7

STOCHASTIC MODELS OF MUSIC AND THEIR APPLICATIONS

In the previous chapter, aspects of Information Theory were used to analyse music selected from three different styles. Some of the selected compositions have a proven record of popularity, while one group is relatively unknown. The aim of the analysis was to discover common entropic factors within each group. Similarities between the various compositions were used to establish broad norms and predictability factors common to three different musical styles.

Chapter 6 also dealt with developing models of the characteristics and style of a group of compositions, which may then be compared to find similarities or differences between the various different styles. However, the range of applications of Information Theory to music may be increased if individual pieces can also be compared with such stylistic models that are derived from a large quantity of music. This chapter deals with the entropy values of an individual piece of music. It shows how the entropy values of a specific composition may be used for comparison with a stylistic model, thereby establishing the degree of similarity (or difference) between the selected composition, and style and characteristics of a pre-determined group of compositions.

Even though there are some significant similarities between the different groups, each composition also has its own unique and distinct characteristics that identify it from the other compositions. The results of the analysis may therefore also effectively be applied to create a uniquely identifying composite image or model for comparison with a global stylistic model.

Most of the generated results were illustrated by means of both tables as well as graphs. The latter are no more than grades on a scale with a maximum of 100, that indicate the contents of information embodied in a composition. The fact that this scale is based on percentage values, and therefore implies relative values, makes it an ideal vehicle by which the individual characteristics of compositions may be compared. Traditional methods of comparison in music frequently use comparative methods whereby a specific piece of music is compared with a theoretical model. An example of this type of analysis is found in musical form of which examples have been given in earlier chapters. While many compositions are said to be in sonata form, very few conform completely to the standard textbook model—usually composers use such a model merely as a general guide, thereby imbuing their music with creative and artistic elements.

Comparison of composed music with an imaginary model requires much description and discourse to show how and where it deviates or conforms to the model. If two or more similar compositions are compared with each other, as well as with the model, the increase in quantity of descriptive material increases likewise.

The method suggested here creates a single model which may include or exclude as many elements as needed, and which immediately provides one with as much statistical information about a piece of music as is required. Although the results so obtained may be used to compare different compositions, there is no need for imaginary or synthetic models for reference.

7.1 Creating an entropy model of music

The additive process involved in creating a graphical identification of music is illustrated below.

For this discussion three of the compositions listed at the beginning of Chapter 6 were randomly selected—one from each group. All the entropic and stochastic values used in this chapter were also taken from the tables in Chapter 6:

1. Stevie Wonder: *You are the sunshine of my life* (P-group)
2. Robert Schumann: *Das ist ein Flöten* (S-group)
3. Benjamin Britten: *Since she whom I loved* (M-group)

7.1.1 One-dimensional entropy combinations

In Chapter 6, a number of single dimensional entropy values for four related music elements were obtained for each of 22 compositions. These are in order of complexity:

1. Pitch entropy

2. Rhythm entropy
3. Pitch - rhythm entropy
4. Pitch ratio entropy

As mentioned before, the easiest element to calculate is pitch entropy; the three entropy values of each are:

You are the sunshine of my life	*Das ist ein Flöten*	*Since she whom I loved*
83.87%	**87.57%**	**91.79%**

Table 7-1. Entropy of pitch distribution for the three selected songs

The differences among the three compositions are obvious and may effectively be illustrated on a graph:

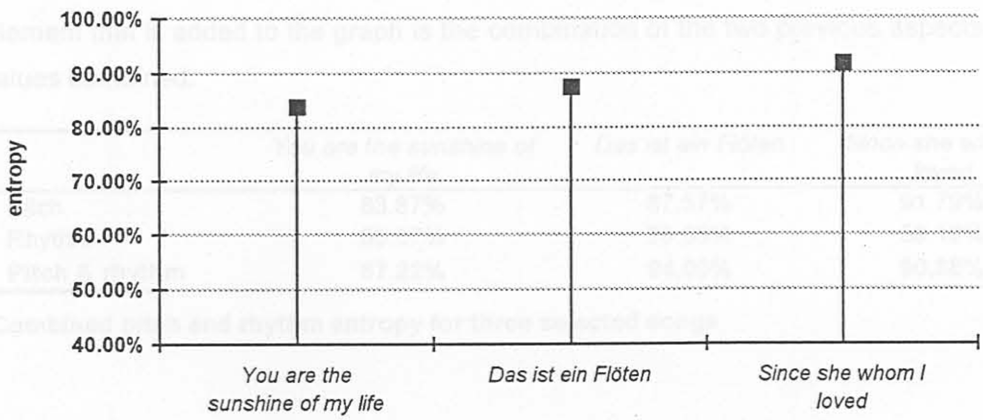

Figure 7-1. Comparison of pitch entropies for three selected songs

The figures shown above clearly show the difference between the pitch distribution of the three compositions expressed as relative entropy, and may already be used as part of a comparative study.

