STYLE IN MUSIC SEEN AS RESTRAINT:
AN INFORMATION THEORY APPROACH

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The subject of this thesis is the application of information theory to the analysis and composition of music. Designed as an introduction to the theory for the musician, the initial sections of the thesis describe six concepts from information theory selected for their value in musical application. These are information, stochastic process (including ergodic sources and Markov chains), entropy, redundancy, channel capacity and noise. The next sections describe the range of existing applications and the concluding sections deal with the criticisms of such applications. As illustration, demonstrations of information theory analysis and generation are offered, including an original tape composition based on the principles outlined in this thesis.

Le sujet de cette thèse applique la théorie d'information à l'analyse et à la composition de la musique. Les sections initiales de la thèse introduisent le musicien à la théorie; elles décrivent six concepts de la théorie d'information choisis pour leur valeur dans l'application musicale. Ceux-ci comprennent l'information, le processus "stochastic" (incluant les sources "ergodic" et les chaînes Markov), l'entropie, la redondance, la capacité du canal et le bruit. Les sections qui suivent décrivent le champ des applications existantes et les sections conclusives traitent des critiques se rapportant à de telles applications. Comme illustration, les démonstrations de la théorie d'information, se rapportant à l'analyse et à la génération, sont présentées incluant l'original d'une composition sur bande magnétique, basé sur les principes énoncés dans cette thèse.

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A hypothesis now appears. Exotic music, primitive music, modern music and experimental music have successively transgressed musical laws without destroying the value of music. Hence the laws transgressed were not true structural laws: their principles were not the true foundations of the art of modulating time. There must exist other, more secret, more fundamental, and more general laws which govern the arts of time. On the basis of a criticism of the theory of harmony, Hindemith maintains that natural laws in music will have to be as concrete as the laws of electron flow or of hydrodynamics.

Abraham Moles[1]

CHAPTER ONE

INTRODUCTION

The subject of this thesis is the application of concepts drawn from information theory (which is also known as statistical communication theory) and cybernetics to the art of music. The basic premise is that there are two ways in which one can approach music through information theory. The first way is to use the theory in its original form as a mathematical theory designed for solving problems in telecommunications. The second functions in a more abstract and flexible manner than the first and consists of using certain generalized concepts derived from the original theory to view music.

This thesis is designed to serve as an introduction to information theory for the musician interested in additional theories through which to view music. The initial sections sketch the development and describe relevant aspects of the theory so as to familiarize the reader with the new and often confusing terminology associated with it. Based upon this familiarity the next sections explore the two approaches which stem from the theory and the subsequent applications and insights which may be gained from the use of information theory in the analysis and composition of music. Included in this portion of the thesis will be a discussion of the cybernetic concept of restraint as a model for style in music, the insights derived from a model of the composition process which was synthesized from algorithms used in the computer generation of music and demonstrations by the author as to how the more general and abstract approach of the theory can be used in the analysis of certain musical events and in composition. The final sections deal with various criticisms of the theory and a summary of previous material.

Due to the flood of interest in information theory following the Second World War and the numerous conferences and publications which emerged in the early fifties, information theory evolved from a telecommunications-oriented view of message transmission to a general model for human communication. As Frank Dance writes:

> 1948, the year in which Shannon's first papers were published in the Bell System Technical Journal was also the year of first publication of Norbert Wiener's classic "Cybernetics, or Control and Communication in the Animal and the Machine". The dual thrust of these seminal works spawned the rapid popularization and dissemination of an almost entirely new vocabulary in the communication field. "Bit", "Entropy", "ergodic theory", "feedback", "information" (in the mathematical or statistical sense), "noise", "probability", "redundancy" and many other terms were quickly integrated into communication terminology and were extended by analogy from their original fields to almost any discipline that had an interest in self-examination from the viewpoint of communication.[2]

Simultaneous to the growth of information theory, developments in Western Art Music (continuing expansion of the tonal system, new instrumental techniques and sound sources, electronic music, etc.) prompted many musicians to search for additional theories and disciplines to aid in their work. Linguistics, psychoacoustics, physics, psychology, perception and later cybernetics, systems theory and information theory all became new tools with which the musician could try to decipher music. In addition, the new technology of the digital computer demanded a re-examination of the composer's role: Many of the parameters of a composition (or the restraints placed upon the universe of sound available to the composer) which had been previously established by environment, training, historical precedent, etc., now had to be consciously considered in order to program the computer. Cybernetics and information theory, with their close ties to computer technology, proved very useful in the computer generation of music.

Although the classical presentations of information theory are technical, the fundamental concepts have great intuitive appeal. This has resulted in a wide range of scholarship in articles dealing with information theory, especially those concerning applications to music. Because of this and the difficulty of the original source material (papers in the Bell System Technical Journal by Nyquist, Hartely and Shannon, Wiener's <u>Cybernetics</u>, Dennis Gabor's "Theory of Communication" and others), my initial motivation was to sort through the diverse literature of this field to gather clear examples, explanations and analogies in order to fuse a coherent description of an often perplexing theory: a description especially geared for the needs of the musician.

The literature can be divided roughly into two categories: engineering and non-engineering. The former deal mainly with the problems of efficient signal transmission and the development of powerful theorems to deal with problems of communications, generally in the area of telecommunication. These texts and papers are mathematical in content and are extremely difficult for the lay reader. In this category one finds the seminal work of Nyquist, Hartely, and Shannon, the work of Dennis Gabor, and part of the work of Norbert Wiener. In addition one also finds textbooks based on Shannon's work which are intended mostly for mathematicians and engineers. These books are not directly relevant to musical applications, although they establish the scientific nature of information theory and its extremely practical side. Representative of these books are the texts by Ash, Bell, Brillouin, Fano, Gallager, Raisbeck and Young which are listed in the bibliography at the end of this thesis.

In the category of non-engineering sources, one finds most of the material relevant to this thesis. Colin Cherry's On Human Communication, J. R. Pierce's Symbols, Signals and Noise and Donald Mackay's Information, Mechanism and Meaning serve as reference for the history and development of information theory, while the work of Cherry and Pierce, Jagit Singh's Information Theory, Language and Cybernetics and Warren Weaver's "Some Recent Contributions to Communication Theory" provide the best general introduction to the theory, and the standard reference texts on the subject.

Leonard Meyer's book Music, the Arts and Ideas and Abraham Moles' Information Theory and Esthetic Perception serve as primary sources for musicians on the application of information theory to music, while Moles' translator, Joel E. Cohen, has an article entitled "Information Theory and Music" which catalogues and discusses most of the important work in the field.

Most of the primary material on style as restraint is derived from Gregory Bateson's Steps to an Ecology of Mind, while Joseph Youngblood's "Style as Information", Fred Attneave's "Stochastic Composition Processes" and the work of Meyer and Moles illustrate this in terms of music.

Most of the sources for reflections and results from the actual use of information theory in the musical endeavour are catalogued in the Cohen article. These include Lejaren Hiller's "Research in Music with Electronics", Ian Mathews' "The Digital Computer as a Musical Instrument" and Hiller and Baker's "Computer Cantata: A Study in Compositional Method" which document the use of information theory in the computer generation of music. Also mentioned in the Cohen article is R. C. Pinkerton's "Information Theory and Melody", one of the first articles to suggest the value of an information theory approach and one which contains instructions on how to generate simple tunes using the theory.

For reference in the related area of perception of musical events and the channel capacity of an audience, D. E. Broadbent's Perception and Communication and George A. Miller's Psychology of Communication provide material on information theory and psychology, with some examples of musical perception research as well.

Epistemological considerations of information theory and its relationship with thermodynamics and entropy is discussed in detail in Lawrence Rosenfield's Aristotle and Information Theory which is an excellent documentation of the implications of information theory and its connection with causality. This material may also be found in an article by Richard Raymond entitled "Communication, Entropy and Life". The chapter in Singh entitled "Information and Entropy" provides the best introduction to this fascinating area.

Lastly, critique and comment on the role of the theory in music can be found in articles by Bruce Vermazen, "Information Theory and Musical Value", by Titchener and Boyles, "Meyer, Meaning and Music", by R. A. Sharpe, "Music, The Information Theoretic Approach" and by J. R. Pierce, "Communication Sciences and the Arts".

This thesis is a compilation of this and other material formed to provide the musician or interested reader with a working knowledge of information theory such that he or she may approach the literature with confidence. I believe that musical application is an excellent vehicle for the understanding of information theory, which, as a general communication theory, may be used to view all human communication.

> The obvious first remark, and indeed the remark that carries the major burden of the argument, is that the mathematical theory is exceedingly general in its scope, fundamental in the problems it treats, and of classic simplicity and power in the results it reaches.
>
> Warren Weaver[3]

General Description of the Information Theory Model

One of the most intuitively appealing aspects of Shannon's theory of communication is the simple block diagram which accompanied his original paper and served as the model for communication. This model has been used in many diverse areas though often slightly altered to suit different needs. The illustration which Shannon used is shown here in Figure 1.1. Many of the concepts used in this thesis are derived from this model and it forms a basis for much of the material which follows.

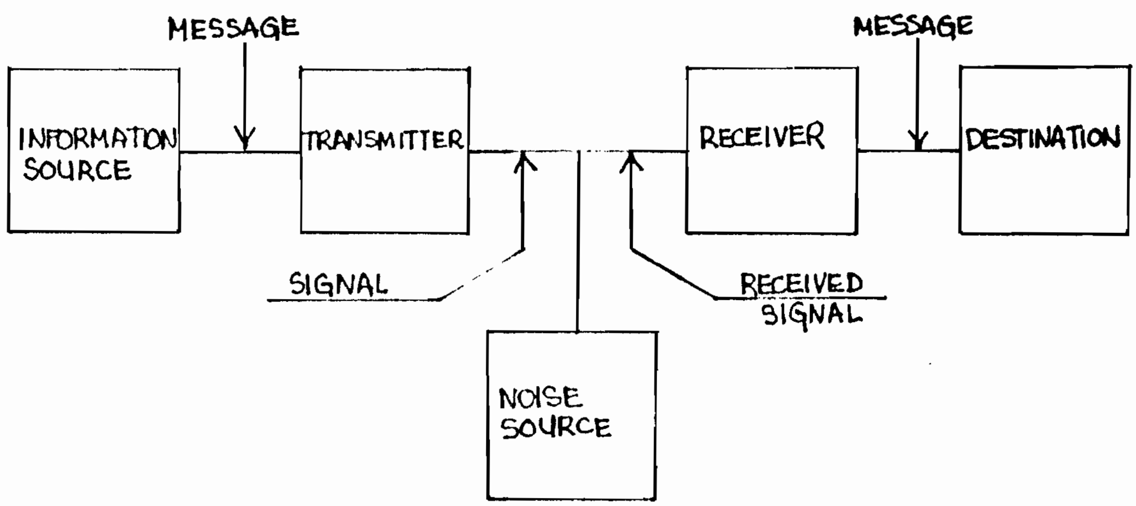

Figure 1.1

In this model, the <u>information source</u> selects a desired <u>message</u> out of a set of possible messages, or put another way, selects signs successively from an alphabet or repertoire, constituting messages. The <u>transmitter</u> changes these messages into <u>signals</u> (the physical form of the message) which are sent over the communication <u>channel</u>, which is the medium of transmission (that is, air, copper wire, light rays, etc.) to the receiver. As an inverse transmitter, the receiver changes the signal into a message which is then sent to the destination: the person or thing for whom the message is intended. This being a symmetrical model, the receiver uses the signal to decide what sign or message should be selected out of a repertoire identical to that of the sender's. In the process of transmission, certain things not intended by the information source are added to the signal (that is, distortion, static, transmission errors, etc.). These changes in the transmitted signal are called noise.[4]

From this description, it is clear that transmission of signals is dependent upon a common repertoire for the sender and receiver. It is the nature of this model that the quantity of information is determined by the surprise value of a particular signal selection from that repertoire, and that signal (or message or event) may be a binary digit, a letter, a note, an image or a specific voltage; in fact, almost anything.

At the heart of an information theory approach to music and an understanding of the theory itself are two vital aspects: an understanding of the term "information" as defined in the theory and the role of meaning within this model. "Information" in the information theory sense (the word "information" in this thesis will always refer to the information theory definition) is very different from the common understanding of the word. Information is not a quality nor is it connected with wisdom or truth; it is a quantity based on the predictability of a selection made from a repertoire of messages or signals by an information source. The message or signal is not the information because the message pre-exists in both sender and receiver. What the information or quantity of information represents is the uncertainty involved in the selection.

At this point it should be mentioned that obviously, information theory cannot be simply transferred from telecommunications to music and human interaction without some difficulties. The most evident is the original theory's requirement of identical repertoires. This problem is sometimes reduced by expanding the definition of repertoire to include either all possible sound (as in the case of music) or by looking at the selection process in terms of primary elements (such as frequency, duration, amplitude) rather than in larger units such as chords or notes, etc. The implications of this problem are discussed in subsequent chapters: For now it is important to note that it can be dealt with in a number of ways.

This new concept of information is crucial to the theory, for it makes a numerical evaluation of a communication source possible and thus gives one a measure for channel capacities, structure in communication, efficiency, etc. From this emphasis on selection from alternative signals, it follows that meaning (in the many ways that concept is understood) occupies a unique position in this theory. As Moles writes:

> Meaning rests on a set of conventions which are <u>a priori</u> common to the receptor and transmitter. Thus it is not transmitted; potentially it preexists the message. Only complexity is transmitted from the transmitter to the receptor; it is precisely what is not present at the receptor; it is what is <u>unpredictable</u>. The measure of information no more depends on the number of symbols transmitted than on

> the effects of the symbols; rather, it measures the originality of the grouping of the symbols, as opposed to the banality of the forseeable.
>
> Abraham Moles[5]

This quotation eloquently sums up the concept of information in the theory and thus demonstrates how meaning is not a component of the theory's original form. Shannon's theory was framed explicitly to require no reference to the meaning of the messages selected in response to a signal. The meaning of these messages was declared not to be the concern of communication engineers: Theirs was the accurate and efficient transmission of signals.

