but this time as a four-note figure. Bars 4-6 is a simple variation on the first 3 bars, this time with the melodic steps occurring in major thirds rather than whole tones. The intention here was to create some development in the melodic line, but in a way that still gave a clear sense of audible relation. The trombone then plays the whole-tone scale in a simple descending melodic contour in bars 7-8, and finally restates the melodic material from bars 1-2 in bars 9-10. Part of the purpose of this opening section was acclimate the listener to the whole-tone scale so that they became familiar with it as a schema and from this have expectations about what will follow.

The next section (bars 11-32) marks the first entry of the electronics which are based on frequency modulation (FM) synthesis (Chowning, 1973). The Max patch contains four carrier oscillators which are fixed at the frequencies 110Hz, 220Hz, 330Hz, and 440Hz. The frequency of the oscillator that is used to modulate each of these carrier frequencies is taken from the live trombone signal using, once again, the [fiddle~] object. As with *Rabbit Hole* (2.3) the setting for the modulator frequency is only taken at specific points in the piece. These are triggered live during the performance and are marked in the score by crotchet notes on a separate line named ‘Elec.’. The resulting complex spectra created by the FM synthesis are then heard as drones accompanying the live trombone.

One of the principles of FM synthesis is that when the carrier and modulator frequencies are harmonically related, the resulting complex tone is also harmonic and therefore consonant, whereas when the relation is inharmonic the resulting complex tone is dissonant. In this piece, the frequencies of the four carrier oscillators are tuned to the first four harmonics of a harmonic series starting on A2. As the whole-tone scale does not always harmonically align with the carrier frequencies, this then creates a tension in the piece. In example 10, the two scales can be seen: on the top line is one octave of the whole-tone scale; and on the second line are partials 8 to 14 of the harmonic series. The figures underneath the notes of the harmonic series show in cents how far off these notes are from their closest pitch in the equally tempered whole-tone scale. Generally anything above 10-15 cents is considered enough to be above the range of just noticeable difference and will be heard as out of tune (Heller, 2013, pg. 473).



Ex.10: Intonation of the whole-tone scale in equal temperament (upper stave) compared with partials 8-14 of the harmonic series (lower stave).

As can be seen, the first two notes of the whole-tone scale A and B match the harmonic series closely enough. The C# of the whole-tone scale is slightly sharp, although this is usual for equal temperament and not excessively dissonant. However, the upper three notes of the whole-tone scale, D#, F and G are significantly out of tune with the harmonic series and so create a conflict for the trombone. It can either maintain melodic consonance by staying within the limited interval set and self-similarity of the whole-tone scale, or it can leave the whole-tone scale to align harmonically with the drones. Either way the choice is between one of two systems neither of which cannot provide a perfect resolution, and it is this tension that plays out for the rest of the piece.

In bars 11-32 the trombone plays a series of sustained notes which move between different degrees of dissonance with the electronics, both in terms of these notes being heard against the electronic drones, and also in terms of these notes setting the frequency of the modulation oscillators. Eventually at bar 23 the trombone begins to move out of the whole-tone scale and move towards the harmonic series in order to align with the electronic drones, however this is just the first small introduction of this and at bar 33 the trombone returns to the whole-tone scale and begins to restate its opening melodic material.

This opening material is then developed during bars 36-56 in a melodic line which grows increasingly dramatic. Firstly, the trombone's melodic contours become more irregular, an effect which is also mirrored by the dynamics; and secondly notes which are used to set the modulation frequencies are increasingly those which do not align harmonically with the carrier frequencies, such as D# and F. This eventually builds the tension between melody and harmony and leads to the section in bars 56-59 in which the trombone moves between E and D#, the sense here being that the trombone is being repeatedly pulled from one scale to the other.

The climax of the piece occurs in bars 60-64 as the trombone states the whole-tone scale in its entirety ascending from A3 to A4. A reading for the electronics is taken from each of these notes so that as the trombone moves up the scale towards D#, F, and G, the electronic drones become increasingly dissonant. After sounding the top A in bar 63 the trombone then switches scales and falls in bar 64 to a G4 which is in tune with the harmonic series, that is 33 cents flat of the G from the whole-tone scale. This is intended to sound ambiguous: in one sense it is melodically dissonant and jarring due to its being out of tune with the whole-tone scale stated in the previous bars, while in another sense it is harmonically consonant as it is in tune with the harmonic series. Following this, the trombone then proceeds to sound various pitches from the harmonic series, the effect here is that even though the trombone is now in tune with the electronics it has lost its sense of intervallic consistency as its melodic intervals are now irregular.

From bar 71 to the end the trombone restates a shortened version of the material from the beginning of the piece with the drones quietly present in the background. The is no compromise or resolution between the two systems and as the drones recede the trombone simply returns to its opening position.

2.4 *An intense and unpleasant excitement,* for solo flute and electronics

The fourth piece completed in this project is *An intense and unpleasant excitement,* for flute and electronics. The initial idea for this piece was to explore the use of roughness both in sustained tones and rhythm. This is based on the idea that, as beats are a temporal phenomenon, they could also be used to create rhythmic dissonance. To achieve this, one feature of the electronics is a sequence of rhythmic clicks that oscillate back and forth across a set of loudspeakers, eventually reaching rates of between 20-30 per second. The title of this piece refers to Helmholtz's description of roughness discussed in 1.2.1.

The use of flute with sine waves, and electronic clicks in this piece were chosen for their contrasting ability to be localised spatially by the listener. As the electronic clicks were intended to move in space, it was important that they could be easily localised, and as has been shown sounds are easiest to aurally locate when they have short transient profiles (Yost, 2017) and high frequency content (Musicant & Butler, 1984). In contrast, the sustained tones played by the flute are harder to locate due to their lower frequency range and lack of clear transient attack. In this way the flute part would remain more aurally fixed while the electronic clicks were heard to move around it and so helping to maintain a sense of differentiation between the two parts. This choice was also influenced by the works of Alvin Lucier, in particular pieces such as *947* (2001) for flute and pure wave oscillators, and also *Vespers* (1968), for echolocation devices.

The piece begins with the introduction of beating in its conventional context of sustained tones. The flute plays three sustained notes on A4 underneath which the electronics produce a sustained frequency of 440Hz. Each of the flute's sustained tones is sharpened slightly in order to create beats against the sine tone, and then lowered back down, causing the beats to speed up and then slow down (the approximate speed of these beats is specified on the electronics line above). Each time, the degree of pitch bend is increased, so that by the third time the beats are fast enough (ie. 20-30 per second) to cause audible roughness as described by Helmholtz (see 1.2.1). At bar 10 the flute adds to the sense of dissonance by also playing harsh flutter-tongue.

These are the two distinct ideas which will be developed in this piece: the roughness caused by the rapid beats, and the gradual speeding up and slowing down of the beats. The rhythmic roughness is a form of dissonance; however, it is my proposition that these gradual changes in speed are a form of rhythmic consonance. Coherent and predictable changes of speed such as an accelerando or a rallentando are another example of schema as discussed in 2.3, and I will refer to these as *rhythmic contours*.

At bar 14 the flute continues the rhythmic contour idea by playing an articulated accelerando whilst bending the pitch of the note from A5 to Bb5, the idea being that both the beats and the speed of the flute's articulations speed up together. The reverse of this then plays out in bars 16-18. Bars 19-41 then develop this use of rhythmic contour further, with the flute and the electronics both playing a series of overlapping accelerandos and rallentandos. For the flute these contours occur as trills and turns which gradually speed up and slow down, while in the electronics these contours occur as a sequence of clicks which oscillate across the speakers. As well as speeding up, these contours also increase in width; the flute gradually widens its range of pitches, while the electronic clicks gradually cover a greater panning width.

Another effect used here is the point at which the accelerandos seem to reach the limit of perceptible speed. At the height of each accelerando, the flute trills and the electronic clicks lose their individual articulations and begin to create a blur of sound. This is an example of a perceptual transition as the musical material crosses from one domain into another. These different domains can be seen as being on different sides of a distinction made by Bregman regarding primitive and schematic perception:

> There are two different processes in the construction of auditory representations, one that I will call primitive scene analysis and the other schema-driven construction of descriptions. The use of the word primitive is meant to suggest that the process is simpler, probably innate, and driven by the incoming acoustic data. The schema-driven (hypothesis-driven) is presumed to involve the activation of stored knowledge of familiar patterns or schemas in the acoustic environment and of a search for confirming stimulation in the auditory input.
>
> (Bregman, 1990, p. 397)

The contours rely on previous data to create an expectation about the expected rate of change, whereas the rapid blurs of sound are too fast to be individually distinguished and are instead processed by the more basic physiological functions which relate to the perception of roughness. In this way the perceptual transition that occurs here is one from a point of cognition to a point of sensation.