Rhythmic entropy is also relatively straight forward to calculate and may now be added to further enhance the graphical representation:

	You are the Sunshine of My Life	*Das ist ein Flöten*	*Since She Whom I loved*
Pitch	83.87%	87.57%	91.79%
Rhythm	**68.07%**	**78.08%**	**59.12%**

Table 7-2. Rhythm entropy for three selected songs

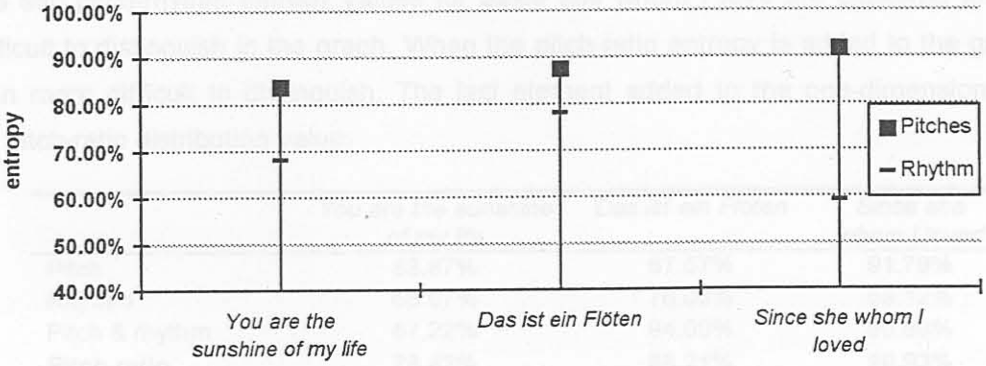

Figure 7-2. Comparison of pitch and rhythm entropies for three selected songs

A second dimension has now been added changing the visual impact of the graph, and the differences among the three compositions are self-evident. Although the pitch entropy of the third song is much higher than that of the first, the rhythm entropy is considerably lower.

The third element that is added to the graph is the combination of the two previous aspects: pitch and rhythmic values combined:

	You are the sunshine of my life	*Das ist ein Flöten*	*Since she whom I loved*
Pitch	83.87%	87.57%	91.79%
Rhythm	68.07%	78.08%	59.12%
Pitch & rhythm	**87.22%**	**94.00%**	**90.88%**

Table 7-3. Combined pitch and rhythm entropy for three selected songs

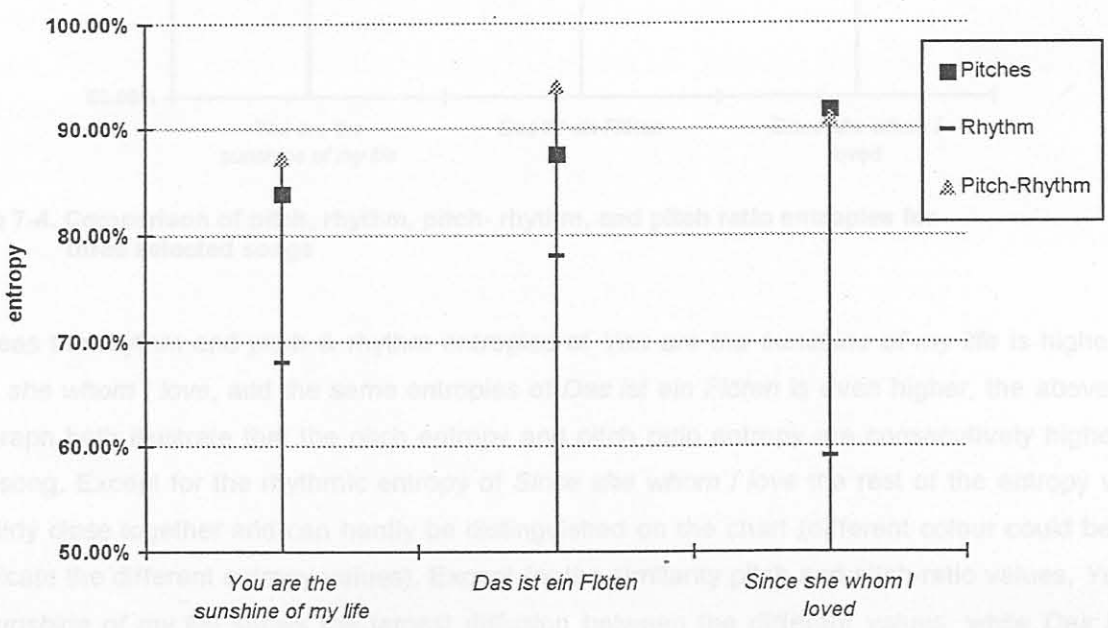

Figure 7-3. Comparison of pitch, rhythm and pitch-rhythm entropies for three selected songs

The pitches and pitch-rhythm entropy values for *Since she whom I love* are clustered around 90% and are difficult to distinguish in the graph. When the pitch-ratio entropy is added to the graph it becomes even more difficult to distinguish. The last element added to the one-dimensional entropy chart is the pitch-ratio distribution value:

	You are the sunshine of my life	*Das ist ein Flöten*	*Since she whom I loved*
Pitch	83.87%	87.57%	91.79%
Rhythm	68.07%	78.08%	59.12%
Pitch & rhythm	87.22%	94.00%	90.88%
Pitch ratio	**78.42%**	**88.21%**	**90.93%**