Leonard Meyer's work approaches the problem of meaning in music, interestingly enough, from something of an information theory standpoint. He defines musical meaning as resulting from the establishment of certain expectations in the syntactical structure of a musical work and the delaying and manipulation of these expectancies. Since in music, relationships of elements and structures are of prime importance rather than reference to extra-musical things, the lack of reference to meaning in an information theory approach is not as serious as it might be in other areas of human communication.

The fundamental tenet of this thesis is that information theory can be used as a tool for the musician to analyze, synthesize and gain new insights into music. However, nowhere will I write that it should be the only theory that a musician should use: The diversity and complexity of musical communication requires many theories; not just one. This thesis is written for the musician who wants the additional insights, ideas and articulations of problems that an information theory approach can provide.

Notes

[1]Abraham Moles, Information Theory and Esthetic Perception, trans. Joel E. Cohen (Urbana: University of Illinois Press, 1966), p. 105.

[2]Frank Dance, "A Helical Model of Communication," in Foundations of Communication Theory, ed. Kenneth K. Sereno and C. David Mortensen (New York: Harper and Row, 1970), p. 103.

[3]"Some Recent Contributions" in The Mathematical Theory of Communication, Claude E. Shannon and Warren Weaver (Urbana: University of Illinois Press, 1964), p. 25.

[4]Claude E. Shannon, "The Mathematical Theory of Communication" in The Mathematical Theory of Communication, Claude E. Shannon and Warren Weaver (Urbana: University of Illinois Press, 1964), p. 4.

[5]Moles, p. 197.

CHAPTER TWO

INFORMATION THEORY: THREE KEY CONCEPTS OF UNCERTAINTY

This chapter is concerned with the first three of six key concepts of information theory which I have selected for their relevance to musical application: Information, Stochastic Process, Entropy, Redundancy, Channel Capacity and Noise. These concepts are described one by one as to their development and position in information theory and as to how they have been used in music. Because information theory is a complex field with its own unique and powerful terminology, some of its concepts are explained using previous definitions as building blocks. For this reason, these six are arranged in a specific order so that the learning process of the reader is cumulative.

The three concepts which are the concern of this chapter; information, stochastic process and entropy, are all very important aspects of information theory when it is used as a statistical methodology to analyze or compose music. As a consequence, they are essential in the computer generation of music, which is one of the few areas of music where the use of information theory as a strict methodology is not fraught with serious difficulties. In addition, in terms of their use in the more general and abstract applications of the theory, these three concepts emerge as vital to a matter at the very heart of information theory; the relationship between uncertainty and information. This relationship is initially defined in terms of the first concept of this chapter, which not surprisingly, is the fundamental building block of the theory: information as quantity.

Information

> Information can be received only where there is doubt; and doubt implies the existence of alternatives--where choice, selection or discrimination is called for . . . discrimination is the simplest and most basic operation performable.
>
> Colin Cherry[1]

Within this quote lies the fundamental strength of the term "information" as used in information theory: It is a measure of the uncertainty related to the selection of signals. The nature of the signal is unimportant, what is vital to the concept is the discrimination or selection of alternatives and the uncertainty or doubt in the form of probability associated with that selection. This chapter will show how the quantity of information might be calculated for most sources, thus giving those interested in communication events a new insight by providing for the first time a measure of a communication source.

The origin of this concept of "information" lies in the early days of telecommunications:

> Perhaps the most important technical development which has assisted in the birth of communication theory is that of telegraphy. With its introduction the idea of speed of transmission of "intelligence" arose. When its economic value was fully realized, the problems of compressing signals exercised many minds, leading eventually to the concept of "quantity of information" . . .[2]

The first experimenter to develop and define information as a quantity was R. V. L. Hartely. He defined a "quantity of information" or H as

$$H = N \log S \qquad (1)$$

where a message of N signs chosen from an alphabet or code book of S signs has S^N possibilities, therefore the quantity of information is most reasonably defined as one. (If $M^X = Y$ then X is the logarithm or log of Y to the base M. In information theory all logarithms are to the base 2.) For example, if two people are communicating by teletype, then S would be the number of characters available on their teletypes (which is their alphabet of signals) and N would be the number of signs that were transmitted from the sender to the receiver. This theory of Hartely's is regarded as the genesis of the modern theory of communication. His logarithmic approach evolved from the work of H. Nyquist, who first suggested a form of the expression (1) which he used to determine the speed of a transmission. The work of these two researchers, plus others like Gabor, Wiener, Boltzmann and Heisenberg, contributed to and formed the roots of the work of Claude Shannon, whose seminal work, The Mathematical Theory of Communication, published in 1948, constitutes the prime and most important source, literally creating the area of information theory.

Both Nyquist and Hartely had seen the necessity of basing a measure of information, in a logarithmic way, on alternative possibilities. What Shannon did was to treat the problem in a more general statistical sense, so that there was not just numbers of possible messages and alternatives but a stated probability of occurrence for each signal or message.[3] In his symmetrical model of communication, illustrated in Figure 1.1, Shannon defined information as a measure of the sender's freedom of choice in selecting a message from an alphabet. Consequently another way to describe the freedom of choice is through a measure of the minuteness of the selection made.

To illustrate this point, imagine an alphabet or ensemble where the different possible messages or signals are pictured as occupying space proportional to their relative probabilities, so that the least probable message occupies the smallest space and thus requires the most minute selective operation.

A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C

ENSEMBLE

Figure 2.1

In the ensemble illustrated in Figure 2.1, the greatest amount of information is obtained when message "C" is selected, assuming that the sender selects successive signals randomly and in an unrelated fashion. Being the most minute selection, it is therefore the least probable and has the most surprise value: It is the selection least expected by the receiver. Similarly, "B" is the most expected message as it requires the least minute selection and thus it conveys the least information.

The amount of information is expressed as the logarithm to the base 2 of the number of alternatives the sender has to select from. The unit is a binary digit or "bit". The simplest expression to determine the number of bits of an information source is Hartely's expression (1). If only one message is to be conveyed (that is, A A A A A A etc.), there is no selection made, no alternatives, no surprise element and therefore no information. The simplest situation is that of two alternatives with an equal probability of occurrence. The amount of information from such a source is defined as 1 bit.

The general expression of this concept therefore, reads like this: the more predictable or expected an event is, the less information it conveys, while the less predictable it is, the more information is conveyed. As Norbert Wiener writes in The Human Use of Human Beings, "Clichés, for example, are less illuminating than great poems."[4] This general expression may be transferred to music in the following way. A pattern of notes like the tune of a well-known nursery rhyme conveys less information than a pattern taken from a piano piece by Karlheinz Stockhausen for example, which is a less predictable sequence. Similarly, if a composer severely restricts the combination of and the extent of the source material for a work (that is, the scale, the range of the sound sources, etc.), that work will convey less information than one which has a less restricted structure and uses many diverse sounds. However, the reasons behind these two illustrations form the bulk of material of this thesis, for they are many and are often quite interrelated and complex. What is important, nonetheless, is that they all hinge upon a measure of expectation and the concept of "information" as quantity.

Since information theory is primarily a mathematical theory, I will describe some of the mathematical tools used to determine the number of bits of a source. The classic illustration of this is the toss of one honest coin. Here the possibility is of one of two signs being selected by chance: heads or tails. Information theory is concerned with not just one toss, but the average probability of a number of selections. Consider that a coin tossed 100 times will most likely land "heads up" half the time. If p_0 is the probability of "heads" landing up and p_1 that of "tails", the amount of information or H may be expressed as:

$$\begin{aligned} H &= -(p_0 \log p_0 + p_1 \log p_1) \qquad (2) \\ &= -\left(\tfrac{1}{2} \log \tfrac{1}{2} + \tfrac{1}{2} \log \tfrac{1}{2} \right) \\ &= -\left[(\tfrac{1}{2})(-1) + (\tfrac{1}{2})(-1) \right] \\ &= 1 \text{ bit} \end{aligned}$$

A more revealing case would be that of the dishonest coin which lands "heads up" 3/4 of the times thrown:

$$\begin{aligned} H &= (3/4 \log 3/4 + 1/4 \log 1/4) \\ &= \left[(3/4)(-.415) + 1/4(-2) \right] \\ &= 0.811 \text{ bit} \end{aligned}$$

Thus one gains less information at each toss of a dishonest coin for as the probability of one message increases, that of the others decreases and the amount of information diminishes.

Two honest coins tossed at the same time results in two bits of information per toss: there are now four possible messages: h-h, h-t, t-h, t-t; (h=head, t=tail); $2^2=4$. Three coins result in three bits per toss: in this case there are eight possible messages ($2^3=8$ or $\log_2 8=3$). The more general expression of (2) which is used to determine these results is

$$H = -Nt \sum_{i=1}^{n} p_i \log_2 p_i \qquad (3)$$

where p_i is the probabilities of occurrence of symbols drawn from a repertoire of n symbols assembled in a sequence of length Nt. This is the mathematical relationship derived from the work of Heisenberg in the uncertainty of wave mechanics and Boltzmann in statistical thermodynamics. Gabor and Shannon adopted it (3) through analogy to compute the uncertainty of messages. This connection between discoveries in physics and information theory contributed a great deal to the initial excitement which greeted the publication of Shannon's paper. This relationship is clearly evident in the section on the role of entropy in information theory, for entropy is the second law of thermodynamics.

Intrinsic to Shannon's model of communication is an alphabet or repertoire of signals or messages which is identical for both sender and receiver and which pre-exists in both prior to the transmission of the message. This aspect of the theory is crucial for a proper understanding of information, for as Cherry writes:

> But signals do not convey information as railway trucks carry coal. Rather we should say: Signals have an information content by virtue of their potential for making selections. Signals operate upon the alternatives forming the recipient's doubt; they give the power to discriminate amongst, or select from, the alternatives.[5]

This aspect of the theory has been incorporated into musical applications in a number of ways. For example, Leonard Meyer sees it reflected in the habit responses of the listener.

If the listener is familiar with the style, then he will share a common repertoire of stylistic probabilities with the composer or the music which will facilitate the transmission of messages. If some of the material is totally unfamiliar, Meyer refers to this as "cultural noise" in as much as it will interfere with the listener's understanding. Meyer goes on to say that such "cultural noise" increases (as one might imagine it would) as the listener's cultural and geographical distance from the style increases. In other words, while some North American might not be familiar with, let us say, a Beethoven Symphony, his understanding would still be greater that that of a Fiji Islander, who would have a great deal more cultural noise as interference in the message transmission: That is, his repertoire of habit responses and stylistic probability would most likely be very different from that needed to appreciate Beethoven. This is of course an extreme case; suffice it to say that "cultural noise" exists in almost any musical communication because it refers to differences in the alphabet of habit responses between the composer and the listener.

One other way the aspect of common repertoire is incorporated in music applications is through expansion of the concept so that the common alphabet of the composer and listener consists of the quanta or total spectrum of sound available to the human ear. In this approach, suggested by Abraham Moles, the repertoire may thus be considered common for most senders and receivers. The sender or composer then selects his message by structuring or restraining the mass of information that is the quanta of sound through paradigms of form, structure, style, etc.

The coin examples used to illustrate the computation of information quantity were a special case in the theory of information: the message source was "ergodic". This implies that the probabilities of occurrence don't change with time: a coin tossed now exhibits the same probabilities it did a year ago. This quality of a message source; being ergodic, or one might say a poll-taker or statistician's dream; is an essential part of information theory and one of its limitations when applications are made in areas other than telecommunications. In musical applications, suggesting that the work of some composer is ergodic would imply that a sufficiently large sample from an infinite sequence has the same statistical structure as the infinite sequence. To do this, one must determine the parameters of style in the work and the sample must be homogeneous. These restraints suggest that very little music may be viewed as ergodic and thus there are limitations to the application of this aspect of information theory as a strict methodology in musical analysis. Nonetheless, this does not prohibit its use in the generation of music and this problem is one of the contributing factors of this author's suggested approach to information theory as a flexible philosophical frame which will be detailed in subsequent chapters.

If we now return to the coin illustrations, it is important to note as well that each toss is not influenced in any way by any previous toss, which makes it a very unique sequence of messages in the world of communication. The more common situation is one where selections are dependent upon previous selections; where there is some manner of feedback between the selected message or messages and the sender selecting the next message. This is called a stochastic process in information theory terminology and is the concept which concerns us next.

Stochastic Process

In an information theory approach, the conceptualization of musical style and some other aspects of musical structure such as melody, stem in part from the area of stochastic process. Consequently, this area is very important for this study, and while the fourth chapter will deal extensively with "style", this section will define the stochastic process and provide illustrations in examples from language and musical communication.

To begin this discussion, I offer a quote from Leonard Meyer's Music, The Arts and Ideas:

> . . . for language and music depend upon the existence of an ordered probability system, a stochastic process, which serves to make the several stimuli or events mutually relevant to one another. Thus the probability of any particular musical event depends in part upon the probabilistic character of the style employed. Randomness of choice is limited by the fact of musical style.[6]

A source of information which selects signals according to probabilities is called a stochastic source, and the message sequence a stochastic series. Inherent to the stochastic process is a consideration of transition probabilities; that is, the relative frequencies with which different signs follow a given sign, or precede it.[7] Shannon describes the stochastic process as a source which chooses successive symbols according to certain probabilities, depending in general, on preceding choices as well as the particular symbols in question. A stochastic series may be a physical system or a mathematical model of a system which produces a sequence of symbols as described above; governed by a set of probabilities.[8]

The concept of the stochastic process has at one time or another invaded linguistics, literature and most successfully, music. It is vital to a large part of the work in music and information theory. However, since the concept must be understood before its usefulness can be appreciated, I will illustrate the terminology with language examples first, since such models are the simplest to deal with, and then I will discuss the role of stochastic process in music.

Stochastic series where the signs are probabilistically related to each other; for example, the probability of the selection of the second sign being dependent on the selection made to determine the first sign; are called "Markov Chains". This latter example is called a "digram" structure: In such a stochastic process, each sign determines the probability of the sign following it. Similarly, in a "trigram" structure, each sign influences the probability of the next two signs, etc. The general expression is m-gram where m is the number of signs which are related to one another probabilistically. M-grams (sometimes called n-grams) are often referred to as Markov chains of m-order: A trigram would be a third-order Markov chain. When a stochastic process is used to generate material, the m-grams are referred to as approximations of m-order.