The next section of the piece begins at bar 42 and starts with both the flute and the electronic clicks playing fast oscillating lines. For the flute this is an ascending and descending chromatic scale, whereas for the speaker it is a left-right panning pattern. The speed of these lines is regularly changed using aliasing (Nyquist, 1928), that is the underlying speed of the oscillation remains the same but only specific points of it are actually heard. For example, in bars 48-50 only every other note or speaker click is heard, whereas in bars 56-58 only every third note or click is heard. The idea here was to create a sense of ambiguity and disorientation for the listener as the rate of audible events seems to slow down, even though the oscillations still have the same rate of apparent motion (Gepshtein & Kubovy, 2007). In bars 63-83 this aliasing process is then used to create a gradual rallentando.

In bars 84-87 the electronic clicks then play a quick accelerando bringing the sense of tempo back up to speed in bar 88. From bar 88-117 the oscillations maintain their rapid pace, but their contours become increasingly broken. The flute's chromatic scale makes random jumps at irregular intervals, and the electronic clicks make irregular jumps to random positions along its line across the speakers. The idea here was to imitate the kinds of glitches that occur when the regular oscillation of a sound wave is interrupted.

This irregularity increases until a climax at bar 118: the flute returns to the harsh flutter-tongue from earlier in the piece, now played fortissississimo and at the top of its range which means that the sound produced by the flute has tonal sharpness (1.2.1). The flute also bends in pitch so that it beats against a sine tone at 1760Hz (A6) creating roughness. Underneath this the electronic clicks move randomly between the speakers at a rate of roughly 30 times per second (the exact timing between clicks is slightly randomised by between 20-35ms). All is brought to a sudden stop at bar 129 when the flute stops playing and the electronics sound a 9-second-long rallentando, allowing the intensity to dissipate.

The next section (bars 131-140) reprises the sustained tones from the beginning, however this time the widest pitch bends and most rapid beats occur at the beginning and then decrease each time. This is because the direction of the piece is now away from dissonance. The coda begins at bar 140, and the electronic clicks and the flute play oscillations with simple consonant contours to give the piece a sense of resolution.

2.5 *Dear Henry* - introduction

Dear Henry, for Pierrot sextet, is a piece for six musicians playing at five different tempos: violin at 144 bpm, vibraphone at 132 bpm, piano at 120 bpm, flute and bass clarinet at 108 bpm, and cello at 96 bpm. The intent of this piece was to explore Henry Cowell's theory of rhythm harmony as a means of creating rhythmic consonance and dissonance. As the following chapter will discuss, Cowell's conceptual basis for rhythm harmony is derived from an erroneous theory of harmonic consonance and dissonance, and therefore on its own terms doesn't strictly work. However rather than just rejecting rhythm harmony outright, the intent became to explore if there were ways in which it could nonetheless create rhythmic consonance and dissonance, and what are the individual perceptual factors involved. The following chapter consists of three main sections: a discussion and critique of Cowell's theory of rhythm harmony; a review of the perceptual processes related to rhythm harmony which can cause rhythmic consonance and dissonance; and finally, a discussion of the piece itself.

2.5.1 Rhythm harmony

Cowell's idea for rhythm harmony is that different rhythmic pulses can be combined in a similar way to how harmony combines different pitches. In this way he is basing rhythm harmony on the idea that both pitch and pulse are manifestations of periodicity. In regards to harmony he argues:

> The tones of the simple chord G, C, and E vibrate at the rate of 48, 64 and 80 in the same interval of time. That is, in the time that G is vibrating three, C is vibrating four and E is vibrating five times. The result, as is graphically shown, is that whereas at no instant within the second of time do the vibrations coincide, at the end of that period all the vibrations coincide… The reason why the simultaneous tones result in harmony instead of a chaos of sounds is that at regular intervals the vibrations coincide; and in tones forming a musical interval, the smaller the number of units that must be passed over before that coincidence is re-established, the more consonant is the interval.
>
> (Ibid., pp. 47-8)

The important point for Cowell here is the points of coincidence, as he then argues that the same thing can occur with rhythm:

> Assume that we have two melodies moving in parallel to each other, the first written in whole notes, and the second in half-notes. If the time for each note were to be indicated by the tapping of a stick, the taps for the second melody would recur with double the rapidity of those for the first… …a parallel can be drawn between the ratio of rhythmical beats and the ratio of musical tones by virtue of the common mathematical basis of both musical time and musical tone. The two times, in this view, might be said to be "in harmony".
>
> (Ibid., p. 50)

From this Cowell then argues that combinations of rhythmic pulses in different ratios can be combined to create various kinds of rhythmic harmonies with varying degrees of consonance and dissonance:

> If we were to combine melodies in two (or four) beats, three beats, and five beats to the measure, we should then have three parallel time-systems corresponding to the vibration speeds of a simple consonant harmony.
>
> (Ibid., p. 51)

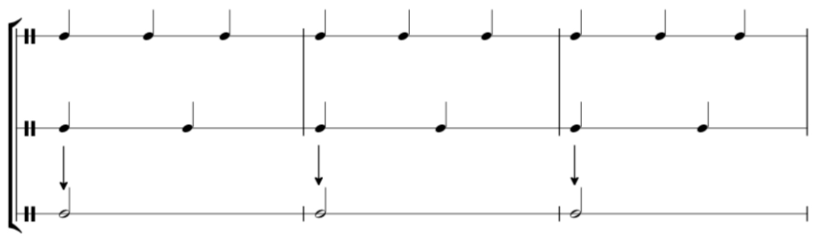
To summarise Cowell's theory: rhythm harmony is created when two or more steady pulses of different speeds are played together and have regularly occurring points of coincidence.

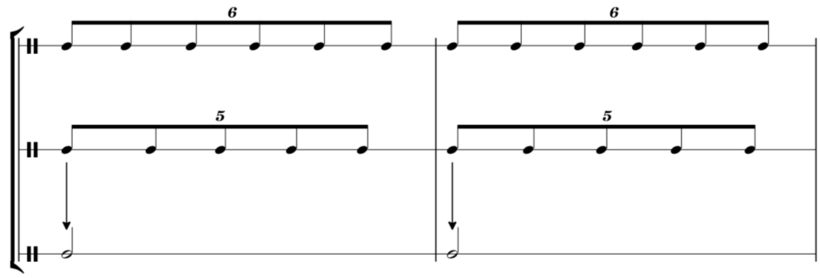
However, the problem is that this idea is based on the theory of harmonic ratios, and therefore the same criticisms levelled at this theory (see 1.2.1) and also at Boomsliter & Creel's related Long Pattern Hypothesis (see 1.2.3) also apply here. Few acoustic signals generate exactly periodic sound waves, and therefore the relationship between the different frequencies in a harmony do not remain exactly in simple ratios. Nonetheless, the sense of consonance is not weakened as long as the frequency variations remain within certain thresholds, and this is because consonance is not caused by harmonic ratios. Furthermore, for rhythm harmony to work the combinations of different pulses must remain exactly in phase with each other in order for the points of coincidence to occur. However, this is not the case with actual harmony: the subtle variations in frequency which are a typical feature of sustained tones will cause any notes in a harmony to move in and out of phase with each other. As long as these phase shifts do not cause rapid beating, they will not weaken the sense of consonance.

Cowell's understanding of harmony is inaccurate, and so it is not strictly accurate to call the rhythmic technique he describes here as 'harmony'. If anything, he is actually begging the question here: he has taken something that works for rhythm, that is the occurrence of points of coincidence between different rhythmic pulses, and then applied it as theory of harmonic consonance and dissonance. Despite this, it is my opinion that rhythm harmony can still be related to rhythmic consonance and dissonance, just not in the way that Cowell proposes. The following is a discussion of the various perceptual factors which relate to rhythm harmony and are capable of causing rhythmic consonance and dissonance.