Table 7-4. Pitch ratio entropy for three selected songs

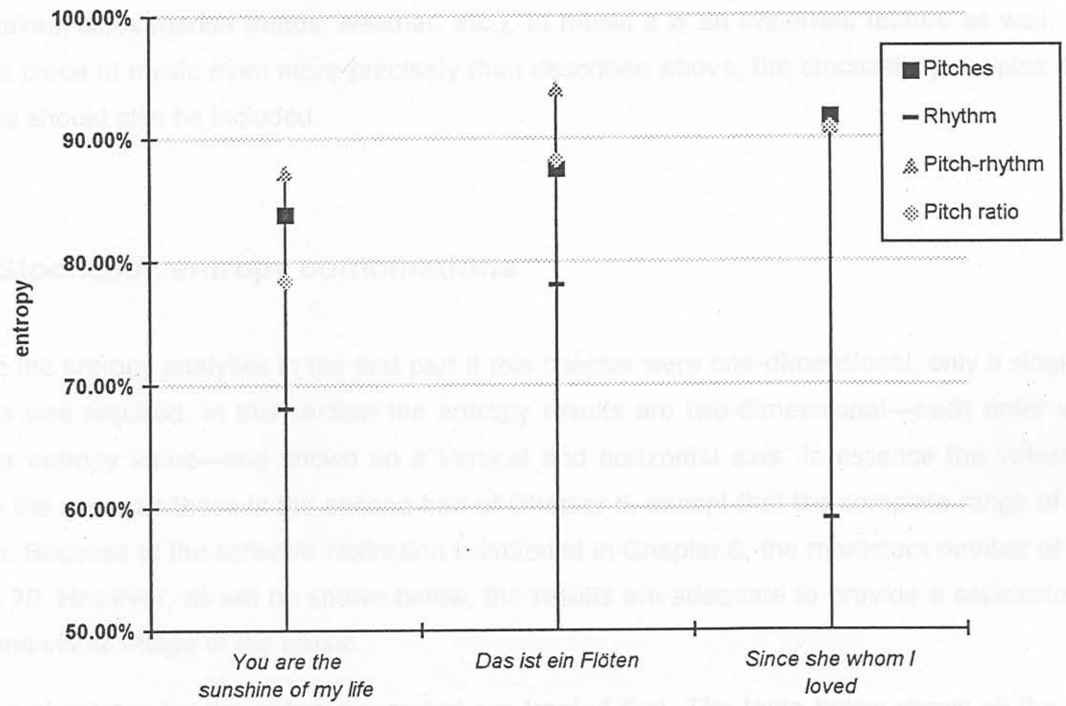

Figure 7-4. Comparison of pitch, rhythm, pitch- rhythm, and pitch ratio entropies for three selected songs

Whereas the rhythm and pitch & rhythm entropies of *You are the sunshine of my life* is higher than *Since she whom I love*, and the same entropies of *Das ist ein Flöten* is even higher, the above table and graph both illustrate that the pitch entropy and pitch ratio entropy are consecutively higher with each song. Except for the rhythmic entropy of *Since she whom I love* the rest of the entropy values are fairly close together and can hardly be distinguished on the chart (different colour could be used to indicate the different entropy values). Except for the similarity pitch and pitch-ratio values, *You are the sunshine of my life* shows the largest diffusion between the different values, while *Das ist ein Flöten* is fairly evenly distributed. In respect of pitch and pitch-ratio values *Das ist ein Flöten* and *Since she whom I love* also show similarities.

At first it was considered to add the average of the four values described above. However, since different aspects of the music (especially pitch and rhythm which are quite divergent elements) are being demonstrated, averaging the values would diminish the distinctiveness of the graphic representation. It would thus not furnish an accurate assessment (for example if the rhythmic and pitch entropy values of two songs are 80% and 40%, and 55% and 75% respectively, the average would be 60% and 65% — not a convincing or significant difference).

For identification or classification of music the basic procedures described so far may be sufficient for certain applications. However, the graphs shown above have only one dimension. Throughout this thesis some stress has been placed on the role of the stochastic dynamics in communication. This applies to many of the arts and speech, and is extensively applied in technologies such as cybernetics and artificial intelligence. In recent times it is increasingly being used to predict future events (earthquakes, stock market trends, weather, etc.). In music it is an important feature as well, and to identify a piece of music even more precisely than described above, the stochastic principles at work in a piece should also be included.

7.1.2 Stochastic entropy combinations

Because the entropy analyses in the first part if this chapter were one-dimensional, only a single, vertical axis was required. In this section the entropy results are two-dimensional—each order with its particular entropy value—and shown on a vertical and horizontal axis. In essence the values used here are the same as those in the second half of Chapter 6, except that the complete range of orders is shown. Because of the software restriction mentioned in Chapter 6, the maximum number of orders remains 70. However, as will be shown below, the results are adequate to provide a satisfactory statistical and visual image of the music.