Such probabilistically related streams of messages are named after A. A. Markov (sometimes spelled Markoff) who published a statistical study of Alexander Pushkin's novel, Eugene Onegin, wherein Markov considered only word digrams. Based on the assumption that English is an ergodic source or statistically stable, most writers of English constitute an approximately ergodic source of text. The following illustrations from Shannon demonstrate the approximation of an ergodic text from zero-order to third order. These illustrations are not meant as a comment on natural language, but rather are used here merely as a vehicle for the concept of generating material through a stochastic structure.

First is a zero-order approximation. Here the symbols (26 letters and one blank) are independent and equiprobable. There are equal numbers of each symbol in, let us say, a hat. They are mixed, a symbol drawn, noted and then returned to the "hat". The process repeats.

1. Zero-order approximation:

XFOML RXKHRJFFJUJ ZLPWCFWKCYJ FFJEYVKCQSG
HYD QPAAMKBZAACIBZIHJQD.

If we change the distribution of symbols in our "hat" such that they represent the frequencies of English text, a first-order approximation of English consists of symbols independent, but with the correct frequencies.

2. First-order approximation:

OCRO HLI RGWR NMIELWIS EU LL NBNESEBYA TH
EEI ALHENHTTPA OOBTTVA NAH BRL.

In a second order approximation, the symbols are no longer independent, but rather the probability of one symbol following another is considered. These are called digram probabilities.

3. Second-order approximation:

ON IE ANTSOUTINYS ARE T INCTORE ST BE S
DEAMY ACHIN D ILONASIVE TUCOOWE AT TEASONARE
FUSO TIZIN ANDY TOBE SEACE CTISBE.

Similarly, a third-order approximation would use trigram probabilities:

4. Third-order approximation:

IN NO IST LAT WHEY CRATICT FROURE BIRS
GROCID PONDENOME OF DEMONSTURES OF THE
REPTAGIN IS REGOACTIONA OF CRE.

As this process continues, more and more English words appear (there are many English-looking words in 4: DEMONSTURES or PONDENOME, for example) and eventually (anywhere from 6-grams to 9-grams) all the words generated will be English; that is, at a certain level and beyond, such an approximation process will merely reproduce the sample text. In other words, in an 8-gram approximation to English, the probability of "t" following "sugges" is .999 etc. %; at this point, based on the transition probabilities of English, the choice of letters is so restricted that very few words (if any) will be created; rather, the sample text or English will be reproduced. When the method of approximation described above is applied to music, similar problems occur: This approach is referred to as an analytic-synthetic application by Cohen:

> Analytic-synthetic studies have used homogeneous bodies of existent music, such as nursery tunes, hymn tunes, and cowboy songs, to derive matrices of transition probabilities to generate musical samples. These studies indicate the order of analysis, i.e., the size of the m-gram, necessary to produce musical samples like the original. The synthetic output indicates what characteristics of the original music the analysis took into account.[9]

One of the first "analytic-synthetic" applications of information theory to music was by Fred and Carolyn Attneave.[10] They analyzed Western cowboy songs to obtain transition probabilities for every note preceding a particular note. From a final note "C", they started a Markov chain with the proper probabilities going backwards, after selecting a standard form and rhythm. They generated "two perfectly convincing" cowboy songs from a few dozen tries at this generation of sequences according to the probabilities of a source or sample.

The next application brought wide attention to the possibility of using information theory in analysis. Pinkerton, writing in Scientific American, calculated the probabilities of the seven tones of the diatonic scale and a rest (or hold) for thirty-nine nursery tunes. From these calculations, he tabulated the probabilities of pairs of notes and from a deck of appropriately labeled cards (which functioned as a random source) he generated songs. In addition, he constructed six transition matrices to account for each of the positions in a measure in 6/8 time. He selected from each either the most probable or the two most probable transitions and created a circular net consisting at most of binary choices which would then generate "banal tunes" with appropriate rhythmic values. Here in Figure 2.2 is a drawing of the banal tunemaker:

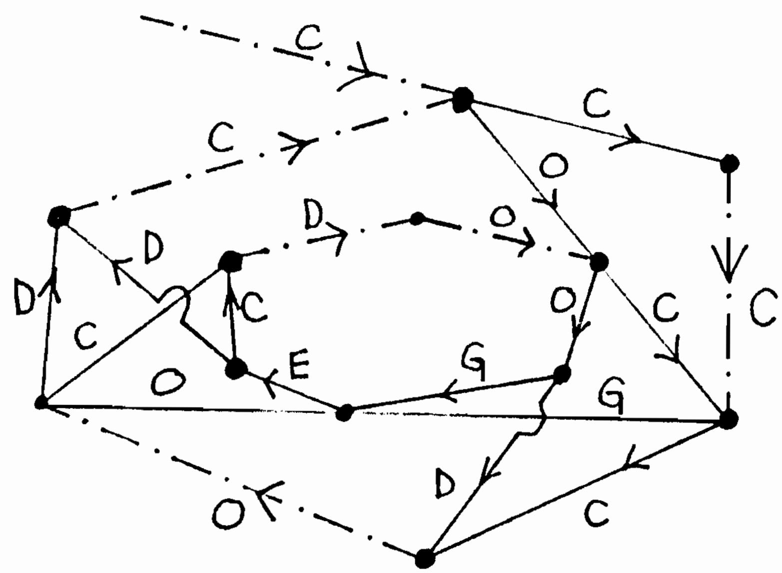

Figure 2.2[11]

A sequence is generated by following the line in the direction of the arrow and recording the note associated with each segment. Where there is a choice at a node, the toss of a coin or other random process may decide the route. (O = rest or hold.) Broken lines show the path from a junction or node where there is no choice.

Cohen presents a generalized schema for analytic-synthetic studies. A computer analyzes a given sample $S_1\ S_2\ .\ .\ .\ S_n$ (where S is a signal) and produces a set of probabilistic generalizations G. The output $S_1^1\ S_2^1\ .\ .\ .$ is generated on the basis of the probabilistic rules in G.

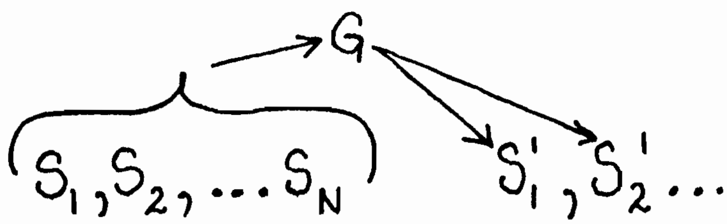

Figure 2.3

> Analysis of the sample consists of determining (1) the set of basic letters, the alphabet, and (2) the combinatorial relationships among them. The statement of combinatorial relationships may be (a) an explicit list of rules, (b) an exhaustive statement of all permissible combinations, or (c) a statement of the probabilities of the occurrence of letters and transitions between them.[12]

Choosing the last method; where a Markov analysis of order m determines the probability of each letter following each (m-1)-gram, Cohen analyzed 37 common meter hymns for his sample to try to generate new hymns with a similar style. The method is clearly outlined in his paper. The computer generated 600 complete hymns from 6000 attempts. As the order m of analysis grew, the higher level of restriction reduced the number of successful hymns. As the earlier example of the approximations to English texts illustrated, when m = 1, that is, when simple probabilities of occurrence were used, the output was hard to sing and definitely not hymn-like. In other words, it bore little resemblance to the sample. When m = 2, the output contained tri-grams and progressions not in the input. The output for m = 4 was less rough, but had extreme ranges for a hymn style. When m = 6, the result was new hymns of a style similar to that of the sample. When m = 8, some of the 9-grams were identical to those of the sample; the "implicit structure" of the 9-grams was strong enough to keep the output like the input, and was therefore too well defined to generate new material.[13]

As was demonstrated earlier in approximations to English, there is a point (which fluctuates according to the material) where the structure of the sample is so predetermined and limited (such as the last letter of a six letter English word, or the seventh note of a children's nursery tune) that only the sample is generated. This problem can be avoided if the sample is infinite, but since this is an unrealistic solution, the other solutions are more sophisticated computer applications and different methods. However, what is interesting is the implications of such a limitation and the question of what kind of ramifications this limit has if it is related to different areas, such as the cognitive process of the human mind. Are there limits to the uses or understanding of models or analogies? Can established structures generate new structures? The questions are many and I raise them here to illustrate the power of an information approach which, no matter what applications it may prove successful in, provides a source of stimulating and provocative ideas; hence the great excitement which arose in most academic circles following its development. It is evident that a purely stochastic view of music is a somewhat simple and limited approach. This is not to deny its usefulness, but merely to state the obvious; most often there is a need for the consideration of other constraints in either the generation or analysis of music. I will continue with the exploration of these constraints through an information theory approach with the concept of "entropy".

Entropy

Boltzmann's statistical concept of "entropy" furnished physicists with a quantitative method of measuring unexpectedness. Shannon and others adapted and extended this procedure to the measurement of the unexpectedness of messages.[14] The general expression of information (3) bears resemblance to Boltzmann's formula for the entropy of a perfect gas. This fascinating and evocative relationship has been exploited, as Cherry points out, to include "entropies" of languages, social systems, economic systems, and is used in "various method-starved studies."[15] There exists as a result a small controversy as to its value to information theory. Often theorists who use information theory for musical analysis or generation will mention expression (3) but not entropy. (Three such important theorists, Moles, Meyer and Cohen, rarely refer to entropy.) Nonetheless, I have included it here for a number of reasons.

Information theory was developed partly as a result of discoveries in physics, particularly work in thermodynamics. Its formulae are related to those used in determining the internal motion of gas molecules; the micro and macro states of volumes of gas. Information theory caused great excitement because of its use of entropy and the parallels drawn to the concept of quantity of information. As L. Brillouin writes in Information Theory and Science: "The theory of information cannot be built as a separate entity. The connection with Thermodynamics is so close that consistency requires a physical theory of information."[16] Norbert Wiener writes in Cybernetics that: "The notion of information attaches itself very naturally to a classical notion in statistical mechanics: that of entropy."[17] Since we have seen how information is a logarithmic measure of organization in a communication system, it is interesting to see that entropy is a logarithmic measure of the organization of a molecular system or macrostate.

Eddington evocatively called entropy "time's arrow" because it is a pointer of the drift of natural processes. I have included this powerful and pervasive law of science in my selection because it is a fundamental aspect of the concept of "information" as uncertainty and as such entropy is thoroughly woven into the fabric of information theory.

"Entropy", an essentially difficult mathematical concept, has the deceptively simple description as the basic tendency for all systems to run down. "Systems can only proceed to a state of disorder." The first law of thermodynamics states that energy cannot be created or destroyed. The second, which is a "statistical" rather than "strict" law, reads that a certain quantity "entropy" will most likely not decrease.[18]

Singh offers an illustration from thermodynamics.[19] Imagine a macrostate which has only a single microstate, that is, a body of gas, whose molecules are all moving with the same speed and in the same direction as the body itself. This is a state of the highest internal order in the motion of molecules. This example of the ultimate organization has the lowest thermodynamic probability. If however, the states of motion of the molecules are highly chaotic and unorganized, each in the anarchistic whirl exhibiting its own unique speed and direction rules, then the number of microstates leading to one and the same macrostate is much more numerous, and its thermodynamic probability becomes exceedingly great. Thus thermodynamic probability, or its logarithm called "entropy", is really an index of molecular chaos that prevails within.

Another illustration is a bottle of perfume left open in a sealed room. Eventually, all the perfume will evaporate and its molecules will be found distributed uniformly throughout the room. Experience and the second law of thermodynamics tells one that the process is irreversible: no matter how long the wait, the perfume molecules will not spontaneously reassemble in the bottle.[20]

It is little wonder therefore, that Eddington, cited in Weaver as declaring ". . . the second law of thermodynamics - holds, I think, the supreme position among the laws of nature,"[21] also refers to entropy as the "arrow of time".[22]

The relationship between entropy and information seems to have been initiated by Leo Sziliard, in a 1929 paper which offered a resolution to the paradox of "Maxwell's Demon" which J. C. Maxwell had enunciated in his "Theory of Heat" in 1871.[23] The demon "received information" about the particle motions of a gas; this information enabling him to operate a heat engine as a perpetual motion machine. This violation of the second law of thermodynamics was corrected by Sziliard who showed that the demon, as an observer, was essentially part of the system and thus used energy to perceive the molecules or particle motion.

This leads to an increase in entropy and a failure of the machine.[24]

In communication theory, the entropy of a message source is measured in bits per second (or per word, letter, character, etc.). The entropy H of a message source is expressed as:

$$H = -\sum_{i=1}^{n} p_i \log p_i \text{ bits/sec.} \qquad (3)$$

The following is a somewhat "musical" example of the entropy of a communication source:[25] There is one performer and four different drums. The drummer hits only one drum at a time. The freedom of choice or information of this source is greatest when all choices are equal, that is, the drummer may hit any of the four drums in any order (random hitting). The sum of the probabilities must always equal one, therefore the entropy of this message source, using (3) is

$$H = -(p_1 \log p_1 + p_2 \log p_2 + p_3 \log p_3 + p_4 \log p_4)$$

where p_1 is the probability of the first drum being hit, p_2 the second, etc., therefore with all probabilities equal, the entropy H

$$H = -(.25\log .25 + .25\log .25 + .25\log .25 + .25\log .25)$$
$$= 2 \text{ bits.}$$

If some constraint is placed on the drummer, that is, some loose "score" where his freedom of choice is limited by defining certain parameters such as the proportions of his hitting: asking that he hit drum 1 half the time, drums 2 + 3 one-eighth of the time and drum 4 one quarter of the time, the result is

$$H = -(.5\log.5 + .125\log.125 + .125\log.125 + .25\log.25)$$
$$= 1.75 \text{ bits}$$

Reason tells us that the information must decrease as any one of the probabilities increases towards one, since the others will at the same time decrease towards zero. The ultimate result is that the drummer hits only one drum, and there are no alternatives, and no information conveyed, no surprise; the entropy of such a source being zero.