2.5.2 Perceptual factors of rhythm harmony

The first factor is the one that Cowell himself identifies, that is the occurrence of points of coincidence between different parts. Harald Krebs in his paper *Some Extensions on the Concepts of Metrical Consonance and Dissonance* (Krebs, 1987) argues that any two temporally coincidental sounds can be considered consonant stating that "such a basis for the definition is suggested by the etymology of the words "consonance" (sounding together) and "dissonance" (not sounding together)" (ibid, p. 101). From here on I will refer to as *temporal convergence.* Ex. 11, below, shows two different rhythmic ratios, the first ratio of 3:2 has more frequent points of convergence than the second ratio of 6:5, and therefore has more points of consonance:



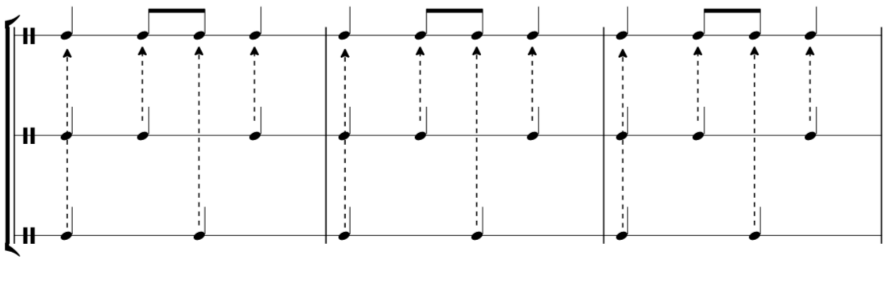


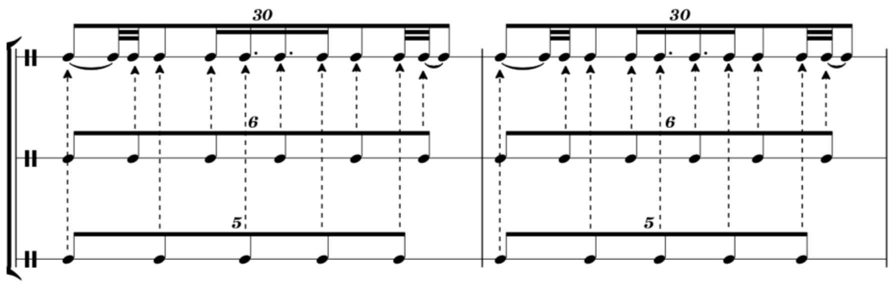
Ex.11: Comparison of points of temporal convergence in 3:2 and 6:5 rhythmic ratios

The next factor is composite rhythm, that is when the rhythms of two different parts combine to create a unified rhythmic surface. For example, the first three bars of variation 21 from J.S. Bach's *Goldberg Variations* BWV 988 consists of three contrapuntal voices which together create a surface rhythm of continuous semiquavers:

Ex.12: Composite rhythm in three-part counterpoint

Composite rhythms can either occur as a continuous pulse, such as the example above, or it can be a composite rhythmic pattern. Example 12, below, shows the composite rhythmic patterns created by the rhythmic ratios of 3:2 and 6:5. As can be seen the 6:5 ratio creates a longer, more complex pattern and is therefore more dissonant:





Ex. 13: Composite rhythmic patterns of 3:2 and 6:5 rhythmic ratios.

In regards to pulses and patterns themselves, I consider both of these to be types of consonance as these are further examples of *schema* (see 2.3). Bregman specifically states that schema relate to both “regular spacing in time” and “other simple repeating rhythms” (1990, p. 136). This idea is also supported by the research of Jones (1976) which shows that listeners are more likely to perceptually fuse sequences of notes which occur in either a regular pulse or pattern.

To summarise, the three elements of rhythm harmony which can be considered rhythmically consonant are: points of temporal convergence, composite rhythm, and occurrence of pulse or repeated pattern.

Another issue which relates to rhythm harmony, but not to rhythmic consonance and dissonance, is the possibility of textural consonance and dissonance. Rhythm harmony can be used to create dissonance by combining complex rhythmic ratios, however at a certain point the effect becomes so dense and complex that it ceases to be discernible as rhythm and instead becomes more like Ligeti’s technique of *micropolyphony*:

> Both *Atmosphères and Lontano* have a dense canonic structure. But you cannot actually hear the polyphony, the canon. You hear a kind of impenetrable texture, something like a densely woven cobweb… I call it micropolyphony.
>
> (Ligeti, & Várnai, 1983, pp. 14-15)

A similar issue was also noticed by Xenakis in his essay *The Crisis of Serial Music*:

> Linear polyphony destroys itself by its very complexity; what one hears is in reality nothing but a mass of notes in various registers. The enormous complexity prevents the audience from following the intertwining of the lines and has as its macroscopic effects an irrational and fortuitous dispersion of sound over the whole extent of the sonic spectrum. There is consequently a contradiction between the polyphonic linear system and the heard result, which is mass or surface.
>
> (Xenakis, 1992, p. 8)

Here we see another example of domain specificity, but this time in relation to the perceptual limits of rhythmic complexity. From Cowell's point of view, dense rhythmic textures are dissonant because they consist of complex rhythmic ratios, however by having an awareness of domain specificity it is possible to hear them as textures instead.

The issue then becomes to what extent these textures can be considered consonant or dissonant. Textural consonance and dissonance can be difficult to define, because many of the terms used to describe texture actually relate to other elements of music. For example, the characteristic feature of a homophonic texture is that all parts move in synchronicity, but as discussed above, this is an example of temporal convergence which I consider to be a factor of rhythmic consonance.

Another element issue that can cause confusion is that some theorists have failed to clearly distinguish between texture and timbre. For example in the following quote about granular synthesis, Curtis Roads discusses the possibility of textural consonance and dissonance but actually seems to be referring more to features which relate to timbre:

> Microsonic synthesis techniques contain a dual potential. On the one hand they can create smooth and pitch-stable continua... On the other hand they can create intermittent particles and non-stationary textures, which in the extreme tend toward chaotic noise bands...The opposition between smooth and rough textures can serve as an element of tension in composition, akin to the tension between consonance and dissonance.
>
> (Roads, 2004, p. 341)

The terms that Roads is using here, such as "pitch-stable" and "chaotic noise", refer to the quality of the timbres in the texture, not the quality of the texture itself, and this approach cannot be considered a coherent explanation of textural consonance and dissonance.

I would argue that the most coherent description of texture is, as Xenakis describes in the quote above, the macroscopic level of the music, the totality of the sound. Any use of the terms *consonant* and *dissonant* in relation to texture must refer to this. A texture can be homogenous or uniform in which case it would be consonant, or it can be described as heterogenous and diverse in which case it would be dissonant.

In addition to the rhythmic elements of temporal convergence, composite rhythm, and pulse and patterns, this piece also explores the use of textural homogeneity as a kind of consonance created when using rhythm harmony. In order to use texture this piece uses domain specificity to make the music move perceptually between rhythm and texture which is achieved by the using the upper and lower limits of rhythmic perception in order to make rhythm became functionally redundant. This includes, as described above, rhythms so complex that the ear can only hear a 'densely woven cobweb', but it also includes, at the other end of the spectrum, rhythms so sparse that the ear cannot hear any sense of metre or pulse. These limits, as described by Fraisse (1984), are set at approximately 20 or more sounds per second for the upper limit of rhythmic perception, and less than one clear rhythmic articulation every 2 seconds for the lower limit.

2.5.3 *Dear Henry,* for Pierrot sextet

As mentioned above, this piece is for six musicians playing at five different tempos. The different tempos in this piece were chosen because they relate in the ratios of 12:11:10:9:8. For every 12 bars the violin plays, the vibraphone plays 11, the piano plays 10, the flute and bass clarinet play 9, and the cello plays 8. The idea was then to combine these different tempos to create different degrees of rhythmic consonance and dissonance. For example, when the violin and the cello play together at 144 bpm and 96 bpm they are in a ratio of 3:2; this is consonant as it results in a simple composite pattern with regular points of convergence. Whereas when the vibraphone and piano play together at the tempos of 132 bpm and 120 bpm they are in the ratio of 11:10; this would be more dissonant due to the lack of convergence and the longer pattern. The reason that different tempos were chosen is because, in my experience, it is very hard for players to execute complex ratios such as 11:10 accurately, and instead it was easier to have the parts play fairly simple rhythmic ideas but at separate tempos.

Due to the use of the ratios between the different tempos, the piece essentially consists of cycles of the same pattern: the players start together on a down beat, move apart at their own tempos, and then after their given number of bars they reconvene on the next shared down beat (the points where the different tempos converge are marked in the score by letters A-Y). Sometimes these points are clearly marked in the music, for example letters E-G coincide with audible moments of change in the piece, and therefore these evenly spaced points of convergence create a predictable structural rhythm, which I think add to the sense of rhythmic consonance. At other times these points are intentionally left unmarked in the music, for example, between letters J-N all of the significant moments of change occur between the points of convergence, and therefore the sense of predictable structural rhythm is absent.