The interval entropy for the orders generated are treated first. The table below shows all the values generated for the three compositions:

Order	*You are the sunshine of my life*	*Das ist ein Flöten*	*Since she whom I loved*
1	81.57%	66.81%	80.95%
2	92.09%	82.61%	88.99%
3	92.78%	92.43%	94.61%
4	93.43%	96.28%	97.23%
5	94.06%	97.34%	98.43%
6	94.59%	98.01%	99.27%
7	95.21%	98.38%	99.65%
8	95.51%	98.96%	99.79%
9	95.63%	99.21%	99.89%
10	95.81%	99.44%	100.00%
11	95.99%	99.61%	
12	96.18%	99.70%	
13	96.39%	99.79%	

Order	*You are the sunshine of my life*	*Das ist ein Flöten*	*Since she whom I loved*
14	96.61%	99.89%	
15	96.83%	100.00%	
16	97.07%		
17	97.32%		
18	97.58%		
19	97.85%		
20	98.14%		
21	98.37%		
22	98.61%		
23	98.77%		
24	98.93%		
25	99.00%		
26	99.08%		
27	99.13%		
28	99.17%		
29	99.21%		
30	99.26%		
31	99.31%		
32	99.37%		
33	99.42%		
34	99.48%		
35	99.55%		
36	99.61%		
37	99.68%		
38	99.76%		
39	99.83%		
40	99.91%		
41	100.00%		

Table 7-5. Stochastic interval entropies for three compositions

To make the comparison between the curves more clearly visible, the values of Table 7-5 are combined in a single graph below. The lowest starting point of each curve lies above 50%, and the lowest entropy value has also been limited to 50% to make the curves more distinct. Ultimately each composition should be drawn on individual graphs, showing the full range from 0% to 100% and the individual curves may be given different colours. Important characteristics of the graph are the starting point of each curve (order 1 values), differences in the length of the curves (orders), the gradient and the general shape of each curve.

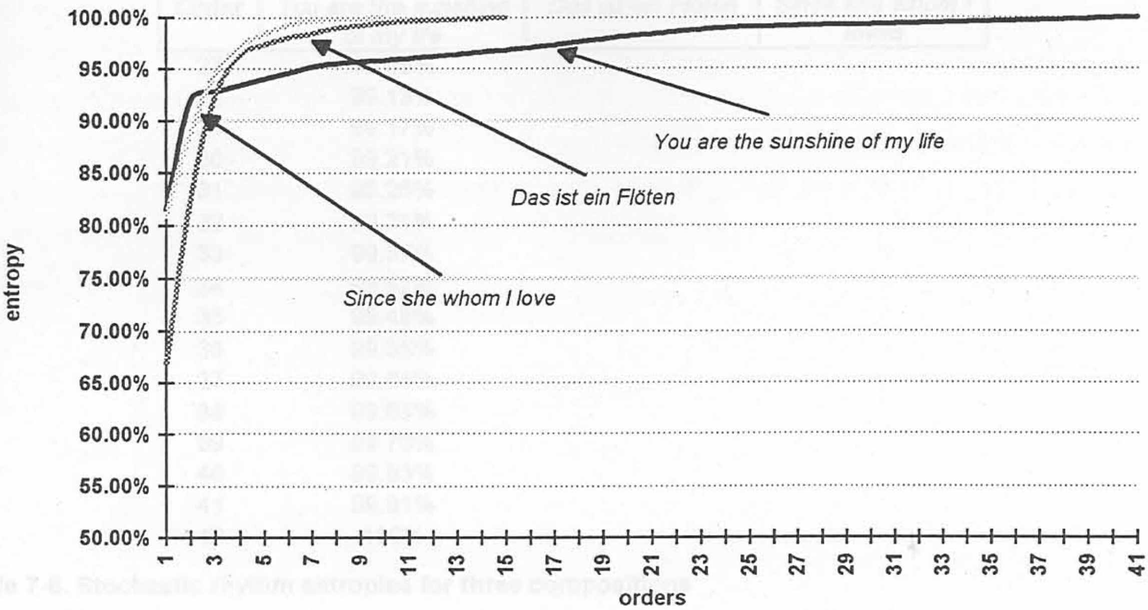

Figure 7-5. Interval entropies of the three compositions

The same principle applied previously for the intervals is also applied to the rhythmic values of the three songs. First the values are shown in tabular form, followed by a graphical rendition of the same values.

Order	*You are the sunshine of my life*	*Das ist ein Flöten*	*Since she whom I loved*
1	68.07%	78.08%	59.12%
2	81.32%	84.78%	72.17%
3	90.14%	85.99%	82.58%
4	93.48%	88.80%	89.45%
5	93.88%	91.35%	93.74%
6	94.74%	93.66%	96.49%
7	95.50%	95.15%	98.01%
8	95.62%	96.68%	99.04%
9	95.76%	97.20%	99.69%
10	95.92%	97.85%	99.89%
11	96.11%	98.31%	99.95%
12	96.31%	98.62%	100.00%
13	96.53%	98.97%	
14	96.75%	99.36%	
15	96.99%	99.79%	
16	97.24%	100.00%	
17	97.49%		
18	97.76%		
19	98.04%		
20	98.33%		
21	98.63%		
22	98.78%		
23	98.95%		
24	98.98%		
25	99.01%		
26	99.05%		

Order	*You are the sunshine of my life*	*Das ist ein Flöten*	*Since she whom I loved*
27	99.08%		
28	99.13%		
29	99.17%		
30	99.21%		
31	99.26%		
32	99.31%		
33	99.37%		
34	99.42%		
35	99.48%		
36	99.55%		
37	99.61%		
38	99.68%		
39	99.76%		
40	99.83%		
41	99.91%		
42	100%		