Summary

In this chapter I have described the first three of six concepts which have been selected from information theory as valuable for musical application. Information, stochastic process and entropy play an important role when the theory is used as a methodology. For example, they can be used to measure the information quantity in bits of a particular source or determine the transition probabilities between events. Based on these results, composers may generate melodies or event streams from the probabilities of a predetermined sample through Markov approximations. These approximations can be done by the composer alone or with the help of computers, all depending on the degree of sophistication required. These concepts of information theory also have an important place in the theory when it is used in more of an abstract and general way and this will be explored after the next chapter, which deals with the final three concepts; redundancy, channel capacity and noise.

Notes

[1]Colin Cherry, _On Human Communication_, 2nd ed. (Cambridge: M.I.T. Press, 1968), p. 170.

[2]Cherry, p. 41.

[3]Wendell R. Garner, _Uncertainty and Sturcture as Psychological Concepts_ (New York: Wiley, 1962), p. 9.

[4](New York: Doubleday, 1954), p. 21.

[5]Cherry, p. 171.

[6]Leonard B. Meyer, _Music, The Arts and Ideas_ (Chicago: University of Chicago Press, 1967), p. 28.

[7]Cherry, p. 182.

[8]Shannon, p. 39.

[9]Joel E. Cohen, "Information Theory and Music," _Behavioral Science_, 7 (1962), 142.

[10]Cohen, p. 143.

[11]R. C. Pinkerton, "Information Theory and Melody," _Scientific American_, 194, no. 2 (1956), 78.

[12]Cohen, p. 144.

[13]Ibid., p. 144-45.

[14]Donald MacCrimmon Mackay, _Information, Mechanism and Meaning_ (Cambridge: M.I.T. Press, 1969), p. 56.

[15]p. 216.

[16](New York: Academic Press, 1962), p. 293.

[17](New York: Wiley and Sons, 1962), p. 11.

[18]Cherry, p. 216.

[19]Jagjit Singh, _Great Ideas in Information Theory, Language and Cybernetics_ (New York: Dover, 1966), pp. 73-76.

[20]David Layzer, "The Arrow of Time," _Scientific American_, 233, no. 6 (1975), 61.

[21]Weaver, p. 28.

[22]Singh, p. 75.

[23]Singh, p. 72.

[24]Cherry, p. 214-17.

[25]After Joseph E. Youngblood, "Style as Information," _Journal of Music Theory_, 2 (1958), 24-35.

CHAPTER THREE

THREE CONCEPTS FROM THE AREA OF TRANSMISSION

The concepts presented in this chapter are closely tied to problems inherent in the transmission of information between the sender and receiver. They also form the backbone of the theory's more general and philosophical approach to music by offering ideas on structure in music (redundancy), audience reaction (channel capacity), and interference and random influences (noise). Thus it is within these three concepts that one may find a great deal of exciting insights into the musical endeavour. I shall begin with the concept of redundancy.

Redundancy

> Redundancy reduces information; it manifests the influence of any internal organization in the message known simultaneously to both receptor and transmitter--more generally, the case of a message from nature, known *a priori* to the receptor. Redundancy expresses statistically the receptor's *a priori* knowledge of the message. Redundancy opposes information in a dialectic banal-original, but conditions the message's intelligibility by creating an internal organization in it.
>
> Abraham Moles[1]

If we return to the illustration of the drummer with four drums of the last chapter, one finds it is often useful to compare the idealized entropy of a source (that is, the case of the equal choices and maximum entropy) with the actual entropy (the case of the constrained drummer). The ratio of the two cases is called the relative entropy. In this example, it would be 1.75 divided by 2 and it would mean that the drummer is 87.5% as free during the second case as in his first performance where no constraints were placed upon him and the entropy and information was maximum. The remaining 12.5% is called the redundancy in the language of information theory. Redundancy is the measure of the restraint on the drummer--that portion of the message which is predetermined by the source. The term is defined as that fraction of the structure of a message which is determined by the statistical rules which govern the use of symbols in that structure. As we shall see in the next chapter, redundancy is very relevant to musical applications because it pertains to the structure of messages and it is a vital aspect of the cybernetic concept of restraint, which in musical applications, is very useful as a model for style.

Redundancy is the set of rules which places restraints upon or defines the structure of a message. The redundancy of English, for example, has been estimated by Shannon to be roughly 50%.[2] This means that about half of what we write is determined by the structure of the language (rules of spelling, grammar, syntax, etc.) and half by our own free will. This 50% figure is arrived at by calculating the entropy of approximations to English; deleting characters, words and then attempting to restore the text. If the texts can be restored when 50% of the material is missing, then the redundancy is probably greater than 50% and so on.

Redundancy is one of the best ways to combat errors in the transmission of signals. Repetitive redundancy, that is, the repeating of each symbol, though cumbersome and time consuming, is one way in which noise (any unwanted signals such as hum, static, transmission error, etc.) may be defeated. There are many examples of redundancy in everyday communication: the word STOP on the red sign on the corner of the street may be redundant, etc.

The following example is a text which has been transmitted through a noisy channel, where static has eliminated some of the characters. The redundancy of English enables us to reconstruct the message and thus ensure transmission under less than ideal conditions.

> THE BABOON OF COURSE IS NO WIT OUT RESOURCE.
> HE IS FAIRLY POWERFUL. IK ALL RIMATES HE
> LACK   CLAWS BUT HIS NAILS ARE FORMIDABLE.
> HE HAS CANINES LIKE AGGERS. AND HE H S
> WITS. IF WHILE HE I PLNDERING A MA COMES
> OUT OF A FARM H USE HE WILL LEE. IF A WOMA
> CO ES OUT HE WILL I NORE HER. BUT I
> DETERM ED MALE H MAN E MY DRE SES IN
> WO ANS CLOTHES THE   BOON WLL IN TANT Y
> TAKE TO HE WOODS.[3]

Because the redundancy of a source is a measure of its internal organization or structure, it has a large role to play in an information theory approach to music. As will be explored in Chapter Four, redundancy reflects the restraint or structure upon the selection of messages which a composer controls when practising his or her craft. Because some selections are more probable than others, the concept of style is closely related to redundancy, for as Cohen writes in "Information Theory and Music": ". . . composition implies, in terms of information theory, imposing redundancy on a sequence."[4] However, since the next chapter will explore the concept of "style as restraint", I will illustrate the concept of redundancy in terms of music now to provide a basis for that exploration.

Perhaps the best way to approach this application is through the extremes: a scale with complete redundancy as one end and a complete lack of redundancy as the other. The latter end reflects sequences which are generated in a completely random manner, thus exhibiting no structure or organization. These sequences have a relative uncertainty or information factor of 1. The completely redundant end of the scale has a relative factor of 0. The music is completely controlled in such a way that the receiver can predict exactly what will occur, thus receiving no information.

There exists therefore, a continuum of increasing redundancy and decreasing relative entropy or information or uncertainty. Most music falls between these two extremes as composers generally choose some point of equilibrium in order to gain coherence as well as interest. However, in his paper, Cohen describes two works which approximate the extremes of maximum redundancy and complete randomness. John Cage's "Music for Piano 21-52" may be seen as having almost zero redundancy, save for the fact that the sounds are limited to the well-tempered scale and must be produced by a piano. By tossing coins and using the I Ching, the notes and performance styles are determined while other variables such as total duration may be decided by the performers. On the other side, Cage's infamous "4:33" which consists of 4'33" of silence may be viewed as a piece with 100% redundancy: "Since the set of possible events in 4:33 has only one letter (a unit of silence), the constant repetition of that letter conveys no additional information and the redundancy is 100%."[5]

Redundancy therefore may be seen as structure, form, organization, etc., and as such, creates order and predictability: thus lessening the information content of a particular source or sender. A basic form of redundancy is simple repetition or the use of patterns. In music, this is illustrated by broken chords or arpeggios or the process of melody and accompaniment, two examples where the structure organizes the material in order to reduce the uncertainty by creating predictability. As George Miller writes:

> Rehearsal or repetition has the very important effect of organizing many separate items into a single unit, thus reducing the load our memory must carry and leaving us free for further thinking. In terms of logic, the process is like the substitution of a single symbol for a longer expression which would be clumsy to write each time we wanted to use it.[6]

Expressed here from a psychological viewpoint is the role redundancy plays in reducing entropy or information. Berger and Luckman relate this from the different viewpoint of habitualization:

> Any action that is repeated frequently becomes cast into a pattern, which can then be reproduced with an economy of effort and which, ipso facto is apprehended by its performer

> as that pattern . . .
> . . . This frees the individual from the burden of all those decisions; providing a psychological relief that has its basis in man's undirected instinctual structure . . .
> . . . The background of habitualized activity opens a foreground for deliberation and innovation.[7]

Thus for the musician, redundancy is an important concept because it reflects the internal coherence of a piece; it is a measure of the form, pattern and structure necessary for musical communication. Redundancy reflects as well the laws governing a structure. In western classical music, the redundancy in the musical message, its internal coherence, stems from the structural rules used to create it. These are known as melody, harmony, counterpoint, orchestration, solfège, etc. These rules are complex but also quite rigid. This rigidity contributes to a great amount of redundancy in the musical message and creates for the specialist in the symbolic code of musical notation a great deal of foreseeability in this message.

The ability of redundancy to reduce uncertainty by establishing internal structure makes it a very important concept and tool for composition, especially when one considers, as we will in the next section, the maximum capacity that an audience might have for information, or its channel capacity.

Channel Capacity

"The largest possible entropy of a message transmitted over an error-free channel is called the channel capacity."[8] Pierce continues to state in his Symbols, Signals and Noise that the two greatest achievements of information theory are the establishment of the channel capacity paradigm and the determining of the number of binary digits (bits) required to transmit information from a particular source. This involves demonstrating that a noisy information channel has an information rate in bits per character or per second up to which errorless transmission is possible, regardless of the noise.[9]

If we consider that any communication channel has a finite capacity for information; an upper limit, which when exceeded results in error, some amount of overload, distortion, etc., then it becomes rather simple to transfer this notion to human receivers, though it is not a radically new concept in psychology.

> . . . one is led to assume axiomatically that the individual possesses an UPPER LIMIT TO THE APPREHENSION OF INFORMATION per "elementary instant" (length of present). If this "length of present" may be considered constant, one supposes that a MAXIMUM FLOW OF PERCEPTIBLE INFORMATION per unit of time exists.
>
> Abraham Moles[10]

According to William James,[11] channel capacity, in essence, is a suggestion of the necessary inclusion of filters in the perceptual system (or at least at the point of interface) such that only a small section of the continuum is internalized due to the inability we have to simultaneously process everything. Broadbent states that "A nervous system acts to some extent as a single communication channel, so that it is meaningful to regard it as having a limited capacity."[12] Huxley suggests in Doors of Perception that the function of the brain in a nervous system is to shut out or filter out most of "this mass of largely useless and irrelevant knowledge" leaving us with only a "very small and special selection" that is likely to be practically useful.[13]

Musicians have generally had an intuitive understanding of a "channel capacity" in terms of their audience. The successful composer knows how much "information" his or her audience can handle and may manipulate them by overloading then relaxing the amount of new material he or she presents. It has been noted that redundancy is one way of dealing with a limited channel capacity. If the rules inherent in a musical event (rules which determine part of its structure) are not known to the audience, or are not so perceived, then one can say the redundancy of the piece is small. In this case, the mass of seemingly unrelated sound may overload the capacity of the new listener.

The most common reaction to excess information is filtering or recoding.[14] The use of mnemonic devices or large macro structures aid in information processing.[15] Examples of such structures are sentences, or words for individual letters or syllables in English: In music, the perceptual organizational form of chords, or arpeggios or the concept of accompaniment and melody might serve to encode many symbols or events into fewer, larger, and more comprehensive forms.

To illustrate the importance of channel capacity one might imagine what occurs when the rate of information exceeds the listener's channel capacity. The first possibility is that the information may be recoded and thus reduced. "For example, rapidly played arpeggios may preclude the perception or awareness of separate notes so the listener combines them into slower moving chordal groups which come at a rate that does not exceed the channel capacity." The next possibility is that of filtering, that is, selecting elements or events from the stream of music: "in listening to a polyphonic work, one might attend only to one line at a time if the total polyphonic web presents too much information." Repeated listening in this manner would enable the listener to gain access to the entire piece despite the large amount of information. However, if the listener is unable to properly select events from the stream of music, then his filtering or recoding may turn out to be a form of random sampling and the result for him would be confusion or boredom.[16]

In the following quotation, George Miller, in his book the Psychology of Communication, describes how the channel capacity of the human communication system can be determined:

> If the human observer is a reasonable kind of communication system, then when we increase the amount of input information, the transmitted information will increase at first and will eventually level off at some asymptotic value. This asymptotic value we take to be the CHANNEL CAPACITY of the observer: it represents the greatest amount of information that he can give us about the stimulus on the basis of absolute judgement. The channel capacity is the upper limit on the extent to which the observer can match his responses to the stimuli we give him.[17]

The following are some simple examples of the human channel capacity in various modes of perception.

Twelve to forty discrete units per second is the range where "clicks" or small bursts of sound begin to seem continuous; similarly, separate images become continuous (as in film). Miller has suggested that the loudness scale cannot be divided into more than five or six discriminable elements. This is interesting because one can discriminate over a hundred different levels, but channel capacity limitations prevent one from keeping track of more than five or six levels, that is, identifying them as they reappear. This discrepancy is discussed in an article by Garner and Creelman[18] where they point out the distinction that should be made between perceptual discrimination and judgemental discrimination. They note that judgement tasks will impose limits on discrimination well beyond those imposed by perceptual factors. As an example of this, we have a huge number of different pitches or frequencies which we may perceive, yet our upper limit for pitch judgement is 2.5 bits or six or seven elements or equally likely alternatives[19] which corresponds nicely to the western scale of seven notes.

The concept of channel capacity is thus not a new one for psychology, but the paradigm is very useful for music studies as I shall continue to demonstrate in the next chapter. Before that, however, I must present the concept which acts as the ultimate limit to communication transmission, noise.