While the use of rhythm and texture are the main musical elements of this piece there is also some use of harmony and melody, for example melodic consonance is once again created by the use of limited interval sets (see 2.3). The intention here was to use a limited number of distinct interval types to create audible similarity between the parts that would in turn help create a sense of textural homogeneity. This use of melodic similarity to create a homogenous texture is obviously similar to Ligeti's technique of micropolyphony in which the multiple lines of his dense textures are canonic. However, in this piece the melodic lines are not actually imitative, but instead are based on the randomised permutation of a limited set of intervals which gives them a sense of audible similarity. Part of the intention here was to avoid the use of actual canonic imitation at different tempos as this is such a distinctive feature of the music of Conlon Nancarrow (Gann, 1995, p. 109).

The use of harmony in this piece is similar to the use of melody as it consists of the use of limited interval types to create homogeneity. Chords used in this piece are primarily inharmonic chromatic cluster chords, their inversions (i.e. stacked major sevenths), and their compound equivalents (i.e. stacked minor ninths). In this way the harmonies are non-functional and so should not unduly influence the listeners perception of rhythm, but nonetheless they have a sense of uniformity.

The piece begins with the parts gradually entering on sustained notes. Due to the lack of sufficient rhythmic events there is not enough information in this section for it to be classed as rhythm, and therefore it is heard as texture, which due to its overall homogeneity is consonant. At letter A, rapid changes of note begin to be introduced, first by the piano and then the vibraphone, and then through letter C more parts begin to do the same. Despite the introduction of more rhythmic events this section is still intended to be heard as texture as there are so many notes that any sense of rhythm is lost in a blur. The sense of textural homogeneity is also supported by the similarity of the melodic lines which are all legato and chromatic.

It is not until letter D that rhythm begins to appear with the parts starting to play more perceptible rhythms: first the violin in its second bar after letter D, then the piano, and then the vibraphone, and these complex layers of rhythm build up until letter E. At this point the rhythm suddenly becomes consonant as the entire ensemble mark a point of temporal convergence with a sharp stab and continue to do this at regular intervals. Alongside this the violin begins to play a clear steady pulse which the cello supports in a simple 3:2 ratio.

Gradually the level of rhythmic dissonance is increased, with the different parts all entering and playing more complex rhythmic ratios against the violin and cello until the ensemble is playing in a full 12:11:10:9:8 rhythmic ratio. The violin and the cello are still playing their 3:2 rhythmic ratio which does provide some sense of consonance, however by letter H these parts become more irregular and this last element of consonance is lost, and by this point the rhythm is so complex that the music is on the verge of becoming texture. However shortly after letter H (page 22 in the score) the piece suddenly snaps back to consonance with the return of the convergent stabs and the regular pulses. Part of my interest in using multiple tempos was the flexibility that this allowed in terms of control over consonance and dissonance - the piece is able to very quickly switch between chaos and order.

The reestablished rhythmic consonance then gradually dies away, firstly as the players begin to weaken the points of temporal convergence by playing the stabs out of time, and secondly because the regular pulse played by the violin and cello fades out.

The next section of the piece begins just before letter J where the ensemble starts to play a composite rhythmic pulse; this is mostly played by the violin, with the other parts taking a note when their tempos align. Gradually this composite rhythm becomes more unstable as the parts begin to interject with their own tempos. The idea here was to use these other tempos to create a sense of turbulence which disturbs the flow of the composite rhythm. Between letters J to L this sense of turbulence builds twice but always suddenly snaps back to stability, the music once again switching quickly between chaos and order. The remainder of the section between letter L and M is a written out rallentando which works its way down through the different tempos. This is another use of a consonant rhythmic contour as discussed in 2.4, which is an element that will be further developed later in the piece. Overall, the idea of this section was to act as a transition in which the rhythm begins to breakdown and the piece begins to focus more on texture.

Letters M-P comprise the next main section, and by this point the rhythms have so little sense of pulse and their ratios are so complex that the perceptual factors which relate to rhythm are largely redundant. Alongside this, the similar register of the notes used, the similar articulations used by the parts, and also the exclusive use of chromatic melodic movement means that this section is texturally highly consonant. The articulations change: starting as staccato, becoming legato after letter O, and then finally leading to a sustained trill (on page 36), but they always change together creating a strong sense of homogeneity. The sustained trill is then gradually slowed down in another written out rallentando, so once again making use of consonant rhythmic contour.

The next section of the piece is letters P-S which is an extended build up that becomes gradually more dissonant and increasingly begins to occupy a borderline position between rhythm and texture. This section begins with the same irregular rhythms from letter M, but this time the use of register and the use of articulation by the different players is far more varied. Additionally, this section also gradually creates a sense of melodic dissonance as it increases the number of distinct melodic intervals used by the parts. Gradually the melodic phrases lengthen until by letter R, rhythm starts to reappear, albeit highly complex. Just before letter S (page 43) the cello brings back its pulse idea from letter E, and it is soon joined by the violin playing once again in a 3:2 rhythmic ratio with regular points of convergence. This was intended to create a sense of rhythm re-establishing itself. However, in contrast to this the rest of the ensemble play fast melodic lines which create a sense of blurry texture.

At letter S the woodwinds, piano, and vibraphone begin to play a written accelerando over the 3:2 ratio played by the violin and cello. While these two elements are rhythmically consonant in themselves, their superimposition makes them conflict with each other. This then builds up to letter T at which point material similar to letters G-H appears, that is with the parts playing in a full 12:11:10:9:8 ratio, and the rhythms so complex that the music is, once again, on the verge of becoming texture.

Then at letter U all of the parts begin to play rapid trills. They then begin to slow down their trills in their own tempo, and whilst rhythmically the interaction of these different tempos is highly complex, the overall effect is of an ensemble rallentando. From letter V the ensemble plays three of these rallentandos, all of which start with a clear point of rhythmic convergence. This is a combination of three types of consonance: textural homogeneity, coherent rhythmic contour, and points of temporal convergence. The intention here was that texture and rhythm, which had been conflicting in the previous section, begin working together.

From letter W a final ensemble rallentando slows all the way down to crotchet notes. This then leads to the coda on page 61, which reprises the chromatic patterns from letter C. These patterns then begin a final rallentando as they move down through the different tempos, and the piece ends with the piano and vibraphone fading out on tremolo chords. In this way the ending is consonant as the rallentando has a clear rhythmic contour and the tremolo chords create a homogenous texture. Another feature of this ending is the return of the harmony from the beginning, in this case stacked minor ninths. In their first use at the beginning these chords would mostly likely have sounded dissonant as they are inharmonic. However, by the end the listener should have heard these chords enough for them to become more familiar, and so their return gives some sense of resolution.

2.6 *Yes and No,* for 22 solo strings

Yes and No is a piece for 22 solo strings which primarily explores the use of harmonic and textural consonance and dissonance. In regards to harmony, this piece explores a conflict between harmonicity and roughness in the use of extended harmonic chords. For many theorists the harmonic series has been one of the primary sources of consonance (see 1.2.3), and as harmonic practices have developed beyond the use of triads some have used the harmonic series to argue for the consonance of extended harmonies:

> With the advent of Claude Debussy, one spoke of appoggiaturas without resolution, of passing notes with no issue, etc.… They have, nevertheless, a

> certain citizenship in the chord, either because they have the same sonority as some classified appoggiatura, or because they issue from the resonant of the fundamental. They are *added* notes… In the resonance of a low C, a very fine ear perceives an F-sharp. Therefore, we are authorised to treat this F-sharp as an added note in the perfect chord.
>
> (Messiaen, 1956, pg. 47)

However, if consonance and dissonance is caused by both harmonicity and roughness (as discussed in 1.2) this leaves extended harmonic chords in a contradictory position: they can be considered consonant as they are harmonically related, but they can also be considered dissonant as the higher intervals of the harmonic series become increasingly small and therefore have roughness.

This piece consists almost solely of a 22-note chord made up of the first 22 partials of a harmonic series on C2. At times it can sound consonant due to its harmonicity, at other times dissonant due to the occurrence of roughness, and at other times it can have an ambiguous combination of both. The title for this work is taken from Peter Abelard's 12th century theological text *Sic et Non* in which he argues that contradictory interpretations can often occur due to the fact that many words have multiple different meanings:

> "In the great multitude of words, even some words of the saints seem not only at variance with each other, but truly opposite… various meanings of the same word, greatly hinders our coming to an understanding, when the same word is set down, here one way, there with another meaning."
>
> (Abelard, trans. Priscilla Throop 2007, pg. 11)

This piece is written using extended Just intonation (Partch, 1974, pp. 109-137). Those intervals which are within 5-limit tuning, and also the 17th and 19th harmonics are notated in standard accidentals. Sixth-tone accidentals are used for the 7th, 14^{th,} and 21st harmonics, and quarter-tone accidentals are used for 11th, 13th, and 22nd harmonics.