Table 7-6. Stochastic rhythm entropies for three compositions

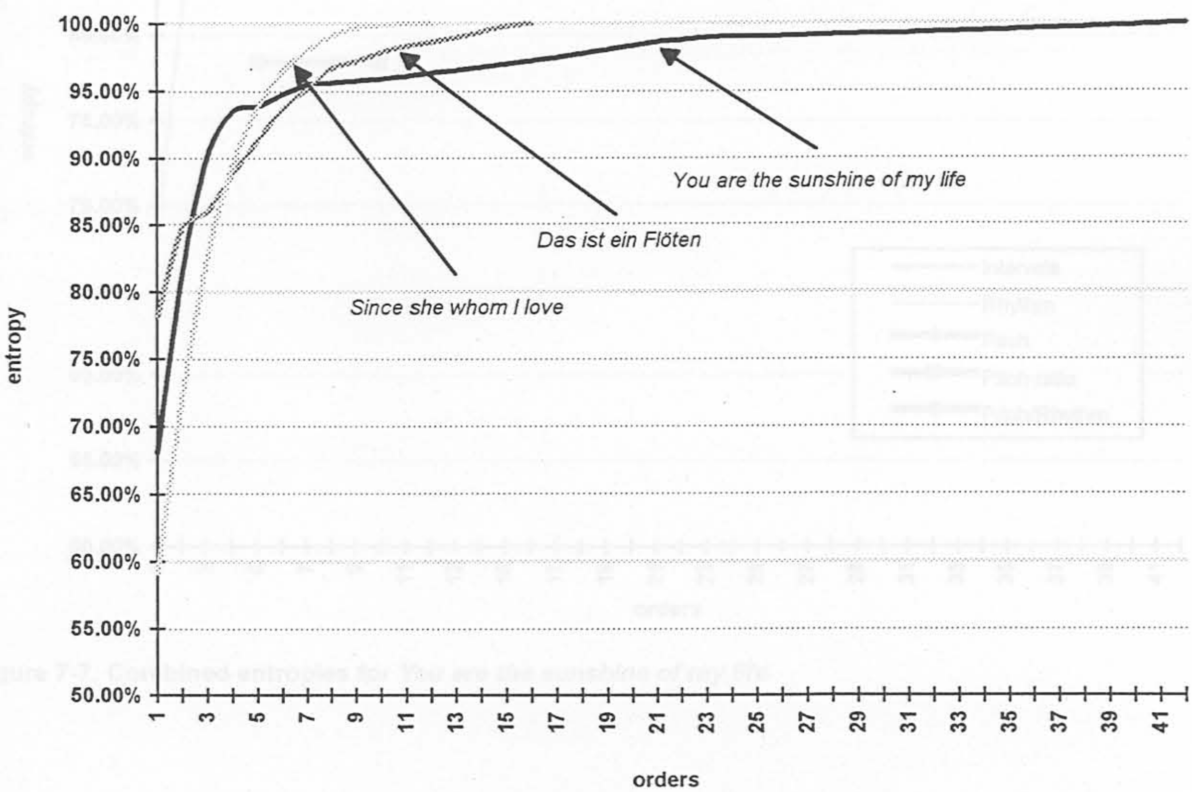

Figure 7-6. Rhythm entropies of three compositions

The differences between the curves are self-evident, each indicating different rhythmic processes at work within the structure of the compositions.

However, to demonstrate the unique properties of each of the three compositions, their individual characteristic entropies may separately be combined into a single graph. This means that the elements peculiar to each of the songs are extracted from Figure 7-4, Figure 7-5 and Figure 7-6 and combined into a single graph. The individual graphs for each song are shown below. To maintain the same proportions between the graphs, the number of orders on the x-axis has been kept the same throughout, even where the higher orders have no entropy values. The short horizontal lines represent entropy values of single dimensions and should, in reality, only be indicated on the vertical axis as a short line or dot. They were made longer to make them more visible and do not imply any specific number of orders.