Noise

> . . . random motions arise among the electrons in all electrical conductors, in telephones, in radio receivers, and in all telecommunication apparatus, and gives rise to the phenomenon of random Gaussian noise. Such random disturbing signals always exist, in varying degrees of magnitude and are microscopically unpredictable and so cannot be allowed for or annulled. Such noise is the ultimate limiter of the fineness with which wave form ordinates may be effectively quantized, . . . and is the ultimate limiter of the information capacity of a telecommunication channel--the ultimate limit set by nature.[20]

Moles refers to noise as that which destroys intent. It is the background of the universe.[21] Noise is a signal that the sender does not want to transmit; what determines noise, therefore, is intent. There is no absolute morphological difference between signal and noise.

We are all familiar with noise. It is the static on the radio, the "snow" on the television screen. Aurally, it is represented by Gaussian or thermal white noise which is a random distribution of the audio frequencies, each occurring independently. This sound is similar to that of a shower, or radio static.

Noise is a perfectly formless message, and as such, is the message carrying the most information, and is therefore the most difficult to transmit. Having no internal structure or organization, if part of the message is lost in transmission, it is irretrievable. The receptor has no a priori knowledge about its structure. The message has no redundancy; no stochastic liaisons; there is no basis from what has occurred to guess about what will come next. Noise is the most fragile of messages, yet it is easiest to render approximately. All Gaussian white noise sounds the same. Lacking any meaning, it creates the paradox of too much information--boredom.

Nonetheless, for all these reasons, Gaussian noise plays a large role in electronic music. Because it is a random distribution of audio frequencies, it may be used as a random control voltage in music synthesis to create any degree of variation in almost any parameter of a sound. It may be processed (filtered, given dynamic shape, echo, etc.) as a rich and extremely complex sound source. When used as a control voltage (most music synthesizers may be controlled through the use of voltage), it adds a "natural" or "organic" quality to a somewhat mechanical sound characteristic of synthesizers because of its unpredictability, high entropy or maximum information potential. Thus, filtered white noise is often used to simulate natural sounds; evocative sound-images of wind whistling, or surf pounding or rain lashing at a forest.

Conclusion

Presented in the last two chapters are those elements of information theory that I feel are relevant to musical application, but at the same time, are also accessible to musicians without any special background in mathematics or engineering. The original information theory paper by Shannon was essentially complex expressions and theorems, well befitting a mathematical theory of communication. His paper and the article by Warren Weaver which precedes Shannon's work in its book form suggests, however, a wider sphere of influence for the theory. Its concepts, in more general forms, have been used subsequently for many diverse communication applications. Thus, following lines similar to those of Meyer, Youngblood and Moles, I have presented those concepts which can be expressed in a more general and philosophical fashion, in order that such an expression may offer a new perspective on music.

In the chapter which follows, I will detail the application of information theory, both in its original and its more abstract generalized form, and demonstrate, based on the material discussed in this and previous chapters, the value of an information theory approach to music.

Notes

[1]p. 124.

[2]Shannon, p. 56.

[3]Moles, p. 45.

[4]p. 147.

[5]p. 147.

[6]George A. Miller, Psychology of Communication (New York: Basic Books Inc., 1967), p. 6.

[7]Peter L. Berger and Thomas Luckman, The Social Construction of Reality (New York: Doubleday and Co. Inc., 1967), p. 53.

[8]J. R. Pierce, Symbols, Signals and Noise (New York: Harper and Row, 1961), p. 106.

[9]p. 107.

[10]p. 59.

[11]William James, The Principles of Psychology (New York: Dover, 1950), p. 288.

[12]D. E. Broadbent, Perception and Communication (New York: MacMillan, 1958), p. 297.

[13](Hammondsworth: Penguin Books Ltd., 1959), p. 21.

[14]Paul R. Pedersen, "The Perception of Musical Pitch Structure," (dissertation, University of Toronto, 1970), p. 33.

[15]Miller, p. 40.

[16]These quotes from Pedersen, p. 29.

[17]p. 17.

[18]W. R. Garner and C. Douglas Creelman, "Effect of Redundancy and Duration on Absolute Judgements of Visual Stimuli," Journal of Experimental Psychology, 67 (1964), 168-72.

[19]Miller, p. 18.

[20]Cherry, p. 200.

[21]p. 86.

CHAPTER FOUR

THE APPLICATION OF INFORMATION THEORY TO THE MUSICAL ENDEAVOUR: STYLE AS RESTRAINT

> The essence and raison d'être of communication is the creation of redundancy, meaning pattern, predictability, information and/or the reduction of the random by "restraint".
>
> Gregory Bateson[1]

The manifestation of information theory in the world of music may be organized into three overlapping areas: the act of composition, the act of listening (or analysis) and the problem of meaning in music. This chapter deals with various forays into these applications, all of which have been headed under the concept of "style as restraint", that is, musical style seen from an information theory / cybernetic viewpoint. This approach involves the perception of music and musical style as a phenomenon resulting from constraints upon what Abraham Moles terms the "psychophysical repertoire of sound elements"[2] or the quanta of aural elements accessible within the physical and psychological limits of the human organism.

In addition, I have presented a model of this "style as restraint" approach which is based upon a synthesis of the involvement of information theory in the computer generation of music and the corresponding algorithm which emerges after the

Second World War. This model is also influenced by a cybernetic view of the role of restraint in communication.

The influence of information theory upon the musical community has occurred in two basic ways. Firstly, as a methodology, that is, where the theory is used in its original form. This consists of a series of theorems and formulae designed to examine discrete and continuous streams of signals to determine (among other things) the information quantity in bits of a specific source, its channel capacity and the proper coding necessary for efficient transmission: in other words, the theory as a tool for the analysis of the statistical probability of a communication source. Secondly, information theory may be used as a philosophical tool, or a conceptual frame with which to view music; using the words and concepts of the theory in a more pragmatic and flexible way than when it is used as a strict methodology.

The view of this thesis towards these two manifestations of the theory is to stress the necessity for understanding some of the formulae, theorems and ensuing statistical manipulations, but to suggest that for the musician, whose communication system is highly complex and rarely discrete, a more general, flexible and selective use of the theory is necessary. This is based on the belief that consideration of concepts such as information as quantity, stochastic process, channel capacity, redundancy, noise, etc., can enhance one's understanding of both the fields of composition and analysis.

To elaborate this point, the thesis is accompanied by an original electronic piece which was composed bearing the above in mind and the conclusion of this chapter includes a discussion of this piece.

Applications of the Theory: Computer Music

Information theory emerges on the musical scene in the early 1950's for a myriad of reasons. It appears partly as a result of the widespread enthusiasm in learned circles about this new communication theory, and partly because of the growing need for theories through which to view a rapidly expanding musical world. Serialization, atonality and other new composition techniques; chance and aleatoric elements in composition and performance; the new technology of computers, tape reproduction, electronics; new instruments, new performance techniques for old instruments and many other forces demanded new theories for musicians. These developments help form the socio-musical setting of the times.

Up until the forties (and often today), musicians and other artists held a somewhat teleological view of art; or as Leonard Meyer puts it, a belief in the "doctrine of inevitability."[3] This was an aesthetic criterion, or test of value; a deterministic view which implied (as in the case of music) that in a good work, every note, rhythmic value, relationship, etc., was unalterable and necessary. However, the social, philosophical and scientific climate of the forties introduced the concept of uncertainty which had eroded the pervasiveness of this concept.

The concept of uncertainty resulted from the decline of three previously held beliefs: (a) the possibility of discovering a single set of laws of the universe which were absolute and eternal, (b) the existence of simple one to one causation, and (c) the deterministic character of biological processes, physical laws, social development, etc. Thus the concept of uncertainty entered into many areas of thought; both in theories of society and natural science, as well as in the realms of epistemology and metaphysics: Laws became hypotheses and were stated in terms of probability and statistics. Stemming from the work of Heisenberg, Boltzmann and Wiener, Shannon's research evolves within this climate. His focus upon information as uncertainty and the entropy of a communication system clearly places his work in this post-war period.

Immediately following the publication of Shannon's paper, many articles emerged speculating upon the use of this new theory in music (in addition to countless other disciplines). Pierce, Pinkerton, Cohen, Shannon's wife and others suggested applications and generated simple tunes, leading to the first important impact of the theory on music in the fifties: computer generation and analysis. This is an area at the heart of the new climate of ideas emerging at this point in time.

Almost synonymous with the subject of computers is that of cybernetics. The book which spawned this exciting field, <u>Cybernetics</u> by Norbert Wiener, emerged almost simultaneously with Shannon's paper and both men cite each other for many contributions to the development of their work. One can speculate that material from Wiener and Gregory Bateson, another important thinker in cybernetics and communication, stimulated many musical developments of the fifties. Certainly, the concept of feedback and restraint in communication, the use of machine models as analogies for human processes and the role of context in communication were all necessary to form the groundwork for the models and algorithms used initially in computer music and eventually expanded into other facets of the art.

The algorithm or model of most concern here is the one used to replicate the creative process of composition and to generate "new" musical material or new arrangements of material. Usually in computer music, the composer creates a program which generates data; data which may be completely specified by the composer or, through the algorithm described below, random events constrained by parameters determined by the composer. This data is usually converted from its digital form to a voltage (digital to analogue conversion) and the voltage is used to control electronics which generate sound. There are, of course, many other ways a program can be converted into sound. In addition, this algorithm also applies to analogue computers, purely digital sound generators, music synthesizers and even the tossing of dice to gain decisions through chance; it is described as follows.

The musical event (that is, pitch, rhythmic value or timbre, etc.) is generated by a random digit or voltage (a digital or analogue approach respectively) being passed or rejected according to a series of flexible parameters. These restraints may function in the manner of a stochastic process or feedback loop or they may deal with only the individual event.

As an example one might imagine a computer program which is designed to generate pitches according to certain parameters. A random number is generated by the computer and subjected to a series of examinations. If it passes all the tests, the number is accepted; if not, another random number is examined and the process repeats. These tests usually take the form of comparisons: is the number bigger than the last one passed but greater than the one before that and an even integer? and so on. Pitch, quality of sound (timbre) etc. may be arbitrarily assigned some numerical value thereby enabling the composer to convert his material into numbers and vice versa.

One of the initial motivations for using information theory in computer music was to free the composer from concern over the "hack work" of calculating pitch value or rhythmical duration on the level of each individual event thus allowing him or her to concentrate upon the macro-gestures, form, texture, timbre, style, etc. Max Mathews, who worked at Bell Labs and contributed much research to this area, writes in his article, "The Digital Computer as Musical Instrument":

> We hope that by this means the composer can avoid having to write out all the individual notes in a piece of music in order to express his ideas--that he will be able, rather, to write directly in parameters that are much more closely related to his musical objectives, letting the machine generate the individual notes.[4]

One of the first experimental uses of digital computers and information theory was the composition of the "Illiac Suite for String Quartet," in 1957. This work was realized by Lejaren Hiller in collaboration with Leonard M. Issacson and is fully described in their book, <u>Experimental Music</u>.[5] This piece was, in essence, a demonstration that a computer could be programmed to generate musical scores according to either conventional musical procedures (counterpoint, harmony, etc.) or novel procedures such as "the employment of stochastic chain processes that yield musical patterns governed by probability distributions."[6]

The University of Illinois computer music laboratory has produced many exciting music studies: Hiller and Baker's "Computer Cantata" makes great use of stochastic process in generating scores (for both the music and for approximations to English-sounding language for the text). Two pieces created there by Max Mathews exploit the capabilities of computer generated musical sounds: "British Grenadiers / When Johnny Comes Marching Home" explores transition possibilities in music by repeating one tune and slowly changing it to the other, while his "Rhythm Developments" explores rhythmic changes and juxtapositions which would be almost impossible for a human performer.

It is within this area of digital computer music, therefore, that information theory is used most extensively and successfully as a methodology. Since ultimately the process is discrete and numerical, it is simpler to use information analysis to generate music in this context than in situations involving human performance on acoustic instruments where there are many complex parameters and variables. Nonetheless, through the process of quantization, continuous sources may be converted into discrete values through approximation and high speed scanning; or as Berlyne suggests in Aesthetics and Psychobiology:

> . . . every element in a work of art is chosen from a set of

> alternatives that can be regarded as signals. For any particular art form and style the set or vocabulary from which each element is chosen is limited. The alternatives that can occur in a particular location constitute a sample space. Their relative frequencies can be calculated and a probability associated with each of them. Consequently, every location in a work of art, whether spatial or temporal, can be allotted an uncertainty value.[7]

The importance of this statement is not its immediate practical implementation, which obviously is fraught with difficulty, but rather the future implications arising from it, especially with a view to the rapidly expanding world of computers. The possibility of an information analysis of every aspect of a complete symphonic work and subsequent comparisons and manipulations of the resulting data is exciting and thought-provoking, although most likely far in the future in terms of practicality.

Thus it is in computer applications to music that information theory in music shifts from potential to actual implementation. This process created new discoveries or new articulations of ideas familiar to musicians though rarely written down. For example, Hiller discovered that simple stochastic models for music are not sufficient as the sole structural guide for generating interesting and successful material: Rather, he expressed the need for more of a hierarchical structure to the guiding parameters. He writes in "Research in Music with Electronics" that "a message comprises (i) major points of articulation that depend more or less directly upon one another, and (ii) lesser components that serve as interstices in a primary network."[8] Another example is an observation by Mathews derived from his construction of sounds from primary sources (such as sine tones);

he notes that "Another unexpected result is the importance of suitable random variations in almost all parameters of a note for introducing richness and interest."[9] He discovered that by introducing a random variation of up to 50% in amplitude at 8 to 20 times per second and a random variation of 7% in frequency at similar rates, simple sounds may be greatly improved.

This is a restatement of two effects singers have long since been aware of; tremolo and vibrato. One finds these techniques throughout the musical world: from the characteristic tremolo (amplitude variation) of vibraphones, electric guitars, etc., to the vibrato (frequency variation) of stringed instruments, music synthesizers, etc. The enhancement of sound through random variation of various parameters can be explained by the increase of information which is the result of introducing unpredictable elements. This perception of vibrato and tremolo is indicative of the rediscovery process of the musical experience and the new articulation for familiar axioms of music which arise out of an information theory approach.