The first section (bars 1-32) consists of the upper 12 notes of the chord. All of the intervals in this group of 12 are smaller than a whole-tone interval and therefore have audible roughness. At first these notes are presented individually, which means that there is no roughness. However gradually through bars 16-30 these individual notes begin to overlap, and the harmonic density thickens, resulting in the roughness becoming increasingly audible. For most of this piece the notes played by the individual parts are sustained and the rate of harmonic movement is fairly slow so that any roughness is highly apparent. This eventually leads to bars 31-32 in which a dissonant 11 note chord is stated which consists of the all of the 12 notes apart from the root C.

The second section (bars 33-63) then presents the lower 10 notes of the chord. The smallest interval in this group of 10 notes is a whole-tone so there is significantly less roughness, and also this chord clearly sounds the fundamental giving it a clear harmonic root. This section follows a similar, albeit more truncated, structure to the first section. Individual notes, which increasingly begin to overlap, eventually build up to a full statement of the 10-note chord in bar 51. However, rather than finishing here this section then descends back down the harmonic series. The intention of these two opening sections was to present the full chord in two parts allowing the listener to hear its two distinct qualities.

Another issue with this section is the occurrence of melodic consonance and dissonance, which had not been originally planned, but nonetheless became a feature. This occurs in terms the melodic contour created by the individual presentation of the notes in bars 1-15. As mentioned above, this was intended as a way of presenting these notes without any roughness, however it soon became apparent that they created a melodic line. This then created a sense of dissonance caused by the difference between those notes which are part of the standard twelve-tone system of Western music, and those which are out of tune with this system, such as the 7th, 11th, 13th, 14th, and 22nd harmonics. This can be seen as another example of schema learning as discussed in 2.3: any listener who is familiar with the twelve-tone scale widely used in Western music is likely to find notes in tune with it more predictable, while any notes from outside of it will be heard as unexpected and therefore jarring. The notes of bars 1-9 were all chosen because they belong to the twelve-tone system and therefore should not be jarring. It is from bar 10 that notes from outside the twelve-tone system begin to appear and have a disconcerting, 'out of tune', effect on the listener, e.g. the F-quarter-#5 played by Vln. 12 in bar 13 that corresponds to the 11th harmonic.

The next section of the piece (bars 64-98) begins to bring together the full chord. Bars 64-70 work as a single phrase that starts with widely spaced chords which, due to their width, lack audible roughness. However, even though all of these chords are harmonic and lack of roughness, they are not all heard as equally consonant. This is because the sparsity of the harmony means that localised template recognition comes into play (see 1.3). The phrase in bars 64-70 starts off using more unfamiliar groups and notes and then eventually moves towards a more familiar C major triad in bar 70, and this movement from unfamiliarity to familiarity creates a sense of movement from dissonance towards consonance. The next phrase (bars 71-77) repeats the chords from bars 64-70 but this time with extra pitches added. These extra pitches are close to other pitches in the chord and so add a degree of roughness to the sound. In one sense this second phrase will have some degree of consonance due to the use of repetition, but this will be counteracted by the added element of roughness.

The next section (bars 78-98) intensifies the contrast between consonance and dissonance. Bars 83-90 consists of a sequence of chords which contrast roughness and harmonicity, that is a rough chord in one bar and then a harmonic chord in the next. From bar 93 these contrasts begin to overlap making the juxtapositions more diffuse. This builds up, eventually reaching a 17-note chord in bar 98.

This leads to the next section of the piece, starting at bar 99, that begins with three ascending statements of the full 22-note chord. The idea here is that the listener can hear both elements of the chord at the same time. Each statement is louder than the one before, and the overall effect is of increasing dissonance and intensity. This intensity then breaks out at bar 120 when the full ensemble begins to play with a variety of different techniques such as sul ponticello, sul tasto, tremolo, and expressive vibrato. Up until this point the piece has been texturally consonant due to the overall homogeneity of playing techniques used. Here, however, the texture becomes dense and highly varied. At bar 134 the intensity begins to get out of control, with each part playing molto vibrato and shaking their particular pitch until the harmonic chord begins to detune in bars 137-139. This is the most dissonant part of the piece so far, consisting of a heterogenous texture, roughness between close intervals, and now an inharmonic chord. The harmony then returns to the harmonic series on C in bars 139-145, only to become inharmonic again in bar 146. Finally, the harmonic chord stabilises in bar 150, and then from bar 163 the sense of overwhelming energy begins to subside.

The idea of this previous section was to use dissonance as a kind of intensity and excitement, and to push it to an extreme so that it becomes almost overwhelming and euphoric. In particular this was influenced by Messiaen’s use of dissonance, which can be seen for example in his description of his own use extended harmonic chords such as his Chord of Resonance:

> My secret desire of enchanted gorgeousness in harmony has pushed me toward those swords of fire, those sudden stars, those flows of blue-orange lavas, those planets of turquoise, those violet shades, those garnets of long-haired arborescence, those wheelings of sounds and colours, in a jumble of rainbows of which I have spoken with love in the Preface of my *Quatuor pour la fin du Temps.*
>
> (Messiaen, 1956*,* p. 52)

The next section of the piece is bars 187-204 and consists of two opposing statements, both of which are designed to show the full 22-note chord in different contexts. The first statement (bars 187-195) consists of a series of widely spaced chords most of which have a clear root note in the bass. After this the full 22-note harmonic chord is sounded, and because the previous chords were consonant, the roughness of the full 22-note chord should be more apparent. The second statement then does the opposite: bars 196-202 consist of a series of cluster chords whose small intervals create significant roughness, then in bars 203-204 the 22-note harmonic chord is sounded once again, but this time its harmonicity should be more conspicuous.

Next is an extended section (bars 205-262) in which all parts play sustained notes fading in and out. The intention for this section was to work within the ambiguous space between harmony and timbre, as described in 2.2, and have overlapping fades create a sense of gradually morphing timbral colour. Furthermore, due to the fact that all parts are playing without vibrato this timbre-harmony has a strong sense of perceptual fusion. This is because as Sundberg demonstrates (1994, p. 58) when the fundamental frequency of a tone is modulated by vibrato, the overtones will follow. If, however, the individual players in this piece used vibrato, the rate and width of their frequency modulations would be unlikely to match. This would then allow the ear to hear that these frequencies were coming from separate sources and they would therefore not be perceptually fused.

This sense of perceptual fusion is then intentionally broken at bar 218, where a few parts begin to play vibrato, causing them to perceptually separate from the rest of the ensemble. Gradually the use of vibrato spreads to the rest of the ensemble and the strong sense of harmonic fusion is lost. The intention here was to create an opposition between two different types of consonance: the first kind of consonance is the perceptual fusion between the different parts of the harmonic chord, and the second kind of consonance is the pleasant richness of the vibrato (Sundberg, ibid, p. 57). As the vibrato is introduced it weakens the sense of harmonic fusion. Eventually, at bar 247, the vibrato stops and the sense of fusion returns.

This then leads to the final section at bar 263, that reprises the rising chords from bar 99. As before the chord is stated three times, each time getting louder. After this the rising chord continues to be repeated, but the dynamics instead become gradually softer. The chords are also repeated with different playing techniques: at bar 290 it is played sul ponticello, then in bar 296 – sul ponticello with tremolo, bar 301- non tremolo and sul tasto, and then finally starting in bar 307 it is played sul tasto and with tremolo. Unlike in bars 120-163 these different playing techniques are used by all of the players at the same time, and this uniformity of sound creates a sense of textural consonance. The other purpose of these changes of technique was to weaken the sense of pitch in the string players tone. This loss of pitch means that both the sense of harmonicity and roughness is weakened. In this way the piece has a kind of ambiguous ending: the loss of harmonicity can be heard as a loss of consonance, whereas the lack of roughness and also the overall sense of textural homogeneity can be heard as consonant.

2.7 *Concerto for Piano and Electronics*

Concerto for Piano and Electronics is both the final and longest work completed in this project. It is a mixed media composition for live piano and pre-recorded video and sound. The initial inspiration for this piece came from Max de Wardener's work *Im Dorfe* (2011) which is also for live soloist and audio-visual accompaniment. Another of my ongoing interests as a composer is how the traditional classical forms relate to contemporary musical practice, and it seemed interesting to me to see how a piece like *Im Dorfe* could relate to the traditional classical concerto. In this way, this piece is essentially classical concerto in the standard fast-slow-fast form, but with electronics as the accompaniment rather than an orchestra.