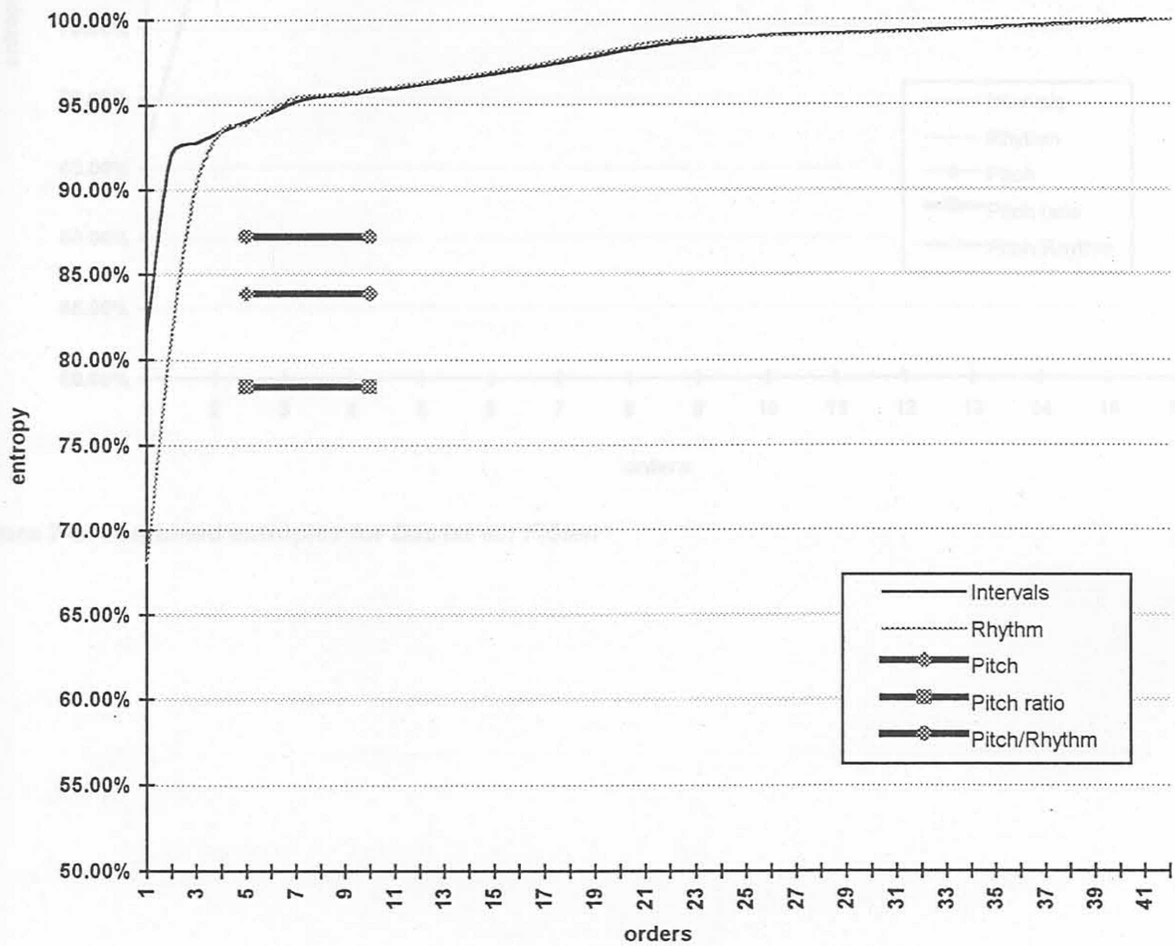

Figure 7-7. Combined entropies for *You are the sunshine of my life*

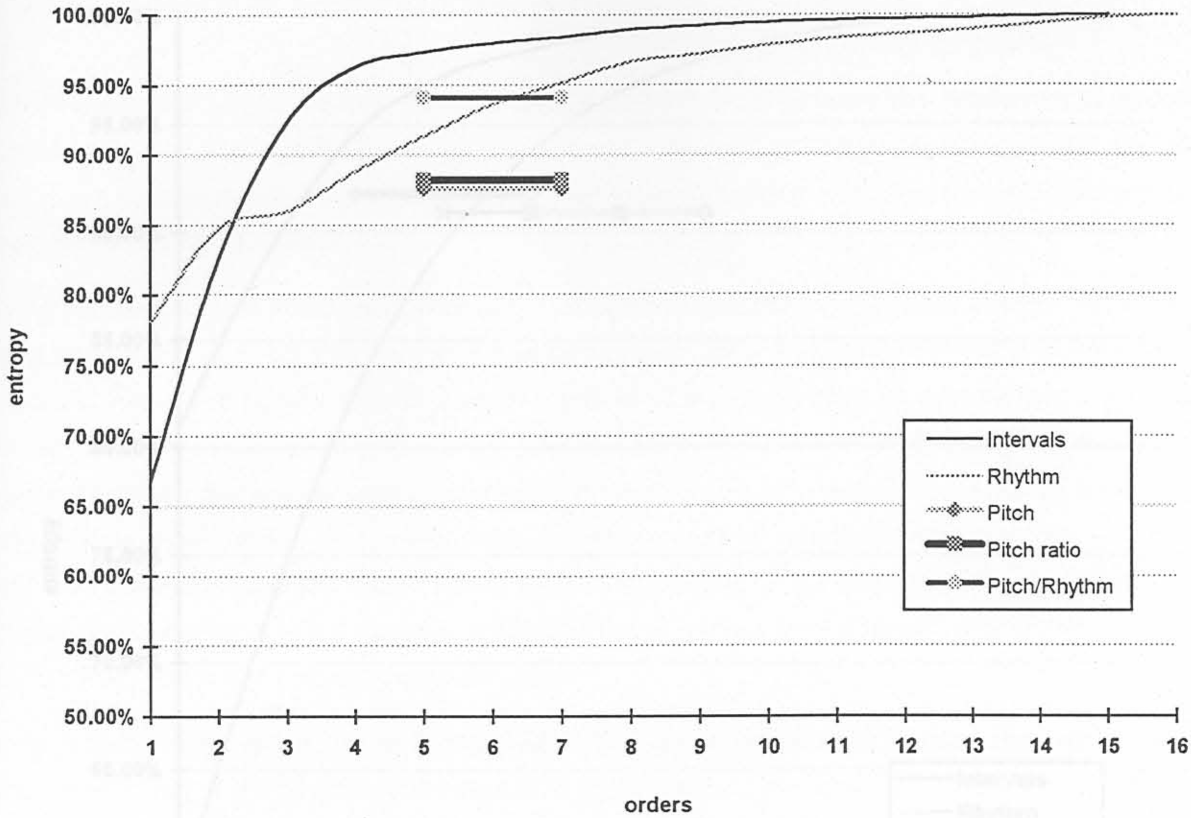

Figure 7-8. Combined entropies for *Das ist ein Flöten*

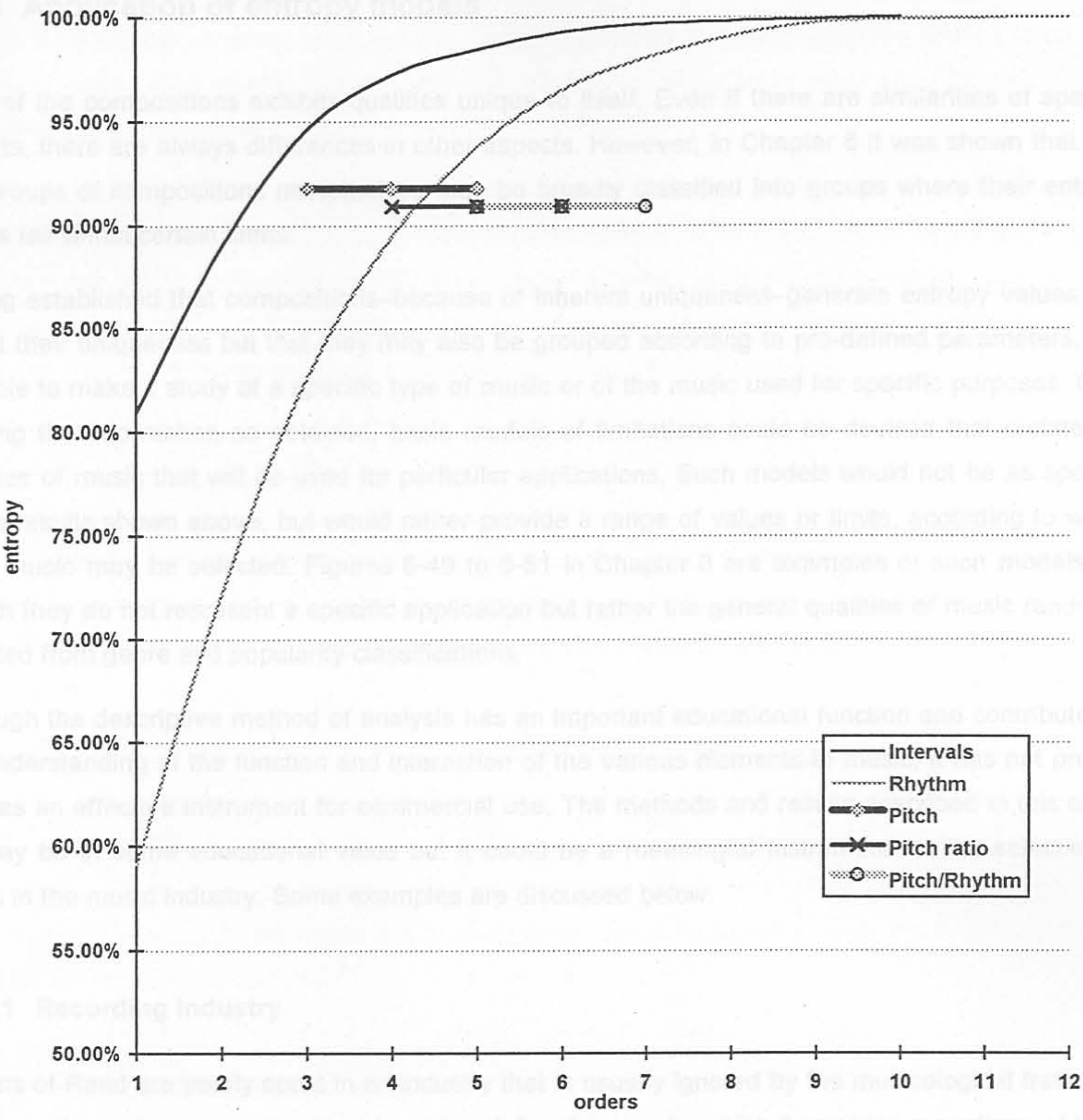

Figure 7-9. Combined entropies for *Since she whom I loved*

A complete set of graphs, together with tables of entropy values, for each of the 22 compositions is found in Appendix II.

Even a cursory perusal of the three graphs above, illustrates that each of the compositions is unique in many ways. Even if two compositions closely resembled each other, there would still be certain aspects where differences could be discerned unless, of course, the works were identical. By comparing the graphs of individual compositions, as shown above, with the models for a larger group of music, similarities and differences may be identified. Depending on the objectives of the comparison, this aspect may be applied to single aspects, such as rhythm, or to a variety of combinations of aspects.

7.1.3 Application of entropy models

Each of the compositions exhibits qualities unique to itself. Even if there are similarities of specific aspects, there are always differences in other aspects. However, in Chapter 6 it was shown that certain groups of compositions nevertheless may be broadly classified into groups where their entropy values fall within certain limits.