Style as Restraint, Probability and a Mirror of Human Thought

> A musical style is a finite array of interdependent melodic, rhythmic, harmonic, timbral, textural and formal relationships and processes. When these are internalized as learned habits, listeners (including performers and composers) are able to perceive and understand a composition in the style as an intricate network of implicative relationships, or to experience the work as a complex of felt probabilities.
>
> Leonard Meyer
> Music, The Arts and Ideas[10]

Style, if viewed as those distinguishing features which identify a particular composer or period, can be explained through the restraints a composer places upon the composition process. These may be the conscious design of a computer program or on the other end of the spectrum, the improvisation of a sophisticated soloist.

Aside from its normal use, the word "restraint" is found in the literature of cybernetics and refers to the influence of parameters which mediate the communication process. As Gregory Bateson writes in "Cybernetic Explanation", "In cybernetic language, the course of events is said to be subject to restraints, and it is assumed that, apart from such restraints, the pathways of change would be governed only by equality of probability."[11] Leonard Meyer relates these concepts to music in his Emotion and Meaning in Music when he writes that "Styles in music are basically complex systems of probability relationships in which the meaning of any term or series of terms depends upon its relationships with all other terms possible within the style system."[12] Following in the same vein, Joseph Youngblood in his paper "Style as Information" notes that musical style may be considered a probability system which must be statistically stationary or ergodic: ". . . wholesale variations would be required before a musical style would become anything but stochastic for it is this homogeneity that makes it recognizable as a style."[13] He concludes that information theory may be used to measure the constraints under which various composers and groups of composers worked and thus can furnish the musical community with numbers with which these styles can be more accurately and meaningfully described.

An interesting aspect of this material, is that the algorithm for generating computer music is seen as an analogue for some functions of the human composition process: using primarily the concept of stochastic process. This facet emerges early in the history of the field. Back in 1956, one of the first articles suggesting a role for information theory in music, "Information Theory and Melody" by R. C. Pinkerton, suggested that: "it is fun to speculate that a composer's individual style may reflect networks of nerve pathways in his brain,"[14] when referring to his scheme of composing simple tunes based on probability. Lejaren Hiller, in remarking on self-generating music programs, wrote: "In general it appears that this type of programming would more clearly approximate conceptual processes that occur when a message is being thought through and composed."[15] He refers to this type of programming as being heuristic. Moles writes in his book, Information Theory and Esthetic Perception, that: "artificial communication channels constructed by man can enlighten us on the process of communication between individuals."[16] And finally, Meyer writes: ". . . music, operating in the realm of pure syntax without reference to external objects or events, would, then, develop an order reflecting and paralleling the structure of human mental processes."[17]

Fred Attneave, in his paper entitled "Stochastic Composition Processes," goes so far as to suggest that mediated through the concept of style as restraint, a style may be replicated and extrapolated upon to the extent of expanding the repertoire of composers long since dead. He writes:

> Giving our imagination free rein . . ., we may conceive of some future computer which would analyze the 41 symphonies of Mozart and render explicit all the varieties of lawfulness existing therein, including trends associated with Mozart's development over his life-span. If the computer then employed these laws to regulate a stochastic process, and fed random numbers into the process, the output would be Mozart Symphony #42. In principle there is nothing ridiculous or impossible about this idea: the point is that once the rules characterizing a given body of music are exhaustively codified, the only remaining decisions necessary for the composition of similar music are random decisions since if they were not random they would be to some degree lawful, and to that degree dictated by rules.[18]

The obvious difficulty with Attneave's proposal is the lack of a general method for the detection of regularity; nonetheless, it demonstrates the importance and function of random elements in this communication model. It is from this material and perspective therefore, that we shall look at a model of the paradigm of style as restraint, one which synthesizes the conceptualization of the composition process suggested by various researchers in this field.

A Model of the Composition Process and Its Applications

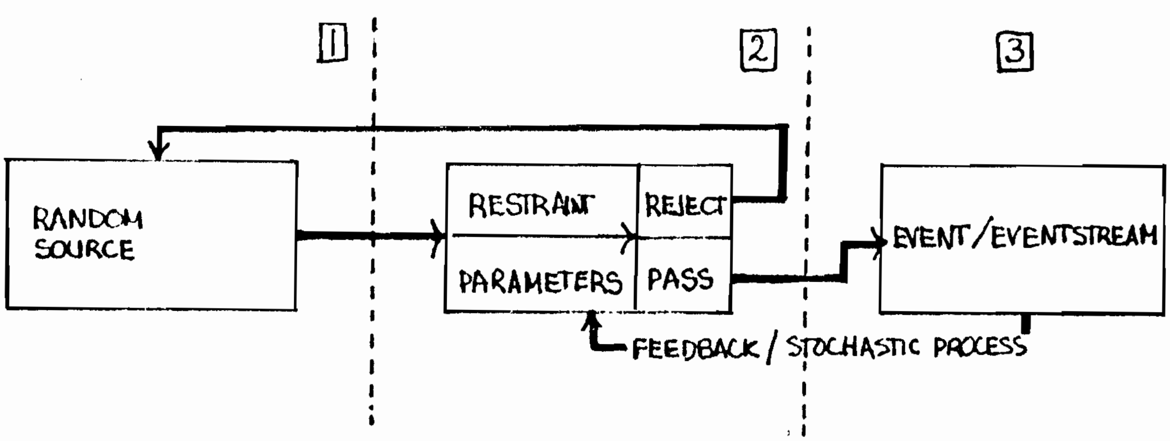

Figure 3.1

If this model is used to describe the human composition process, then section $\boxed{1}$ is the source of musical material, experience, etc., $\boxed{2}$ and $\boxed{3}$ determine the style by rejecting or passing material according to the restraints or parameters designed by the composer. These constraints change according to feedback from $\boxed{3}$ in a stochastic process involving the last event or whole streams of events.

Thus an information theory/cybernetic approach to music coupled with experiments in computers has resulted in a machine-like model for explaining the composition and listening process. Figure 3.1 is a simple block diagram of (a) the computer generation of music, (b) the stochastic process in information theory and (c) the process of human composition of music.

In terms of (b), the random source or $\boxed{1}$ represents the element of chance or random in information (as the receiver views the message as being selected in a random fashion governed only by statistical probability), while $\boxed{2}$ represents that probability limiting the selection, or in cybernetic terms, restraining it. Area $\boxed{3}$ of Figure 3.1 and its connection with $\boxed{2}$ illustrates the feedback and stochastic process involved in sophisticated communication. The arrow from the "event stream" to "parameter" shows the influence of existing material upon the decision process of generation.

As a model of the human composer, this diagram is representative of some music composition, but the portrayal is clearly deficient because it neglects the fundamental concept of macro-gesture or gestalt, that is, a theory of the whole. These cannot be approached through information theory, though they are a vital part of human perception. However, this is not to deny the usefulness of the model in Figure 3.1 as an analytical tool and generating process. One example is the insight offered into the areas of electronic music and the synthesis of natural sounds by this approach; insight reached from the function of the random in this model.

From experience in synthesizing natural sounds, composers learned that for a sound to appear natural, organic or "real", a certain random element must be included to overcome the residue from the machine which is creating the sound, that is, its predictable mechanical repetition or oscillation. As previously mentioned, noise is the most difficult type of material to transmit accurately, while at the same time a moment of noise sounds like any other, though by definition it must be different. Electronic musicians have taken advantage of this fact by using noise to approximate the complexity of natural or so-called "concrete" sounds as a control source for determining frequency, amplitude or position in time, or as part of the signal itself. For example: characteristic to the sound of a flute is its quality of attack or the complex sound which occurs at the beginning of a note. This attack sound can be approximated through the use of noise which has been filtered and given certain shape to its amplitude and duration. The actual pitch sound of the flute can be represented by a sine tone, or pure tone, whose frequency and amplitude may be randomly varied by noise (although very slightly) to create an organic sound. In this example, noise is the sound analogy for random elements: By restraining noise through coloring and dynamic shaping or by having the noise itself modify some parameter, it can aid the electronic composer in creating naturally sounding events.

Another interesting application of Figure 3.1 is, as mentioned earlier, as a model for the human composition process. The composer is viewed as selecting material from the field of sound available to him through the use of restraints. These may result from the media employed, the redundancy inherent in the choice of style, the unique decisions of the composer, those established through mechanical means (such as serialization) or chance. One of the main concerns of the composer in this model is the manipulation of the information content of the music; affecting the audience through the limits of their channel capacity. The composer creates tension by generating excess information, thereby straining the channel capacity of the audience: He or she relaxes them by reducing the information or uncertainty as to what will follow. This technique, discussed previously under the heading "redundancy", can also be seen through "Arousal Theory" as described by D. Berlyne in his book <u>Conflict Arousal and Curiosity</u>. This theory is a measure of how wide awake the organism is and how ready it is to react. The lower pole of the continuum is represented by sleep or coma, while the upper pole would be reached in states of frantic excitement. What are usually called emotional states, therefore, seem to be states of high arousal. These occur if a listener is unfamiliar or uncomfortable, as is the case when the information content exceeds his or her channel capacity.[19] On the other hand, low information content may cause boredom or even sleep in some situations (as some concert-goers will certainly attest to).

What emerges from all this material is that through an information theory approach one gains a new perspective on music. The result of this perspective is new ideas of music composition and listening, some of which have been discussed previously, and others which concern us now. What is interesting about some of these ideas is that they are simply an articulation of old thoughts and ideas in new terminology.

In regards to those ideas which result from an information theory approach, a fundamental concept is stated by Meyer in Music, The Arts and Ideas:

> If a situation is highly organized so that the possible consequents have a high degree of probability, then if the probable occurs, the information communicated by the message (i.e. the musical event) is minimal. If the musical situation is less predictable so that the antecedent-consequent relationship does not have a high degree of probability, then information contained in the musical message will be high.[20]

Pedersen extends this idea by noting that if uncertainty reaches the point where any successive musical event is possible, then the unexpected is always expected and occurs as the listener predicted. For there to be psychological uncertainty, there must be redundancy and probabilistic constraint or else there is no possibility of structure.[21]

As previously discussed, the reaction to excess information can result in filtering, rejection of some or all of the message material or recoding. As Berlyne notes in Aesthetics and Psychobiology: "The tendency to group perceptual elements is universal and irresistible. This can easily be appreciated by listening to a monotonous sequence of identical sounds, like a ticking of a clock."[22] What is in reality tick-tick-tick etc., we sometimes perceive as tick-tock, etc. Recoding and filtering may thus be one reason why some music endures for centuries. If we accept that the listener has some limited channel capacity, then, by making the antecedent-consequent relationships relatively clear on a macro-level in a multi-layered structure, repeated listening gives the listener a chance to predict certain events and thus shift his or her focus to other relationships. In addition, familiarity with the music reduces the information content and enables the listener to hear material previously rejected or recoded.

Moles writes that to create a form in music is to assure in the message a redundancy (or at least some statistical foreseeability). The degree of predictability is related to the degree of coherence which is related to the proportion of regularity. Foreseeability in this case is a statistical liaison between the past and the future, or stated another way, expressing a coherence, or a correlation, between what has happened up to time t and what will happen at time $t + r$, r being the interval between correlated points. Mathematicians (and as Moles notes, particularly Norbert Wiener) express this correlation by the autocorrelation function. This is a function of the interval over which the considered foreseeability extends.

Practically, correlating what occurs at time t with what occurs at the later instant $t+r$ requires the simultaneous existence in some place of (t) and $(t+r)$, or some sort of recoding device to compare the two functions. This is a functional view of memory. The concept of auto-correlation is very important in all statistical phenomena, because it expresses their internal coherence, and hence their tendency to become structures. The auto-correlation function is zero for completely random phenomena and tends to plus or negative one for a perfectly ordered or indefinitely foreseeable one.[23] In the model in Figure 3.1, the memory or auto-correlation function would be represented by the feedback from the event and incorporated into the parameters restraining the random material.

Meyer deals at length in his books and articles with this function, using it as a tool to gain access to the role of "meaning" in music, though he never refers to it as the auto-correlation function, but rather as expectation, impulse, prediction, tendency, etc.

Meaning, Style, and Information Theory in Music: Meyer's Approach

For Meyer, music gives rise to two types of meaning. The first, which is not dealt with extensively, he calls designative meaning; music is meaningful in this sense when it "refers to things outside itself, evoking associations and connotations relative to the world of ideas, sentiments and physical objects."[24] The second type is clearly derived from an information theory view of music and is referred to as embodied meaning. If the first can be described as iconic, then embodied meaning is syntactic because it is based on relationships within the musical structure of elements and an auto-correlation function analysis which determines expectancy of an element. In other words, Meyer writes: ". . . within the context of a particular style one tone or group of tones indicates - leads the practised listener to expect that another tone or group of tones will be forthcoming at some more or less specified point in the musical continuum."[25] In this case, musical meaning arises when our expectant habit responses are delayed or blocked: ". . . when the normal course of stylistic-mental events is disturbed by some form of deviation."[26]

Meyer views style as internalized probability systems; a concept not new to this discussion, and suggests that out of these systems the expectations and tendencies upon which musical meaning is built, arise. He deems it important, however, to differentiate between latent expectation and active expectation. The former relates to normal expectations from the probabilities of the style employed, while the latter arises when these normal expectations are disturbed. Latent expectations can be seen as necessary for musical communication while their disturbance is a sufficient condition for musical communication.

Meyer's work parallels most of the research in the field of information theory as to the speculations and stress upon the potential use of the theory which occupies the bulk of his work as well as his adaptation of it for music. For example, he suggests that information in music is related to two types of redundancy; internalized and compositional:

> The amount of musical "information" that the community can comprehend and the speed with which it can do so is a function both of the extent of internalized (cultural) redundancy, that is, the depth and strength of stylistic learning; and of the amount of compositional (structural) redundancy presented by a particular work, that is, its objective order and regularity.

He also suggests that the lower internalized redundancy is (that is, as in what he calls the "preclassic" period when a style is new and unfamiliar) in order that the musical work be understood, the compositional redundancy must be higher. However, as a style becomes familiar (entering its "classic" period), the internalized redundancy increases; therefore, the amount of compositional redundancy may decrease and the compositions's rate of information correlatively may increase.