2.7.1 Movement 1: Maestro-Vivace

In the first movement the electronics consist of a collage of 146 different recordings (see Appendix II for a list of all sources used). This collage is used to create dissonance in two ways: firstly through rapid edits which eventually reach a rate of over 20 per second and so create auditory and visual roughness (see 1.2.1); secondly through the use of stylistic dissonance, that is the juxtaposition of music from disparate genres which creates a jarring sense of discontinuity. This use of collage made from pre-existing works was influenced by works such as John Oswald's *Plunderphonics* (1988) and the third movement of Luciano Berio's *Sinfonia* (1969).

Another idea this movement explores is the relationship between the piano and the electronics in terms of traditional concerto roles. Kerman (1999) argues that classical concertos fall into one of two characteristics: polarity and reciprocity (ibid, p. 37). For example, Mozart's concerto style tends towards reciprocity with the soloist and the orchestra typically sharing thematic material. Whereas Beethoven's concerto style tends more towards polarity between the soloist and the orchestra. One example of this can be found in the opening of his Piano Concerto No.5 in Eb major (1811):

> Beethoven presents themeless, rhythmless essences here - the essence of weight and the essence of virtuoso display. Single full-orchestra chords, fortissimo. Cascades of piano arabesques between them… The agents do not engage with each other. Here they are polarised.
>
> (Ibid., pp. 23-4)

This movement uses both of these characteristics, beginning with a clear sense of polarity between the piano and electronics; then leading to some reciprocity as they exchange themes; however, this eventually leads to the electronics taking the piano's role and becoming the virtuoso, and so restoring the sense of polarity. The 'virtuosity' of the electronics comes from its use of rapid edits between multiple different recordings creating a degree of speed and variety that the piano cannot compete with. The overall character of this movement is of a tendency towards excitement, and at first the rapid edits and juxtapositions of different styles are intended to be enjoyable and exciting. However, over the course of the movement they become increasingly dissonant and the music reaches a point of sensory overload.

The movement begins with an introduction (bars 1-25) which is intended to be reminiscent of Beethoven's Piano Concerto No.5: the piano plays rising and falling arpeggios while the electronics provide weighty chords as accompaniment. For the electronics these chords are taken from recordings of pieces such as Beethoven's Symphony No.4 in Bb major

(1806) and Mozart's Symphony No.35 in D major, K.385 (1782). There were three intentions with this section: firstly to establish the sense of polarity between the soloist and the 'orchestra'; secondly to establish the idea of classical music as a style; and finally to establish a sense of dissonance caused by the fact that although the music clearly references the opening of the *Emperor Concerto* it is actually in the wrong key - D major rather than Eb major.

After the introduction, the main vivace section begins at bar 25 and is intended to establish a sense of excitement. The electronics consist of edits of pieces such as Ligeti's *Concert Romanesc* (1951), Stravinsky's *The Rite of Spring* (1913), and Penderecki's *St. Luke's Passion* (1966). Overall the edits are not too fast and there is a sense of stylistic consistency which means that this section is not particularly dissonant. Also, the piano part consists mostly of chromatic scales which means that this section has a high degree of melodic uniformity.

In the next section (bars 62-81, letter B) the piano introduces the first melodic-thematic idea of the piece: a series of phrases based on two chromatic scales moving in contrary motion. The end of each of these phrases is punctuated by a stab from the electronics. These contrary motion chromatic scales are melodically consonant as they use audibly related melodic contours and consist only of semitones. There is also a new approach to rhythmic consonance and dissonance here: the use of limited *rhythmic* intervals sets. By rhythmic interval I mean a specific duration such as a crotchet or a quaver. In this section the rhythms for the ascending and descending chromatic scales are based only on crotchets and quavers, and these are used in randomised alternations to create rhythms which are continuously varied yet always of a consistent and uniform character. This was intended as an extension of my use of limited melodic interval sets in *Dear Henry* (2.5.3). At first, in bars 62-65, these rhythmic intervals are used to create a composite rhythm, that is the alternations of crotchets and quavers pass between the left and right hand. Then in bars 66-69 each hand uses the rhythmic interval set independently, the rhythm of each hand consisting of crotchets and quavers. From bar 70 more layers of the same idea are added to each hand: in bars 70-73 the right hand has two independent layers, then in bars 74-81 the left and right hand have two independent layers each.

The next section (bars 82-103, letter C) is intended to refer back to the introduction, but this time everything is significantly shortened to heighten the intensity. The orchestral chords are now sharp and powerful stabs on the beginning of each bar, and the piano's rising and falling figures are now only two and a half beats long. In bars 96-103 the piano begins to play these figures continuously, moving them over a rising chromatic bass line. This, along with the video edits speeding up, make the overall sense here one of increasing excitement building to a point of transition.

This transition occurs at bar 104 with the first moment of stylistic dissonance: the electronics leave the classical style and become an Indonesian gamelan orchestra. The intention here was to create another point of ambiguity: in one sense this section can be perceived as dissonant due to the stylistic juxtaposition, however the sound of the gamelan orchestra is harmonically consonant and has bright and joyful sound. The intention here was that this first point of stylistic dissonance should be enjoyable for the audience, and only later do the stylistic juxtapositions become more disjunct and jarring. Additionally, in this section, we see a clearer movement towards reciprocity as a melody played by the gamelan orchestra in bars 104-111 is imitated by the piano in bars 112-119. Here we see that the piano is now beginning to lose its dominant role and the electronics are starting to lead, both in terms of taking the music out of the classical concerto genre, and also in terms of starting to control the melodic-thematic material.

At bar 127 there is a brief moment of calm and a return to reciprocity. The electronics create sustained chords over which the piano plays gentle arabesques. However, in keeping with the piece's overall tendency towards dissonance, the sustained chords soon turn into more dissonant chromatic clusters, which the piano copies in its arabesques. After this, at bar 136, the piano tries to reestablish the introduction by playing its rising and falling arpeggios, and the electronics briefly seem to go along with this, playing its weighty chords again. Also, this time the music is actually in E♭ major, the correct key of the *Emperor Concerto.* However, just at this point when the music seems so close to its point of reference, the electronics once again begin to jump between different styles.

The dominance of the electronics develops even further at bar 145 (letter F) as they take the piano's contrary motion chromatic scales from bars 62-81. This time the ascending and descending chromatic scales are sounded using individual notes taken from different recordings. Here we see the repetition of a familiar melodic material which can be heard as a form of consonance, however there is an element of dissonance added due to the rapid edits between different recordings. The roles then become fully reversed at letter G (bar 162) as the electronics play the piano's rapid rising and falling figures from bars 82-103, while the piano plays the stabs at the beginning of each bar. The electronics become increasingly fast and intense; the piano tries to compete with this intensity by playing its stabs as clusters, but it cannot really contend.

This eventually builds to bar 186 where once again the music begins to jump between different styles. At first the speed of the edits slows down which decreases the degree of dissonance, but to counteract this the juxtapositions of style created by the electronics become increasingly disjunct. From this point to the end of the movement the edits in the electronics accelerate, eventually reaching over 20 per second. The intention here was to create a point of maximal dissonance, both in terms of the speed of the edits, and in terms of the discontinuity between the different musical styles. Against this the piano makes a final attempt to establish its dominant role by reprising the contrary motion chromatic scales from bars 62-81, however it cannot compete with the intensity of the electronics and becomes increasingly worn down. At bar 223 (letter I) the piano makes one last statement of the opening arpeggios, but by now it is flailing, unable to stand the barrage from the electronics.

Despite my attempt to create a point of maximal dissonance in this final section, there is one type of consonance that occurs here. The gradual speed up of the edits in the electronics means that this section has a clear sense of accelerando, which is an example of a coherent rhythmic contour as discussed in 2.4. I tried re-working this section to make the speed of the edits more randomised, however the overall effect was too static and the sense of the electronics increasing intensity was lost. Therefore, I decided that it was worth allowing this one element of consonance to occur in order to maintain the sense of build up at the end.

2.7.2 Movement 2: Adagio sostenuto

After the intensity of the end of the first movement, the start of the second movement is intended to be a complete contrast: the screen instantly goes dark and the only sound is a sine wave on C5. The intention here was to make this seem, at first, like a technical error, as if the electronics had overloaded and broken down. However eventually a white circle appears on the screen which corresponds to the sustained sine wave. The idea of this opening section of the second movement was to create a point of absolute purity, in this case a sustained sine wave and a perfect circle in black and white. The visuals for this movement are Lissajous figures created from the audio of the electronics.