Having established that compositions–because of inherent uniqueness–generate entropy values that reflect their uniqueness but that they may also be grouped according to pre-defined parameters, it is possible to make a study of a specific type of music or of the music used for specific purposes. Considering the information so obtained, basic models of limitations could be devised that dictate the qualities of music that will be used for particular applications. Such models would not be as specific as the results shown above, but would rather provide a range of values or limits, according to which other music may be selected. Figures 6-49 to 6-51 in Chapter 6 are examples of such models, although they do not represent a specific application but rather the general qualities of music randomly selected from genre and popularity classifications.

Although the descriptive method of analysis has an important educational function and contributes to the understanding of the function and interaction of the various elements in music, it has not proven itself as an effective instrument for commercial use. The methods and results described in this chapter may be of some educational value but it could be a meaningful instrument for the selection of music in the music industry. Some examples are discussed below.

7.1.3.1 Recording industry

Millions of Rand are yearly spent in an industry that is usually ignored by the musicological fraternity. The recording industry has developed a strong infra-structure by which it provides recordings of thousands of popular musicians to the public. In the employment of many of these large corporations are specialists who know what qualities are required to make a best-seller; which qualities are preferred for the specific echelon of the population for which they cater. This ability, or 'feel' by talent hunters and promoters is usually acquired by many years of close contact with the types of music in which they specialise.

It is suggested here that the learning processes involved in obtaining this experience are essentially an acquired ability to recognise the entropic properties of music—the quantity of information that is generated and the rate at which it is generated, in other words the predictability of the music. However, the trial-and-error method is not fail-safe, and thousands of recordings are made that never become well known and are quickly forgotten. Few people ever know about these failures, because active promotions of such records are quickly ceased to save on the costs.

To help reduce the number of failures that are produced regularly, the system described in this chapter could be used to develop basic models for specific types of music that have proven to be commercially viable. New additions to the repertoire could be compared to ascertain if they entropically fall within the set limits indicated by the models.

It is not implied that this is a fail-proof method, since the promotional efforts involved in bringing a musician or group of musicians to fame is an important factor. Prior popularity of artists also plays an important role but even the most popular artists regularly produce music that is quickly forgotten. Only those songs that have the required quality to maintain the public's interest eventually become 'classics', a quality that can solely be ascribed to the musical characteristics.

7.1.3.2 Copyright controversies and litigation

Every so often, there are controversies concerning plagiarism in the world of popular music. Since the traditional methods of analysis are often vague and open to interpretative manipulation, conclusive decisions are rare. Especially when such cases end up in court it often results in costly and inconclusive fiascos.

Information Theory, and particularly the methods illustrated in this thesis, could effectively be applied to help solve copyright contraventions and controversies about plagiarism; perhaps even before these reach the courts. The degree of entropic similarity between two compositions may easily be measured using stochastic analysis. Since certain elements, such as the drum rhythms and chord progressions are common to many types of popular music, these could be ignored while the essential melodic qualities are isolated for scrutiny.

7.1.3.3 Specific applications of music

The last fifty years has seen a steady increase in the use of music for specific applications, very often related to psychological matters. In other words, music is often used to influence, directly or subliminally, the behaviour of people. Some examples are:

1. Music Therapy: specific types of music used by therapists working with mentally disadvantaged children, the depressed; music used by dentists to calm their patients, and many more. Once a model of the required type of music has been developed additional music, of which the characteristics fall within ranges specified by the model, may be selected with relative ease.

2. Accelerated learning: ever since accelerated learning has become popular there is a constant search for music that conforms to specific qualities. Although much of this research is based on hit or miss results, stochastic analysis could generate models of the music that has proven effective for this use and to select music that adheres to the model.

3. Music in Commerce: an example of commercial application of music is the music that is subliminally piped through speakers in shopping centres to increase purchasing by the public. Models of the most effective music may be constructed using the methods described herein and used as model for selection of the most suitable music. Obviously, the kind of music that is suitable, first needs to be established by research but many marketing institutions have already done research in this direction.

4. Advertising: most television and radio advertisements are accompanied by music to achieve specific effects or to influence the public somehow by associative processes. The musical characteristics that are most effective under specific circumstances may be developed as a statistical model to ensure that the best results are obtained.

5. Market research in broadcasting: broadcasting houses constantly need to asses their ratings with their listening public. Depending on the kind of broadcaster such market research is often based on the musical tastes for which they cater. Having established the preference of their listening public, stochastic models may be devised and the music that is being broadcast compared with the models.

7.2 Conclusion

Each different composition generates unique entropy values that can be shown in a graph of two dimensions. The results so obtained could serve as a kind of 'finger-print' unique only to that composition. In chapter 6 methods were illustrated on how characteristics of stylistically similar compositions could provide the information to create a model specific to the characteristics of that group. Individual pieces may then be compared with the pre-defined model to establish to what extent the piece conforms to the group-model.

The process shown is accumulative in that any number of elements may be included in the creation of an identifying chart and therefore also in the comparison. The simplest aspect being the quantification of pitch or rhythm and their factors of distribution. As additional elements are added to the model, so the model becomes more complete and allows for more precise comparisons.

Having established the possibilities that stochastic analysis offers, it is possible to apply the methods in commerce and areas where music plays an active role in mood and behaviour modification.