The basic assumption here (as in most information studies) is that the community of listeners demands an amount of information which tends toward the maximum compatible with sensitive understanding. This is drawn from the studies done by George A. Miller, Broadbent, Bruner, Postman and others on the limits of a human's channel capacity for audio and other types of information.[28] As Pedersen writes, based upon these studies: ". . . it is evident that there are some definable limits to the ability of human beings to handle information."[29] It follows from these discoveries that there exists a rate of information in a particular situation which is optimum for the artist's purposes; a rate neither boring or upsetting but rather of great interest requiring various degrees of attention. Based on these assumptions, then, as the internal redundancy increases with stylistic learning, the redundancy of the composition decreases; providing that musical information consistently tends toward the maximum for this specific situation. The decrease of compositional redundancy means an increase in compositional information rate.

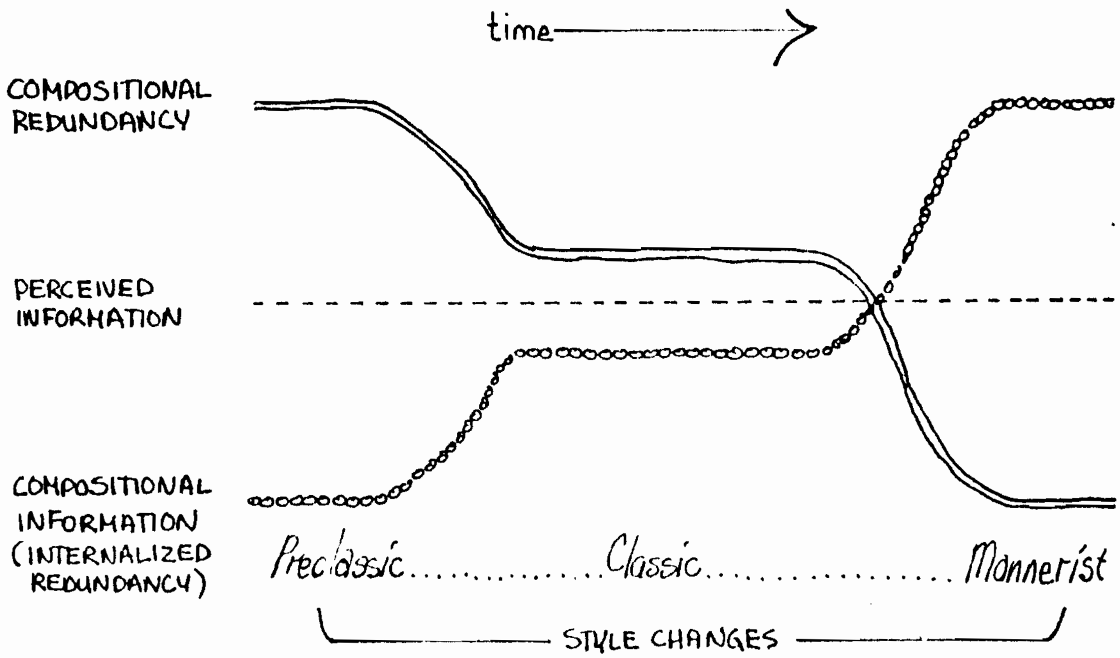

Figure 3.2
after Meyer, p. 119[30]

This diagram taken from Meyer includes the "Mannerist" stage of a style: This occurs when a composer may drastically reduce compositional redundancy due to the familiarity which the audience has of his or her music. At this stage, the composer may operate on an extremely sophisticated level, suggesting ideas rather than presenting them, focusing on subtle differences etc. This pattern of style change depicted in Figure 3.2 is neither necessary or invariable of course, but it is interesting for its utilization of information theory to predict style change. Meyer himself lists several reservations in connection with this schema. He notes that a reduction in redundancy may manifest itself by the addition or deletion of information, and based on other factors, may not preclude an increase of information. He concludes by stressing that a common pattern of change in styles does not imply a teleological viewpoint: There is no goal towards which a style moves.

The work of Leonard Meyer is representative of what I referred to at the beginning of this chapter as the flexible, pragmatic and general use of the theory. This approach, which extends the concepts of information theory into more generalized statements, lacks the precise power of the original theory in its mathematical form, but provides exciting new insights into musical communication. Expanding from an understanding of the fundamentals of Shannon's theory, one can re-examine the role of the composer, the development and nature of style, the role of meaning in music or the function of noise in generating sound: One can find new expression of existing ideas or codes and new ideas as well. A generalized form of information theory does not address the whole world of music; rather it must be used flexibly and pragmatically where it can provide another perspective. Shannon's original theory as a strict methodology is also limited in the scope of its effectiveness. It is clear though, that in some areas of music, especially when one is dealing with computers and digital representation of sound, it has an important role to play. In addition, the algorithm of computer music derived from information theory offers a general model of musical communication which is functional and worthwhile in certain instances.

The point of all this is that the application of information theory to music must be seen, not as the answer to the music theorist's dreams, but as another specialized tool for his or her kit of theories.

In the final section of this chapter, the material of Chapters Two and Three has been used to analyze certain phenomena of musical communication somewhat in the form of case studies. The chapter concludes with a discussion of "november, setting", a work which I generated through electronics with these concepts of information theory as my main guiding force.

Applications: The General, Flexible and Pragmatic Approach in Analysis and Composition

One of the areas of music which benefits from an information theory approach is that of contemporary art music. Many authors have suggested that one of the difficulties that this area has in gaining a large audience (aside from problems of gaining exposure and acceptance in various communication media) is that its composers often don't ensure a high enough degree of redundancy in a style basically unfamiliar to the audience. Because of this lack of predictability, the audience is confronted with too much information and the music is often unsuccessful.

In addition, Abraham Moles, in his book, Information Theory and Esthetic Perception, stresses that music must not be seen merely as musical events occurring in time, but as a multidimensional matrix whose parameters are frequency, time, timbre, intensity, coupled with the listener's perception threshold, saturation limit, etc. Redundancy can occur in any one of these dimensions or axes or combinations thereof. Creating forms in frequency structure (pitch) and time elements (rhythm or duration) is not the only way to limit information: Forms in other dimensions can limit information while allowing for random or seemingly random events in the pitch domain or in rhythmic value. It is important, therefore, not to view melody as the only domain for the organization of the musical message. As Moles writes:

> The musical message must be approached in its immediate materiality, not through the artificial operating scheme of the score, which interests essentially only the performer. Phenomenological study of the message, which ought to be descriptive, reveals the existence of the successively subordinated structures, which in fact characterize the most general message. The structures are built from the psychophysical elements of hearing. Assembled according to "harmonic laws" which include operationally the concepts of harmonics and timbre, these elements compose symbols, present within the quantum of duration, whose temporal evolution constitutes the sonic object . . .[31]

One illustration of Moles' ideas on forms in music is the work of composer Steve Reich. His music usually consists of short and very limited or restrained pitch and rhythmic patterns which change very slowly, juxtaposed in something of an audio analogue of a Moiré effect, where patterns in the sound move in and out of phase with each other. He has experimented with acoustic instruments and with loops of audio tape, where these loops containing almost identical sound material move out of synchronous motion while being played on two tape reproducers, creating new sound structures.

His highly moving and engaging music might retain the audience's attention because of this extreme redundancy or predictability in certain levels of the sound mass of the music. If one assumes a certain level of information is required to sustain interest, then this technique of Reich's (creating a predictable or banal form on one level of the sound mass to achieve originality on another) shifts the attention focus of the audience into the rich shimmering world of the sum and difference tones, harmonic spectrum and the accompanying intricate rhythmic and phase relationships which his musical technique produces. In other words, by maintaining form and a great deal of predictability in areas which for the most part are the center of interest in other types of music, a composer can guide his audience during initial listenings to concentrate upon areas which normally only receive such attention after many listenings.

Based upon a familiarity with information theory, therefore, one might easily speculate as to why certain techniques, such as repetition, which are somewhat opaque to traditional music analysis, are successful.

Popular music also provides illustrations of insights gained from an information approach. A measure of the information quantity of a "Top Forty" tune (the "45" or disc being likened to a transmission channel in the information theory sense), might be its duration on the "charts" or "Top Forty" list. A hit reaches "number one" at the point when the audience finds it both unpredictable (interesting) yet coherent (that is, sufficiently redundant). It drops from "number one" as the level of information drops due to familiarity: the entropy of the song decreases, the predictability increases and another song takes its place.

To prolong this "number one" status, I suggest that certain "pop" techniques, such as multi-track recording and the masking of lyrics are well explained by information theory. The voice, when the words are difficult to discern, still functions as an interesting musical source--with much information inherent, yet not perceived as such until the information provided by the general "soundscape" of the song reduces through familiarity. Similarly, multi-track redording affords the record producers the ability to introduce many sounds (large complex sound sources, imperceptible gestures or changes) which may function and be perceived initially as accompaniment and thus don't overload channel capacity, since they are predictable through larger forms. As the overall structures become predictable however, these sounds can be perceived without overloading the channel capacity of the audience and therefore provide a rich information source--prolonging the popularity of the song and demonstrating a skillfully executed subliminal experience at times. This extra information may be vital to a song which can be played once every half hour on an AM radio station.

In conclusion, I offer as documentation for the ideas expressed in this thesis my own composition entitled "november, setting" (1974). In this two channel electronic tape piece, I have used an information theory approach to help guide decisions arising out of the composition process.

For example, sounds which appear simple, like the harpsicord-type chord gestures in the first section and the sustained clusters of the last, are actually generated through complex procedures involving voltage control from random sources. This is (hopefully) to ensure high rates of information in the sound, balanced by predictability in other levels. To eliminate redundancy in the temporal area, that is, to focus the listener's attention upon time and to experiment with the experience of time, the position in time of certain events (like the chords of the first section and especially the high frequency events of the third) is determined randomly. In addition, I have tried to shift the perspectives (through filtering, transitions from one event to another, rhythmic quality) so slowly as to defy perception of the change until the material is substantially different. The effect I wish for from such a technique is that the listener becomes aware of new material only after it has actually appeared for some time. This can create interesting temporal experiences by focusing the listener's attention back in time (When did that change? What sound was before this? etc.). In the last section I have included some very random, almost noise-like events, but at very low amplitude levels so that most likely one will not perceive them on initial listenings. My intention is that the mind may recode or structure these unpredictable elements and organize them; that is, some people think these sounds are organic in nature; for example, I usually hear voices or the mumble of a crowd; other people hear words, etc.

To ensure some redundancy in the music, some of the material is repetitive (like the opening chords) in order that the listener may focus his or her attention on different areas of the soundscape and also to reduce the information content. To ensure restraint and interest, I have tried to create many structures which are not readily perceivable yet still serve to organize the material. The high frequency buzz of the first section and the low frequency rumble, in fact all the sounds, are just parts of one huge major triad created with sawtooth waves (tones containing all the harmonics) and spanning several octaves. The individual gestures are created through selective filtering and dynamics etc. of one mass of sound which was the original source. The two channels of the second section are identical; however, one is playing in reverse alongside the other. The sound source for this section is white noise which has been filtered and manipulated, controlled mostly by random sources. Most of the parameters of the piece were controlled in this way; either through white noise as a control or by a waveform created from the interaction of many oscillators and thus exhibiting very little structure. I also used myself as a random control source by turning dials or pushing buttons sporadically without listening to the result, and by slow changes of parameters: that is, moving a potentiometer 180° in ten minutes, etc. Lastly, one other technique I used to create structure and consistency in the piece was to have all the material generated by electronic means; that is, voltage controlled synthesizers. The only exception to this is a small utilization of my voice, which was multi-tracked to create the effect of many voices singing in unison and severely "compressed" and "limited" so that the amplitude fluctuates in an almost unpredictable way.

In summary, the basic technique which I used was to restrain a random source (like noise or a complex waveform) through selective filtering or gating (selecting quick bursts of sound) and then use this source to control certain parameters (through the manipulation of voltages) of the sound source. I also created many sounds which I mixed and controlled to create a stereo image. My fundamental idea was to limit myself to relatively few decisions, mostly those of gesture and color, and to establish parameters which would restrain the machines into generating material which I wanted. I felt that if the control was random and complex but balanced by my own intervention at critical points (like macro gestures and transitions), then the feeling of the piece would be "organic" as opposed to machine-like. Perhaps the best description of the piece is the program note I wrote accompanying the first performance on May 7, 1975, in McGill University Pollack Concert Hall:

> "november, setting" is based on a desire to create an organic field from voltage control machines, inspired by information theory. Some forms remain static; redundancy shifts attention, others change in these four small pieces. The sounds evolve by their own suggestion, in their own time, these two thoughts foremost. The only concrete sound, a small use of my voice.

Conclusion

Essentially my intention in this chapter has been to illustrate the influence that information theory in its original form and as a general theory has had upon the musical world. I have not tried to catalogue all the existing applications of the theory, but rather the range of such endeavours and the exciting results; such as a model for human composition and the various insights and new articulations of old ideas which I have noted. In addition, I have suggested through my own approach in analysis and composition the possible direction which can result from the use of information theory, especially a generalized view of the theory, as represented by the work of Leonard Meyer.

The application of information theory to music has received a certain amount of criticism, as has been hinted at throughout previous chapters. This material is the subject of the next and final chapter.

Notes

[1]Gregory Bateson, Steps to an Ecology of Mind (New York: Ballantine Books, Inc., 1972), p. 131.

[2]p. 174.

[3]Music, The Arts and Ideas, p. 147.

[4]Science, 147 (November 1963), 556.

[5](New York: McGraw-Hill, 1959).

[6]Lejaren Hiller and James Beauchamp, "Research in Music with Electronics," Science, 150 (October 1965), 161.

[7]D. E. Berlyne, (New York: Meredith Corp., 1971), p. 93.

[8]p. 168.

[9]Mathews, p. 556.

[10]p. 116.

[11]Bateson, Steps, p. 399.

[12](Chicago: University of Chicago Press, 1956), p. 54.

[13]p. 14.

[14]p. 86.