After staying on this point of purity for roughly ten seconds, the music begins to move tentatively towards dissonance and beating is gradually introduced. After this, bars 16-30 then consist of a sequence of sustained sine tones fading in and out. These sine tones are all tuned to a harmonic series on C2 and so in this sense are consonant. However, as with the extended harmonic chord in *Yes and No* (2.6), some of the intervals created by these sines are within a whole-tone and so there is some beating.

Eventually the sine tones settle on C4, and at rehearsal letter J (bar 32) the piano enters playing the same pitch on a regular semiquaver pulse. The idea here is that there is a high degree of perceptual blending between the piano and the electronics. They then play two phrases in unison, however due to their differences in intonation there are points at which their combined frequencies cause beating. In the first phrase (bars 32-36) all of the notes chosen (C4, G4, D5, and C5) are very close in both tuning systems, so the beating is minimal. The second phrase starts the same as the first but moves to pitches in which the piano and the electronics are more noticeably out of tune, in particular the notes E6, Bb6, and F#6, all of which result in audible beating. The end of both phrases returns back to the tonic of C and the beating stops. The intention here was to create a tension, not from dissonance, but from the opposition of consonance and dissonance. As discussed in 1.5, the points of consonance are too bare and lacking in euphony, however as the music moves towards dissonance it finds it jarring and recoils back to consonance, and so on in a restless cycle.

A same process as before then occurs in bars 43-62, but this time with chords rather than just single notes. Three chords are built up, each of which is more dissonant than the last. As each of these chords builds up to a point of dissonance, the music suddenly pulls back and returns to bare consonance. It is only with the third of these chords that the music leads to a new, more energetic, section at bar 63 (rehearsal letter M). This section is a combination of the piano chords from bars 43-62 and the electronic sine waves from bars 16-30. The sine waves move between various pitches from the harmonic series on C2, while the piano doubles these pitches using rolling chords. Again, there is perceptual blending between the piano and the electronics on some pitches due to the similarity of intonation, and audible beating on others due to the differences. Gradually this section moves higher up the harmonic series until it builds to a peak at bar 109 on harmonic cluster chord consisting of harmonics 7 to 12 for the electronics, or Bb4, C5, D5, E5, F#5, and G5 for the piano. This is followed by another sine wave fades section for the electronics, which like the previous section moves between various degrees of consonance and dissonance and finally arriving on 11^{th} and 12^{th} harmonics. These two frequencies create audible roughness, so once again the overall pattern is a movement towards dissonance which stops abruptly once it is reached.

After the electronics fade out, the piano responds with an extended solo section which is used in place of a traditional cadenza. My decision to avoid a standard virtuosic cadenza was due to the role that virtuosity played in the first movement, that is the virtuosity of the electronics was the driving force that led the music towards the intense dissonance at the end. Instead this section is intended to be more like a monologue in which the soloist proposes a resolution to the tension between consonance and dissonance that has characterised the second movement. In order to clarify that this section is a moment of change in the narrative of the piece, the piano moves away from the tonal centre of C to F#.

The piano begins by restating the opposition between consonance and dissonance. In bars 128-131 it plays pure perfect consonances, then in bars 132-139 it moves up the harmonic series towards dissonance, only to retreat back to perfect consonance in bars 140-141. Through bars 142-156 it does the same again, moving up the harmonic series towards dissonance in bars 142-153, but then once again returning to perfect consonances in bars 154-156. It is only in the final section of this movement (bars 157 to the end) that the piano finds the resolution to this instability, which comes not from a movement towards consonance but by finding an intermediate point between the two. The piano plays chords that have an element of consonance as they have a clear harmonic root but with added dissonances such as the semitone clashes between C# and B# in bar 157. During this final section the electronics return with the sine wave fades, this time based on a harmonic series on F#. The idea here is to further emphasise this idea of resolution: the opposition between the piano and the electronics from the first movement has also been resolved.

2.7.3 Movement 3: Rondo Allegro

The intention of the final movement was to continue the sense of resolution achieved at the end of the second movement, which is why this movement is a rondo allegro. As Kerman argues “there is nothing apocalyptic about the mutual rondo. It spells accommodation, acceptance, and collusion” (ibid., p. 104). In particular, this movement was intended to capture the playful character of some of Mozart's concerto rondos, such as the finale of his Piano Concerto No.19 in F major, K.459 (1784). The sense of balance and reciprocity is also reflected by the choice of material for the electronics which is entirely based on recordings of a piano.

The piano begins by playing a repeated three note chord consisting of the notes A#, B#, and C#. These are the upper three notes of the chord which closed the previous movement. Without the perfect fifth in the left hand this chord lacks its harmonic root and so could be heard as dissonant, however this dissonance should be weakened by the fact the listener is fairly familiar with this chord by now. Also, the fact that this chord is played staccato means that there isn't much time for any beating to be heard (see 1.3). The rhythm for this chord is once again based on a limited rhythmic interval set of crotchets and quavers, as discussed in the first movement. These two elements, the three-note chord of A#, B#, and C#, and the randomised crotchet/quaver rhythm constitutes the rondo theme. Due to the randomised nature of the rhythm, this theme will never reappear exactly the same as before, but nonetheless should be immediately identifiable.

Underneath this the electronics consists of percussion sounds from various parts of the strings and body which are also played in randomised rhythms created from a limited rhythmic interval set. In this case it starts as a slower rhythm of minims and dotted minims but gradually speeds up. At bar 13 the piano adds a second line in the left hand which plays in the gaps created by the right hand to create a continuous quaver pulse. The melodic movement of this line is intentionally random as its primary function is intended to be rhythmic.

Bars 34-53 then use two different types of rhythmic consonance. First in bars 34-41 the piano and the electronics combine to create a composite stream of continuous semiquavers. Then from bar 42 the piano and the electronics play rhythmic ratios together. Gradually these rhythmic ratios become increasingly dissonant, however just as they seem to be on the verge of losing control the rondo theme returns at bar 54 (letter R) to bring back a sense of consonance and stability. This is the pattern for the rest of the piece. The music is intended to occupy an intermediate position somewhere between consonance and dissonance. Sometimes it veers towards dissonance, and sometimes towards consonance, however it always manages to re-balance itself.

At bar 62 the piano plays a four-bar section of fast repeats. At bar 66 the piano joins in with these creating a continuous composite rhythmic surface. At bar 70 these glitches turn into glissandi with the piano and electronics beginning to play over each other. This leads to a reprise of the rondo theme at bar 78, but this time it is more dissonant. This dissonance is created by the piano adding some extra dissonant pitches to its chord, while the electronics play very fast glitches. This is the most dissonant section of the piece in terms of the sounds used by the piano and the electronics; however, their similarity of character does mean that they seem to be consonance in relation to each other.

This is then followed by a quieter section starting at bar 92 (letter U) in which the electronics consist of recordings of piano strings being plucked. In bars 92-98 the notes played the electronics all relate to the harmonic series on F#. From bar 99 the pitches then become fully chromatic with the notes moving without any coherent sense of pattern. Despite the fact that these two elements make this section harmonically and melodic dissonant, the overall character of this section is intended to be consonant. This is because the sound of the plucked piano strings is consonant in terms of timbre, that is they lack sufficient spectral content for there to be audible roughness, and also because they are consonant in terms of texture due to the overall homogeneity of the sound.

At bar 106 (rehearsal letter V) the live piano enters plucking strings in the same way as the piano in the video. The intention here was to create a high degree of perceptual similarity between the two. At first, in bars 106-108 the two parts pluck the same note, C#6. Then they play a composite stream of continuous quavers on a randomly chosen sequence of notes. In the case of the piano the exact choice of notes is indeterminate, this is due to the practical difficulty in playing pizzicato on a variety of different notes. However, as the stream of notes is intended to be randomly chosen, it was fine to leave the exact choice of notes up the soloist. At bar 117 the live piano then begins to play glissandi by brushing across the strings, and the electronics soon do the same. The intention here is that the imitation between the two parts is now genuinely reciprocal as it goes both ways. These glissandi increase in dynamic and density until they come to a stop at bar 131 leaving the open strings to fade out.

At bar 135 the rondo theme returns, but this time the intention was to make it more consonant in order to balance out the more dissonance version from bar 78. The piano gently brushes the strings and the electronics pluck individual notes of the chord so the two parts harmonise. At bar 160 (letter X) an extended build up section begins. The piano and the electronics both play randomised rhythms based on two rhythmic durations. At bar 167 the piano begins to fill in the gaps created by the left hand in order to create a continuous rhythmic surface. From bar 176 (letter Y) the piano begins to move up in pitch and the rhythms played by the electronics become faster, creating a sense of increasing excitement and intensity. Once again, just as this excitement seems to be on the verge of losing control the rondo theme returns at bar 194 (letter Z). This time the piano plays its right-hand chord supported by a full F# major chord in the left hand, and the electronics play both the percussion sounds from the piano body and the string pizzicatos. The intention here was to create a complex yet coherent texture which occupies a stable position between consonance and dissonance.

The piece finishes with a coda which reprises various ideas from earlier in the movement. This starts in bars 210-211 with fast glitches played by the electronics. This is then followed in bars 212-213 by the piano and the electronics playing a composite stream of semiquavers. After this in bars 214-215 the electronics play string pizzicatos using notes from a harmonic series on F#, which then leads to an ascending flourish on the F# harmonic series played in octaves by the piano and electronics together. Finally, the piece finishes with the piano playing a single staccato chord on the first beat of the bar, which the electronics accompany with a piano lid slam.

Conclusion

Overall this research project has been beneficial to my work as a composer. A number of the techniques which were explored in the portfolio have now become a standard part of my compositional style and have been used in subsequent works, such as *Fever Dream,* for string quartet, and *This is not a manifesto,* for 13 players and video (see Appendix II for full list of pieces completed up to September 2019). Both of these pieces include the use of limited melodic interval sets to create melodic uniformity, the use of limited rhythmic interval sets to create a similar sense of uniformity in constantly varied rhythms, and the use of extended microtonal harmonies based on extended Just intonation.

In terms of how my compositional approach developed during this project, the issue which had the greatest effect in the early stages of this project was the multi-dimensional nature of consonance and dissonance. As was discussed in 2.1, the first five pieces completed during this project were written before I was fully aware of this particular issue, and were sufficiently weakened by this that only one of them, *I would go home but my house is on fire,* was included in the final portfolio. However, subsequent works such as *Rabbit Hole* (2.2) and *Dear Henry* (2.5) were in turn significantly influenced by this issue and exploit the different perceptual processes effectively.

The issue which had the greatest effect on the later stages on this project, and which will mostly likely form the basis of future research, is the role of learning in the perception, as discussed in 1.2.3 and 1.3. As mentioned in the Introduction, my original intention had been to establish a single coherent definition of consonance and dissonance and then apply this across the different musical elements. It had also been my expectation that this definition would have an innate and therefore objective cause, and my initial research focused on theorists who favoured this approach, such as Helmholtz and Plomp & Levelt. Having started from this position, it admittedly took me some time to be willing to fully accept the role of learned factors, but once these factors were accepted, it then opened up new approaches in my work. Without this development in my understanding it is impossible that I would have written a piece such as the first movement of *Concerto for Piano and Electronics*. My interest in composing like this and creating dissonance through the juxtaposition of different styles came about only through my awareness the role of learning in perception.

There are areas in which this innate/learned conflict could be further explored, such as in the use of limited rhythmic interval sets. As Fraisse and Voillaume (1971) have argued, the perception of pulse is most likely innate, whereas, according to my arguments in 2.7.1, rhythmic interval sets have to be learned. The way in which limited rhythmic interval sets were used in the 3rd movement of *Concerto for Piano and Electronics* (see 2.7.3) did not cause any significant conflict between these two innate and learned factors, as the alternations of crotchets and quavers used in the solo piano part could be heard as part of an incomplete continuous quaver pulse:

Ex.14: rhythm from bars 1-4 of 3rd mvt. of *Concerto for Piano and Electronics* compared with continuous quaver pulse.

However, rhythmic interval sets in which the component durations do not relate so simply, i.e. the longer duration is not exact double the shorter duration, will not relate so clearly to a single pulse, and therefore the primitive and schematic elements, to use Bregman's terminology, are more likely to come into conflict. This is something which would be interesting to explore in future works.

Another example can be seen in ideas that I have been currently sketching which explore the tension between the harmonic series and a symmetrical scale made up of solely of 5/4-tone intervals.

Ex.15: harmonic series compared with a symmetrical 5/4-tone scale

This is similar to the approach that was used in *Two Systems,* for solo tenor trombone and electronics (2.3) but with the use of a microtonal scale. My use of the traditional whole-tone scale in *Two Systems* had been something of a compromise: the time available for the soloist to learn and record that piece were limited, so I decided not to overly complicate the issue by asking the soloist to learn a microtonal melodic scale alongside the harmonic intervals that piece required. However, I continue to be interested in microtonal music, and it would be interesting in future pieces to explore whether the ideas I developed in relation to melodic consonance, such as use of limited interval sets, could also work in relation to non 12-ET scales.

Appendix I

Accompanying media:

1. ***I would go home but my house is on fire*:**

Audio file: live recording by players from RLPO, October 2014.
Max/MSP patch used in live performance

2. ***Rabbit Hole*:**

Audio file: studio recording by Hilary Browning, June 2015.
Max/MSP patch used in studio recording

3. ***Two Systems*:**

Audio file: studio recording by Simon Powell, July 2016
Max/MSP patch used in studio recording

4. ***An intense and unpleasant excitement*:**

Max/MSP patch used in live performance
Video file: live performance by Richard Craig, March 2017
Audio file: due to some errors in the live video performance, a MIDI realisation of the piece has also been included.

5. ***Dear Henry*:**

Audio file: workshop performance by players from RLPO, October 2017.

6. ***Yes and No*:**

Audio file: MIDI realisation created December 2017

7. ***Concerto for Piano and Electronics*:**

Video file: studio recording by Ian Buckle, July 2019
Audio and visual media for live performance

Appendix II

Chronological list of pieces completed during PhD:

Common Factor, for solo cello (2013)

Compressed Message, for mixed sextet (2013)

Nothing New, for solo piano and electronics or two pianos (2014)

Consonances, for 10 players and electronics (2014)

I would go home but my house is on fire, for Pierrot sextet and electronics (2014)

Rabbit Hole, for solo cello and electronics (2015)

Berlin: Symphony of a Metropolis Act 4, live soundtrack for quintet and electronics (2015)

Two Systems, for tenor trombone and electronics (2016)

CD Requiem, for a large group of portable CD players (2016)

An intense and unpleasant excitement, for solo flute and electronics (2017)

Dear Henry, for Pierrot sextet (2017)

Yes and No, for 22 solo strings (2017)

Concerto for Piano and Electronics (2018)

Fever Dream, for string quartet (2018)

This is not a manifesto, for 13 players and video (2019)

Appendix III

Sources for *Concerto for Piano and Electronics*:

N.B.: All videos for movement 1 were taken from Youtube.com. The following list gives the title of the video as posted, the date it was originally posted, a link to the video, and the date the video was last accessed on Youtube.com by the author.

276 Bridgewater - Second Ireland Sacred Harp Convention, 2012. (2012). Available at: https://www.youtube.com/watch?v=0P7XZ6KeogI [Accessed at 10 July 2019]

2014 Vienna New Years Concert Johann Strauss, Radetzky March (01Jan14). (2014). Available at: https://www.youtube.com/watch?v=2ORHVroiWHk [Accessed at 10 July 2019]

Abime des oiseaux O. Messiaen. We Agree To Disagree concert. (2014). Available at: https://www.youtube.com/watch?v=VpI_BrypuVo [Accessed at 10 July 2019]

ACDC - Back In Black (from Live At Donington). (2013). Available at: *https://www.youtube.com/watch?v=6vImyP5EYc8* [Accessed: 27 August 2019]

Aesop Rock - None Shall Pass live at ZeroFriends, SF. (2011). Available at: https://www.youtube.com/watch?v=3a9KQxsFCmI [Accessed: 27 August 2019]

Alex Jones Funniest Moments of All-Time. (2018). Available at: https://www.youtube.com/watch?v=rmEeIymSamc [Accessed: 27 August 2019]

Anoushka Shankar - Traveller - 2012 - two ragas - Live at Les Nuits de Fourvière - Lyon, France. (2014). Available at: https://www.youtube.com/watch?v=H_eiD8Al0A0 [Accessed: 27 August 2019]

Anthrax & Public Enemy - Bring The Noise (Official Video). (2016). Available at: https://www.youtube.com/watch?v=kl1hgXfX5-U [Accessed: 27 August 2019]

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