[15]Hiller, Research, p. 168.

[16]p. 40.

[17]Meyer, Music, p. 82.

[18]Journal of Aesthetics and Art Criticism 17 (1959), 508. Hereafter cited as JAAC.

[19]Pedersen, p. 20.

[20]p. 27.

[21]p. 27.

[22]p. 103.

[23]Moles, p. 66.

[24] Meyer, "Meaning in Music and Information Theory," JAAC, 15 (1957), 413.

[25] loc. cit., p. 413.

[26] loc. cit., p. 417.

[27] Meyer, Music, The Arts and Ideas, p. 117.

[28] Cherry, p. 282.

[29] p. 4.

[30] Music, The Arts and Ideas.

[31] p. 198.

CHAPTER FIVE

CONCLUSION

Criticisms

The transference of a theory from one discipline to another is a tricky and complex business. The extrapolation involved in fitting a specific theory to a new area often destroys the integrity of the theory, while if a theory is general enough to apply to many fields, it usually follows that such a theory is weak and not very useful. Information theory seems at times to lie at both extremes: it is obviously a very specific theory created to solve very specific problems, yet it also speaks for fundamental aspects of communication. Its terminology and definitions however, may also be used to clarify the nature of a communication event and in this way it may also be considered a general theory.

In its classical form, as evidenced in the Shannon paper and subsequent engineering articles and textbooks on telecommunication, information theory consists of theorems, axioms, mathematical formulae etc., addressed to the very specific problems of electronic communication channels. It provides for a measure (in bits or bits per second) of the amount of information or complexity or unpredictability of a specific source, a measure of the capacity of a finite channel to handle this quantity, and it outlines methods for efficiently encoding signals for near errorless transmission over these channels. As Pierce writes, "Information theory . . . was devised to help engineers in understanding electrical communication channels and their capability for transmitting messages generated by various message sources."[1]

Nevertheless, while the classical presentations of the theory are technical, the fundamental concepts and the accompanying block diagram of sender - receiver (Figure 1.1) have great intuitive appeal. In addition, though they have very specific special meanings, the terminology of information theory, words like information, redundancy, and entropy are very evocative. The article by Warren Weaver which accompanies the book form of the Shannon paper has, in this author's opinion, helped to create the excitement which surrounded the emergence of information theory upon the academic community by stressing these aspects of the theory and by translating the formulae and statistics of Shannon into exciting phrases and general applications: ". . . a general theory at all levels will surely have to take into account not only the capacity of the channel, but also (even the words are right!) the capacity of the audience."[2] This quote offers a somewhat enthusiastic example of Weaver's expansion of the theory to deal with wider areas of communication.

Thus, aside from those colleagues of Shannon's who were experimenting with digital computers and music (Mathews, Hiller, Pierce) and were able, therefore, to use his statistical view to manipulate their material, most people involved in applications of information theory tended to begin with studies of certain relevant aspects of the theory and then expanded and extrapolated these concepts to apply to musical problems. The criticism of applications of information theory falls into two overlapping classes: that concerned with transference of the theory and the subsequent generalizations of it, and that concerned with music being such a unique communication system that classical information theory cannot deal properly with it because music is neither statistically homogeneous or stationary etc. to be analyzed properly.

> Information theory is a structuralist theory; it claims that the observer chops up the world, or at least the messages from the Umwelt to the receptor, into simple elements which form the repertoire. Following certain rules, the theory tries to reassemble these elements in a certain order, so as to reconstruct a likeness of "reality" which is as exact as possible on the observer's level of observation. The set of assembly rules, collected in a code of constraints, represents what may be called the "structure" of these messages. This procedure has the enormous advantage of being perfectly operational; indeed this virtue is intrinsic to a structuralist theory. But the arbitrariness of this atomistic chopping-up is usually held against the theory, even if such chopping is only an algorithm of scientific reasoning.[3]

As Moles writes, one of the main criticisms of an information theory approach to music is the digital nature of the theory: It is atomistic and considers the individual receptor as scanning apparatus, rejecting whole, or aggregate "Gestalt Theories".[4]

Moles suggests the discrete nature of messages in information theory paradigms is practical for the psychophysiologist but a conflict arises in assuming that all psychology may be reduced to psychophysiology. He also adds that within the mechanistic model of the information-receiving-subject suggested by the theory, there is no consideration of the "prodigious mutability" of man's psychophysical apparatus characteristics: that is, the ability humans have to hear a sound scarcely stronger than the random agitation of the atmosphere's molecules or a jet plane taking off, for example.[5]

The information theory applications to music are criticized mainly for five assumptions which they tend to make. These are that the source is (1) stochastic, (2) ergodic, (3) stationary, (4) consistent with regard to its Markov properties and (5) that the listener has a perfect memory.[6]

In regard to music, the first assumption is easily satisfied: Stochasticity implies that no letter not already known to be in the alphabet can occur. If every possible event is included in the alphabet (such as in Moles' suggestion that the repertoire be the entire inventory of sounds available to the human ear), then those not occurring in a particular sample can be described as having zero-probability.

The assumption of ergodicity implies that all sufficiently large samples from a given sequence have the same statistical structure and this raises many problems:

> While the entire body of existing music may be ergodic, the fact is useless because it yields no stylistic differentiation. Less inclusive but stylistically homogeneous corpora may be assumed to be ergodic; but an operational definition of their homogeneity would have the smaller samples selected either arbitrarily or on the basis of values of a stylistic parameter based on information theory. The latter operational definition of homogeneity assumes that small samples are ergodic, which cannot be established.[7]

Thus, the only other way to define homogeneity in an operational manner is to find some non-intuitive stylistic parameter which is not based on information theory (thus defeating the goal of an information theory approach). Therefore, the only way ergodicity may be assumed is based on intuitive criteria of homogeneity.

The next assumption of the source being statistically stationary is difficult to prove in music. There hardly ever is enough music in a particular style (which is intuitively assessed) to test this assumption. One merely has to examine almost any piece or group of pieces by a serious composer to find sequences which occur only once: And no true estimate of relative frequency may be made on just one occurrence. In addition, within a given piece, the relative frequencies of the various m-grams will change. For instance, in a sonata-form movement, the three sections, exposition, development and recapitulation have different statistical structures; the first and last generally are similar in structure, but the middle is thought of as less redundant (freer) than the other two. Finally, Cohen gives the example of the six partitas of Bach's Clavier-Uebung which although intuitively seem to possess stylistic homogeneity, actually contain many sequences which occur only once.

The assumption of Markov consistency assumes that there is the same order of m-gram patterning throughout the sample: This is a problem because in the beginning of a work there is only a small amount of patterning while at the end, each event is affected by all the preceding events and thus the probabilities are also affected.

The last assumption of an information approach suggested by Cohen is that the encoder of a sequence of musical events has an infinite memory or that there exists an unlimited delay in the decoding of messages so as to enable the transmission of maximum amount of information. Such an unlimited delay of infinite memory is not possible in the human receiver. Kraehenbuehl, who suggests similar limitations to those expressed by Cohen, adds:

> It is evident that such an assumption is only reasonable if we possess a long past experience with the set of events under consideration and can establish at least that it has always demonstrated heretofore the prerequisite qualities for a useful probability analysis. A new musical composition does not provide us sufficient data, even in its entire length, to justify such an assumption.[8]

Colin Cherry sums up the problem this way: "In most fields of real human communication, the assumption of stationary sign behaviour cannot be made and this is one principal obstacle to the application of the mathematical theory to individual human behaviour."[9]

Meyer's work, which represents the area of information theory used for analysis and philosophical/epistemological discussions of music has been criticized on two counts. The first is the suggestion that his theory is dependent upon an "Ideal Auditor" and the second is a criticism of the connection he makes between surprise or the unexpected and musical value and is based on the day to day experience that one has of enjoying music even though one may predict what will occur: This is called the Information Theory Paradox. Let us begin however with a discussion of the former criticism by Titchener in "Meyer, Meaning and Music":

We could easily determine the statistical frequency with which a given kind of ending appears in the inventions, or the preludes etc. But our concern arises out of the subjective assessment of probability, for Meyer is clearly committed to what we call the Ideal Auditor hypothesis. Like the Ideal Observer once popular in moral theory, the Ideal Auditor is a very well placed judge or critic. He knows the style of the piece and the styles of the period and thus has an experimental basis for the expectations which Meyer's theory requires that he have. Given paradigmatic cases which generate the Information Theory paradox, the Ideal Auditor's subjective assessment of the probable outcome is quite likely to be very close to the statistical frequency prediction.[10]

Sherburne, in commenting upon Meyer's Emotion and Meaning in Music,[11] formulates what might be called the Information Theory Paradox. He is of the opinion that such a paradox exists because, if a set of musical events has only one highly probable, if not certain, consequent musical event, then, according to the definition of "information" employed, none is conveyed because the listener knows what to expect. As Titchener writes:

> If the theory were correct, the first hearing of the work should reek with meaning and send emotional tingles to the tips of the toes: but with subsequent hearings the significance and emotional impact ought to decline rapidly as the unexpected becomes the expected, as expectations become replaced by recollection and anticipation. In fact, the far more common experience is that the works tend to become more compelling as one gets inside them and obtains a growing familiarity with them.[12]

Some of the arguments to defend Meyer's position are as follows: man does not have a perfect memory; there is a distinction between knowing what will occur and experiencing that occurrence and finally, that repeated listenings focus one's attention on different relationships of differing levels of organization such that what seems to be a certain relationship on one hearing may reveal itself as something else upon the next. Titchener suggests that the Information Theory paradox may be argued against by interpreting the "emotional tingles" as anticipation based on the listener's knowledge of what will happen (as in the case of teleological music as opposed to random or kinetic/mechanistic music where the sequences are not linked or suggested by one another). Thus the excitement results from the hearing or experiencing of the predicted result.

A colleague of Shannon's, J. R. Pierce, feels that musicians have been misled by the mathematics and words of the theory trying to make it more general and more elegant than it actually is. He writes in 1972 after most of the excitement of an information theory approach has died down that:

> We are left with two matters directly relevant to information theory: man does not produce words or symbols at random, but in a manner which exhibits both randomness, that is unpredictability, and probabilistic patterns or constraints, that is predictability. In responding to words or symbols or patterns, man is limited in his capacity: in speed, in ability to remember and in ability to detect patterns which are objectively there and can be detected by suitable tests.[13]

Pierce feels that since either complete randomness or redundancy is boring, perhaps the best approach is that suggested by Ludwig Van Beethoven that everything in music should at once be surprising and expected. Pierce feels that this is as wise as any statement that can be arrived at through information theory.

Summary

It is obvious at this point that information theory is not a complete and exhaustive model of composition or listening. It does not address itself to theories of the whole or gestalt which are important to any art, nor does it deal successfully with macro-structures which organize sequences or have anything to say about the sensitive relationship which exists between a gesture and the time required to execute it. A great deal of what occurs in music (some types more than others) is a biological response to frequency relationships and especially, rhythm. This kind of response cannot be placed under an information theory paradigm. These limitations however, do not deny the value of an information theory approach to music.

In this thesis I have illustrated some of the insights and capabilities of the theory. It is my belief that armed with a familiarity with the material in Chapters Two and Three, a musician can formulate new ideas about his or her craft, particularly those areas which are not amenable to standard analysis; like contemporary art music, top forty radio hits, electronic music, etc. I have documented this belief with examples of such an information analysis and the use of the concepts in generating and composing music in Chapter Four.

Information theory is also well suited for use in computer music and has been used successfully to analyze pitch and rhythmic sequences or organize material to achieve different levels of stochastic relationships in the computer generation of music and musical scores. As a general theory, information concepts can provide insightful analysis of other parameters such as texture, timbre, etc., though not in a precise way. For an art form which inevitably must consider the audience, the concepts of channel capacity and redundancy are vital for the musician. Important also is the new perspective and terminology which the theory offers; like a communication model which is concerned with quantity of information and disregards the meaning attached to sequences, but rather deals with their predictability. Information theory offers explanations as to the nature of style and the value of homogeneity in a piece, it suggests reasons for audience reactions to restraint in material or lack of it, and the theory offers in the concept of noise, a useful analogy and technique with many applications.

It is clear that information theory provides insights into music not available from the primary theory used to view music; so-called "music theory" which consists of harmony, counterpoint, solfège melody, etc., that is, the type of analysis taught in conservatories of music. However, both "music theory" and information theory do not complete the tools of the musician. Even now Faculties of Music offer courses in psycho-acoustics, acoustics and the physics of music to their students. Since music is often thought of as a language, linguistics should be a part of the musician's awareness as well. The work of Chomsky, which deals in the hierarchy of structure, has much to offer music studies. Communication theories, systems theory, and cybernetics provide many insights: After all, music is a communication phenomenon. Lastly, an awareness of history and philosophy of science is important for the musician, so as to place the art in context with developments in natural science. I have shown the relationship with the concept of uncertainty that exists between music, entropy and information theory. It would be interesting to explore other liaisons and influences between prevailing epistemologies and music, and changes in mankind's view of nature contrasted with approaches to music.

Since its spectacular burst upon the scene in the late forties, information theory has taken what I feel is its rightful place; not "the" theory of communication, but rather one of many, although with its own unique contributions and effectiveness. An awareness of the theory must surely stimulate the musical mind and it serves well as one of many theories from diverse areas which can contribute to a musician's understanding of the complex communication process that is music.

Notes

[1] J. R. Pierce, "Communication Sciences and the Arts," _Arts in Society_, 9 (1972), 244.

[2] p. 27.

[3] Moles, p. 144.

[4] Ibid., p. 56.

[5] Ibid., p. 144.

[6] Following material on criticisms from Cohen.

[7] Moles, p. 156.

[8] David Kraehenbuehl and Edgar Coons, "Information as a Measure of the Experience of Music," _JAAC_, 17 (1959), 511.

[9] p. 178.

[10] John M. Titchener and Michael E. Broyles, "Meyer, Meaning and Music," _JAAC_, 32 (1974), 17.

[11] Donald W. Sherburne, "Meaning and Music," _JAAC_, 24 (1966), 579-83.

[12] p. 18.

[13] Pierce, _Communication_, p. 247.

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